IODP Expedition 363: Western Pacific Warm Pool

Site U1484 Summary

Background and Objectives

International Ocean Discovery Program (IODP) Site U1484 (proposed Site WP-71A) is located ~15 km offshore the northern coast of Papua New Guinea at 3°07.93′S, 142°46.98′E, and 1031 m below sea level (mbsl). The site is situated on seismic reflection profile Line RR1313-WP7-2, ~900 m south of the cross-point with seismic reflection profile Line RR1313-WP7-5, and ~1.5 km east of the location of piston core RR1313 32PC. This ~7 m piston core and a companion gravity core from this site are characterized by a mixture of clay and volcanic sand containing relatively high numbers of planktonic and benthic foraminifers in an excellent state of preservation. Preliminary isotope analysis of planktonic foraminifers from the cores indicates >6 m of Holocene implying sedimentation rates of ~60 cm/ky. The multichannel seismic (MCS) survey shows >650 m sediment coverage at this site. The MCS profiles exhibit remarkable uniformity of acoustic stratification indicating a succession of alternating clay-, silt-, and sand-dominated sediment beds down to 0.28 s two-way traveltime (TWT) below the surface with estimated depth of 225 m below seafloor (mbsf), our target drilling depth. Below this depth, the MCS profiles suggest a disturbed zone. We note also a possible disturbed interval between 0.14 and 0.16 s TWT.

Site U1484 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 (mbsl), the sediment is bathed in Antarctic Intermediate Water.

The high sedimentation rates at Site U1484 provide the potential to resolve late middle to late Pleistocene centennial- to millennial-scale climate variability in the Western Pacific Warm Pool (WPWP). 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 mid- to late Pleistocene. Finally, Site U1484 will allow us to examine the southern Pacific contribution to the Indonesian Throughflow.

Operations

After a 2097 nmi transit from Site U1483, which was completed in 7.5 d at an average speed of 11.6 kt, the vessel stabilized over Site U1484 at 2245 h (all times are local ship time; UTC + 10 h) on 6 November 2016. We cored three holes at Site U1484 (proposed Site WP-71A), in accordance with the original operations plan that included coring with the advanced piston corer (APC) to 225 m below seafloor (mbsf) in three holes.

Hole U1484A was cored to 195.0 mbsf with the APC coring system using orientation and nonmagnetic hardware (Cores 363-U1484A-1H through 21H). We had poor recovery within an interval of sand from ~110 to 130 mbsf. After encountering APC refusal, we switched to the half-length advanced piston corer (HLAPC) and continued coring to 223.2 mbsf (Cores 22F through 27F) where we terminated the hole. Downhole temperature measurements using the Advanced Piston Corer Temperature Tool (APCT-3) were taken on Cores 4H (37.1 mbsf), 7H (65.6 mbsf), 10H (94.1 mbsf), 13H (122.6 mbsf), and 16H (147.5 mbsf), obtaining reliable results on three of the five deployments. A total of 220.60 m of sediment was recovered over 223.2 m of coring (99% recovery) in Hole U1484A.

After encountering sand between ~110 and 130 mbsf in Hole U1484A, we altered the operations plan for the remaining holes to include using the HLAPC over that interval to improve recovery. Hole U1484B was cored with the APC coring system using orientation and nonmagnetic hardware to 104.8 mbsf (Cores U1484B-1H through 12H), including one 2 m drilled interval to offset core gaps for stratigraphic correlation. We then switched to the HLAPC system and continued coring to 133.0 mbsf (Cores 13F through 18F), which allowed us to better recover the sand found through that interval (average recovery of 88% in Hole U1484B, compared with 57% in Hole U1484A). We then switched back to the APC and cored to 190 mbsf (Core 19H) using orientation. The remainder of Hole U1484B was cored with the HLAPC to 222.9 mbsf (Cores

25F through 31F) after encountering APC refusal. We recovered 220.51 m of core over 220.9 m of coring (100% average) in Hole U1484B.

Oriented APC coring with nonmagnetic hardware then continued in Hole U1484C to 106.1 mbsf (Cores U1484C-1H through 12H). We then switched to the HLAPC and cored to 145.7 mbsf (Cores 13F through 21F) to recover the sand interval. One drilled interval (2 m) advanced the hole without coring to avoid alignment of core gaps for stratigraphic correlation. We then switched back to the APC and cored to 193.2 mbsf (Cores 22H through 26H). After encountering APC refusal, we finished coring the hole to 221.4 mbsf (Cores 27F through 32F) using the HLAPC coring system. A total of 225.46 m of core was recovered over 219.4 m of coring (103% recovery). Operations at Site U1484 ended at 0945 h on 10 November 2016. Total time spent on the site was 83.0 h (3.5 d).

A total of 55 APC cores were recovered at this site, collecting 515.91 m of sediment over 508.4 m of penetration (102% recovery). We also collected 33 HLAPC cores, recovering 150.66 m of sediment over 155.1 m of penetration (97% recovery).

Principal Results

The sediment cored at Site U1484 is assigned to a single lithologic unit composed of ~224 m of middle Pleistocene to recent terrigenous and hemipelagic sediments. Lithologic Unit I is composed of three main components: dark greenish gray clay, silt, and sand. The relative abundances of clay and silt 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. The upper ~10 mbsf is characterized by decimeter to meter thick clay layers with variable amounts of silt and a few thin (centimeter to decimeter) sand layers. From ~10 to 150 mbsf, the abundance and thickness of sand layers increases downhole. Clay is more abundant between ~150 and 175 mbsf, whereas in the deepest part of the succession, sand and clay layers are present in subequal proportions. The amount of clay and nannofossils in the sand layers is negligible; however, large benthic foraminifers are present within some of the coarse sand layers. Sulfide patches and sponge spicules are found in clay-rich intervals, whereas wood and shell fragments are more common in sand layers. The sand layers typically have sharp bases and show both normal and reverse grading. The sand-size material at Site U1484 consists of four main components: minerals (feldspar, pyroxene, amphibole, and chlorite), volcanic and plutonic rock fragments, mineraloids (pyritized glauconite), and biogenic particles (foraminifers). Several discrete tephra layers up to 5 cm thick are present in the succession.

The sediment succession at Site U1484 contains well-preserved calcareous nannofossils, planktonic foraminifers, and benthic foraminifers. Calcareous nannofossils are not as abundant compared with Sites U1482 and U1483, but benthic foraminifers are more common, with

planktonic to benthic foraminifer ratios reaching 70:30 between ~60 and 150 mbsf. The benthic foraminifer assemblages change downhole, with deeper water species present in the upper and lower parts of the succession, whereas the middle sections include mixed deeper and shallow water benthic foraminifers, including some reef-dwelling forms.

Calcareous nannofossil and planktonic foraminifer biostratigraphy indicates that Hole U1484A spans the upper part of the middle Pleistocene to the late Pleistocene. The upper ~200 mbsf of the succession is within Zone NN21 (late middle to late Pleistocene), identified by the biohorizon base *Emiliania huxleyi* (0.29 Ma) between ~195 and 200 mbsf. The absence of *Globorotalia tosaensis* (the marker for Subzone Pt1a) assigns the entire section recovered at Hole U1484A to Subzone Pt1b. 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 ~100 mbsf. Average estimated linear sedimentation rates based on calcareous nannofossil and planktonic foraminifer bioevents are ~75 cm/ky, indicating that the age at the bottom of Hole U1484A is ~0.29 Ma.

Paleomagnetic investigations at Site U1484 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 as a field of 10–15 mT effectively removes the vertical overprint induced by the drill string. Forty-seven discrete samples were also taken to investigate paleomagnetic carriers and rock magnetic properties. Whole-Round Multisensor Logger (WRMSL) magnetic susceptibility (MS) data average 426×10^{-5} SI units that, when coupled with average mass corrected MS (χ) ($2.2 \pm 3.3 \times 10^{-6}$ m^3 kg^{-1} as 2 standard deviations) and saturation remanent magnetism (SIRM) ($9.1 \pm 10.4 \times 10^{-3}$ Am^2 kg^{-1} as 2 σ) values, suggest relatively high (ferri)magnetic mineral concentration in the sediments deposited at Site U1484, which is located ~15 km north of Papua New Guinea and thus receives a high influx of lithogenic components. 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. Despite observations of pyrite in the lower part of the three holes, the relatively high values of MS and SIRM and relatively fine ferrimagnetic grain sizes suggest that 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.

Azimuthally corrected declination from APC cores from all holes is internally consistent between adjacent cores although it maintains an ~180° baseline offset in absolute values as declination should cluster around 0° for normal polarity. To align declination of 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°. Inclination plots around, or slightly steeper than, 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 that is not removed in a field of 10 mT.

Sediments in all three 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 recovered cores. These observations are consistent with all the sediment recovered at Site U1484 being deposited during the Brunhes Chron (C1n), less than 0.781 Ma. These findings are consistent with biostratigraphic datums that suggest the base of Site U1484 is <0.44 Ma.

The physical properties correlate well with the alternating clay and silty sand lithologies found at Site U1484, even in terms of short-term, decimeter-scale variability. 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 increases rapidly from the seafloor to ~12 mbsf (from 1.5 to 1.75 g/cm^3), and then gradually increases to ~1.8 g/cm^3 at the bottom of the hole. The GRA bulk density probably underestimates the true bulk density compared with discrete moisture and density (MAD) bulk density, in particular in the sand layers. This underestimation is probably due to the gas expansion in the sand-rich layers. The high bulk and grain density values additionally correspond to low carbonate content values (~2–3 wt%) and low total organic carbon content (0.1–0.2 wt%). MS ranges from 50 to >1200 × 10^{-5} SI, with lower values corresponding to clay-rich intervals. Natural gamma radiation (NGR) counts range between ~10 and 30 counts/s, with the lower values corresponding to sand intervals. In all holes, twelve distinct 10–15 m cycles are observed in the GRA bulk density, NGR, and especially in the MS, which broadly reflect alternations between clay-rich and silty sand-rich layers. Downhole temperature measurements made with the APTC-3 indicate a geothermal gradient of 40°C/km.

For Site U1484 we constructed a splice for the entire site using all three holes, but there are gaps in the splice mainly because of incomplete recovery of sand intervals. 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. These factors resulted in relatively high growth factors and made it difficult to correlate data between holes. Tie points were established mainly with WRMSL MS data, supplemented with NGR data. The splice is continuous from 0 to 133.98 m core composite depth below seafloor (CCSF). Below this from 133.98 to 153.85 m CCSF there are at least three core gaps and some tentative tie points. This is underlain by an interval from 153.85 to 270.85 m CCSF that is continuous except for one core gap at 172.55 to 175.28 m CCSF. The deepest interval, from 270.85 to 284.61 m CCSF, has a few core gaps. In sum, although there were some intervals with discontinuous recovery, we calculated offsets for all cores in all three holes, and constructed a nearly continuous splice that has a few gaps.

A total of 24 interstitial water (IW) samples were collected from Hole U1484A from the seafloor to 222.4 mbsf. The IW geochemistry indicates a typical sequence of early diagenetic processes,

driven by the presence of organic matter within the sediment. The total organic carbon (TOC) content ranges between ~0.1 and 1.8 wt% (average of 0.88 wt%). The TOC/total nitrogen (TN) ratios in most samples are lower than 10, suggesting that the organic matter deposited at Site U1484 is mainly of marine origin. The correlations between the downhole profiles of TOC and TN contents suggest that the majority of the nitrogen is organic-bound, with little preferential degradation between organic carbon and nitrogen. Carbonate content at this site is low, ranging from ~2 to 15 wt%.

Peak enrichments of dissolved Mn and Fe concentrations in the sediments marks a transition between the overlying oxic sediment and underlying suboxic conditions at ~3 mbsf. At ~20 mbsf, the sudden increase in methane concentration coincides with near-complete depletion of dissolved sulfate, indicating the presence of the sulfate-methane transition zone (SMTZ). The Ca^{2+} concentration at the SMTZ is relatively low (~2 mM), suggesting that active carbonate precipitation takes place at this depth, possibly associated with formation of authigenic aragonite, as suggested by the concomitant drop in Sr concentration. Below the SMTZ, the hydrocarbon gas is characterized by very high methane/ethane ratios (C_1/C_2), which suggests that the methane is mostly of biogenic origin.

A striking feature of IW geochemistry at Site U1484 is the large increase of alkalinity (up to 50 mM) from the seafloor to between ~40 and 50 mbsf. This alkalinity peak is accompanied by enrichments in dissolved Mg^{2+}, K^+, and Na concentrations, which indicates that partial dissolution of silicate minerals probably occurs within this interval. At Site U1484, this process is most likely driven by the presence of substantial amounts of easily alterable fresh volcanogenic material derived from the nearby Papua New Guinea highlands. This anoxic silicate weathering (Wallmann et al., 2008) typically represents a net sink for carbon dioxide (CO_2) in methanogenic sediments, which releases HCO_3^-, dissolved cations, and silica into surrounding interstitial waters. It may also lead to formation of secondary clay minerals (e.g., smectite) in the methanogenic sediments, which at Site U1484 could possibly explain some of the observed decrease of dissolved Mg below 50 mbsf. In contrast, the comparatively low dissolved Fe concentration throughout Hole U1484A (except for the upper 10 mbsf) could also be explained by significant formation of pyrite within the sediment column.

References

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