IODP Expedition 353: Indian Monsoon Rainfall
Site U1445 Summary

Background and Objectives

Site U1445 is located near the southern end of the Mahanadi Basin, on the eastern margin of India. This location, ~94 km offshore, offers the opportunity to drill sediments underlying the low salinity waters of the Indian margin, a result of summer-monsoon rainfall and runoff from the peninsular rivers of India, including the Ganges/Brahmaputra and Mahanadi. The objectives at this site are to recover late Miocene to Holocene sediment sections in order to reconstruct changes in the Indian summer monsoon at orbital to suborbital timescales.

Operations

At Site U1445, Holes U1445A, U1445B, and U1445C were drilled to total depths of 672.6 m, 33.0 m, and 305.6 m DSF, respectively. In Holes U1445A and U1445C, the APC system and the XCB systems were primarily used; only the APC system was used in Hole U1445B. For Holes U1445A and U1445C, the APC system was used to refusal. Following refusal of the APC system, the XCB was deployed to total depth. Overall, 117 cores were recovered for the site. A total of 487.34 m of core over a 476.3 m cored interval were recovered using the APC system (102% recovery). The cored interval with the XCB system was 534.5 m with a recovery of 518.02 m of core (97%). The overall recovery percentage for Site U1445 was 99%. The total time spent on Site U1445 was 9.3 days.

Principal Results

Lithostratigraphy

The sediments recovered at Site U1445 are principally composed of hemipelagic clays with a significant biogenic component, and occasional thin turbidites, of Holocene to late Miocene age. Due to the homogeneous nature of the sediments only one stratigraphic unit is recognized, divided into two subunits (Ia and Ib) primarily based on nannofossil and biosilica content. Subunit Ia is a 165 m thick sequence of Holocene to middle Pleistocene olive gray to dark greenish gray clay with biosilica, and clay with nannofossils, with occasional beds of biosilica-rich clay. Foraminifers are a persistent but variable component of the Subunit Ia clays. Subunit Ib is a 502 m thick sequence, the top of which

is defined by the first downcore occurrence of biosilica-rich clays in Hole U1445A. Subunit Ib is dominated by very dark greenish gray biosilica-rich clay with glauconite, with significant periods of increased diatom content between ~160 m and 330 m CSF-A. Foraminifers and nannofossils are both much less common in Subunit Ib than in Ia, but are present in small numbers throughout, particularly between ~570 m to 670 m CSF-A where an increase in calcareous nannofossils is observed. Thin (~2–20 cm) turbidites are present in sediments from both Subunits Ia and Ib, varying in composition from silt-sized quartz-rich silt/sands, to foraminifer-rich sands, with occasional bioclastic-rich sands. Soupy and mousse-like intervals, characteristic of gas hydrate dissociation, were identified in sediments recovered in all holes using the APC system from both Subunits Ia and Ib. Overall, cores from Hole U1445C were considerably less disturbed by drilling disturbance and gas expansion than those recovered from Hole U1445A at equivalent depths, possibly due to reduced heave during Hole U1445C operations.

Biostratigraphy

Calcareous and siliceous microfossils are present in Hole U1445A with variable downcore abundance trends. Calcareous nannofossil preservation is good to moderate, and their abundances vary between rare and abundant. Pleistocene to late Miocene nannofossil assemblages are typical of tropical/subtropical paleoenvironments. Foraminifers are dominant to abundant in the uppermost 188 m CSF-A in Hole U1445A. Abundance decreases rapidly below 188 m CSF-A and falls to few or rare below 290 m CSF-A. Foraminifer preservation is good to moderate, with the exception of three samples that show poor preservation. Diatom preservation ranges from good to poor and tends to be better whenever diatom abundance is higher.

All Pleistocene nannofossil marker species are found, with the exception of *Reticulofenestra asanoi*. The Pliocene/Pleistocene boundary (2.59 Ma), located between Cores U1445A-31X and 38X, is bracketed by a number of *Discoaster* last occurrences that are dated between 2.39 Ma and 2.8 Ma. The Miocene/Pliocene boundary (5.33 Ma) is well constrained between 603.22 m to 606.19 m CSF-A and is based on the last occurrence of *Triquetrorhabdulus rugosus* (5.28 Ma) and the first occurrence of *Ceratolithus acutus* (5.35 Ma) in this interval. The oldest calcareous nannofossil sample studied, U1445-A-77X-CC (667.46 m CSF-A), contained *Discoaster quinqueramus* and *Discoaster berggrenii*, suggesting an age between 5.59 Ma and 7.53 Ma. Besides the age

model, nannofossil biostratigraphy was of great use to date some rip-up clasts found in several horizons in Holes U1445A and U1445C. The matrix surrounding the clasts was of the same age as the sediment above and below the horizons containing the clasts, whereas the rip-up clasts themselves were of different ages, ranging from the Late Pleistocene to late Eocene.

Planktonic foraminifer biostratigraphy is based on the onboard study of core catcher samples from Hole U1445A. The percent of planktonic foraminifers is high (mean of 86.4%) in the uppermost 158.97 m CSF-A, but lower (mean of 59.9%) throughout the remaining Hole U1445A core catchers. The total number of foraminifers per 10 cm^3 raw sediment is highly variable, ranging from 0 to over 24,000, with a marked decrease below 180 m CSF-A. The number of benthic foraminifers per 10 cm^3 raw sediment follows the same pattern, averaging 1667 between 0–180 m CSF-A and 129 below. Reworking is apparent in many late Miocene through Pleistocene samples. Pleistocene planktonic foraminifer assemblages were recovered from 6.9 m to 261.51 m CSF-A. Planktonic assemblages are dominated by tropical to warm-subtropical species as well as by some temperate species. Species commonly associated with upwelling zones are common to abundant throughout Samples U1445A-1H-CC to 20H-CC, indicating coastal upwelling or vertical mixing of intermediate and deep waters during this period. Species of markedly different last appearance ages are found in samples within a zone between Samples U1445A-9H-CC and 18H-CC, which implies the occurrence of reworking. Pliocene planktonic foraminifer assemblages are recovered from Samples U1445A-29X-CC to 68X-CC. Miocene sediments span Samples U1445A-69X-CC to 77X-CC. The occurrence of *Globigerinoides conglobatus* in Sample U1445-A-76X-CC suggests a maximum age of 6.20 Ma.

Diatoms are useful for age-estimation throughout the entire sedimentary column of Hole U1445A. Several diatom events are recognized between the last occurrence of *Nitzschia reinholdii* (0.90–1.0 Ma) and the LO of *Nitzschia miocenica* (5.7 Ma). Valve preservation is mostly good to moderate. Strong variations in abundance and shifts in the species composition of the diatom assemblage will help to reconstruct paleoceanographic changes in the eastern Indian Ocean between the late Miocene and the Late Pleistocene. The highly diverse diatom community mainly consists of species typical of warm to temperate, low-latitude ocean waters. High-productivity species, including

Thalassionema nitzschioides var. *nitzschioides* and resting spores of *Chaetoceros*, tend to dominate whenever total diatom abundance is higher than "few." A certain degree of freshwater/land input (through winds or river run-off) above Site U1445 is revealed by the recurrent presence of numerous phytoliths and freshwater diatoms.

The age model for Site U1445 was established by combining nannofossil, planktonic foraminifer, and diatom datums with paleomagnetic reversal datums. Age-depth relationships for Hole U1445A of the three fossil groups studied (diatoms, planktonic foraminifers and calcareous nannofossils) show good agreement and match the magnetochron boundary datums very well. The combined biostratigraphy/ magnetostratigraphy age model suggests a mean sedimentation rate of 11.4 cm/k.y., assuming a linear fit of all data.

Geochemistry

The geochemistry at Site U1445 strongly reflects the processes of sulfate reduction and methanogenesis associated with microbial degradation of organic matter. High methane concentrations are found in headspace and void space gas samples. High methane/ethane ratio suggests that the methane is mostly of biogenic origin. The organic carbon content is as high as 4 wt% and carbonate is associated with intervals of more abundant calcite microfossils. The interstitial water chemistry at Site U1445 reflects reducing conditions with pore water sulfate depleted at around 18 m CSF-A. Other examples are alkalinity peaking at around 30 mM near 50 m CSF-A and dissolved barium and silicate increasing downhole. The influence of seawater contamination and oxygen during processing associated with XCB coring is noticeable in the profiles of some elements, most notably sulfate, phosphate, and iron.

Paleomagnetism

Paleomagnetic measurements were conducted on the archive-half sections for all three holes at Site U1445, with alternating field (AF) demagnetization typically up to 10 mT. Discrete samples (N = 219) taken from the working-half sections were also analyzed, with AF-demagnetization typically up to 30 mT. Characteristic remanent magnetizations (ChRMs) of discrete samples were calculated using the principal component analysis (PCA) technique. Additionally, the bulk magnetic properties of the discrete samples were assessed.

Remanence intensities drop significantly in the uppermost 10–20 m CSF-A due to diagenetic reduction. Nonetheless, a magnetic polarity stratigraphy was produced, except for the lower part of Hole U1445A (below ~470 m CSF-A). Rock magnetic measurements on the discrete samples provide promising variations in the bulk magnetic properties for the last 6 Ma. The significance of these trends has yet to be evaluated; however a periodicity, possibly on the order of 40–60 ka, could be underlining astronomical-scale cycles.

Physical Properties

The physical properties data collected at Site U1445 were found to be in good agreement with the lithostratigraphic data; however, the physical property unit division boundaries differ. Three physical property units are identified in Hole U1445A and two units in Hole U1445C. The data between Holes U1445A and U1445C correlate well. The distinct change in physical property characteristics of Hole U1445A between Unit I and Unit II is likely related a lithological change to biosilica-rich clay at the top of Unit II, based on smear slide analysis. The magnetic susceptibility, density, and NGR values are lower while the porosity values are high in the more diatom-rich clays of Unit II. Changes observed in color reflectance could be a result of a change from APC to XCB coring. A zone containing high NGR peaks in Unit III could be related to drilling disturbance or coarse-grained fractions in a few turbidites.

Stratigraphic Correlation

A composite scale (CCSF-A) and a splice were constructed for Site U1445 using Holes U1445A and U1445C using magnetic susceptibility, natural gamma ray and RGB data. Splicing among these holes enabled us to construct a continuous stratigraphic sequence down to ~252 m CCSF-D. Due to data quality issues, correlation should be viewed with caution below ~50 m CCSF-A and especially below ~236 m CCSF-A.

Downhole Logging

Wireline logging in Hole U1445A was initiated following coring operations. The hole was swept with a heavy weight, seawater-based mud that included barite as a weighing additive to improve hole stability. The presence of barite in the mud must be taken into consideration when interpreting the logging results; incoming gamma rays will be blocked, attenuating the NGR measurement, and the photoelectric factor should be used cautiously. Two passes were made with both the triple combo and FMS-sonic tool strings

for better data comparison of repeatability. The first logging run was made with the triple combo which encountered a bridge at ~440.0 mbsf. Several fruitless attempts were made to pass the bridge before logging the hole from the bridge to the bottom of the drill string at 80 mbsf. All subsequent passes were limited to this depth.

Highlights

Sediments at this site were remarkably conducive to rotary coring. The deepest hole at Site U1445 was cored to 673 mbsf, 447 m of which was rotary coring (XCB), with an overall recovery of 99%. Within intervals where core expansion was strong, due to microbial gas, an 8 m advance of the XCB was employed to provide expansion room within the liner, thereby significantly reducing the loss of sediment.

Discrete intervals in the late Miocene, middle Pliocene, and middle Pleistocene are characterized by abundant diatoms, including species characteristic of high productivity environments as well as those found in coastal and fresh waters. Similarly, species of planktonic foraminifera characteristic of higher productivity environments increase in abundance in the middle Pliocene and Pleistocene possibly suggesting nutrient input due to changes in surface water stratification or runoff.

Given the likelihood of minor hydrate occurrences, an infrared camera was used to scan cores on the catwalk, prior to sectioning. A number of cm-scale cold spots were detected, having up to 7°C difference relative to background core temperatures. Rhizon pore water sampling confirmed the presence of hydrates, indicating chloride values below that of seawater.