Expedition 320: Pacific Equatorial Age Transect (PEAT I)

13 April 2009

Site U1332 Summary

Three holes were cored at Site U1332 (11º54.722'N, 141º02.743'W, 4924 meters water depth), which is the second north-westernmost site drilled during the Pacific Equatorial Age Transect (PEAT) program. At Site U1332, Eocene age seafloor basalt is overlain by 150.4 m of pelagic sediment, comprising radiolarian and nannofossil ooze with varying amounts of clay and zeolitic clay. Hole U1332A provided high quality and recovery APC cored sediments from the mudline to 125.9 m DSF (Core U1332-14H), which encountered chert and after which we switched to the XCB cutting shoe. XCB coring advanced to 152.4 m DSF, through a ~10 m thick porcellanite rich interval with reduced recovery. In the basal section, XCB Core U1332A-18X recovered a short, ~3.8 m long interval of barren very dense and stiff clay above basalt, ~10 m shallower than predicted from the seismic profile. Basement was reached at 152.4 m core depth below seafloor (CSF-a).

The sediment column at Site U1332 has a strong resemblance to that of ODP Site 1220 (Lyle et al., 2002a). The uppermost 17.7 m of section is a late Miocene to Pleistocene-Pliocene clay, with varying amounts of radiolarians and zeolite minerals, overlying about 130 m of Oligocene to middle Eocene nannofossil and radiolarian ooze with porcellanite deep in the section. A thin ~3 m thick unit of middle Eocene zeolite clay bearing small chert nodules was recovered at the base of the sedimentary sequence, above basaltic basement. The sedimentary sequence at Site U1332 was divided into five major lithologies.

The upper stratigraphy at Site U1332 has a strong resemblance to that of Site U1331, but without the sharp erosive contacts that were described for U1331. Several meters of white to beige colored Pleistocene-Pliocene clay (Lithological unit I) overlie lower Miocene to lowermost Oligocene nannofossil ooze (Lithological units II and III). There is a sharp lithological change at the Eocene–Oligocene (EO) transition (multiple recovery due to slumping within Cores U1332A-8H, U1332A-9H, U1332B-9H and

U1332C-9H) to alternating radiolarian ooze with nannofossils and nannofossil ooze (Unit IVa). The lithology then gradationally changes downhole into radiolarian ooze with nannofossils and clay intercalated with sporadic occurrences of chert (Lithological Unit IVb), and a basal cherty interval (Lithological unit IVc, down to at least 138 m CSF). Lithological unit V, below the chert horizon and between ~138 to at least ~147 m CSF, is comprised of very dark grayish brown to black clay, very dark grayish brown to black zeolite clay and chert. The sediments directly above basaltic basement are partially lithified. Basalt is designated as lithological Unit VI, at ~150 m CSF.

Carbonate content approaches 85% in Lithological Unit III within the Oligocene nannofossil oozes, and cycles between 0 and 40% to 60% in the middle Eocene section (Unit IV). All major microfossil groups have been found in sediments from Site U1332, and provide a consistent, coherent and high resolution biostratigraphic succession from basement up to the top of Lithological unit II. Calcareous nannofossils are abundant and moderately well preserved in the Oligocene, and poor to moderately well preserved in the Miocene and Eocene. Most of middle Eocene sediments commonly contain nannofossils, with several barren intervals. Radiolarians are common to abundant throughout most of the section, apart from the lowermost sediment section above basalt, and are well preserved in the Eocene. Radiolarian and nannofossil datums and zonal determinations agree, and range from nannofossil zone NP13/14 in the basal dark clay section (~48.4–50.7 million years before present, Ma) to NN1, and radiolarian zones RP13 above basement through to RN1 (earliest Miocene, ca. 22.3 Ma) below the upper Pliocene-Pleistocene clay cover in Core U1332A-3H. Planktic foraminifers are generally rare throughout the Oligocene, but absent in the Miocene and Eocene. Benthic foraminifers are present through most of the section but rare in Miocene and Eocene sediments. They indicate lower bathyal to abyssal paleo-depths. Diatoms have been observed throughout the column, but will have to await analysis by specialists not onboard Expedition 320. Apparent sedimentation rates, as implied by the biostratigraphic age determinations, vary throughout the section, and are about 5 m/myr in the Eocene section, and about 2.5 m/myr in the Oligocene, with two prominent hiatuses in the Miocene, and between the Miocene and younger sediments. 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 arrive at an integrated Cenozoic stratigraphy and age calibration (e.g., Pälike et al., 2006) for major parts of the Oligocene and Eocene.

Magnetostratigraphic studies as well as high-resolution biostratigraphy and stratigraphic correlation determined that a ~4 m interval from the base of Core U1332A-8H was repeated in the top of U1332A-9H, which comprises magnetochron C13n, and the lowermost Oligocene. This repetition also occurs in Cores U1332B-8H, U1332B-9H, and within Core U1334C-9H. The lithological succession from the lower occurrence of C13n downwards as well as from the upper occurrence of C13n upwards both appear complete and continuous, and hence Site U1332 achieved the fortuitous feat of recovering the complete Eocene-Oligocene transition four times and the upper part of magnetochron C13n five times at a triple cored site.

A full physical property program was run on cores from all three holes, comprising whole-round multi-sensor core logger measurements of magnetic susceptibility, bulk density, P-wave velocity, non-contact resistivity and natural gamma radiation, followed by discrete measurements of color reflectance, index moisture and density properties, sound velocities and thermal conductivity. Bulk density measurements show a marked increase in the carbonate rich Oligocene section, as well as in carbonate bearing horizons in the Eocene ("CAE" cycles, Lyle et al., 2005). Magnetic susceptibility measurements are variable throughout the section, allowing a detailed correlation between different holes. Natural gamma radiation measurements are elevated by an order of magnitude in the surficial clay layer. Porosity values are generally high in the radiolarian rich sediments (85%), and decreased within the Oligocene and Eocene carbonate section, which also show higher thermal conductivity values of around 0.9 to 1.2 W/(K·m), compared with around 0.8 W/(K·m) in the radiolarian oozes and surficial clay.

Stratigraphic correlation allowed us to obtain a composite section down to a depth of ~125.5 m CSF near the top of the cherty interval in Hole U1332A, equivalent to a composite depth of ~140 m CCSF. The growth factor, which is caused by core expansion and calculated by the ratio between the CCSF and CSF (formerly mcd and mbsf) depth scales, is about 10%. The top of APC cores were often affected by approximately 3 m heave that occurred during operations on Site U1332. Statigraphic correlation supports the biostratigraphic, paleomagnetic and sedimentological description of a repeated sequence, possibly due to slumping, spanning the Eocene-Oligocene transition.

A full range of paleomagnetic analyses was conducted on cores and samples from Site U1332, and resulted in a spectacularly well-resolved magnetostratigraphy. Shipboard analyses conducted suggest that a useful magnetic signal is preserved in all APC cored intervals, and that it was possible to remove the drilling induced steep inclination overprint after demagnetization. Comparison of biostatigraphic data and changes in magnetic paleo-declinations suggest the recovery of magnetic reversals C1n/C1r.1r down to C2An.3n/C2Ar above a hiatus, and then a continuous sequence of magnetic reversals from C5En/C5Er (18.52 Ma) in the Miocene at around 12.95 m CSF (U1332C-02H-4, 95 cm) down to C19r/C20n (42.54 Ma) at U1332A-14H-5, 80 cm. Magnetostratigraphic interpretation supports the presence of a slump through multiple recovery (five times) of parts of C13n in a triple cored sequence. Paleomagnetic directions from discrete samples agree well with those from split-core results.

A standard shipboard suite of geochemical analysis of porewater, organic and inorganic properties was conducted on sediments from U1332. Alkalinity values increase from about 2.2 mM to 3.4 mM downsection, while [Sr^{2+}] increases from ~80 to ~110 µM. H_4SiO_4 remains relatively stable between 400-600 µM above 90 m depth in the Oligocene nannofossil oozes, but increases to 800-1000 µM in the Eocene silica rich radiolarian oozes, approaching opal solubility values. Carbonate coulometry yielded carbonate concentrations of around 85% in the Oligocene nannofossil ooze, and horizons with up to 60% $CaCO_3$ in the middle Eocene radiolarian rich oozes. Total organic carbon concentrations (TOC) were measured both by difference between total carbon and total inorganic carbon as well as by using an acidification method. Using the acidification method, TOC values were below 0.3% for all measured samples. The top ~5 m show values of 0.2% TOC. Between ~40 and 70 m CSF the measurements indicate TOC below the detection limit of 0.03%. Between ~90-150 m CSF there appear three peaks of TOC reaching around 0.2 to 0.27 % TOC. We conducted a high-resolution Rhizon porewater experiment across the prominent alkalinity trough around 40 m CSF, which highlighted differences between squeezed and Rhizon sampled porewaters. Additional ephemeral samples were taken for shore-based microbiology and permeability studies.

Wireline logging provided valuable information to constrain the interval of chert formation within the borehole. Downhole natural gamma, density, and magnetic susceptibility logs provide important constraints on the poorly recovered lithologies below and between cherty horizons. The logging data documents the occurrence of two thin chert or porcellanite horizons around 126 and 130 m WSF and an approximately 14 m thick interval of increased magnetic susceptibility, reduced conductivity, and enhanced density and photo-electric factor that appears to be the dark and dense clays and zeolitic clays above basement, rather than carbonate. Integration with the seismic data will allow further improvements with the regional seismic interpretations. Data from Site U1332 indicate that the top of seismic horizon "P2" (Lyle et al., 2002b) correlates with the top of the chert section, just as it did for Site U1331. No FMS data were collected, as it was not possible to retrieve the "Paleo-" triple combo tool string back into the bottom hole assembly. Eight downhole temperature measurements were conducted in Holes U1332B and U1332C with the APCT3 tool. Three of these yielded good data, the other measurements were impaired by strong, sometimes larger than 3 m heave, during operations on Hole U1332B.

The downhole temperature measurements, when combined with the thermal conductivity values obtained from the cores, indicate that Site U1332 had a heat flow of about 67 mW/m^2, and a thermal gradient of 74.5°C/km. This is significantly lower than the values obtained for Site U1331, but comparable to values obtained for ODP Sites 1218 and 1219.

Highlights

1) Shallow early Eocene carbonate compensation depth (CCD)

Coring at Site U1332 was designed to capture a very short period of time (~2 Ma) at around 50 Ma during which this site was thought to be located above the very shallow Eocene CCD (~3.3 km; Lyle et al. 2002a; Rea and Lyle, 2005) just after the Eocene Climatic Optimum ("EECO", Zachos et al. 2001a). Unlike Site U1331, Site U1332 cored a ~10 m thick section of dense and dark brown clays, zeolite clays and chert above basement. This finding will provide important new constraints on the depth of the CCD at around 48–50 Ma at the paleoequator, indicating that the CCD was even shallower than previously thought.

2) Stratigraphic integration.

One of the primary objectives of the PEAT science program is the integration of different stratigraphic methodologies and tools. Site U1332 contains all major fossil groups (nannofossils, radiolarians, foraminifers, and diatoms), as well as an excellent magnetostratigraphy and composite depth correlation, which can be tied to nearby ODP Leg 199 sites (e.g., ODP Site 1220) by way of physical property variations. The possibility of a cycle-by-cycle match between Sites U1332 and 1220 has been demonstrated, using magnetic susceptibility and bulk density data, providing additional stratigraphic tie-points and a verification of the completeness of the stratigraphic section on a regional scale. Thus, Site U1332 will help us to achieve an integrated statigraphy for the Cenozoic Pacific Ocean, ranging from the Miocene to the middle Eocene.

3) Eocene/Oligocene and Oligocene/Miocene transitions and depth transects

Site U1332 forms the second oldest and deepest component of the PEAT 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 U1332 is estimated to have been approximately 4 km deep during the Eocene–Oligocene transition, approximately 1 km shallower than today, and 200 m shallower at that time than Site U1331. Sediments rapidly change from radiolarian ooze below the transition into nannofossil oozes above, and unlike Site U1331, also contains carbonate bearing sediments across the Oligocene–Miocene transition (e.g., Zachos et al., 2001b). For the Eocene–Oligocene transition, Site U1332 will provide a tie point for calcium carbonate burial at around 4º to 5º paleolatitude.

4) Variations in the CCD

Site U1332 has provided important constraints for variations and depth of the CCD from the early Eocene to the lower Miocene. This site shows increased carbonate content, and much increased mass accumulation rates approaching 200 mg

$CaCO_3/cm^2/kyr$, around the middle of magnetochron C18r to the base of C19r during the middle Eocene, and can be correlated to an interval of enhanced carbonate burial that was previously documented by Lyle et al. (2005) in cores from ODP Site 199. The high early Oligocene $CaCO_3$ concentrations decrease significantly in sediments younger than about 27 Ma. By around 22 Ma, in the early Miocene, carbonate is no longer preserved. This is presumably related to Site U1332 sinking below the prevalent CCD, and coincides with a CCD shoaling event between ~20 and 15.5 Ma described by Lyle (2003).

5) Formation of porcellanite

Together with Site U1331, Site U1332 is providing important new information on the formation of porcellanite and chert. Coring has shown that the top of the porcellanite rich interval is mapped by seismic horizon "P2" (Lyle et al., 2002b). In lithological subunit IVc, layers and pebbles of very dark brown partially- to well-lithified mudstones, often layered or even laminated, are observed within alternating sequences of nannofossil ooze and radiolarian ooze of late to upper middle Eocene age. In hand-specimen, the partially lithified mudstones are particularly rich in clay, and show evidence of partial secondary silicification. Pieces of porcellanite contain clay minerals, microcrystalline quartz, opaques and calcite as well as biogenic shells and fragments from radiolarians and foraminifers. Sediments from Sites U1331 and U1332 appear to document the silicification process in clay rich horizons near basement, which will likely extend the findings by Moore (2008).

6) An age transect of seafloor basalt

Site U1332 recovered what appear to be fresh fragments of seafloor basalt, aged between 49 and 50 Ma. This material will, when combined with other PEAT basalt samples, provide important sample material for the study of seawater alteration of basalt.

References

Coxall, H.K., P. A. Wilson, H. Pälike, C. H. Lear, and J. Backman, 2005. Rapid stepwise onset of antarctic glaciation and deeper calcite compensation in the pacific ocean. Nature, 433(7021):53–57.

Lyle, M., P. A. Wilson, T. R. Janecek et al., 2002a. Init. Rep., Proc. Ocean Drill. Prog. 199, Ocean Drilling Program, College Station, TX.

Lyle, M., Liberty, L.M., Moore Jr., T.C., and Rea, D.K., 2002b, Development of a seismic stratigraphy for the Paleogene sedimentary section, central equatorial Pacific Ocean: Proceedings of the Ocean Drilling Program, Initial Reports, v. 199, p. on web.

Lyle, M., 2003. Neogene carbonate burial in the Pacific Ocean. Paleoceanography, 18(3):1059. doi:10.1029/2002PA000777

Lyle, M.W., Olivarez Lyle, A., Backman, J., and Tripati, A., 2005, Biogenic sedimentation in the Eocene equatorial Pacific: the stuttering greenhouse and Eocene carbonate compensation depth, in Lyle, M., Wilson, P., Janecek, T.R., and Firth, J., eds., Proceedings of the Ocean Drilling Program, Scientific Results, Leg 199: College Station TX, Ocean Drilling Program.

Moore, T.C., 2008, Chert in the Pacific: Biogenic silica and hydrothermal circulation, Palaeogeogr., Palaeoclimat., Palaeoecol., 261, 87 – 99, doi:10.1016/j.palaeo.2008.01.009

Pälike, H., Norris, R.D., Herrle, J.O., Wilson, P.A., Coxall, H.K., Lear, C.H., Shackleton, N.J., Tripati, A.K., and Wade, B.S., 2006. The heartbeat of the Oligocene climate system. Science, 314(5807):1894–1898. doi:10.1126/science.1133822

Rea, D.K., and Lyle, M.W., 2005. Paleogene calcite compensation depth in the eastern subtropical Pacific: answers and questions. Paleoceanography, 20(1):PA1012. doi:10.1029/2004PA001064

Zachos, J., Pagani, M., Sloan, L., Thomas, E. & Billups, K., 2001a. Trends, rhythms, and aberrations in global climate 65 Ma to present. Science 292, 685–693.

Zachos, J.C., Shackleton, N.J., Revenaugh, J.S., Pälike, H., and Flower, B.P., 2001b. Climate response to orbital forcing across the Oligocene–Miocene boundary. Science, 292(5515):274–278. doi:10.1126/science.1058288