IODP Expedition 369: Australia Cretaceous Climate and Tectonics

Site U1513 Summary

Background and Objectives

IODP Site U1513 (proposed Site MBAS-4C), on the western margin of the Mentelle Basin, had the following objectives: (1) to obtain a continuous late Cretaceous sediment to improve the record of the rise and fall of the Cretaceous Hot Greenhouse climate at southern high latitudes; (2) to characterize how oceanographic conditions changed during the Cenozoic opening of the Tasman Passage and the restriction of the Indonesian Gateway; and (3) to obtain basalt from the base of the sedimentary sequence to provide stratigraphic control on the age and nature of the pre-Gondwana breakup succession. A particularly important goal was to obtain a complete Oceanic Anoxic Event (OAE) 2 sequence across the Cenomanian/Turonian boundary (CTB). Site U1513 is ~1 km east-northeast of DSDP Site 258.

Operations

The transit to Site U1513 covered 795 nmi at an average speed of 9.1 kt. The ship arrived on site, lowered the thrusters and ended the sea voyage at 1445 h on 18 October 2017. The acoustic positioning beacon was deployed at 1510 h. Overall, Site U1513 consisted of coring operations in four holes and logging operations in two. Hole U1513A (33°47.6084′S, 112°29.1338′E; 2789 m water depth) was cored with the advanced piston corer (both full length [APC] and half-length [HLAPC] core barrels) and the extended core barrel (XCB) systems, and was started at 0340 h on 19 October. Coring extended to 292.5 m in Hole U1513A, and crossed one of the critical boundaries for the expedition (Cenomanian/Turonian [CTB]). The APC system recovered 69.98 m of 71.2 m cored (98%), the HLAPC recovered 23.89 m from 24.5 m cored (98%), and the XCB system recovered 76.73 m of 196.8 m cored (39%). At the conclusion of coring, the hole was displaced with heavy mud and the drill string was pulled back to logging depth (83.9 m). A modified triple combination tool string (44.48 m long) 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. In this modified tool string, the HNGS was moved to the bottom of the tool string and the DSI was added from the Formation Micro-Scanner (FMS) tool string. These instruments measured density, downhole sonic velocity, resistivity, and natural gamma radiation of the borehole, while the EDTC transmitted data upstring to the ship. The tool string was deployed at 0500 h on 23 October. A complete log was accomplished from the end of the pipe to 289.8 m. The tool string was back on the rig floor at 0950 h and disassembled and stowed by 1130 h. The drill string cleared the seafloor at 1210 h on 23 October, ending Hole U1513A. The vessel was offset 20 m east, and Hole U1513B (33°47.6087′S, 112°29.1471′E; 2787 m water depth) was started at

1425 h on 23 October, and was cored with the APC/HLAPC. Cores 1H through 14F were recovered to 98.6 m. Cores 1H to 8H were oriented with the IceField orientation tool. In total, the APC recovered 75.07 m of 72.3 m cored (104%) and the HLAPC recovered 26.99 m from 26.3 m cored (103%). The drill string was pulled clear of the seafloor and Hole U1513B ended at 0625 h on 24 October. The vessel was offset 20 m south, and Hole U1513C (33°47.6190′S, 112°29.1468′E; 2787 m water depth) was started at 0730 h on 24 October. Two APC cores were recovered to 17.1 m (recovery 17.37 m; 102%) and were completely sectioned into 30 cm whole rounds then placed into opaque bags on the catwalk for postexpedition analysis of optically stimulated luminescence (OSL). Hole U1513C ended at 1645 h on 24 October. Preparations were then made to core with the rotary core barrel (RCB) system and the vessel was offset 20 m west. Hole U1531D (33°47.6196′S, 112°29.1339′E; 2789 m water depth) was started at 0135 h on 25 October. After drilling without coring to 95 m, coring initiated with the recovery of Core 2R and continued through Core 15R to 229.4 m. Half-length (4.8 m) advances were cut to recover Cores 16R to 19R, to improve recovery across the CTB at ~240 m. Cores 20R to Core 56R were full length penetrations and extended the hole to 603.8 m. Core 56R was were recovered at 1200 h on 28 October. The weather was forecast to deteriorate so we stopped coring and deployed a free-fall funnel at 1437 h. An attempt was made to verify its landing with the subsea vibration isolated television (VIT) camera system, but this was aborted at 700 m due to rough seas and a strong current. The VIT was back onboard at 1615 h. The end of the pipe was then set at 139.2 m, and we waited for the weather to calm. At 1200 h on the 29 October, the drill string was lowered back down the hole and the bit reached the bottom of the hole at 2215 h. RCB coring resumed with 57R at 603.8 m. Cores 58R to 65R were then recovered. A hard contact was encountered at 692 m while coring Core 66R—this was the sediment/basalt contact. Cores 66R through 75R were recovered to 757.4 m at 1700 h on 31 October. In total, 437.05 m was recovered from 662.4 m cored (66%) with the RCB system. After releasing the RCB bit at the bottom of the hole and bringing the drill pipe up to logging depth (146.3 m), the same modified triple combination tool string as run in Hole U1513A was assembled, but with the magnetic susceptibility sonde (MSS) added. The tool string was deployed at 0200 h on 1 November. The tool string encountered an obstruction at 346 m and several unsuccessful attempts were made to move past it. The hole was logged up from that depth and the tool string recovered to the rig floor. We then replaced the bottom tool on the triple combination tool string (MSS) with the hole-finder tool. It was deployed again at 0955 h, but also encountered an obstruction at 337 m. The logging run was aborted; the tool string was back on the rig floor at 1405 h and disassembled at 1545 h. The drill string was then pulled out of the hole, clearing the seafloor at 1637 h. The drill string was back on the rig floor at 0130 h on 2 November, which ended Hole U1513D and Site U1513. While bringing the drill string back up to the rig floor, several attempts were made to release the acoustic positioning beacon. The beacon responded, recognizing the command to release, but the release mechanism malfunctioned. As a result, the beacon was abandoned. The thrusters were raised and the transit to Site U1514 began at 0142 h on 2 November. Overall, 14.4 d (18 October to 2 November) were spent at Site U1513.

Principal Results

Lithology

The cored section at Site U1513 is divided into six lithostratigraphic units, five that are sedimentary and one igneous, based on a combination of data from Holes U1513A, U1513B, and U1513D. Lithostratigraphic units and boundaries are defined by changes in lithology as identified by macroscopic core description, microscopic examination of smear slides and thin sections, and X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses. Unit I is a 64.93 m thick sequence of light gray to pale yellow calcareous ooze and nannofossil ooze with sponge spicules that is Pleistocene–late Miocene in age. Unit II is a 182.93 m thick sequence of Campanian–Cenomanian white to greenish gray calcareous and nannofossil ooze/chalk, and clayey nannofossil chalk with intervals of silicified limestone. Unit III is a 21.87 m thick sequence of alternating greenish gray, light gray, and black nannofossil-rich claystone that is Cenomanian in age. Unit IV is a 187.12 m thick sequence of black claystone and nannofossil-rich claystone that is Cenomanian–Albian in age. Unit V, described only from Hole U1513D, is a 234.25 m thick sequence of sandstone with siltstone and silty claystone that is Aptian to Valanginian in age. Unit VI is a 66.49 m thick alternation of extrusive basalt flows and breccia intruded by a diabase dike, all with unknown ages, and also only recovered from Hole U1513D. The four extrusive sequences and three intercalating volcaniclastic breccia in Unit VI comprise Lithologic Units 1–7.

Biostratigraphy and Micropaleontology

Samples from all core catchers from Holes U1513A and U1513D were analyzed for calcareous nannofossils as well as planktonic and benthic foraminifera.

Calcareous nannofossils

From Hole U1513A, Sample U1513A-1H-CC is in calcareous nannofossil Zone CN15 (upper Pleistocene/Holocene). The base of Cores U1513A-2H and 3H are assigned a Middle Pleistocene age (Zone CN14a) and Sample U1513A-4H-CC is in upper Pliocene Zone CN12a. Samples U1513A-5H-CC through 7H-CC contain mixed assemblages of Neogene and Paleogene species. The base of Core U1513A-8H is a calcareous ooze with fragmented manganese oxide nodules and phosphatized limestone that contains a mixed assemblage with species derived from the late Cretaceous, Paleogene, and the Neogene. Cores U1513A-9H to 15F are dated to the earliest Campanian. Upper Santonian Subzone CC16b is in the base of Core U1513A-16X, and lower Santonian Subzone CC16a is found in Sample U1513A-17X-CC. The interval between Cores U1513A-18X to 23X is assigned to upper Coniacian Zone CC15. Cores U1513A-24X to 28X are assigned to middle to lower Coniacian Zone CC14. The Turonian to lower Albian succession is described from Hole U1513D. The base of Core U1513D-10R is assigned to upper Turonian Zone CC13. The late to middle Turonian ranges from Cores U1513D-11R to 14R, while Core U1513D-15R is assigned to lower Turonian Zone CC11. Cores U1513D-16R to 20R contains a

succession that spans the CTB. Cores U1513D-20R and 21R are correlated with Subzones CC9c-10a of middle to late Cenomanian age. Lower Cenomanian Subzone CC9c is placed from Cores U1513D-23R to 27R. Core U1513D-28R indicates upper Albian Subzone CC9a-b, and Cores U1513D-29R to 31R are placed in Subzone CC8d of late Albian age. The middle Albian spans Cores U1513D-32R to 36R, and Cores U1513D-37R to 39R are early Albian age. Sediments deeper than Core U1513D-39R (~440 m CSF-A) are barren of calcareous nannofossils.

Planktonic foraminifera

Planktonic foraminiferal communities span the Pleistocene though late Miocene and unconformably overlay a lower Campanian through Albian sequence. Pliocene planktonic foraminiferal zones PL5 to PL2 were identified based on the presence of indicative taxa between Samples U1513A-3H-CC and 6H-CC. Sample U1513A-8F-CC is assigned to Miocene Zones M14 to M11, immediately above the unconformity. Beneath the hardgound is a lowermost Campanian through Albian sequence. Samples U1513A-11H-CC to 18X-CC, as well as U1513D-5R-CC to 7R-CC, are assigned the Santonian *Planoheterohelix papula* Zone. Samples U1513A-19X-CC to 27X-CC and U1513D-8R-CC to 11R-CC are of Coniacian age and represent the interval between the base of the *P. papula* Zone and the top of the *F. maslakovae* Zone. The *F. maslakovae* Zone spans Samples U1513A-28X-CC to 32X-CC and U1513D-12R through 15R-CC. Samples U1513A-33X-CC through 46X-CC and U1513D-16R-CC to 25R-CC are frequently barren of planktonic foraminifera or have rare, poorly preserved specimens. From Core U1513A-46X-CC to the bottom of this hole, a middle Cenomanian to late Albian age was inferred. As Hole U1513D extends beyond the base of Hole U1513A, it is subdivided into the *Thalmanninella appenninica*, *Pseudothalmanninella ticinensis,* and *B. breggiensis* Zones of the upper Albian. Samples below U1513D-33R-CC are barren of planktonic foraminifera.

Benthic foraminifera

The Cenozoic benthic foraminiferal assemblages recorded in Cores U1513A-1H to 8F are characterized by abundant calcareous-walled taxa. The species present indicate a bathyal water depth. Two distinctively different benthic foraminiferal assemblages were recorded from the Cretaceous strata. From Cores U1513A-9H to 36X, a bathyal benthic assemblage dominated by calcareous-walled forms was present. The percentage of planktonic foraminifera relative to benthic forms in this interval fluctuates between 80% and 99%. In the Turonian strata, there is a decrease in the number of planktonic individuals, and the percentage of planktonic foraminifera drops to 40% (Cores U1513A-28X to 42X). From Samples U1513A-34X-CC through 49X-CC and U1513D-22R-CC to 40R-CC, agglutinated foraminifera dominate. *Glomospira* spp. is the most common taxon within this interval, suggesting a bathyal water depth. Samples below Core 40R are barren of all benthic foraminifera.

Paleomagnetism

The natural remanent magnetization (NRM) of all archive-half core sections and 98 discrete samples collected from the working halves of Holes U1513A, U1513B, and U1513D were measured. 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 or 80 mT and measured with the spinner magnetometer or the SRM. The NRM intensity of the recovered cores is in the order of 10^{-5} to 1 A/m and broadly covaries with lithology. The calcareous ooze/chalk in the upper part and the basalt in the basal part of Hole U1513D display the weakest and the strongest NRM intensity, respectively. Despite the weak NRM of the calcareous ooze/chalk, the demagnetization results show that inclinations after the 20 mT demagnetization show zones dominated by positive and negative values, defining a magnetic polarity sequence from Chron C1n to C2An.3n for the top ~65 m interval. The inclinations of the ~65 to 450 m CSF-A interval are mostly scattered and the dominant negative values from 200 to 450 m CSF-A indicate a normal polarity, which is assigned to Chron C34n based on the shipboard biostratigraphy. The inclinations below 450 m CSF-A exhibit a distinct pattern of zones of either positive or negative values, establishing a well-defined magnetic polarity sequence. The polarity sequence between 450 and ~690 m CSF-A is tentatively correlated with Chrons M0r to M10N, indicating the absence of most of the Aptian strata and increasing sedimentation rates between ~530 and ~690 m CSF-A. The well-defined reversed and normal polarities below ~690 m CSF-A occur in the basalt unit and cannot be correlated with the geomagnetic polarity timescale (GPTS) without constraints from numerical ages from the basalt.

Petrophysics

Physical property data were obtained with the Whole-Round Multisensor Logger (WRMSL), natural gamma radiation (NGR) logger, *P*-wave velocity caliper, Section Half Multisensor Logger (SHMSL), and discrete samples. The uppermost 35 m preserves cyclicity in NGR (~15 counts/s amplitude, ~5 m thickness) and was deconvolved into uranium, thorium, and potassium concentrations. The CTB interval showed a distinct plateau of ~40 counts/s in NGR values at ~240–245 m CSF-A. Additionally, NGR values preserved a broad trend to higher counts through a mudstone interval spanning 230–455 m CSF-A with a trough near 320 m CSF-A. Below a contact with underlying volcaniclastic sandstones at 455 m CSF-A, NGR values decreased by nearly an order of magnitude from 75 counts/s to 10 counts/s, and magnetic susceptibility (MS) increased by two orders of magnitude from ~10 counts/s to ~1000 counts/s. Similarly, both grain and bulk density step to higher values across this transition. NGR values, and more specifically uranium content, spike across an interval near 675 m CSF-A, possibly signifying abundant terrestrial organic matter. The indurated breccia and crystalline rocks of Unit VI showed spikes in MS and density, along with nearly undetectable counts of NGR. In the overlying sedimentary sequence (Units I–V), trends in porosity and caliper *P*-wave velocity

measurements demonstrated a gradual, but occasionally punctuated, change to lower and higher values, respectively.

Downhole logging was conducted in Holes U1513A and U1513D using the modified triple combination tool string, measuring NGR, density, sonic velocity, and resistivity. The measurements from each hole yielded similar results for the overlapping depth intervals in intervals with good hole conditions. In general, logs from Hole U1513A are more complete; the logging tools encountered obstructions in Hole U1513D and provided no data deeper than that already obtained from Hole U1513A. The wireline logging data provided continuous coverage and filled several coring gaps. The most striking features included a strong positive response in resistivity, density, and sonic velocity values through intervals of silicified limestone (96–123 m and 152–180 m WMSF; Lithostratigraphic Unit II), as well as a downhole shift from high to low sonic velocity, resistivity, and density, and a shift from low to high NGR across the CTB interval (~240–245 m WMSF). In situ temperature measurements were attempted from Hole U1513B, but this experiment returned only one reliable measurement of 4.55°C from Core 5H.

Geochemistry

The geochemistry program at Site U1513 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 U1513A and U1513D. All of the 90 headspace gas samples showed only low concentrations of methane (≤60 ppm) and trace levels of ethane and propane.

For IW analyses, 60 samples were recovered from squeezing 10 cm whole rounds, covering 0–366.44 m CSF-A and 471.83–687.35 m CSF-A. The salinity of IW samples was generally constant, with the exception of distinctly fresher IW between 281.81–303.03 m CSF-A; this is also seen in the bromide and chloride profiles, and may reflect a low salinity water source in this interval. The dissolved magnesium, potassium, and sodium concentration profiles reflect alteration of volcanic material found in lithostratigraphic Units IV and V. No evidence for significant sulfate reduction was detected; sulfate is present throughout, and barium concentrations are correspondingly low. The dissolved calcium and strontium concentration profiles primarily reflect the release of these elements during the alteration reactions of volcanic material. Lithium appears to have been released in Unit IV, then is incorporated into alteration products in Unit V. Dissolved silicon reflects the presence of biogenic opal A in Units I and II; lower concentrations in Units III and V may reflect the opalA/CT and CT to quartz transition, respectively. Elevated manganese concentrations demonstrate the reducing character of the sedimentary sequence below Unit I.

In addition, 129 bulk sediment samples were collected down to ~690 m CSF-A (Core U1513D-65R), the contact with igneous material. Additional samples were measured at a higher resolution through the putative OAE2 and OAE1d intervals. $CaCO_3$ content varies from 0–93 wt%, reflecting variations in lithology. The total organic carbon (TOC) was broadly less than

1% except in the OAE2 interval where TOC reached 10.5%. Total nitrogen was generally below detection limit. A total of 57 samples with TOC ≥0.8% and working-half samples from the OAE2 and OAE1d intervals were analyzed with the source rock analyzer. While the lower TOC samples were generally inconclusive, samples with higher concentrations of TOC (>3%) were found to be predominantly marine in source.

Stratigraphic correlation

Four holes were cored at Site U1513. Recovery in any one hole ranged from poor to excellent, but when combined overall recovery was excellent for most of the interval penetrated and spanned the Valanginian through the present. Splices were constructed for the intervals from 0 to 95 m CCSF (Holes U1513A and U1513C) and from 220 to 295 m CCSF (Holes U1513A and U1513D). These splices cover the late Miocene through present and the middle Cenomanian through the middle Turonian, respectively, as estimated from bio- and magnetostratigraphy. Portions of both splices were formed by appending subsequent cores from the same hole due to aligned core breaks or to poor recovery in the other hole (i.e., there was no bridge across core breaks in these intervals). However, correlation to downhole logging data minimized the uncertainty introduced by this approach. The interval from 95 m to 220 m CSF-A was recovered in both Holes U1513A and U1513D. Despite this, no splice was attempted because recovery was too low to meaningfully correlate at the meter scale in this interval, but pooled data suggest recovery should be sufficient to generate good records with 1 My resolution. The interval from 295 m to 757.4 m CSF-A was only cored in Hole U1513D, but recovery was generally very good to excellent. It averaged 82% across ~70 m of basalt and basaltic breccia (Unit VI) and 75% over the 395 m of overlying sandstones and claystones (Unit V) between the basalt and the lower splice. The oldest biostratigraphic date for these overlying sediments is middle Albian, whereas magnetostratigraphy suggested portions could be older.