

## **IODP Expedition 356: Indonesian Throughflow**

### **Site U1460 Summary**

#### **Background and Objectives**

Site U1460 lies in the northern part of the Perth Basin, about 18 nmi north of Site U1459 and adjacent to the Morangie-1 industry well on the Carnarvon Ramp (James et al., 1999; Collins et al., 2014). It is north of the Houtman-Abrolhos main reef complex, which contains the most southerly tropical reefs in the Indian Ocean. The site sits at the northern edge of the modern winter-dominated rainfall zone of southwestern Australia and was targeted to chart the timing of this regime; prior to drilling, we suggested that this site was not likely to yield an orbital-scale climate record due to slope erosional processes. However, coring recovered a 300 m thick late Pliocene to Pleistocene record that may, in fact, reveal orbital-scale climate variability and complement the record at Site U1461. Site U1460 is south of a climatic divide between the Australian monsoon-dominated north and the westerly wind-driven, winter rainfall-dominated south. It is near the southern end of our north–south latitudinal transect and also provides a shelf to shelf-edge record of the tropical–subtropical transition related to Leeuwin Current activity. It is influenced by the anticlockwise, colder West Australian Current gyre; the relative influence of this gyre versus the Leeuwin Current produces variations in paleoproductivity that may be documented over millions of years. Subsidence rates in this region are estimated to be significantly less than in the Carnarvon Basin further north because of variations in mantle dynamic subsidence between the Perth and Carnarvon Basins. Paleobathymetric analyses should produce the first detailed >1 m.y. subsidence record for this part of the West Australian margin, where previous subsidence estimates only extend to 125 ka (Collins and Testa, 2010).

#### **Operations**

The vessel arrived at Site U1460 after an 85 nmi transit (7.9 h) from Site U1459. The vessel was offset 50 m to the west of the site coordinates and a seafloor positioning beacon was deployed at 2130 h on 12 August. After offsetting the vessel from the beacon, drill floor activities commenced. Given the previous difficulty establishing the mudline at Site U1459 (broken core barrel), we decided to tag the seafloor with the bit to determine depth and hardness. Hole U1460A coring started at 0115 h on 13 August. Based on the recovery of the mudline core, the seafloor depth was calculated as 214.5 mbsl. Cores

U1460A-1F to 65F were recovered to 300.1 mbsf. Core recovery was excellent (300.1 m cored, 291.39 recovered, 97%). Hole U1460A ended at 0605 h on 14 August. The total time spent on Hole U1460A was 33.25 h.

After offsetting the vessel 20 m north of Hole U1460A, Hole U1460B coring started at 1920 h on 15 August. Based on the recovery of the mudline, the seafloor depth was calculated as 214.4 mbsl. After establishing the mudline, the advance on each core was by recovery in an attempt to recover missing sections of core from the previous hole. Cores U1460B-1F to 68F were recovered to 306.6 mbsf with the HLAPC system. Core recovery was excellent with 296.41 m recovered from 306.6 m cored (97%). In situ temperature measurements with the APCT-3 were taken on Cores U1460B-12F, 20F, 28F, 33F, and 36F. Site U1460 ended at 1945 h on 15 August with the vessel prepared for transit. The total time spent on Hole U1460B was 37.75 h.

## **Principal Results**

### ***Lithostratigraphy***

The lithostratigraphic units and their boundaries at Site U1460 are defined by changes in lithology (identified by visual core description and smear slide observations), physical properties, color reflectance ( $L^*$ ,  $a^*$ , and  $b^*$ ), and petrographic section analyses. Site U1460 consists of two lithostratigraphic units, with three subunits in the upper unit. Unit boundaries are defined as the first occurrence of a new lithology downhole. Subunits are distinguished primarily by differences in the most abundant fossils, diagenesis, and mineralogical components. Lithified layers characterized by authigenic mineralization, and interpreted as hardgrounds, define the boundaries between subunits. The lithologic descriptions are based on sediments recovered from Hole U1460A (0–300.10 mbsf) and U1460B (0–306.65 mbsf).

Unit I encompasses most of Holes U1460A (0–252.70 mbsf) and U1460B (0–252.00 mbsf) and consists of predominantly unlithified to partially lithified, skeletal packstone with wackestone and grainstone intervals. This unit is subdivided into three subunits based on the abundances of macrofossils, sponge spicules, and degree of diagenesis. Macrofossils are concentrated in Subunit Ia (0–44.90 mbsf in Hole U1460A; 0–44.94 mbsf in Hole U1460B). Sponge spicules are concentrated in Subunit Ib (44.90–174.53 mbsf in Hole U1460A; 44.94–173.36 mbsf in Hole U1460B). Subunit Ic (174.53–252.7 mbsf in Hole U1460A; 173.36–252 mbsf in Hole U1460B) has high authigenic

glaucinite, and increased dolomite and macrofossil content. Unit II (252.7–300.1 mbsf in Hole U1460A; 252–306.65 mbsf in Hole U1460B) consists of unlithified to partially lithified packstone, mudstone, and wackestone. Unit II is defined by the first appearance of a mass-wasting deposit. Mass-wasting deposits in Unit II are characterized by graded or contorted beds and interpreted to be turbidity current deposits, slumping sediments, and debris flows.

### ***Biostratigraphy & Micropaleontology***

A total of 54 smear slides were examined for biostratigraphically significant marker species and common calcareous nannofossils. Calcareous nannofossils were common to dominant and showed overall good preservation in the (predominantly) packstone sediments recovered at Site U1460. The nannofossil assemblages are dominated by placolith-bearing members of the Noelaerhabdaceae family, most notably by small (<4  $\mu\text{m}$ ) *Gephyrocapsa* spp. and *Reticulofenestra* spp. The earliest Pleistocene–late Pliocene marker species *Discoaster brouweri* (Top at 1.93 Ma) is rare from Sample U1460A-45F-CC (208.85 mbsf) to the base of Hole U1460A (U1460A-65F-CC; 300.8 mbsf). The top occurrence of *Sphenolithus* spp. in Samples U1460A-63F-CC (293.45 mbsf) and in U1460B-65F-CC (295.04 mbsf) indicates that the bottoms of both holes are of (late) Early Pliocene age.

Preservation and abundance of planktonic foraminifers is significantly better at Site U1460 than at the previous Sites U1458 and U1459. The middle Pleistocene, defined as biozone Pt1a (0.61–1.93 Ma; Top *Globorotalia tosaensis* and Base *G. truncatulinoides*) can be identified between Samples U1460A-19F-CC (86.5 mbsf) and U1460A-57F-CC (265.2 mbsf). Below Sample U1460A-60F-CC (279.3 mbsf) a Pliocene faunal assemblage is present (biozone PL4) which indicates a minimum age of 3.47 Ma (Top *Dentogloboquadrina altispira*). The bottom of Hole U1460B (Sample U1460B-68F-CC; 306.6 mbsf), is within biozone PL2 (Top *G. margaritae*) and is based on the presence of *G. crassaformis*. Site U1460 has an oldest age of 4.3 Ma (base biozone PL2).

The samples contained between 13%–63% benthic foraminifera, and *Cibicides* spp. and *Cibicidoides* spp. were the most common taxa. Four assemblage trends can be identified by abundances of *Uvigerina peregrina*, *Siphogenerina raphana*, *Bolivina* spp., *Trifarina* spp., *Cibicides* spp., and *Cibicidoides* spp. Samples observed contain from 7 to 35 species. Except for the top three samples from Hole U1460A from 2.13 to 35.6 mbsf, preservation

was poor and affected by fragmentation and abrasion. The proportion of planktics suggest outer shelf to upper slope (100 to 500 m) paleodepths.

### ***Geochemistry***

At Site U1460, 64 samples were analyzed for headspace gas content, 31 samples (5 cm whole rounds) for interstitial water geochemistry measurements, and 31 samples for total organic carbon (TOC), carbonate, and total nitrogen. In general, elevated salinity also characterizes the site, with values of 35 at the top, increasing with depth to values of 61 at 287 mbsf. Increasing trends of most of major elements in the interstitial water samples are reflected in the salinity record. However, potassium decreases slightly downhole from 10.9 mM to 8.2 mM, possibly reflecting the decreasing clay content in the deeper sediments. Silica is 381  $\mu\text{M}$  at the surface and increases to a maximum value of 1683  $\mu\text{M}$  at 137 mbsf. From 137 to 193 mbsf, silica concentration decreases to  $\sim 1200$   $\mu\text{M}$ , followed by relatively stable values to the bottom of Hole U1460A. Variations in silica might imply the importance of biogenic silica in these sediments, related to the interval of high sponge spicule content (lithologic subunit Ib). The site is also characterized by high percentages of calcium carbonate (mean value of 90%), low total organic carbon (mean value of 0.48%) and total nitrogen (mean value of 0.03%). Relatively low calcium carbonate content seems to be related to the section of higher sponge spicule fragments. In contrast, relatively lower TOC values are probably related to the intervals of low clay content.

### ***Paleomagnetism***

Paleomagnetic investigations at Site U1460 included routine measurements and partial AF demagnetization of natural remanent magnetization (NRM) of archive-half split-core sections and selected discrete samples from working-half sections of Hole U1460A. Hole U1460B was not measured since lithological similarities to Hole U1460A indicated overlapping stratigraphy. Isothermal remanent magnetization (IRM) and backfield IRM curves from discrete samples provide coercivity of remanence values ranging from 40.7 mT to 67.0 mT. Further cumulative log-Gaussian analysis indicates three components—two of them providing the main contribution to the IRM pattern and exhibiting low magnetic coercivity behavior, parameters indicative of granulometric distribution related to magnetite and/or titanomagnetite. A third component presented high coercivity behavior ( $B_{1/2} = 263$  mT), which suggests the presence of hematite

and/or goethite. Residual NRM intensity values range from  $10^{-2}$ – $10^{-5}$  A/m after AF demagnetization with peak fields of 30 mT. Based on nannofossil-based age constraints (0.91 Ma at 129 mbsf), an observed polarity reversal at ~120 m may be indicative of the C1r.1r (0.988–0.781 Ma) subchron Brunhes/Matuyama boundary (C1n, C1r.1r) at 0.781 Ma.

### ***Physical Properties***

Core recovery at Site U1460 was very high (97%), so physical property measurements were clearly able to demonstrate how these parameters vary with depth. Magnetic susceptibility (MS) shows large-scale trends from both the Whole-Round and Section Half Multisensor Loggers (WRMSL and SHMSL, respectively) that are similar between both holes. All MS records showed a general decrease of ~2 SI from the top to 180–200 mbsf. From that depth to the bottom of both holes (~300 mbsf), an increase of 1–2 SI is observed in all MS records. However, the meter-scale variability was not consistent from hole to hole and between the WRMSL and SHMSL. The NGR data are characterized by strong variations, with an amplitude up to 30 cps, that can be correlated between the holes at vertical scales of tens of meters, despite measuring at different resolutions between Hole U1460A (10 cm) and Hole U1460B (20 cm). Moreover, a few hardground and condensed layers produced major peaks in the NGR data (over 140 cps), facilitating an accurate correlation of these layers between holes. Porosity decreased from 50%–60% at the top to 39%–49% at the bottom of both holes. Correlation between the porosity decrease and the increase in *P*-wave velocities ( $R = 0.405$ ), bulk densities ( $R = 0.88$ ), and thermal conductivities ( $R = 0.67$ ) suggests that these long-term variations may be due in part to compaction. In situ formation temperature measurements were made in Hole U1460B to complement the thermal conductivity core measurements. This allowed for the calculation of the geothermal flux ( $62 \text{ mW/m}^2$ ).

### ***Stratigraphic Correlation***

Attempts to correlate Holes U1460A and U1460B were made using NGR data. NGR data was collected at 10 cm resolution on Hole U1460A cores and 20 cm on Hole U1460B cores. Gamma ray attenuation data collected on the Special Task Multisensor Logger (STMSL) and  $b^*$  collected on the SHMSL were also used for correlation purposes. Correlations were also somewhat further constrained by the core photos and lithologic descriptions, particularly debris flows and hard grounds. The lithologic descriptions

showed considerable variation across the two holes, especially in the lower part of the section where debris flows were found. Unfortunately, the fact that only two holes were cored using the HLAPC did not allow for the generation of a complete splice, although the rough correlation is useful for Site U1460 sampling.

## **References**

- Collins, L.B., and Testa, V., 2010. Quaternary development of resilient reefs on the subsiding Kimberley continental margin, Northwest Australia. *Brazilian Journal of Oceanography*, 58: 67–77.
- Collins, L. B., James, N. P. and Bone, Y, 2014. Chapter 19 Carbonate shelf sediments of the western continental margin of Australia. *In: Continental Shelves of the World: Their Evolution During the Last Glacio-Eustatic Cycle*, eds. F. L. Chiocci and A. R. Chivas, Geological Society, London, Memoirs 2014, v.41; p255–272.
- James, N.P., Collins, L.B., Bone, Y., and Hallock, P., 1999. Subtropical carbonates in a temperate realm: modern sediments on the southwest Australian shelf. *Journal of Sedimentary Research*, 69(6): 1297–1321.