IODP Expedition 363: Western Pacific Warm Pool

Site U1485 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1485 (proposed Site WP-72A) is located ~19 km offshore the northern coast of Papua New Guinea at 3°06.16′S, 142°47.59′E, and 1145 m below sea level (mbsl). The site is situated on seismic reflection profile Line RR1313-WP7-2, ~2000 m northeast of the cross-point with seismic reflection profile Line RR1313-WP7-5, and ~3.2 km north–northeast of the location of Site U1484. A ~7 m piston core retrieved ~4 km to the southwest of the site location is characterized by a mixture of clay and volcanic sand containing relatively high numbers of planktonic and benthic foraminifers in excellent state of preservation. Preliminary isotope analysis of planktonic foraminifers from that core indicates >6 m of Holocene implying sedimentation rates of ~60 cm/ky. The multichannel seismic (MCS) profiles exhibit remarkable uniformity of acoustic stratification indicating a succession of alternating clay-, silt-, and sand-dominated sediment beds down to 0.4 s two-way traveltime (TWT) below the surface with estimated depth of 350 m below seafloor (mbsf), just deeper than our target drilling depth of 325 mbsf. There is evidence for a disturbed layer between 0.16 and 0.19 s TWT, but bedding is very uniform below this interval down to the target depth. This site extends the record recovered at Site U1484.

Site U1485 is located in a tectonically complex region east of the Cyclops Mountains and west of the Sepik/Ramu river mouth. The region is bounded to the south by the Bewani-Torricelli fault zone on land, which links to offshore transform faults that eventually connect with seafloor spreading along the Bismarck Sea seismic lineation to the east (Baldwin et al., 2012). Northwest of the site, the southward subduction of the Caroline microplate forms the New Guinea trench. The continental shelf in this region is exceedingly narrow (<2 km), allowing large amounts of terrigenous sediment discharge from coastal rivers to bypass the narrow continental shelf and eventually accumulate in deeper water (Milliman et al., 1999).

The climatology and oceanography of northern Papua New Guinea is strongly influenced by the seasonal migration of the Inter-Tropical Convergence Zone, with enhanced precipitation during boreal winter. Interannually, precipitation decreases during El Niño events. Monsoon winds control the surface hydrography of the region, such that the New Guinea Coastal Current flows westward over the drill sites during the boreal summer southeasterly monsoon (also referred to as the austral summer monsoon in the southern hemisphere) (Kuroda, 2000). These currents distribute sediments originating from the Sepik/Ramu river mouth and multitudes of other tributaries along the coast over the northern slopes of Papua New Guinea and adjacent deep basins. The surface current reverses during the boreal winter northwesterly monsoon (Kuroda, 2000), and the surface sediment plume from the Sepik River is observed to meander out across the Bismarck Sea (Steinberg et al., 2006). However, the New Guinea Coastal Undercurrent persists in a westward direction year round at a water depth of ~220 m, widening and strengthening during boreal summer (Kuroda, 2000). This undercurrent supplies terrigenous sediments from the near bottom river plumes to the drill sites. At a depth of ~1000 m below sea level, the sediment is bathed in Antarctic Intermediate Water.

The high sedimentation rates at Site U1485 provide the potential to resolve late middle to late Pleistocene centennial- to millennial-scale climate variability in the Western Pacific Warm Pool. Comparing these high-resolution records with comparable ones for the North Atlantic and eastern equatorial Pacific will allow us to better constrain the mechanisms influencing millennial-scale variability. This site will also provide insights on orbital-scale variability during the late middle to late Pleistocene. Finally, Site U1485 will allow us to examine the southern Pacific contribution to the Indonesian Throughflow (ITF).

Operations

After a 1.85 nmi transit in dynamic positioning mode from Site U1484, the vessel stabilized over Site U1485 at 1110 h (all times are local ship time; UTC + 10 h) on 10 November 2016. The operations plan included three holes using the advanced piston corer (APC) and half-length advanced piston corer (HLAPC) to 315 mbsf. We ultimately cored four holes: U1485A and U1485B were cored to ~300 m below seafloor (mbsf). Hole U1485C was terminated after three cores when it proved unsuitable for covering core gaps for stratigraphic correlation. Hole U1485D was cored to 63.9 mbsf to fill core gaps and intervals where significant numbers of interstitial water (IW) samples were taken from each core in Hole U1485A.

Hole U1485A was cored to 188.0 mbsf with the APC coring system using orientation and nonmagnetic hardware (Cores 363-U1485A-1H through 20H). After pumping Core 20H out of the core barrel, we switched to the HLAPC coring system and continued coring to 300.8 mbsf (Cores 21F through 44F), where we encountered a partial stroke, indicating HLAPC refusal. Since we had reached our age target, we decided not to deepen the hole further using the extended core barrel (XCB) coring system. As Site U1485 is located only ~3.2 km from Site U1484, we opted not to take downhole temperature measurements. Whole-round samples for high-resolution interstitial water (IW) analyses were taken at a frequency of one per section in the upper ~54 mbsf of Hole U1485A. A total of 312.36 m of sediment was recovered over 300.8 m of coring (104% recovery) in Hole U1485A.

Since core recovery was generally good in the upper 190 mbsf, we opted not to switch to the HLAPC coring system over the interval with higher sand content that had resulted in poor recovery with the full length APC at Site U1484. Hole U1485B cored to 173.5 mbsf (Cores 363-U1485B-1H through 20H) using the APC coring system with orientation and nonmagnetic hardware. We then switched to the HLAPC coring system and continued coring to 297.7 mbsf (Cores 21F through 47F), with one 2 m drilled interval to offset core gaps for stratigraphic correlation. We recovered 291.18 m of core over 295.7 m of coring (98% recovery) in Hole U1485B.

Oriented APC coring with nonmagnetic hardware then continued in Hole U1485C; however, after data collected for stratigraphic correlation indicated that Core 363-U1485C-2H was a copy of Core U1485C-1H, we terminated the hole. Hole U1485C cored to 27.5 mbsf (Cores 1H through 3H) and recovered 29.35 m of sediment (107% recovery). Hole U1485D was cored specifically to contribute material to the stratigraphic splice, particularly over the interval of high-resolution IW sampling above 55 mbsf. Oriented APC coring with nonmagnetic hardware penetrated to 63.9 mbsf (Cores U1485D-1H through 8H), with one 1 m drilled interval to cover a core gap. A total of 68.22 m of core was collected over 62.9 m of coring (108% recovery). Operations at Site U1485 ended at 2330 h on 13 November 2016. Total time spent on the site was 85.8 h (3.6 d).

A total of 50 APC cores were recovered at this site, collecting 452.28 m of sediment over 451.9 m of coring (100% recovery). We also collected 50 HLAPC cores, recovering 248.73 m of sediment over 235 m of coring (106% recovery).

Principal Results

A ~300 m succession was recovered in four holes at Site U1485. The upper ~225 mbsf is similar to the stratigraphy at Site U1484, which is located only ~3.2 km south–southwest of the site. The sediment at Site U1485 is assigned to a single lithologic unit composed of ~300 m of middle Pleistocene to recent terrigenous and hemipelagic sediment. Lithologic Unit I is divided into two subunits. Subunit IA is an ~216 m sequence of middle Pleistocene to recent sediment composed of three main components: dark greenish gray clay, silt, and sand that is equivalent to lithologic Unit I at Site U1484. The relative abundances of these terrigenous components vary downhole. Subordinate amounts of nannofossils and foraminifers are mixed with the terrigenous sediment and fine-grained intervals alternate with discrete layers of sand- and silt-size sediments. As in Site U1484, the upper ~8 mbsf is characterized by thick (decimeter to meter) clay layers with variable amounts of silt and several centimeter to decimeter thick sand layers. From ~8 to 127 mbsf, coarser-grained material becomes more abundant, with the frequency and thickness of sand layers increasing downhole, although clay-rich intervals are still present over this interval. Two thick sand intervals occur between ~127 and 165 mbsf, separated by a 6 m thick interval of hemipelagic clay. From ~165 to 216 mbsf, the sediment consists of clay with variable amounts of silt and nannofossils, interbedded with thinner sand layers. Shallow-water benthic foraminifers are less frequent in the sand layers at this site compared with Site U1484, whereas shell and wood fragments are common. The sand layers typically have sharp bases and show both normal and reverse grading. The sand-size material at Site U1485 consists of four main components: minerals (feldspar, pyroxene, amphibole, and chlorite), volcanic and plutonic rock fragments, mineraloids (pyritized glauconite), and biogenic particles (foraminifers). Sulfide patches are also present, with pyrite occurring frequently below ~165 mbsf. Lithologic Subunit IB is an ~85 m succession dominated by dark gray clay with variable amounts of silt and nannofossils. The absence of thick sand layers distinguishes this subunit from Subunit IA. A nannofossil-rich clay layer is present from ~226 to 240 mbsf. This interval also has higher carbonate content than the rest of the succession. A number of discrete tephra layers up to 4 cm thick are present throughout the succession at Site U1485.

The succession at Site U1485 contains well-preserved calcareous nannofossils, planktonic foraminifers, and benthic foraminifers. Calcareous nannofossil and planktonic foraminifer assemblages are very similar to those at Site U1484; however, the benthic foraminifer assemblages show less influence from downslope transport. The planktonic to benthic foraminifer ratios are consistently around 99:1 (compared with 70:30 at Site U1484). Only a few intervals contain the shallow-water taxon *Rotalinoides compressiusculus*, whereas the bulk of the assemblage is dominated by typical bathyal forms.

Calcareous nannofossil and planktonic foraminifer biostratigraphy indicates that Hole U1485A spans the upper part of the middle Pleistocene to the late Pleistocene. The upper ~183 mbsf of the succession is within Zone NN21 (late middle to late Pleistocene), identified by the biohorizon base *Emiliania huxleyi* (0.29 Ma) between ~179 and 186 mbsf. From ~183 to 255 mbsf, the sequence is assigned to Zone NN20 based on the absence of *E. huxleyi* and *Pseudoemiliania lacunosa*. The biohorizon top *P. lacunosa* (0.44 Ma), found between ~254 and 257 mbsf, indicates the top of Zone NN19. The remainder of the cored succession to 300 mbsf is assigned to the upper part of Zone NN19 (middle Pleistocene). The absence of *Globorotalia tosaensis* (the marker for Subzone Pt1a) assigns the entire section recovered at Hole U1485A to Subzone Pt1b (<0.61 Ma). Together, nannofossil and planktonic foraminifer biostratigraphy indicates an age between 0.61 and 0.44 Ma for the bottom of the succession at Hole U1485A. The middle/upper Pleistocene boundary (0.126 Ma) is located between the biohorizons top acme *Gephyrocapsa caribbeanica* (0.28 Ma) and top *Globigerinoides ruber* (pink) (0.12 Ma) at a depth of ~84 mbsf. Sedimentation rates based on calcareous nannofossil and planktonic foraminifer bioevents are ~62.5 cm/ky.

Paleomagnetic investigations at Site U1485 involved measurement of the natural remanent magnetization (NRM) of archive halves from all holes before and after demagnetization in a peak alternating field (AF) of 10 mT (Holes U1485A and U1485D) and 15 mT (Holes U1485B and U1485C). Sixty-three discrete samples were also taken to investigate paleomagnetic carriers and rock magnetic properties. Whole-Round Multisensor Logger (WRMSL) magnetic susceptibility (MS) data average 433×10^{-5} SI units that, when coupled with average mass corrected MS (χ) ($2.2 \pm 1.4 \times 10^{-6}$ m^3 kg^{-1} as 2 standard deviations) and saturation remanent magnetism (SIRM) ($10 \pm 4.2 \times 10^{-3}$ Am^2 kg^{-1} as 2 σ) values, suggest relatively high (ferri)magnetic mineral concentration in the upper 180 mbsf at Site U1485. High (>95%) isothermal remanent magnetization $(IRM)_{300mT}/IRM_{1000mT}$ ratios suggest that ferrimagnetic minerals (e.g., (titano)magnetite [$Fe_xTi_xO_4$], maghemite [γ-Fe_2O_3]) are the main remanence carrier of the sediment, which likely results from high terrigenous input as Site U1485 is located only ~19 km north of Papua New Guinea. Accompanied by relatively fine ferrimagnetic grain sizes, these data suggest that sediment diagenesis has relatively little effect on the primary magnetic assemblage and that rock magnetic properties are dominated by relatively unaltered terrestrial source inputs. As a result, the NRM is more likely to result from (post-) depositional remanent magnetization (pDRM) acquisition and can potentially be used to understand and reconstruct paleogeomagnetic field behavior. Below 180 mbsf, WRMSL MS and χ decrease to relatively low values (WRMSL MS average 110×10^{-5} SI units; χ average $0.6 \pm 0.6 \times 10^{-6}$ m^3 kg^{-1}). SRM measured NRM, NRM_{10mT}, and NRM_{15mT} are lower and more variable below ~180 mbsf and ferrimagnetic grain size is distinctly coarser (lower χARM/SIRM) in the more variable NRM intensity interval below ~240 mbsf. This interval was not cored at Site U1484 and it is coincident with the occurrence of extensive pyrite in the recovered sediments. These signatures are indicative of sediment diagenesis that may be progressively altering the magnetic assemblage at depth (e.g., Karlin and Levi, 1983; Rowan et al., 2009).

Declination in all APC cores from Holes U1485A and U1485B was corrected using the Icefield MI5 tool. For Hole U1485B, azimuthally corrected declination is internally consistent between adjacent cores although it maintains an ~180° baseline offset in absolute values as declination should cluster around 0° during normal polarity. Orientation for Hole U1485A recorded an issue similar to that observed for Hole U1483C, where corrected declination of adjacent cores varies by ~30°–90°. Between core offsets are not observed in the other holes at Site U1485, so the results in Hole U1485A likely result from incorrect correction from the Icefield tool. The tool deployed (Icefield #2007) was the same orientation tool that gave a similar issue at Site U1483C and we conclude that this is a tool-specific issue. This tool will not be used for the remainder of the expedition. To align declination of Holes U1485A and U1485B HLAPC cores (for which orientation tools cannot be deployed) with the corrected APC cores, we average the HLAPC declination record on a core by core basis to a mean of 180°. A similar approach was used for Holes U1485C and U1485D due to battery failure in the Icefield tool during operations.

Inclination for all four holes plots around the expected values of −5.7° for the site latitude assuming a geocentric axial dipole (GAD) field. Steeper values likely result from a steep positive pervasive overprint imparted by the drill string; however, given that declination is not strongly overprinted, we chose not to demagnetize the sediment at higher AFs than 10 or 15 mT.

Sediments in all four holes appear to have been deposited (quasi-)continuously with no major hiatus or erosional surfaces. Inclination plots around a GAD predicted value for the site latitude and declination maintains a consistent value averaging around 180° for all corrected APC cores in Hole U1485B. These observations are consistent with sediment deposition during the Brunhes Chron (C1n) after 0.781 Ma. These findings are in agreement with biostratigraphic datums that suggest that the base of Site U1485 is between 0.61 and 0.44 Ma.

The physical properties correlate well with the alternating clay and silty sand lithologies at Site U1485 over both short and longer scales. Due to the high sedimentation rates, the effect of increased compaction with depth is only minor at this site. The gamma ray attenuation (GRA) bulk density and MS are particularly sensitive to variations in clay and sand content, recording high frequency variations. GRA bulk density increases rapidly from the seafloor to ~10 mbsf (from 1.5 to 1.65 g/cm^3). From ~10 to 135 mbsf, GRA bulk density displays 10–15 m cycles, with values ranging from 1.4 to 1.85 g/cm^3. Below 185 mbsf, GRA bulk density shows significantly decreased amplitude variability, ranging between 1.35 and 1.5 g/cm^3, which reflects the dominance of clay. Over most of the record, GRA bulk density and MS covary. MS is generally low in clay-rich intervals and shows more variability and higher values in silt- and sand-rich intervals. MS values are consistently low from 0 to 10 mbsf (~150 × 10^{-5} SI). Below this, MS shows similar 10–15 m scale cyclicity as the GRA bulk density record, with values ranging from 50 to >1200 × 10^{-5} SI. In the clay-rich Subunit IB, MS is significantly lower and shows less variability, averaging ~100 × 10^{-5} SI. Natural gamma radiation (NGR) counts range between ~10 and 40 counts/s, with the lower values corresponding to sand intervals. The NGR record also exhibits 10–15 m scale cyclicity, particularly in the interval from ~10 to 135 mbsf.

For Site U1485 we constructed a splice for the entire site using three holes (U1485A, U1485B, and U1485D), but there are gaps in the splice mainly because of incomplete recovery of sand intervals. Hole U1485C was not used for construction of the splice, as the second core appears to repeat the section recovered in the first core, which resulted in termination of coring after only three cores. Gas expansion frequently caused extrusion of sediment out of the top and bottom of the core liner and onto the rig floor, resulting in disturbed sediment, especially in the top and bottom sections of each core, as well as voids throughout the recovered sequence. Tie points were established mainly with WRMSL MS data, supplemented with NGR data. The splice is continuous and well constrained from 0 to 157.41 m core composite depth below seafloor (CCSF). Reduced core recovery in the relatively sand-rich interval from 157.41 to 222.11 m CCSF and gaps aligned between HLAPC cores of adjacent holes from 222.11 to 267.34 m CCSF resulted in a discontinuous splice over this interval. From 267.34 m CCSF to the bottom of the cored section at 373.35 m CCSF the splice is tentative due to voids caused by gas expansion, low amplitude magnetic susceptibility values, and low resolution natural gamma radiation counts used to establish correlations.

A total of 60 interstitial water (IW) samples were collected from the seafloor to 295 mbsf in Hole U1485A. Thirty-six IW samples were analyzed on the ship, whereas the remainder were fixed for shorebased analyses. The IW geochemical profiles at Site U1485 closely resemble those obtained at nearby Site U1484. Near complete consumption of dissolved SO_4^{2-} is achieved at ~12 mbsf, coincident with an abrupt increase of CH_4 at the sulfate-methane transition zone (SMTZ). Below the SMTZ, most samples are characterized by high methane/ethane ratios (C_1/C_2), suggesting that methane is mostly of biogenic origin. The total organic carbon (TOC) content at Site U1485 is slightly higher than at Site U1484, ranging from ~0.3 to 1.2 wt%. The

TOC/total nitrogen (TN) ratios are usually lower than 10, suggesting that the organic matter deposited at Site U1485 is predominantly of marine origin.

As at Site U1484, Site U1485 displays evidence for anoxic silicate weathering occurring within the methanogenic zone, as inferred from marked enrichments of alkalinity (up to 50 mM), K^+ (13.5 mM), and Mg^{2+} (50 mM) between about 20 and 120 mbsf. These IW patterns most likely indicate partial dissolution of silicate minerals within the anoxic sediment (Wallmann et al., 2008). Similarly, the carbonate content of Site U1485 is generally low, ranging from to 0.7 to 27.0 wt% with an average of 9.0 wt%.

Penetration to deeper depths at Site U1485 (300 mbsf) compared to Site U1484 (223 mbsf) provides a more comprehensive understanding of the sediment/water interactions that occur deeper in the sedimentary sequence at the Papua New Guinean margin. A notable feature is the pronounced downhole depletion observed for several elements (Mg^{2+}, K^+, B, PO_4^{3-}) at depths ranging from about 50 to 120 mbsf, following their respective IW enrichments in the overlying sediment. These depletions also coincide with decreasing total alkalinity and a sudden drop of pH from 8.1 to 7.9. In agreement with results from previous investigations (Michalopoulos and Aller, 1995; Wallmann et al., 2008; Kim et al., 2016), these findings are consistent with secondary clay authigenesis (reverse weathering), a process that releases CO_2, which leads to removal of major cations/anions in the surrounding IW, thereby explaining the observed drop of pH and IW geochemical patterns, respectively.

Finally, abrupt changes in concentration or slope are observed in IW profiles of several elements (e.g., K^+, Mg^{2+}, Na, Br, PO_4^{3-}) coincident with changes in lithology. These changes in lithology likely act as diffusive caps, interrupting communication in IW between the sediments above and below these distinct lithologic changes, thereby imparting slight variations in concentration that overprint the general trends dominated by anoxic sediment weathering and clay mineral authigenesis.

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