Expedition 320: Pacific Equatorial Age Transect (PEAT I)

30 April 2009

Site U1335 Summary

Two holes were cored at Site U1335 (PEAT-6C, 5º18.735'N, 126º17.002'W, 4327.5 meters water depth), targeting paleoceanographic events in the late Oligocene and into the early and middle Miocene, including and focusing on the climatically significant Oligocene–Miocene transition and the recovery from the Mi-1 glaciation event (Zachos et al., 2001b; Pälike et al., 2006b) and the expansion of the East Antarctic cryosphere (Holbourn et al., 2005). Site U1335 is also providing data towards a depth transect across the latest Oligocene and Miocene that will allow exploitation and verification of a previous astronomical age calibration from ODP Site 1218 (Pälike et al., 2006a).

Site U1335 (~26 Ma crust) is situated halfway between Site U1336 ~340 km towards the northwest and Site U1337 ~390 km towards the southeast, approximately ~250 km south of the Clipperton fracture zone (Lyle et al., 2006). At Site U1335, late Oligocene age (26 Ma) seafloor basalt is overlain by ~420 m of pelagic sediment. Unless otherwise stated, all depths used here are given in m core depth below seafloor (CSF-A).

The sedimentary sequence at Site U1335 is divided into two major lithological units. The topmost ~64 m thick lithological Unit I comprises an alternating sequence of earliest late Miocene to Pleistocene calcareous nannofossils, diatoms, radiolarians and foraminiferal oozes. The topmost sediment of lithological Unit I is younger than the Pleistocene/Pliocene boundary as recognized by top planktic foraminifer *Globigerinoides fistulosus* (between Section U1335A-1H-CC and interval U1335A-2H-2, 104-106cm), and then follows a continuous biostratigraphic succession down to the early late Miocene. Below, lithogical Unit II comprises a ~350 m thick succession of late Miocene to late Oligocene (calcareous nannofossil zone NP25) nannofossil ooze and chalk, overlying basalt (lithological Unit III). One of the prominent features of Unit II is the occurrence of at least 49 described beds (2 to 176 thickness) of nannofossil foraminifer ooze that have sharp basal boundaries, many of which are irregular, and some of which are inclined, interpreted as gravity flow deposits from the nearby seamounts, and representing ~2% of the total sediment recovered.

Holes U1335A and U1335B provided high quality APC cored sediments from the mudline to ~341 and 378 m, respectively (Cores U1335A-36H, U1335B-41H). The APC cored interval from Hole U1335B represents the second deepest APC cored depth in ODP and IODP history. Below this depth we encountered stiffer and harder sediment, after which we switched to the XCB cutting shoe. XCB coring advanced to ~420 m DSF, through early Miocene and lower Oligocene sediments with high recovery. In the basal section, Core U1335B-46X recovered pieces of basalt up to 10 cm in length, with a glassy rim and overlain by nannofossil chalks of Unit II.

The sediment column at Site U1335 represents the youngest end member drilled during Expedition 320, and provides one of the most stratigraphically complete and expanded early Miocene section from the equatorial Pacific yet (~320 m cored depth from the earliest to latest Miocene).

At Site U1335 carbonate content fluctuates between 12 and 87% within lithological Unit I, presumably reflecting the close proximity of the seafloor to the lysocline. With the exception of the depth interval from 140 m to 220 m, the remainder of lithological Unit II exhibits uniformly high calcium carbonate content of between 80-90%. Within the interval of ~150-210 m (approximately equivalent to Cores U1335A-16H through -22H), carbonate content cycles between ~50 and 90%, and corresponds to a change in dominant sediment color from light-greenish gray to tan, and also displays higher magnetic susceptibility (MS) values of up to $25x10^{-5}$ SI.

A series of late Oligocene through late middle Miocene cores (Cores U1335A-8H through U1335A-40X) were recovered with distinct colors ranging from light grayish green to light blue, similar but much thicker in total stratigraphic thickness (~70-170 m and ~200-350 m) than those observed in Site U1334. The uniquely colored carbonate oozes exhibit extremely low magnetic susceptibilities that complicated a confident stratigraphic correlation. These colored oozes lost almost their entire magnetic susceptibility signal from ~70 to ~105 m and from ~210 m. Similar colored cores have previously been described for DSDP Sites 78 and 79 (Hays et al., 1972).

All major microfossil groups have been found in sediments from Site U1335, representing a complete biostratigraphic succession at the shipboard sample resolution level of Pleistocene to latest Oligocene sediments, including a thick sequence of lower Miocene nannofossil ooze and chalk. Radiolarians are present through most of the section apart from the basal 3 m of nannofossil chalk. They provide a coherent, high-resolution biochronology through a complete sequence of radiolarian zones from RN14 (Pleistocene) down to RP21 (upper Oligocene). Calcareous nannofossils are present and moderately to well preserved through most of the succession, representing the complete sequence from NP25 (upper Oligocene) above basaltic basement through NN20 (Pleistocene). Planktic foraminifers are present through most of the succession and are moderately preserved throughout, but absent in the immediate vicinity of the Oligocene/Miocene (OM) boundary. Recognized planktic foraminifer zones range from PT1a (Pleistocene) to O6 (upper Oligocene). The nannofossil, radiolarian, and planktic foraminiferal datums are in good agreement. Benthic foraminifers are present through most of the section and indicate lower bathyal to abyssal paleodepths. The Oligocene-Miocene transition at Site U1335 was encountered at ~350 m, and fully recovered in Cores U1335A-37X and U1335B-38H, as defined by the planktic foraminiferal datum base *Paragloborotalia kugleri* between samples U1335A-37X-4, 136-138 cm and U1335A-37X-CC-PAL (midpoint 348.6 m), in good agreement with the calcareous nannofossil event top *Sphenolithus delphix* at 349.7 m between Samples U1335A-37X-6, 50 cm and U1335A-37X-CC-PAL. The oldest sediment overlying seafloor basalt has been zoned within calcareous nannofossil zone NP25 (24.4-26.8 Ma).

Apparent sedimentation rates, as implied by the magneto- and biostratigraphic age determinations, vary throughout the section, and are about 6 m/m.y. in the late to middle Miocene to recent sediment cover, ~17 m/m.y. in the middle early Miocene, and as high as ~25 m/m.y. throughout the late Oligocene and early Miocene. There is no apparent hiatus at the shipboard biostratigraphic resolution, although some condensed horizons are apparent (e.g. near the early/middle Miocene boundary, and in the early late Miocene). The presence of all major fossil groups as well as a detailed and well resolved magnetostratigraphy will allow us to achieve one of the main PEAT objectives of arriving at an integrated Cenozoic stratigraphy and age calibration for the Miocene, and late Oligocene.

A full physical property program was run on cores from Site U1335. This program comprises whole-round multi-sensor core logger measurements of magnetic susceptibility, bulk density, P-wave velocity, natural gamma radiation, and measurements of color reflectance, followed by discrete measurements of moisture and density properties, sound velocities and thermal conductivity on Hole U1335A. All track data are variable throughout the section, allowing a detailed correlation between different holes, with the exception of a low susceptibility signal within an interval extending slightly above and below the light greenish gray tinted cores of Unit II, between ~70-110 m and ~200 m to ~380 m. MS varies between 5-20x10^{-5} SI in the upper parts of Unit I, and then increase to around 25x10^{-5} SI towards the lower portion of Unit I, coinciding with the occurrence of clayey radiolarian ooze within the major lithology of nannofossil ooze. MS values decrease at the top of Unit II (~64 m), and then fall to values around -1x10^{-5} SI near 70 m. Between ~110 and 150 m, MS values increase slightly and become highly variable (0-10x10^{-5} SI). MS values are higher in the interval from 160-200 m, coinciding with an observed decrease in Fe-reduction. Below 200 m, the MS signature is largely diamagnetic, with values close to zero. MS values are slightly increased again in the basal 20 m of Unit II (below ~400 m). NGR is elevated at the surface sediment (~73 cps), but low throughout the rest of the sedimentary column. Compressional-wave velocities from the multisensor track (MST) agree with discrete velocity measurements and reflect key lithological transitions, particularly the ooze to chalk transition near ~220 m. Compressional-wave velocities are between 1460 and 1490 m/s in Unit I and the upper portion of Unit II, and then increase to above 1500 m/s. Slightly below the ooze/chalk transition near 345 m, velocities increase significantly, reaching 1600-1750 m/s at the bottom of Unit II. This partly explains the thicker sediment section than expected from seismic data prior to coring (~60 m thicker). Bulk density and grain density increase with depth, with a decrease in wet bulk density from 1.2-1.6 g/cm^3 in Unit I to ~1.7g/cm^3 at the top of Unit II, and ~1.8 g/cm^3 in the basal part of the section. Sediment porosity ranges from 70-90% in Unit I to 50-60% at ~300 m in Unit II. Ephemeral whole-round samples were collected at ~96 m, ~196 m and ~305 m for shore based studies of sediment permeability.

The coring effort in Holes U1335A and U1335B was successful at covering stratigraphic gaps between cores at this site from the surface throughout most of the APC cored section, with the exception of a gap (~1 m) at the bottom of Core U1335A-16H due to flow-in (~146.40-151.46 m CSF). Features in the MS and GRA density are well aligned down to a depth of 337 m CSF (Hole 1335A) and 344 m CSF (Hole U1335B), corresponding to ~398 m CCSF. Between ~230 m and ~398 m CCSF-A, GRA density data allowed confident alignment of cores despite very low magnetic susceptibility values. The section below ~398 m CCSF-A was mostly XCB cores and lacked clearly identifiable features; therefore it had to be appended to the splice. A single spliced record was assembled for the aligned cores down to Section U1335B-37H-6 (343.76 m CSF-A, 398.15 m CCSF-A). Stratigraphic correlation between individual holes indicates an overall core expansion (ratio of CCSF-A over CSF-A depths) of ~ 16%. Stratigraphic correlation resulted in a complete splice through the Eocene-Oligocene transition almost to basement (~38 Ma).

A full range of paleomagnetic analyses was conducted on 78 archive halves and 257 discrete paleomagnetic samples from Site U1335 for the APC cored section (upper ~378 m). The most prominent feature of the records is the magnetic intensity and susceptibility low that occurs between about 70 and 110 m, and below about 210 m. We could not obtain any reliable paleomagnetic directions from this interval because the magnetic intensity after 20 mT AF demagnetization is in the order of 10^{-5} A/m, which is comparable to the noise level of the super-conducting rock magnetometer. Except for these low magnetic intensity intervals zone, we found distinct declination reversals at 20 mT demagnetizations. The drilling overprint was generally weak when non-magnetic core barrel was used (Cores U1335A-1H to 16H and U1335B-1H to 19H). In contrast, those cores collected with the steel core barrels are highly overprinted. Except for the low magnetic intensity interval, the cleaned paleomagnetic data provide a series of distinct ~180° alternations in the declination. When combined with biostratigraphic age constraints, the data allow a continuous magnetostratigraphy from Chron C1n (0-0.781 Ma) down to C5n.2n (9.987-11.040 Ma) for intervals of 0-65.95 m in Hole U1335A, and from Chron C1n down to C5r.1n (11.118-11.154 Ma) for intervals of 0-66.225 m in Hole U1335B. Below the bottom of the first magnetic-low zone (about 70-110 m), magnetostratigraphy is again interpretable downhole: Chron C5Br (15.160-15.974 Ma) down to C6n (18.748-19.722 Ma) for intervals of 155.35-208.40 m (CFS-A) in Hole U1335A, and from Chron C5AAn (13.015-13.183 Ma) down to C5Er (18.524-18.748 Ma) for intervals of 107.95-202.60 m (CFS-A) in Hole U1335B. The highlights of the magnetostratigraphy at Site U1335 are the identifications of (1) a previously observed cryptochron (C5Dr-1n) in both two holes and (2) 40 potential geomagnetic excursions (10 of which are recorded in both holes).

A standard shipboard suite of geochemical analysis of porewater, organic and inorganic properties was undertaken on sediments from Site U1335. Site U1335 is marked by alkalinities between 2.5-4.3 mM throughout, sulfate concentrations between 23 and 28 mM, and dissolved phosphate concentrations of ~2 μM in the shallowest sample, decreasing to ~0.5 μM in the uppermost ~50 m. The most striking features in the interstitial water geochemistry are three dissolved manganese peaks with concentrations of up to 44, 13 and 5 μM around 0-40 m, 50-80 m, and 150-210 m. Dissolved iron also shows three peaks, with concentrations of up to 6 μM around 6 m, between 90-170 m, as well as 190-370 m. Minima in dissolved Fe correspond to elevated Mn concentrations. The alternating pattern of dissolved Mn and Fe correspond well to apparent color changes in the sediment column. Lithium concentrations decrease from ~26 μM at the sediment surface to 5 μM around 300 m, below which Li concentrations increase strongly to ~32 μM. The Sr concentration profile mirrors that of Li, with concentrations ranging between 82 and 250 μM. Sr values show an increase from the top towards 200 m, followed by a decrease towards basement. Calcium carbonate, inorganic carbon (IC) and total carbon (TC) concentrations were determined on sediment samples from Hole U1335A. $CaCO_3$ concentrations ranged between 13-96 weight %. In the uppermost ~67 m, the carbonate concentration ranges from 12 to 87%, and concentrations are then consistently high ~72-96% between 67 and 157 m and below 222 m. Concentrations vary more widely 37-89% from 157-222 m. Total organic carbon (TOC) concentrations were determined by acidification, with a range from below the detection limit of the method up to 0.08%.

TOC is significantly higher in the uppermost ~57 m and around 220 m (0.08% and 0.04% respectively), corresponding to intervals with lower carbonate concentrations.

Wireline logging was not conducted at Site U1335. Five downhole temperature measurements were conducted in Hole U1335B with the APCT3 tool and reveal of thermal gradient of 7.5°C/km. The temperature data combined with whole-round core temperature conductivity measurements indicate the heat flow is 7 mW/m^2 at this site. This is much lower than values obtained for any of the other Expedition 320 sites drilled so far, and would suggest a recirculation of seawater through basement, consistent with some of the interstitial porewater results.

Highlights

1) Highly expanded Miocene sedimentary section

One of the highlights from Site U1335 is the recovery of a very thick Miocene carbonate dominated section from the central equatorial Pacific, one of the high priority objectives of the PEAT program. The early Miocene (~7 m.y. duration) is captured in ~190 m of sediment, corresponding to 27 m/m.y. The middle Miocene (4.5 m.y. duration) is recovered in ~95 m sediment, with a sedimentation rate of ~21 m/m.y. The sedimentation rate from the late Oligocene into the Miocene has a sedimentation rate of just under 20 m/m.y. These high sedimentation rates will facilitate the study of paleoceanographic processes at unprecedented resolution for the equatorial Pacific.

2) Oligocene/Miocene (OM) transitions and depth transects

Site U1335 was planned as the youngest and shallowest component of the PEAT OM depth transect, which will allow the study of critical intervals (such as the Mi-1 glacial inception, Zachos et al., 2001b; Pälike et al., 2006b) and variations of the equatorial CCD throughout this transition as well as the latest Oligocene and early Miocene. Site U1335 is estimated to have been approximately 3.3 km deep during the OM transition, approximately 1.5 km shallower than today. The dominant lithologies are nannofossil ooze and chalk, with better preservation of calcareous microfossils than any other site drilled during Expedition 320, which will allow us to achieve the prime objective for this coring site. Physical property data from Site U1335 provide an important contribution towards the Cenozoic "megasplice", connecting with younger sediments from ODP Leg 138 (e.g., ODP Site 850), and older sediments from ODP Leg 199 (Site 1218), allowing the generation of astronomically calibrated datums and isotope stratigraphies from the Miocene into the Eocene.

3) Geochemical front

Site U1335 recovered an interval of multi-colored carbonates, that show a distinct Mn increase and elevated Fe porewater concentrations, characteristic of a geochemical alteration front. At Site U1335, this zone is similar but much thicker in total stratigraphic thickness (~70-170 m and ~200-350 m) than that observed in Site U1334 (~50 m; see Site U1334 chapter). Although the paleomagnetic signal was lost in most parts of this section, sediments recovered will provide the opportunity to study organic matter degradation while these sites migrate from south to north through the equatorial belts of high productivity. Paleolatitude reconstructions show that these characteristic geochemical alteration fronts can be mapped to similar equatorial positions between Sites U1334 and U1335, roughly between the equator and ~2º N. One feature of interest at Site U1335 is the observation that the multicolored interval of sediments is interrupted between ~170-200 m (Cores U1335A-18H through 20H), which shows again higher magnetic susceptibility values. It remains to be established whether this interruption in the geochemical alteration front is related to the shape and position of the equatorial high productivity zone, or instead is the result of reduced sedimentation rates during this time (late early Miocene). Interstitial porewater profiles are providing additional important information about the redox chemical processes operating in this zone, which have also been observed in DSDP Sites 78, 79 and 574 (e.g., Hays et al., 1972a, 1972b)

4) Gravity flow deposits

One of the prominent features of Unit II is the occurrence of at least 49 described beds (2 to 176 thickness) of nannofossil foraminifer ooze that have sharp basal boundaries, many of which are irregular, and some of which are inclined, interpreted as gravity flow deposits from the nearby seamounts, and representing ~2% of the total sediment recovered. Their grain size fines upward from medium sand to silt, are often darker colored than immediately overlying deposits, and instantly recognizable by their coarser texture. Angular basalt fragments (<1 mm), fish teeth and pyritized foraminifers and radiolarians are also found within the basal parts of these beds, of which at least three show parallel or cross laminations in their upper or middle part. These beds, interpreted as gravity flow deposits, occur with an approximate frequency of one or two beds per core. The abundance and thickness of these beds is highest within Cores U1335-21H through -37X (189.4-350.1 m). No gravity flow deposits were observed in Cores U1335A-3H through U1335A-8H. The provenance of these deposits, as indicated by the observed basalt fragments, is inferred to be from the nearby seamounts situated ~15-20 km towards the northeast and southeast of Site U1335, with a present summit water depth that is 400-600 m shallower than Site U1335. Initial indications are that these gravity flow deposits, unlike those observed at Site U1331, might not be very erosive, and therefore essentially add to the sediment column, rather than removing large sections of geological time. The high sedimentation rates at Site U1335 will allow paleoceanographic studies to avoid the generally thin layers of gravity flows.

5) An age transect of seafloor basalt

Site U1335 recovered what appear to be fresh fragments of sea-floor basalt, with an age around 26 Ma as inferred by the oldest biostratigraphic datums from the sediment above. This material will, when combined with other PEAT basalt samples, provide important sample material for the study of seawater alteration of basalt.

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