**Expedition 320: Pacific Equatorial Age Transect (PEAT I)**

25 April 2009

**Site U1334 Summary**

Three holes were cored at Site U1334 (7º59.998'N, 131º58.408'W, 4799 m water depth), targeting the events bracketing the Eocene-Oligocene (EO) transition as part of an investigation of the wider Cenozoic climatic evolution (e.g., Zachos et al., 2001a), as well as providing data towards a depth transect across the Oligocene that will allow exploitation and verification of a previous astronomical age calibration from ODP Site 1218 (Pälike et al., 2006a).

Site U1334 is in the center of the Pacific Equatorial Age Transect (PEAT) program, approximately 100 km north of the Clipperton fracture zone, and ~380 km to the southeast of the previously drilled ODP Site 1218. At Site U1334, late middle Eocene age (38 Ma) seafloor basalt is overlain by ~285 m of pelagic sediment. Unless otherwise stated, all depths used here are given in m core depth below seafloor (CSF-A).

The topmost ~47 m thick lithological Unit I comprises a 15 m thick interval of brown radiolarian clay overlying ~32 m of alternating radiolarian clay and nannofossil ooze. The uppermost section (Core catcher of Core U1334A-1H) is of late Miocene age (radiolarian zone RN7, ~8.5 Ma). Below, lithogical Unit II comprises a ~200 m thick succession of upper Miocene to Oligocene nannofossil ooze and chalk, above a ~35 m thick sequence of late Eocene age nannofossil chalk, radiolarite, and claystone (Lithological Unit III). The basal lithological unit (IV; ~ 1 m) consists of middle Eocene intercalated micritic chalk and limestone on basalt.

Holes U1334A through U1334C provided high quality APC cored sediments from the mudline to ~210 m (Cores U1334A-22H, U1334B-22H, U1334C-22H). Below this depth we encountered increasingly stiffer and harder sediment, after which we switched to the XCB cutting shoe. XCB coring advanced to 288.5 m DSF, through lower Oligocene and Eocene sediments with high recovery. In the basal section, Core U1334A-32X recovered an intercalated unit of basalt and hard micritic chalk and limestone, below a 10-20 thick basal section of nannofossil ooze and chalk.

The sediment column at Site U1334 has a strong resemblance to that of ODP Site 1218 (Lyle et al., 2002), but with a thinner uppermost clay layer, and higher Oligocene and Eocene sedimentation rates, as well as higher carbonate content in the middle and late Eocene sections, as was planned for this site.

Carbonate content exceeds 92% in the upper lower Miocene section below Section U1334A-5H-3, and remains high throughout the Oligocene. The Eocene sediments still contain considerable amounts of carbonate, and nannofossil ooze and chalk are dominant lithologies, apart from several short less carbonate rich intervals (e.g., Section U1334A-28X-3). In the middle Eocene section, carbonate content cycles between ~40% and 85%), with higher values encountered towards the basal part of the Eocene section. Two short intervals in the late Eocene (~249 m to ~ 257 m) exhibit carbonate content of less than 20%.

A series of the middle Oligocene cores (Cores U1334A-16H through U1334A-21H) were recovered that had a very distinct colors ranging from light grayish green to light blue. These uniquely colored carbonate oozes exhibit extremely low magnetic susceptibilies that complicated a confident stratigraphic correlation. These colored oozes lost almost their entire magnetic susceptibility signal from ~145 to ~215 m. Similar colored cores have previously been described for DSDP Sites 78 and 79 (Hays et al., 1972a, 1972b).

The Eocene-Oligocene transition at Site U1334 is much more expanded than at Expedition 320 Sites U1331, U1332, and U1333, and even ODP Site 1218. The Eocene-Oligocene transition was encountered at ~250 m, and fully recovered in Cores U1334A-27X and U1334B-26X, while Hole U1334C was used to fill small stratigraphic gaps. The Oligocene-Miocene transition was fully recovered in all three holes: in Cores U1334A-10H (based on magnetostratigraphy, the boundary is at Interval U1334A-10H-6, 98cm), U1334B-10H (top of Section 2), as well as U1334C-10H.

All major microfossil groups have been found in sediments from Site U1334, and provide a consistent, coherent and high resolution biostratigraphic succession spanning near continuous sequence from the middle Miocene to the uppermost middle Eocene. The uppermost 12 m of radiolarian clay are barren of calcareous microfossils, but contain radiolarians of middle Miocene age, similar to the site survey piston core RR0306-08JC

(Lyle et al., 2006). Nannofossil ooze and radiolarian clays occur in the Miocene and Eocene parts of the section, with nannofossil ooze dominant in the thick Oligocene section. Radiolarians are present through most of the section, apart from the lowermost cores, and are well preserved in the Eocene. They provide a coherent, high resolution biochronology, and indicate a complete sequence of radiolarian zones from RN7 (late Miocene) down to RP17 (uppermost middle Eocene). Calcareous nannofossils are present and moderately to well preserved through most of the succession and there appears to be a complete sequence of nannofossil zones from NN6 (middle Miocene) down to NP17 (uppermost middle Eocene), providing a minimum age estimate for basaltic basement of 37 Ma. In the Eocene, base *Chiasmolithus oamaruensis* is determined in Sample U1334A-30X-1, 66 cm, and top *Chiasmolithus grandis* in Sample U1334-30X-2, 74 cm. Intriguingly, both species are mid to high latitude taxa (Wei and Wise, 1989), and are present only rarely and sporadically at Site U1334. Planktic foraminifers are present through most of the succession and are relatively abundant and well preserved from the lower Miocene to the lower Oligocene. The lower Miocene is characterized by the presence of *Dentoglobigerina* spp., *Paragloborotalia siakensis – mayeri*, *P. kugleri* and *P. pseudokugleri*. Oligocene sediments contain *Catapsydrax* spp*., Paragloborotalia opima-nana* and characteristic *Dentoglobigerina* spp. The preservation and abundance of planktic foraminifers is more variable in the middle Miocene and upper Eocene/lowermost Oligocene. No Eocene/Oligocene boundary marker hantkeninids were identified. Benthic foraminifers are present through most of the section and indicate lower bathyal to abyssal paleodepths.

Apparent sedimentation rates, as implied by the magneto- and biostratigraphic age determinations, vary throughout the section, and are about 4 m/m.y. in the topmost sediment cover, vary between ~12 and 14 m/m.y. in the early Miocene through late early Oligocene section, increase to around 24 m/m.y. in the early Oligocene, and are about 8 m/m.y. in the late Eocene. There is no apparent hiatus at the shipboard biostratigraphic resolution. 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 major parts of the Miocene, Oligocene and Eocene.

A full physical property program was run on cores from Site U1334C. This program comprises whole-round multi-sensor core logger measurements of magnetic susceptibility, bulk density, P-wave velocity, non-contact resistivity, natural gamma radiation, and measurements of color reflectance, followed by discrete measurements of moisture and density properties, sound velocities and thermal conductivity on Hole U1334A. All track data are variable throughout the section, allowing a detailed correlation between different holes, with the exception of a very low susceptibility signal within an interval extending slightly above and below the light greenish gray tinted cores of Unit II, between ~140-210 m. MS varies between 10-40x$10^{-5}$ SI in Unit I, oscillates around 5-10x$10^{-5}$ SI above the colored sediments, then drops to near zero and negative values, and returns to values around 10x$10^{-5}$ SI in the lower part of Unit II and Unit IIIa. NGR shows a slight increase at the Eocene/Oligocene boundary ~246 m (from 4 to 7 counts per second). Compressional-wave velocities remain continuous through the upper 150 m of sediment (varying around 1500 m/s), but increase rapidly below the ooze/chalk boundary to around 1600 m/s. This explains the slightly thicker sediment section than expected from seismic data prior to coring (~20 m thicker). For Hole U1334B, no P-wave velocity multisensor track data were collected between ~125 m to 240 m to allow for a more timely stratigraphic correlation of cores within the iron reduction dominated colored cores with the GRA instrument. Bulk density and grain density increase gradually with carbonate content until ~204 m to a maximum of ~1.8 g/$cm^3$, and then shows stepped decreases in the lower part of this succession. Ephemeral whole round samples were collected at ~50 m and ~165 m for shore based studies of sediment permeability.

Multisensor-track data were used to achieve stratigraphic correlation between holes at Site U1334. Magnetic susceptibility was initially the main parameter used for real-time correlation, as a second loop of the susceptibility meter is mounted on the special purpose fast-track scanner; the second bulk density instrument on this track was not working. In the very low (negative) susceptibility interval between ~145 and ~198 m (Cores U1334A-16H through -21H), the magnetic signal was not useful for correlation, and we measured the corresponding cores from Hole U1334B out of sequence to establish the amount of core overlap using bulk density. The coring effort in Hole

U1334C was successful at covering gaps between cores at this site down to a depth of ~111 m CCSF-A, as well as from 250 to 335 m CCSF-A, almost to the bottom of the section. The correlation was challenging between the three holes at Site U1334 in the greenish-light gray interval (Cores U1334A-15H through -22H, U1334B-14B through 22H, and U1334C-14H through -22H), and in the bottom 80 m of the section, where XCB coring compromised the GRA density variations that would otherwise help stratigraphic correlation. Visual inspection, comparison with core imagery, and biostratigraphic datums were used to establish and verify hole-to-hole correlation where track data lacked clearly identifiable features. Stratigraphic correlation between individual holes indicates an overall core expansion (ratio of CCSF-A over CSF-A depths) of around 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 66 APC cores and 188 discrete paleomagnetic samples from Site U1334 for the APC cored section of Site U1334 (upper ~209 m). Unlike Sites U1331 and U1332, the drilling overprint was generally weak for Site U1334 cores, but only for those collected with the non-magnetic core barrel (Cores U1334A-1H to 16H, U1334B-1H to 15H, and U1334C-1H to 15H). In contrast, those cores collected with the steel core barrels are highly overprinted to the extent the that overprint is so severe that even demagnetization at 20 mT is only partially able to remove some of it. This extreme overprint notably degrades the paleomagnetic declination data as can be noted by their higher variability, which makes polarity determination much more difficult in the intervals collected with steel core barrels. The problem is exacerbated by the decay in the intensity (and susceptibility), which occurs at about 135 m depth in all three holes as a result of apparent reduction diagenesis. Even within the highly reduced interval, an interpretable signal was present prior to switching to steel core barrels. Susceptibility in the upper 45 m of Hole U1334A averages ~$18 \times 10^{-5}$ SI (volume normalized) and decreases to a mean of $6 \times 10^{-5}$ SI from 45 to 135 m. A notable low occurs from about 142 to 204 m, where the average susceptibility is $0.6 \times 10^{-5}$ SI. This low interval is associated with a change in sediment color from yellowish tan to very light green, blue and gray at ~140 m and another abrupt change to reddish brown tones at ~205 m, which corresponds to middle early Oligocene (~30 Ma). Just below 205

m the susceptibility steps up to an average of $5 \times 10^{-5}$ SI, and then increases again across the E/O boundary (~245 m) to an average of $18 \times 10^{-5}$ SI. The magnetostratigraphy in Hole U1334A has been interpreted from the top of Chron 11r (29.957 Ma), which occurs around 55 cm below the top of Section U1334C-21H-4 (~195 m), up through the base of C3n.4n (5.235 Ma) in U1334A-1H. Magnetic reversals have also been interpreted from C1n through C2r.1r in the upper ~2 m of Core U1334A-1H.

A standard shipboard suite of geochemical analysis of porewater, organic and inorganic properties was undertaken on sediments from Site U1334. We also conducted a high resolution (1 per section) Rhizon porewater investigation across the interval middle Oligocene cores (Cores U1334A-16H through U1334A-21H) that exhibited the colored sediments. Site U1334A is marked by alkalinities between 3-4 mM throughout. The most striking features in the interstitial water geochemistry are a dissolved manganese peak from ~20 to ~240 m, with a maximum of ~6 μM at ~110 m, and a dissolved iron peak up to >15 μM centered at 165 m. The depth range of the dissolved iron peak, indicative of iron oxide reduction, coincides with the colorful interval seen in the lithology, and with the interval of low magnetic susceptibilities (~140 to 205 m). Sulfate results indicate limited sulfate reduction. Calcium carbonate contents are low in the uppermost ~35 m of Site U1334, and initial results indicate high calcium carbonate contents below the uppermost clay layer.

Wireline logging was attempted in Hole U1334C, with a re-designed toolstring configuration after the loss of equipment at Site U1332. However, this attempt had to be abandoned after the logging winch failed when the tool was on its way down the drill pipe.

Five downhole temperature measurements were conducted in Hole U1334B with the APCT3 tool and reveal of thermal gradient of 33°C/km. The temperature data combined with whole-round core temperature conductivity measurements indicate the heat flow is 31.6 $mW/m^2$ at this site. This is somewhat lower than values obtained for the nearest ODP Site 1218. Seafloor temperature is approximately 1.5ºC.

## Highlights

### *1) Eocene/Oligocene (EO) and Oligocene/Miocene (OM) transitions and depth transects*

Site U1334 is planned as the youngest and shallowest component of the PEAT EO depth transect, which will allow the study of critical intervals (such as the Eocene-Oligocene transition, see Coxall et al., 2005) and variations of the equatorial CCD. Site U1334 is estimated to have been approximately 3.5 km deep during the EO transition, approximately 1.3 km shallower than today, and 800 m shallower at that time than Site U1333. Unlike at the previously drilled sites, the dominant lithology is still nannofossil ooze and chalk below the EO transition, with significant amounts of carbonate present, which will allow us to achieve the prime objective for this coring site. The EO transition, which was cored multiple times at Site U1334, has much higher sedimentation rates than ODP Site 1218. The remaining Oligocene is also much more expanded than ODP Site 1218, with better preservation of planktic foraminifers over a longer time interval, allowing a more detailed study of the Oligocene climate system. Site U1334 also contains carbonate bearing sediments across the Oligocene-Miocene transition (e.g., Zachos et al., 2001b; Pälike et al., 2006b). Physical property data from Site U1334 can be correlated cycle by cycle to ODP Site 1218, allowing the correlation to a previously astronomically calibrated site for the Oligocene.

### *2) Geochemical front*

Site U1334 recovered a ~50 thick interval of multi-colored carbonates, that show a distinct Mn increase and elevated Fe porewater concentrations, characteristic of a geochemical alteration front. A detailed Rhizon porewater sampling program will provide insights into limited sulfate reduction processes. A similar, but much thicker, alteration zone is also observed in Site U1335, and provides the opportunity to study organic matter degradation while these sites migrate from south to north through the equatorial belts of high productivity.

***3) An age transect of seafloor basalt***

Site U1334 recovered what appear to be fresh fragments of sea-floor basalt, aged around 38 Ma. This material will, when combined with other PEAT basalt samples, provide important sample material for the study of seawater alteration of basalt.

## References


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