**IODP Expedition 359: Maldives Monsoon and Sea Level**
**Site U1467 Summary**

## Background and Objectives

Site U1467 is the easternmost site drilled in the Inner Sea of the Maldives during IODP Expedition 359. It is located at 4°51.0274′N and 73°17.0223′E at a water depth of 487.4 m, 24.8 km east of the eastern end of the northern transect and 29.4 km east of the eastern end of the southern transect. The cores at this site record a 630 m thick succession of drift deposits lining the southern flank of Kardiva Channel. The main objectives at this site were to constrain the timing of sequence boundaries in the drift succession and to date precisely the onset of the drift deposition; to analyze the cyclostratigraphy of carbonate drift deposits, therefore providing reconstructions of changes in the current regime and monsoon cyclicity; and to recover an undisturbed sedimentary sequence for further paleoceanographic studies.

The Mid-Miocene to recent drift succession contains several sequences that are likely caused by fluctuations in the current system flowing through the Kardiva Channel. Dating these sequence boundaries will provide the ages of changes in strength and direction of the currents. Further linking of these physical stratigraphic data with postcruise sedimentological and geochemical data will address the question of changes in the monsoon intensity. Moreover, the periplatform sediments deposited at this site offer the opportunity to retrieve a complete record of $\delta^{13}C$ through the Middle Miocene that, together with the other sites drilled during Expedition 359, will provide another data set of the carbon isotopic record that is needed to calibrate the periplatform record against the pelagic record.

## Principal Results

Five holes were drilled at Site U1467, one of them (U1467E) as a dedicated logging hole. The sediment recovered at Site U1467 is a fine-grained succession of wackestone to packstone. Compositional changes are minor but there is an alternation of lighter and darker intervals of variable thickness that persists downhole even through the increasing degree of lithification until approximately 640 mbsf. Six lithostratigraphic units were differentiated. Lithostratigraphic Unit I (0–110.0 mbsf) consists of unlithified, foraminifera-rich wackestone to packstone with a predominance of very fine- to fine-

grained wackestone. The unit is characterized by thick (30–100 cm) to very thick (>100 cm) intervals defined by color changes ranging from light gray to grayish brown. The dark intervals correlate with low lightness L* reflectance values and display an inverse relationship with the NGR trends, with higher NGR (CPS) observed in the darker intervals.

Lithostratigraphic Unit II (110–215 mbsf) is defined by interlayered unlithified and partially lithified planktic foraminifera-rich wackestone and mudstone with pteropods and particulate organic matter. The matrix of the sediment contains calcareous nannofossils and sponge spicules. Celestite is common as nodules and layers up to 3 cm thick and as disseminated crystals in the fine fraction.

Lithostratigraphic Unit III (215–303 mbsf) consists of partially lithified very fine-grained mudstone to wackestone with a dominance of wackestone. The unit also shows thick to very thick interlayered color changes, from light gray to light olive gray and light brownish gray. The sediment contains abundant planktic foraminifera; echinoid spines and sponge spicules are common, but benthic foraminifera are rare. Celestite nodules and fragments, bioclasts, and particulate organic matter are common, especially in the darker intervals. Bioturbation is common with *Thalassinoides*, *Planolites*, *Palaeophycus,* and possibly *Zoophycos*. Traces appear better developed in the darker colored intervals.

The deposits of Lithostratigraphic Unit IV (303–498.5 mbsf) are lithified, very fine- to medium-grained, planktic foraminifera-rich wackestone to packstone. As with previous units, particulate organic matter is present and changes in abundance, which is linked to color variations from light gray to light brownish gray and pale yellow with gradational and commonly bioturbated contacts. Ichnofauna consist of *Thalassinoides*, *Planolites*, *Zoophycos, Chondrites,* and *Palaeophycus*. Lithostratigraphic Unit V (498.5–607 mbsf) still consists of planktic foraminifera-rich wackestone to packstone with an alternation of light and dark intervals, but Lithostratigraphic Unit VI below 607 mbsf lacks dark layers within the fine-grained wackestone.

Biostratigraphic analyses show that an apparently continuous succession of Holocene to Middle Miocene age has been recovered at Site U1467. This can be divided into three intervals. The Pleistocene and late Pliocene extends from the seafloor to ~130 mbsf. Throughout this interval planktonic foraminifers were well-preserved, and benthic

foraminifers and calcareous nannofossils were well preserved in the top but moderately well preserved below 40 mbsf. The early Pliocene and much of the late Miocene extends from ~130 to 540 mbsf. Preservation throughout this thick interval was poor to moderate for all microfossils, except in the deepest core in this interval (Core U1467B-69X) from which very well preserved nannofossils were recovered from a few darker, probably clay-rich levels. The late Miocene and later part of the Middle Miocene extends from 540 to 714 mbsf. In the upper part of this interval all groups of calcareous microfossils were rare and poorly preserved; preservation improved downcore and, in the lower part of the interval, was moderate to good.

A decrease in the $SO_4^{2-}$ concentration and alkalinity in the interstitial fluid geochemistry from Site U1467 indicates that significant remineralization of organic material has occurred below 50 mbsf. An odor of $H_2S$ was also noted upon core recovery and squeezing of the whole-round samples, suggesting that bacterial sulfate reduction (BSR) probably accounts for the observed trend. As large amounts of $NH_4$ are released during the decomposition of sedimentary organic matter, a negative correlation between $SO_4^{2-}$ and $NH_4^+$ is also related to the oxidation of organic matter. There is an increasing trend in $Cl^-$ from the sediment surface to around 100 mbsf. This is believed to be related to the last glacial period when salinity was altered as a result of northern hemisphere glaciation.

Sediments at Site U1467 contain up to 60% aragonite in the upper 50 m of the core, as revealed by XRD analysis. Below, aragonite content decreases to less than 10%–15% and drops to less than 10% down to 500 mbsf. This decrease is interpreted to reflect aragonite dissolution, based on an increase of $Sr^{2+}$ concentration in the pore fluids. Deposits are again richer in aragonite between 500 m and the bottom of the hole, while the $Sr^{2+}$ concentrations of the pore fluids exhibit a slight decreasing trend in this interval, while $Li^+$ concentrations increase. The decrease in $Sr^{2+}$ probably is controlled by a sink of $Sr^{2+}$ located at a deeper interval that was not cored. The XRD analyses also show that there are several occurrences of celestite ($SrSO_4$) between 163 and 393 mbsf, indicating that the pore water concentrations of $Sr^{2+}$ and $SO_4^{2-}$ attain supersaturation with respect to this mineral. At Site U1467, the celestite occurs in an interval of unusually high sedimentation. Hence, in spite of the reduction of $SO_4^{2-}$ in this interval, there was sufficient $Sr^{2+}$ to produce supersaturation in the pore waters with respect to celestite.

Organic carbon content in the sediments at Site 1467 fluctuates between 0 and 12 wt%, with the organic carbon richest samples at 89, 112, and 168 mbsf. Methane remained at concentrations between 1.6 and 12.0 ppmv, showing a slight increase from the surface to the depth at 300 mbsf, and then remains mostly stable around 5 ppmv with some scattering values. Ethane is only presented in measurable quantities (~1 ppmv) between 249 and 277 mbsf and at 324, 580, and 706 mbsf.

Natural remanent magnetization (NRM) analysis at Site U1467 was only possible on limited core sections because of a pervasive contamination, presumably from rust in the drill pipe, that affected the first two to three sections of every core, even despite the cleaning of the drill pipe interior conducted in Hole U1467C. Discrete samples showed less overprint than the archive section-halves, and shore-based analyses should yield better quality results. Nevertheless, a series of magnetozones in the intervals between ~100 to 200 mbsf in Hole U1467C and between 195 to 255 mbsf in Hole U1467B were identified, which were interpreted as C2Ar to C3n.3n. Another series of possible normal and reverse polarity intervals based only on the analysis of inclinations, which is below 20° and consistent with the paleocolatitude for this site, was recognized between 580 and 714 mbsf in Hole U1467C (Cores 24X through 37X) and interpreted to be Chrons C5n.2n to C5An.2n.

The physical properties of the sediment reflect the rather monotonous nature of the lithological succession at Site U1467, whose main characteristic is the changes of color from darker to lighter intervals in generally fine-grained, bioturbated wackestone. Four distinct units of physical properties are identified. The first three units (0–465 mbsf) are divided mainly based on a slightly higher variability of velocity in the second unit and a concomitant small step in the downhole increase in the density and a coeval decrease of porosity at 105 mbsf, as well as increased variability of density and porosity. Below 465 mbsf, where the formation became more lithified, density and velocity increased significantly and showed large variations. High-frequency fluctuations in natural gamma radiation (NGR) also follow these color variations that are likely produced by small admixtures of organic material (dark color) and more early marine cements (light color). In addition, NGR data displayed five longer-term variations that loosely follow the lithostratigraphic units. Magnetic susceptibility is low throughout the entire core.

Thermal conductivity on the other hand had an increasing trend downhole—the rate of this increasing trend is reduced in physical property Unit 2.

In the dedicated logging Hole U1467E, three tool strings were deployed: the triple combo, the Versatile Seismic Imager (VSI), and the FMS-sonic. The caliper log from the first logging run indicated that much of the borehole was ~14 inch in diameter, thus suitable for a vertical seismic profile (VSP) experiment. The VSI tool string recorded good sonic waveforms at 13 stations at a 50 m interval. After shorebased processing, logging data were analyzed and subdivided into four logging units. Boundaries of logging units correlate with some of the lithostratigraphic units. Most variations in the downhole logs are seen in the gamma ray values, triggered by differences in the uranium content, which correlates to variations in the amount of organic matter as revealed by smear slide analysis. The VSP experiment produced good stacks of sonic waveforms. VSP data and sonic velocity logs therefore helped to establish the conversion between depth and two-way traveltime (TWT) and thus allowed us to exactly tie in seismic and core data.

We attempted four formation temperature measurements in Hole U1467B; however, no evidence of frictional heating occurred upon insertion into the formation on any of them, so no reliable formation temperatures were obtained. The average mudline temperature appeared to range from 13.8°C to 15°C.

The stratigraphic correlation, using available biostratigraphic and paleomagnetic age control points, allowed us to refine and establish a precise age model for Site U1467 correlating the different physical property measurements and the downhole logging data. The bottom of the hole is in 12.7 Ma old deposits. A composite depth scale and splice at Site U1467 are constructed from 0.0 to 220.25 m (CCSF-D) (from the “mudline” in Hole U1467C to bottom of Core U1467B-22H).

In the seismic profiles, the drift sequences at Site U1467 are represented by well-stratified, nearly horizontal, low to medium amplitude reflections, and in the lower part by a succession of strong reflections separated by zones of weak echoes comprising drift sequences DS1 to DS3. The base of the drift succession lies at 1337 ms TWT and is underlain by the drilled distal bottomsets of the platform sequences. Site U1467 is located in a basinal position, where all sequence boundaries appear as continuous parallel reflections which are the correlative conformities to the unconformities along the basin

margin that define the sequence boundaries. The thickness of the of the drift sequences varies from minimal 24.5 m (DS7) to a maximum of 104 m (DS6) and 173 m (DS4), respectively. Starting with sequences DS1 to DS3, the depocenter was situated at the western basin margin and dominated by a southward bottom water inflow from the NE-Kardiva Channel and in inflow from the newly opened NW-Kardiva Channel. Sequences DS4 to DS7 mark the gradual eastward shift of the depocenters. The uppermost sequences DS8–DS9 exhibit a more uniform thickness throughout the Inner Sea of the Maldives.