IODP Expedition 371: Tasman Frontier Subduction Initiation and Paleogene Climate

Site U1506 Summary

Background and Objectives

Integrated Ocean Drilling Program (IODP) Site U1506 (proposed Site LHRN-3A; 28°39.7180′S, 161°44.4240′E, water depth 1495 m) is located on the northern Lord Howe Rise, ~290 km south of Deep Sea Drilling Project (DSDP) Sites 208 and 588. Geophysical surveys imaged a regional unconformity, which at DSDP Sites 208 and 588 corresponds to an unconformity with foraminiferal and nannofossil chalk of early Oligocene age overlying middle Eocene siliceous-fossil-bearing chalk, radiolarite, and diatomite. The scientific objective at Site U1506 was to test the hypothesis that the Lord Howe Rise was transiently uplifted to near sea level during Paleogene time, and has since subsided by ~1500 m. The drilling target, which was identified from seismic reflection data, is a buried flat-topped feature with ~100 m of relief above the regional unconformity surface. The feature has a positive-polarity seismic reflection at its top, but also internal reflections. We hypothesized that it could be a Paleogene coral reef or wavecut surface. Rotary drilling was chosen because consideration of the seismic reflection amplitude and seismic refraction velocity of 3.2–3.8 km/s suggested the material might be too hard for advanced piston corer (APC) or extended core barrel (XCB) coring.

Operations

Site U1506 (proposed Site LHRN-3A) was the first site occupied during Expedition 371. After an 1167 nmi transit from Townsville, Australia, the ship arrived at Site U1506 at 1912 h on 3 August 2017 (UTC + 10 h). The thrusters were lowered and the dynamic positioning system was engaged. At 1948 h, the drill floor was cleared for operations, beginning Hole U1506A. At 2033 h, a seafloor positioning beacon was deployed.

The rotary core barrel (RCB) bottom-hole assembly (BHA) was assembled and deployed. All drill string tubulars were strapped and drifted during the pipe trip. The top drive was picked up and a wiper “pig” was pumped through the drill string to clean debris from the inside of the drill string prior to coring. The core barrel was deployed, and Hole U1506A was spudded at 0600 h on 4 August.

The seafloor depth was determined to be 1505.8 m DRF based on tagging it with the drill string, establishing a water depth of 1495 m. RCB coring proceeded at 9.5 to 9.7 m intervals through Core U1506A-28R (263.1 m DSF). Core 29R encountered the expected hard formation at ~265 m DSF. We recovered cores in half intervals (4.5–5.0 m length) below this depth to minimize risk of core loss due to jams in the bit or inner barrel. We obtained an average core recovery of 76% in this depth interval.

We decided to stop coring after Core U1506A-36R, which arrived on the rig floor at 1345 h on 5 August. Total recovery for the 306.1 m drilled at Hole U1506A was 192.38 m (63%). A single 15-barrel mud sweep of high viscosity gel mud was pumped during drilling in this hole. The drill string was retrieved, disassembled, and inspected, the acoustic beacon was recovered, and the rig floor was secured for transit, ending Hole U1506A operations at 1935 h. The time spent on Hole U1506A (and Site U1506) was 47.75 h or 2.0 d.

At 2000 h we departed for Site U1507 (proposed Site NCTN-8A).

Principal Results

Lithostratigraphy

Site U1506 consists of ~265 m of Pleistocene–middle Eocene nannofossil ooze and chalk (Lithostratigraphic Unit I) overlying ~40 m of volcanic rocks (Lithostratigraphic Unit II). The sediments of Unit I are further divided into three subunits.

Subunit Ia (0 to 258.2 m CSF-A) consists of relatively homogenous Pleistocene to upper Miocene white nannofossil ooze or chalk with foraminifers, with carbonate content ranging from 88% to 95%. Faint decimeter-scale white and greyish white color banding, rare blebs of pyrite framboids, and an ~3 cm long pyritized burrow occur in this subunit. The ooze to chalk transition occurs in Subunit Ia in Cores 24R to 26R. Fine structures and texture, including bioturbation with slightly darker *Zoophycos*, *Planolites*, *Skolithos*, and *Chondrites* burrows, are better preserved and visible in the chalk than in the ooze.

Subunit Ib (258.2 to 264.3 m, CSF-A) is an ~6 m thick interval of pale yellow to white upper Oligocene nannofossil chalk with foraminifers. The Subunit Ia/Ib boundary is marked by a color change from white gray to pale yellow and a slight increase in magnetic susceptibility, and represents an ~10 My hiatus from the late Miocene to late Oligocene. Subunit Ib is moderately bioturbated with common *Zoophycos* and *Planolites* trace fossils.

Subunit Ic (264.3 m to 264.6 m, CSF-A) is a 34 cm thick interval of middle Eocene glauconitic nannofossil chalk with foraminifers. The Subunit Ib/Ic boundary, defined by the appearance of glauconite and a coincident color change to light greenish gray, represents an ~20 My hiatus from the late Oligocene to the middle Eocene. Subunit Ic is intensely bioturbated, with burrows filled with the pale yellow Oligocene nannofossil chalk of overlying Subunit Ib.

Lithostratigraphic Unit II (264.6 m to 305.3 m CSF-A) represents the top ~41 m of a volcanic rock sequence. It consists of microcrystalline to fine-grained basalt. This unit can be further divided into intervals of (1) dark reddish brown, microcrystalline, highly vesicular, and amygdaloidal basalt with common veins, and (2) dark gray, fine-grained intervals of massive, aphyric basalt with rare carbonate veins. Thin sections and X-ray diffraction (XRD) measurements showed that the basalt is dominated by Ca-plagioclase and clinopyroxene, alongside various alteration minerals such as Fe-Ti oxides and chlorite. The carbonate veins and vesicle fills display a variety of composition and texture, including large (>1 cm grain size) fibrous calcite crystals and fine-grained, bioclastic packstone.

Biostratigraphy and Paleoenvironment

Nannofossil and planktic foraminifera biostratigraphy assign a Pleistocene to late Oligocene age to lithostratigraphic Subunits Ia and Ib. Higher resolution sampling allowed identification of a condensed interval between Samples 28R-3W, 75 cm, and 28R-4W, 75 cm (257.25–258.75 m CSF-A), lasting ~10 My. Subunit Ic is of middle Eocene age. A sample of a burrow fill (29R-2W, 70 cm, 264.36 m CSF) is late Oligocene in age, indicating erosion or nondeposition of middle Eocene to late Oligocene sediment.

Microfossil assemblages consist of well-preserved calcareous nannofossils, planktic and benthic foraminifera, and ostracods, indicating a depositional depth well above the lysocline. The middle Eocene benthic foraminifera are characteristic of an upper bathyal environment, about 500 to 1000 m shallower than the late Oligocene and younger intervals. The ostracod assemblages indicate a deep-water setting throughout Subunits Ia and Ib, and upper bathyal for Subunit Ic.

Rare, heavily recrystallized radiolarians of unknown identity were found in Sample 23R-CC. Otherwise, this site is barren of radiolarians and other siliceous microfossils.

A palynological reconnaissance study carried out on four samples from Hole U1506A (core catcher samples from Cores 24R, 26R, and 28R, and one additional sample from the middle Eocene glauconite-rich layer in Section 29R-2) yielded no palynomorphs.

Paleomagnetism

All section halves were measured with the superconducting rock magnetometer (SRM) at 5 cm or 10 cm intervals to obtain a continuous record of remanence after alternating field (AF) demagnetization treatment at 10, 15, and 20 mT, in order to establish a magnetostratigraphy and age control through correlation with the geomagnetic polarity timescale (GPTS). The SRM measurements were integrated with a total of 44 discrete samples collected from working section halves from all sediment cores and measured with a spinner magnetometer after stepwise AF demagnetization from 10 to 70 mT.

Measurements from ooze samples, representing most of lithostratigraphic Subunit Ia, yielded unstable paleomagnetic directions, largely due to reworking of the sediments (bioturbation) and drilling disturbance associated with the RCB coring system. Integration with discrete sample-derived directions does not allow reliable correlation with the GPTS. However, stable paleomagnetic directions with several polarity reversals were obtained in the chalk interval (below ~245 m CSF), and clarity was improved by AF demagnetization at 20 mT. Principal component analysis (PCA) of paleomagnetic directions after stepwise AF demagnetization of discrete samples reveals a stable remanent magnetization component above 10–20 mT, confirming observation from SRM measurements. Considering biostratigraphic data, we correlated the normal polarities N1 and N2 within Core 27R with chron C5An.1n and C5An.2n, respectively. Within Core 28R, the normal polarity N3 is possibly correlated to C5Ar.1n, and N4 can be correlated to C7n.2n.

Lithostratigraphic Unit II yields a stable paleomagnetic signal after removing the overprint with AF demagnetization at 20 mT. A normal polarity was obtained from most of the volcanic rock samples. Some intervals not affected by AF demagnetization showed a reversed polarity after 20 mT demagnetization. Further analyses (e.g., thermal demagnetization) are required to investigate the paleomagnetic signal of the volcanic materials.

Petrophysics

Cores recovered from Hole U1506A were taken through the entire suite of physical properties measurements, but the hole was neither wireline logged nor were downhole temperature measurements made. Variations in gamma ray attenuation (GRA) bulk density, magnetic susceptibility (MS), color, and natural gamma radiation (NGR) are of small amplitude in lithostratigraphic Unit I, and vary with significantly higher range in Unit II.

In Unit I, GRA varies between 1.6 and 1.8 g/cm^3, and porosity decreases from ~63% to 52% from the seafloor down to the base of Unit I, typical of calcareous ooze and chalk. *P*-wave increases gradually with depth from ~1600 to ~2000 m/s. Intermittently higher *P*-wave velocity values of ~2200 m/s occur in Cores U1506A-26R and 27R, reflecting the diagenetic transition of ooze to chalk. MS is low throughout the sedimentary section, with a few local MS spikes up to 100 IU. NGR is generally low too (1–4 counts/s), but increases to ~25 cps in glauconitic Subunit Ic.

Thermal conductivity shows a gradual and increasing trend with depth from 1.1 to 1.4 W/m·K over the top ~250 m CSF-A, consistent with expected values for calcareous ooze and chalk. Vane shear strength increases from ~18 kPa near the seafloor to ~40 kPa at 190 m CSF-A. Compressive strength from penetrometer measurements shows very low strength in the top ~72 m of Unit I, then increases and becomes variable (~60 to ~100 kPa) down to 186 m CSF-A.

The most significant change in physical properties is associated with the transition from lithostratigraphic Units I to Unit II. This sediment-rock contact is associated with a major impedance contrast at 264 m CSF-A, corresponding to a major increase in bulk density (up to 2.8 g/cm^3) and *P*-wave velocity (4400 to 6500 m/s). This impedance contrast can be correlated with the major reflection seen in the multichannel seismic profiles used in the site surveys (2.29 s TWT [two-way traveltime]). MS (0–1500 IU), NGR (~3 to 9 counts/s), bulk density, and color reflectance show much higher amplitude variations in Unit II than in Unit I. Porosity drops to 9% to 20% within Unit II.

Geochemistry

A total of 15 interstitial water (IW) samples were collected from the top of Hole U1506A and from Cores 4R to 28R (26–261 m CSF-A; lithostratigraphic Unit I). Sulfate concentration decreases from ~29 mM at the “mudline” to ~20 mM at depth. The ammonium profile mirrors that of sulfate, increasing from 0 to 150 μM. This suggests sulfate reduction of particulate organic carbon in the sediments. The product of this reaction, H_2S, once reacting with Fe, also explains the abundant iron sulfide mineral horizons observed in the cores. From the top to the bottom of the sedimentary section, Ca increases from 10.6 to 18.3 mM and Mg decreases from 52.9 to 36.2 mM. This could reflect reactions between porewater and the basement rock. Si and Mn increased from 160 to 200 mM and 0.4 to 3 mM respectively at the transition from ooze to chalk at ~260 m CSF-A.

Headspace gas samples were collected from each core. Hydrocarbon gas concentrations in all samples were below detection limits.

Carbonate ($CaCO_3$) content was high (>88 wt%) throughout Unit I, showing an increasing trend with depth in the top 70 m CSF-A, and with highest values (~95%) at 85–143 m and 200–228 m CSF-A. Total organic carbon (TOC) percentages are accordingly low, with values ranging between 0.2% and 0.4% in the top ~210 m CSF-A, and with slightly higher values of 0.6%–1.0% from 219 to 247 m CSF-A. Trace amounts of nitrogen are present in the uppermost two samples (0.65 and 14.32 m CSF-A). No samples were taken for bulk sediment geochemistry from Subunit IC or Unit II.