Expedition 320: Pacific Equatorial Age Transect (PEAT I)

22 March 2009

Site U1331 Summary

One of the objectives of the combined Pacific Equatorial Age Transect (PEAT) Science Program (IODP Expeditions 320 & 321) comprises obtaining palaeoceanographic records from the Pacific ocean during the time period around the "Early Eocene Climatic Optimum (EECO)", targeted by Site U1331. ODP Leg 199 drilled a N-S transect across the equatorial region at about 56 Ma. Sites on this transect had generally drifted below the CCD by 52-53 Ma. Thus we presently lack calcareous sediments from the region of the equatorial circulation system during this time of maximum Cenozoic warmth (Zachos et al., 2001), elevated atmospheric pCO_2 concentrations (Lowenstein & Demicco, 2007), and a shallow early Eocene CCD (3200-3300 m; Lyle et al., 2002a; Lyle et al., 2005; Rea and Lyle, 2005). Site U1331 (PEAT-1C) has been located on crust with a planned age of about 53 Ma in order to intercept the interval between 53 and 50 Ma in basal carbonate sediments above the CCD, an interval that was poorly sampled on the 56 Ma transect of ODP Leg 199, and forms the oldest component of Expeditions 320 and 321.

Average (non-carbonate) accumulation rates at this time were estimated to be moderate, showing only slight increases in some of the more northern sites on the ODP Leg 199 latitudinal transect (Sites 1215, 1220; Lyle et al., 2002). The records of Leg 199 suggest that the very shallow CCD of this early Eocene time appears to deepen to the north, perhaps suggesting a northern source for the bottom waters. Sites targeting this time interval would ideally give us sediments with sufficient carbonate material to better constrain the isotopic and biotic characteristics of the near surface equatorial waters. We have positioned Site U1331 to the south of the estimated paleo-equatorial position at the target age in order to maximize the time that drill sites remain within the equatorial zone (i.e., ±2° of the equator), to allow for some southward bias of the equatorial sediment mound relative to the hotspot frame of reference (Knappenberger, 2000), and to place the interval of maximum interest above the basal hydrothermal sediments. We

located the site using the digital age-grid of seafloor age from Müller et al., 1997, heavily modified and improved with additional magnetic anomaly picks from Petronotis (1991), Petronotis et al. (1994) and DSDP/ODP basement ages, as well as the magnetostratigraphic designations of Cande et al. (1989) and Cande and Kent (1995). For this grid, each point is then backrotated in time to zero age, using the fixed-hotspot stage-poles from Koppers et al. (2001) and Engebretson et al. (1985), and the paleo-pole data from Sager and Pringle (1988). From the backtracked latitudes for each grid point we then obtained the paleo-equator at the crustal age by contouring. A secondary objective of the PEAT program is to provide a limited depth transect for several Cenozoic key horizons, such as the Eocene Oligocene transition (Coxall et al., 2005). For this objective, Site U1331 will form the deepest paleodepth constraint.

Site U1331 is the north-westernmost site to be drilled during the PEAT program, and is situated about 6º north of the Clipperton fracture zone, 3º south of the Clarion Fracture zone, and about 90 nautical miles (ca. 170 km) to the east of the nearest ODP Site 1221.

During the Site Survey for Site U1331, we found a region of abyssal hills bound by a large volcanic rise to the east, and several seamounts to the SW. The abyssal hills are more widely spaced than at previous sites, and trend NW rather than northeast. We noted a change in trend of abyssal hills between our next site PEAT-2C and U1331, perhaps associated with the Pacific plate reorganization that occurred at about 50 Ma (Rea and Dixon, 1983).

Three holes were cored at Site U1331.

Hole U1331A provided high quality and recovery APC cored sediments from the mudline to 138.2 meters below seafloor (Core U1331-15H), after which we switched to the XCB cutting shoe to determine the exact position of a predicted chert horizon. XCB coring advanced to 157.3 mDSF, above a ca. 20 meter cherty interval with very poor or no recovery. Below this horizon, XCB Core 22X recovered a short, ca. 42 cm long interval of radiolarian and carbonate ooze above basalt in a ca. 10 m interval of soft sediments above basement. Basement was reached at 188.5 meters core depth below seafloor (mCSF).

A “paleo” triple-combo logging run was obtained for the full length between basement (established at 190 m wireline log depth below seafloor (WSF)) and the depth of the BHA at around 80 mDSF. A planned FMS logging run was abandoned due to problems with the logging winch. A malfunctioning wireline heave-compensator did not impede the logging due to calm seas. The logging data confirmed a cherty horizon between ca. 157 and 177 m CSF.

Hole U1331B was vertically offset by 5m, and provided good overlap with sediments from U1331A over the entire recovered interval. The cherty horizon was drilled with a center-bit, and both an APC and XCB coring attempt of the soft sediment underneath was unsuccessful.

Hole U1331C was designed to provide stratigraphic overlap, and confirm stratigraphic correlations made between Sites U1331A and U1331B. Three APC cores were taken above the cherty interval, which was then again drilled through with a dropped center bit. An attempt was made to clean the borehole annulus with drilling mud, followed by two successful APC cores that recovered 14 m of soft sediment and chert fragments between 177 mCSF and basement at 189 mCSF. The basal part contains a red stained lithology within carbonate ooze. No basement rock was recovered in U1331C, but the APC cutting shoe indentation and drilling characteristics indicated basement was encountered. Rate of coring penetration averaged around 135 meters per 24 h.

The sediment column at Site U1331 has a strong resemblance to that of ODP Site 1220, but with noteworthy sharp erosive contacts concentrated within the upper two thirds of the section. Six meters of Pleistocene-Pleiocene clay (Lithological unit I) overlie lower Oligocene to lowermost Oligocene nannofossil ooze (Lithological unit IIa), with a sharp lithological change at the Eocene Oligocene transition (~26 mCSF) to alternating radiolarian ooze with nannofossils and nannofossil ooze (Unit IIb), grading into radiolarian ooze with nannofossils and clay with sporadic occurrences of chert (Lithological Unit IIIa), and the basal cherty interval (Lithological unit IIIb, down to ca. 157 mCSF). Lithological unit IV, below the chert horizon and between 157 to 177 mCSF is comprised of radiolarian ooze and nannofossil ooze with hydrothermal red staining, deposited on top of mid-ocean ridge basalt (Lithological Unit V, at 188.5 m CSF). Carbonate content approaches 80% in Lithological unit IIa within the Oligocene

nannofossil oozes, and cycles between 0 and 40% in the middle Eocene section (units II and III). There is a concentration of sharp erosive contacts apparent in the interval between 80 to 120 mCSF, with calcareous material dominating the basal portion of these contacts, and then fining upwards in grain size into the radiolarian oozes. Rarely, the sediment above a sharp contact contained well-rounded clasts up to 1 cm in diameter (Interval U1331B-10H-6, 117-130 cm).

All major microfossil groups have been found in sediments from Site U1331, and provide a consistent and coherent biostratigraphic succession from basement up to the top of Lithological unit II. Nannofossils are common in the Oligocene and lower Eocene, but sporadic from the upper Eocene due to dissolution. Most of middle Eocene sediments commonly contain nannofossils, with several barren intervals. Radiolarians are common to abundant throughout the section. Radiolarian and nannofossil datums and zonal determinations agree, and range from nannofossil zone NP12 in the basal carbonate section (~51–53 million years before present, Ma) to NP 24, and radiolarian zones RP8 just above basement through to RP21 (late Oligocene, older than 25 Ma) in the uppermost section, below the Pleistocene clays. Both radiolarian and nannofossil assemblages contain reworked, older components (deeper than ~50 mCSF), but within a coherent and ordered stratigraphy. Planktic foraminifers are generally absent, except sporadic samples, often associated with sediment just above sharp lithological contacts and also in the basal carbonate section (provisionally zones E5/E6). Benthic foraminifers are generally rare, and indicate lower bathyal to upper abyssal paleodepths. They are also frequently found in the graded coarse sediment above the base of sharp contacts, but suggest there is no apparent difference in the depth habitat between benthic foraminifers from just above sharp contacts and other parts of the section. Marked differences in productivity indicators have been observed between the Eocene and Oligocene parts of the sections, which will help us to achieve one of the PEAT objectives. 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. The radiolarian rich section between ca. 80 mCSF and basement was deposited at a rate of 10 m/Myr, while the late middle Eocene to Oligocene section was deposited at a rate around 4 m/ Myr, with an apparent

inflection between 60–80 CSF. The chert horizon spans a time interval of around 2–3 Myr. The presence of all major fossil groups as well as a detailed magnetostratigraphy will allow us to achieve one of the main PEAT objectives arrive at an integrated Cenozoic stratigraphy and age calibration (Pälike et al., 2006).

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. Magnetic susceptibility measurements are variable throughout the section, allowing a detailed correlation between different holes, and picking out sharp contacts and clay layers by increased susceptibilities. Natural gamma radiation measurements are elevated by an order of magnitude in the surfacial clay layer. Porosity values are generally high in the radiolarian rich sediments (80%), and decreased within the Oligocene carbonate section, which also shows higher thermal conductivity values. Discrete physical property measurements will prove useful to calibrate the multi-sensor track velocity and density estimates. Discrete sound velocity measurements are significantly higher (50-100 m/s) than track measurements.

Using whole-round magnetic susceptibility measurements, Holes U1331A, U1331B and U1331C can be spliced to form a continuous section to at least 140 mCSF or 150 m core composite depth (CCSF), with no apparent gaps. Core expansion is approximately 15%. It is possible that cores from U1331C can provide additional spliced section down to the top of the cherty interval at around 157 mCSF. Between ca. 177 and 188.5 mCSF Cores U1331A-22X, U1331C-16H and U1331C-17H achieved our Site objective of recovering carbonate bearing material from the time interval just after 52 Ma.

A full range of paleomagnetic analyses was conducted on cores and samples from Site U1331. Aims are to determine the magnetostratigraphy, to study the geomagnetic field behaviour, environmental magnetism as well as the Pacific plate paleogeography. Shipboard analyses conducted so far suggest that a useful magnetic signal is preserved in

most APC cored intervals, helped by the use of an orientation ("Flexit") tool during coring. Preliminary comparison of biostatigraphic data and changes in magnetic paleo-declinations suggest the recovery of Oligocene magnetochrons to base of the middle Eocene (C21n, ~47 Ma). 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 U1331, including a pilot study of high-resolution "Rhizon" porewater sampling, which does not require the cutting of core whole rounds for squeezing. Carbonate coulometry yielded carbonate concentrations of around 80% in the Oligocene nannofossil ooze, and sporadic horizons with up to 40% CaCO3 in the radiolarian rich oozes. Alkalinity values range between 2.5 and 3 mM throughout the section. More analyses are currently underway. 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, and further interpretation will aid in interpretations of carbonate content and lithologies. Integration with the seismic data will allow further improvements with the regional seismic interpretations. Data from Site U1331 indicate that the top of seismic horizon "P2" (Lyle et al., 2002b), correlates with the top of the chert section.

References

Cande, S.C., J.L. LaBrecque, R.L. Larson, W.C. Pitman III, X. Golovchenko, and W.F. Haxby 1989. Magnetic lineations of the world's ocean basins. *American Association of Petroleum Geologists Map Series.*

Cande, S.C., and Kent, D.V., 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *J. Geophys. Res.,* 100:6093-6095.
H. K. Coxall, P. A. Wilson, H. Palike, C. H. Lear, and J. Backman. Rapid stepwise onset of antarctic glaciation and deeper calcite compensation in the pacific ocean. NATURE, 433(7021):53–57, Jan 2005.

Engebretson, D.C., Cox, A., and Gordon, R.G., 1985. Rel*ative Motions Between Oceanic and Continental Plates in the Pacific Basin*. Spec. Pap. - Geol. Soc. Am., 206.

Gripp, A.E., and Gordon, R.G., 1990. Current plate velocities relative to the hotspots incorporating the NUVEL-1 global plate motion model. *Geophys. Res. Lett.,* 17:1109 1112.

Koppers, A.A.P., J. Phipps Morgan, J. W. Morgan, H. Staudigel, Testing the fixed hotspot hypothesis using 40Ar/39Ar age progressions along seamount trails, Earth and Planetary Science Letters, 185, 237-252, 2001.

Knappenberger, M., 2000, Sedimentation rates and Pacific plate motion calculated using seismic cross sections of the Neogene equatorial sediment bulge: Boise, ID, Boise State University, MSc. Thesis

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

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.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.

Lowenstein, T. K. & Demicco, R. V. Elevated Eocene atmospheric CO2 and its subsequent decline. Science 313, 1928 (2007).

Müller, R. D., Roest, W- R., Royer, J.-Y., Gahagan, L. M., Sclater, J. G.,D. Digital isochrones of the world's ocean floor. J. Geophys. Res., 102(B2), 3211-3214, 1997.

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

Petronotis, K.E., 1991. Paleomagnetic studies of the skewness of Pacific plate marine magnetic anomalies 25–32R: implications for anomalous skewness and the motion of the Pacific plate and hotspots [Ph.D. thesis]. Northwestern Univ., Evanston, IL.

Petronotis, K.E., Gordon, R.G., and Acton, G.D., 1994. A 57 Ma Pacific plate paleomagnetic pole determined from a skewness analysis of crossings of marine magnetic anomaly 25r. *Geophys.J. Int.*, 118:529-554.

Rea, D.K., and Dixon, J.M., 1983, Late Cretaceous and Paleogene tectonic evolution of the North Pacific Ocean: Earth and Planetary Science Letters, v. 65, p. 145-146.

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

Sager, W.W., and M.S. Pringle, Mid-Cretaceous to Early Tertiary apparent polar wander path of the Pacific plate, J. Geophys. Res., 93, 11753-11771, 1988.

Shackleton, N. J., M. A. Hall, I. Raffi, L. Tauxe, J. Zachos 2000, Astronomical calibration age for the Miocene-Oligocene boundary, *Geology,* 28: 447-450.
Shipboard Scientific Party, 2004. Leg 2008 summary. In Zachos, J.C., Kroon, D., Blum, P., et al., Proc ODP, Init. Repts., 208: College Station TX (Ocean Drilling Program (1–112).

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