IODP Expedition 369: Australia Cretaceous Climate and Tectonics

Site U1514 Summary

Background and Objectives

The primary objectives for coring Site U1514, the northernmost site of Expedition 369, were: (1) to obtain a continuous Cenozoic sediment record in the Mentelle Basin to characterize how oceanographic conditions changed during the opening of the Tasman Passage and the restriction of the Indonesian Gateway; (2) to reconstruct middle through late Cretaceous paleotemperature changes to document when the Cretaceous Hot Greenhouse climate initiated, the duration of extreme warmth, and when a switch to a cooler climate occurred; and (3) to obtain complete and well preserved sediment records across mid-Cretaceous Oceanic Anoxic Events (OAE) to better understand their cause and accompanying changes in the climate-ocean system as well as in the marine biota.

Operations

The ship arrived on site after a 51 nmi voyage at an average speed of 8.1 kt (6.25 h) at 0800 h on 2 November. Site U1514 consisted of coring and logging operations in three holes. All four of the available coring systems were used. The advanced piston corer (APC), half-length APC (HLAPC), and extended core barrel (XCB) systems were used in Hole U1514A; Hole U1514B was cored with the APC only, and the rotary core barrel (RCB) system was used in Hole U1514C. We started Hole U1514A at 2220 h on 2 November. A 8.15 m mudline core was recovered, and the water depth was calculated at 3838.2 m. We continued APC coring with orientation through Core 19H to 178.1 m. Successful in situ formation temperature measurements were taken with the advanced piston corer temperature tool (APCT-3) while recovering Cores 4H, 6H, and 8H. We switched to the HLAPC to recover Cores 21F through 24F to 202.1 m, at which point piston coring refusal was reached. We switched over to the XCB and cut Cores 25X to 31X to 255.6 m. At this point, the rate of penetration had slowed significantly and we decided to stop coring with the XCB. The drill string cleared the seafloor at 2015 h on 4 November, ending Hole U1514A. The APC system recovered 185.96 m from 178.1 m cored (104%), the HLAPC recovered 24.88 m of 24.0 m cored (104%), and the XCB system recovered 44.36 m from 53.5 m cored (83%).

The vessel was then offset 20 m east and Hole U1514B was started at 2200 h on 4 November. The seafloor was calculated as 3838.7 m. Two APC cores were taken to 15.1 m and were completely sectioned into 30 cm whole rounds on the catwalk for postexpedition optically stimulated luminescence analyses. Hole U1514B recovered 15.45 m of 15.1 m cored (102%). The drill string was pulled up, clearing the seafloor at 2355 h. Hole U1514B ended at 0930 h on 5 November.

Preparations were made to core with the RCB system, and while the drill string was being lowered down to the seafloor, the vessel was offset 20 m south. Hole U1514C was started at 1940 h on 5 November with the water depth determined to be 3838.8 m via the offset. A center bit was dropped and we drilled without coring to 195.6 m by 0115 h on 6 November. The center bit was pulled at 0200 h and we recovered Cores 2R through Core 35R to 516.8 m. The last core was recovered at 1605 h on 8 November. In total, 247.47 m was recovered from 321.2 m cored (77%).

After coring, the hole was circulated twice with high viscosity mud and displaced with heavy mud. At 1635 h, the RCB bit was then released to the bottom of the hole. The drill string was then pulled up to 82.2 m for downhole logging. A modified triple combination tool string was assembled with the following tools: Hostile Environment Natural Gamma Ray Sonde (HNGS), High-Resolution Laterolog Array (HRLA), Dipole Sonic Imager (DSI), Hostile Environment Litho-Density Sonde (with source) (HLDS), Enhanced Digital Telemetry Cartridge (EDTC), logging equipment head-q tension (model QT) (LEHQT), and a centralizer for centralizing the DSI and the HRLA. The magnetic susceptibility sonde (MSS) was added to the bottom of the tool string. The tool string was deployed at 0015 h on 9 November. The entire length of the open borehole (82.2 to 514.0 m) was logged. The logging tools were recovered at 0630 h on 9 November and dissembled by 0815 h. The drill string was then brought up to the rig floor at 1735 h on 9 November, ending Hole U1514C. The rig floor was then secured for transit to Site U1515.

Overall, 7.4 d (2–9 November) were spent at Site U1514. A total of 21 APC, five HLAPC, seven XCB, and 34 RCB cores were recovered from the site, penetrating to a total depth of 516.8 m. Of the 591.9 m cored, 518.12 m of material was recovered (87.5%).

Principal Results

Lithology

Site U1514 is divided into three main lithostratigraphic units based on data from Holes U1514A and U1514C, with Units I and III further divided into two subunits. Unit I is a 81.20 m thick sequence of very pale brown to pale yellow nannofossil ooze, foraminiferal ooze, and sponge spicule-rich nannofossil ooze that is Pleistocene–Eocene in age. It is subdivided into Subunits IA and IB at 30.38 m CSF-A in Hole U1514A. Subunit IB spans Miocene–Eocene and differs from IA in that it is characterized by an increased abundance of sponge spicules. Further, the color of this subunit changes to yellow/brown, which is distinctively darker than Subunit IA. Unit II is a 308.01 m thick sequence of Eocene–Paleocene light greenish gray clayey nannofossil ooze, sponge spicule-rich clay, and nannofossil-rich clay that gradationally transitions into clayey nannofossil chalk and nannofossil-rich claystone. Unit III is a 126.43 m thick sequence of greenish gray, brown, and black claystone that is Paleocene–Albian in age. Unit III is subdivided into Subunits IIIA and IIIB at 454.33 m CSF-A in Hole U1514C. Subunit IIIB was deposited during the Cenomanian/Albian to Albian and is distinguished from overlying Subunit IIIA

(Paleocene to Cenomanian/Albian) in that it is characterized by darker greenish-gray/black claystone. Soft sediment deformation, including convoluted and overturned bedding, is also present in Subunit IIIA (Cores U1514C-27R to 29R, 430.4–455.31 m CSF-A).

Biostratigraphy and Micropaleontology

Samples from core catchers in Holes U1514A and U1514C were analyzed for calcareous nannofossil, planktonic, and benthic foraminifera. As necessary, additional samples from split core sections were evaluated for calcareous nannofossils and/or planktonic foraminiferal assemblages. Calcareous nannofossil and planktonic foraminiferal datums form the chronologic framework for Site U1514. Sediment accumulation rates vary throughout the section with the lowest values recorded in the Neogene and Cretaceous (3–9 m/My) and highest values (~14 m/My) in the Eocene and Paleocene. There are major unconformities present in the lower Pleistocene, Pliocene, Miocene, and Oligocene.

The nannofossil biostratigraphy of Hole U1514A spans from Pliocene Subzone CN12a to lower Eocene Zone CC9b, while Hole U1514C spans middle Eocene Subzone CP13b to Subzones CC8b–c of the early Albian. Planktonic foraminiferal assemblages recovered at Site U1514 are generally rare and show poor to moderate preservation, although discrete samples in the Pleistocene, Paleocene, Turonian, and Albian contain seemingly unrecrystallized specimens. Planktonic foraminiferal communities in Hole U1514A span Pleistocene Zone Pt1a through lower Eocene Zone E4. Hole U1514C ranges from middle Eocene Zones E8–E9 to the *Thalmanninella appenninica*/*Pseudothalmanninella ticinensis* Zones of the upper Albian. A seemingly complete (at least to biozone level), although bioturbated, Cretaceous/Paleogene boundary section was recovered in Section U1514C-23R-2. Benthic foraminiferal assemblages are dominated by epifaunal, calcareous-walled taxa indicating bathyal to abyssal paleowater depths throughout the recovered interval.

Paleomagnetism

The natural remanent magnetization (NRM) of all archive-half core sections and 82 discrete samples collected from the working halves of Holes U1514A and U1514C was determined. The archive halves were stepwise treated with up to 20 or 30 mT alternating field (AF) demagnetization and measured with the pass-through superconducting rock magnetometer (SRM) at 5 cm intervals. Discrete samples were progressively demagnetized up to 60 mT and measured with the SRM. The NRM intensity of the recovered cores is in the order of 10^{-6} to 1 A/m and broadly covaries with lithology. The demagnetization results show that inclinations after the 20 mT demagnetization step exhibit intervals dominated by positive and negative inclination values, defining an almost complete magnetic polarity sequence from Chron C1n (Brunhes Chron) to C34n, the long Cretaceous Normal Superchron, with 74 identified and dated reversals. The magnetic data are of excellent quality in the cores recovered with the APC system (0 to ~180 m CSF-A) and exhibit larger scatter caused by drilling disturbance in the cores recovered with the XCB and RCB systems. The sequence is interrupted by four hiatuses at 11,

18, 30, and 41 m CSF-A, identified by sharp lithological boundaries in conjunction with biostratigraphic constraints.

Petrophysics

Magnetic susceptibility (MS), gamma ray attenuation (GRA), natural gamma radiation (NGR), thermal conductivity, *P*-wave velocity, color reflectance spectroscopy and colorimetry (RSC), and moisture and density (MAD) were measured on whole-round, split-core sections, and discrete samples from Site U1514. Several unique features are identifiable using the physical properties data—these include distinct signals in the NGR, MS, and GRA data near the C19r event (~152 m CSF-A), the Paleocene–Eocene Thermal Maximum interval (~275–280 m CSF-A), the Cretaceous/Paleogene boundary (382–415 m CSF-A), as well as the Cenomanian–Turonian interval (415–445 m CSF-A). However, the latter is within a zone of soft sediment deformation. The MS values vary between 1.76 to 50.48 IU and consist of sections of high and low frequency variations downhole. Bulk density estimated from GRA ranges from 1.6 to 1.9 g/cm^3. The NGR values range from 0 to 105 counts/s, with high amplitude cyclic fluctuations downhole coincident with changes in sediment color observed using RSC. The bulk density, grain density, and porosity of cored material were measured on discrete samples. These data show several unexpected trends. There are several sections where porosity increases with depth. This is assumed to reflect small-scale lithological changes and/or is associated with soft sediment deformation that may have led to several packages of material being more compacted than over- or underlying beds. *P*-wave velocities range from ~1500 m/s near the seafloor to up to ~2100 m/s by ~290 m CSF-A. However, there is a zone where the velocities are scattered between 165–290 m CSF-A. At greater depths, *P*-wave velocities incrementally increase, reaching values of up to 2050 m/s. In addition, in situ temperature measurements were obtained from Hole U1514A with the APCT-3 tool and these were combined with thermal conductivity data to determine heat flow (45–49 mW/m^2).

Downhole logging was conducted in Hole U1514C and provided information over coring gaps when recovery is <100%. The most striking features include several peaks in NGR values at ~395 m, ~425 m, ~445 m, and between 455–480 m WMSF. Interestingly, the two peaks in the NGR log at ~395 m and ~425 m WMSF correspond to a decrease in bulk density, sonic velocities, and resistivity, as well as more clay-rich lithofacies. There are also notable slower sonic velocities between 420–440 m WMSF, which could (at least partially) reflect a thick zone of soft sediment deformation.

Geochemistry

The geochemistry program was designed to characterize the composition of interstitial water (IW) and bulk sediments and to assess the potential presence of volatile hydrocarbons for routine safety monitoring. Samples were taken from both Holes U1514A and U1514C. A total of 56 headspace gas samples were taken, with only low concentrations of methane (≤90 ppm) and trace levels of ethane detected.

For IW analyses, 54 samples were recovered from Holes U1514A (0–247.75 m CSF-A) and U1514C (254.96–515.66 m CSF-A). The salinity of IW samples is generally constant, with the exception of distinctly fresher IW in lithostratigraphic Unit IIIB. This low salinity interval is reflected as decreases in concentration for many elemental profiles, particularly the bromide and chloride profiles, and reflect an input of fresher water. The dissolved magnesium, potassium, calcium, lithium, strontium, and sodium concentration profiles reflect alteration of volcanic material from depths below the cored interval. Moderate sulfate reduction was detected, as sulfate is present but decreases with depth, and barium concentrations are correspondingly low. Dissolved silicon reflects the presence of biogenic opal A in Units I, II and the top part of IIIA; lower concentrations at the bottom of Unit IIIA and in IIIB may reflect the opalA/CT transition. Periodic elevated manganese and iron concentrations demonstrate the reducing character of the sedimentary sequence at certain intervals at this Site.

A total of 64 bulk sediment samples were collected to ~513 m CSF-A (Core U1514C-35R). Additional samples were measured from suspected OAE intervals. $CaCO_3$ content varies from 0–90 wt%, reflecting variations in major lithologic components. The total organic carbon (TOC) was generally less than 0.3%, except in the OAE 1d interval where TOC reached 1.2%. Total nitrogen was generally below the detection limit. A total of eight working-half samples from the potential OAE intervals were analyzed on the source rock analyzer. While the lower TOC samples were generally inconclusive, kerogen in samples with higher concentrations of TOC (>1%) were found to be predominantly terrestrial in source.

Stratigraphic correlation

Three holes were cored at Site U1514. Recovery in Hole U1514A was excellent (near 100%), and the summed recovery of Holes U1514A and U1514C was 65%. Before and during the coring of Hole U1514C, target depths were recommended, which aided the bridging of coring gaps in Hole U1514A. A splice was created for the overlapping portion of the lower Eocene, spanning 195.6 to 266.1 m CCSF in Holes U1514A and U1514C. This splice was established by identifying similar trends in NGR and subsequent comparison of high-resolution physical property data. Recognition of sharp peaks in NGR enabled correlation of core data to wireline logging results and confirmed the accuracy of the splice. Together, Holes U1514A and U1514C span the end-Albian to the present, with good coverage over much of the Paleogene and the late Cretaceous, including a seemingly complete record over the Cretaceous/Paleogene boundary in Core U1514C-23R. Downhole, a multicolored interval of deformed sediments spanning Cores U1514C-27R to 29R suggests significant downslope transport for this interval.