Expedition 320/321: Pacific Equatorial Age Transect (PEAT I and II)

19 May 2009

Site U1336 Summary

Two holes were cored at Site U1336 (PEAT-5C, 7º42.067’N, 128º15.253’W, 4286 meters water depth), targeting paleoceanographic events in the late Oligocene and into the Miocene, including a focus on the Oligocene–Miocene transition, the recovery of the Mi-1 glaciation event (Zachos et al., 2001; Pälike et al., 2006b). In conjunction with Sites U1335 (PEAT-6C) and U1337 (PEAT-7C), it was also designed to provide a latitudinal transect for early Miocene age slices. Site U1336 provides data towards a depth transect across the late Oligocene and Miocene that allow us to verify and apply a previous astronomical age calibration from ODP Site 1218 (Pälike et al., 2006a).

At Site U1336, APC Cores were taken from the seafloor to 184.8 m (U1336A-1H to 21H) and 173.6 m (Cores U1336B-1H to 20H). Non-magnetic core barrels were used for Cores U1336A-1H to 16H and Cores U1336B-1H to 16H and steel barrels were used for all other cores. Two hard layers, one at ~121 m CSF-A (Cores U1336A-14H and 1336B-14H) and one at ~135 m CSF-A (Core U1336B-16H) caused core loss and prevented the development of a continuous sediment section. XCB cores (Cores U1336A-22X to 35X) were taken from 184.8 to 302.9 m in Hole U1336A. We stopped coring before reaching the basement objective because of the decreasing rates of penetration, the relatively low recovery, and the possibility of obtaining a stratigraphically complete Miocene section.

At Site U1336 about 300 m of pelagic sediments are divided into three major lithologic units. The sediments are composed mainly of nannofossil oozes, nannofossil chalks, and chert. The early to middle Miocene sedimentary sequence of Unit I (0-74.54 m CSF-A) contains more radiolarians, clay, foraminifers, and diatoms relative to the early Miocene to early Oligocene sediments below about 70 m CSF-A. Subtle changes in the relative proportions of these minor components produce meter-scale dark-light color cycles and two diatom rich layers. Numerous rounded fragments of pumice occur throughout this unit.

Unit II (74.50 to 189.50 m CSF-A) is dominated by nannofossil ooze. Sediment color changes occur downhole from pale yellow to light greenish gray at 92 m CSF-A. Below this boundary, the color of Unit II alternates between light greenish gray and white down to 184.80 m CSF-A. The oxidation-reduction reactions responsible for the observed vivid colors and pore water chemistry changes are likely fueled by enhanced availability of organic carbon relative to overlying and underlying sediments. Occasional thin chert layers were encountered below 120 m in Unit II. Mainly broken chert fragments were recovered except for a small in-situ chert fragment at 159.6 m CSF-A in Section U1336B-18H-4, 106 cm. More abundant chert layers are common in the lower third of the recovered sequence.

Unit III (189.5 to 299.6 m CSF-A) was only recovered in Hole U1336A. The dominant lithologies of this unit are light greenish gray and white nannofossil chalk with light greenish gray mm-scale color banding and chert layers. The chert shows many different colors including black, dark greenish gray, very dark greenish gray, dark gray, olive yellow, dark brown, and pink. The Unit II/III transition is identified by the uppermost common occurrence of chert. Below 289 m CSF-A, nannofossil chalk contains increasing amounts of micrite and the cherts vary in color. The lowermost cherts are olive yellow, then pink and, finally, dark brown at the base. The chalk changes color to white below 298.54 m CSF-A. $CaCO_3$ contents remain above 88% in the chalk layers. Igneous basement was not recovered at Site U1336.

All major microfossil groups have been found in sediments from Site U1336, representing a complete biostratigraphic succession at the shipboard sample resolution level of middle Miocene to early Oligocene sediments. They provide a coherent, high-resolution biochronology through a complete sequence. Calcareous nannofossils are moderately to poorly preserved throughout the succession. There appears to be a complete sequence of nannofossil zones from NN6 (middle Miocene) through NP22 (lower Oligocene), except for Zone NN3, which could not be resolved. Planktic foraminifers are present throughout the succession ranging from Zones N12 through O1. They are moderately well preserved in the Miocene, and less well preserved in the Oligocene. The radiolarian stratigraphy at Site U1336 spans the interval from just above the RN6 – RN5 boundary (middle Miocene) to the upper part of RP22 (upper Oligocene) at about 170 m CSF-A. Below this level the sediments are barren of radiolarians. Above this level the assemblages tend to have good to moderate preservation, with intermittent intervals of good preservation in RN3 and RN4 (lower to middle Miocene). The down-section decrease in preservation and ultimate disappearance of the radiolarians below Core U1336A-19H appears to be associated with dissolution and reprecipitation of the biogenic silica as intergranular cement and as chert.

The diatom stratigraphy at Hole U1336B spans the interval from just above the *Cestodiscus peplum* zone (middle Miocene) in Core U1336B-1H to the lowermost part of *Crucidenticula nicobarica* zone (upper lower Miocene) in Core U1336B-7H. Below sample U1336B-7H-CC, the sediments are barren of diatoms. Above this level the valves tend to be mostly poorly preserved. Sample U1336B-1H-CC contains the highest diversity with *Cestodiscus pulchellus* as dominant component, accompanied by *Synedra jouseana* and *Thalassiosira yabei*. Fragments of the large centric diatom *Ethmodiscus* are present in the upper part of Hole U1336B.

Benthic foraminifers are present throughout the section, although abundances are overall quite low. The preservation of tests is moderate in the upper part of Site 1336 (U1336A-1H-CC through 19H-CC: 8.22 – 170.63 m CSF-A and U1336B-1H-CC through 20H-CC: 1.68 – 174.01 m CSF-A), but deteriorates below this level. The Oligocene to middle Miocene benthic foraminiferal assemblage is relatively diverse, and indicates oligotrophic, lower bathyal to abyssal paleodepths.

The Oligocene/Miocene boundary is placed between the bioevents base *Paragloborotalia kugleri* (23.0 Ma) and top *Sphenolithus delphix* (23.1 Ma) The base of planktic foraminifer *Paragloborotalia kugleri* (23.0 Ma) occurs between Section U1336A-16H-CC and Sample U1336A-17H-2, 38-40 cm (142.96 m CSF-A), and Sample U1336B-16H-1, 52-54 cm and Sample U1336B-17H-3, 80-82 cm (137.72 m CSF-A). Calcareous nannofossil event top *Sphenolithus delphix* is recognized between Samples U1336A-17X-2, 90 cm and U1336A-17X-4, 90cm (145.9 m CSF-A), and between Section U1336B-16H-CC and Sample U1336B-17H-1, 150cm (137.56 m CSF-A).

Paleomagnetic measurements were conducted on archive half sections of 21 APC cores from Hole U1336A and 20 APC cores from Hole U1336B. Measurements of NRM above ~80 m CSF-A in Holes U1336A and U1336B indicate moderate magnetization intensities ($1x10^{-3}$ A/m) with a patchy but generally weak viscous (VRM) or isothermal remanent magnetic (IRM) coring overprint and polarity reversal sequences are clearly recognized in general. Demagnetization data from discrete samples above ~ 80 m CSF-A indicate that the characteristic remanent magnetization (ChRM) of the sediments is identified at the 10 - 20 mT demagnetization steps.

Below ~80 m CSF-A, a zone of diagenetic alteration involving dissolution of remanence carriers reduces remanence intensities after AF demagnetization of 20 mT to values close to magnetometer noise level in the shipboard environment (~ $1x10^{-5}$ A/m). In this zone, sediment magnetizations have been partly or entirely overprinted during the coring process, and remanence inclinations are sometimes steeply negative after AF demagnetization at peak fields of 20 mT. At about 130 to 140 m CSF-A (Cores U1336A-15H to 16H, and U1336B-15H) and below ~160 m CSF-A (Cores U1336A-19H to 21H and U1336B-18H to 20H), polarity reversals are apparently present but the inclinations are steep (up to 80°) indicating that the drilling overprint has not been effectively removed during shipboard demagnetization.

The biostratigraphic datums and magnetostratigraphic results allow the calculation of average linear sedimentation rates (LSRs) that are 9 m /m.y. for the upper 74 m of the section on the CCCSF-A depth scale. The LSRs of Site U1336 increase from 12 m/m.y. in the lower Miocene and to 15 m/m.y. in the Oligocene. There are no apparent hiatus at the shipboard biostratigraphic resolution.

A complete physical property programs conducted on whole cores, split cores, and discrete samples. Physical properties measurements on whole-round sections and samples from split cores reflect the differences among lithologies drilled at Site U1336. The nannofossil ooze with varying amounts of clay, radiolarians, and diatoms that makes up Unit I is characterized by high amplitude and high frequency variations in bulk density, magnetic susceptibility, natural gamma radiation, and color reflectance. Magnetic susceptibility is highest in Unit I with values ranging from 5 to 30 $x10^{-5}$ SI. Natural gamma radiation is also high in this unit with values up to 56 cps near the seafloor. Wet-bulk densities are lowest in Unit I with values ranging from 1.4 to 1.7 g/cm^3. Porosity is highest in this interval, ranging from 65% to 80%. The grain density of most of the sediments of Unit I, as well as Units II and III, range from 2.6 to 2.9 g/cm^3, reflecting the dominance of carbonate constituents at Site U1336. The sediment velocity in Unit I is low, averaging 1500 m/s. The color reflectance of Unit I is marked by luminance (L*) values that are slightly lower and more variable than values determined for sediments in Units II and III.

Below Unit I, a more uniform increase in wet bulk density and decrease in porosity in Units II and III reflect the increasing compaction of the sediments. A slight step increase in wet bulk density marks the transition between Unit II and Unit III. In Unit III wet bulk density and porosity average 1.9 g/cm^3 and 51%, respectively. Magnetic susceptibility and natural gamma radiation are low and nearly uniform in Units II and III. Magnetic susceptibility typically is below 5 $x10^{-5}$ SI and natural gamma radiation is approximately 2 cps. Lower clay abundance in Unit II is marked by an increase in L* at the boundary between Units I and II. At 92 m CFS-A, within Unit II, sharp decreases in the a* and b* reflectance parameters mark the change in sediment color from pale yellow to greenish gray. One of the most pronounced changes in physical properties at Site U1336 is the sharp increase in velocity that accompanies the change from nannofossil ooze to nannofossil chalk at the boundary between Units II and III. The velocity at the base of Unit II is approximately 1,700 m/s. Below 190 m CFS-A, in Unit III, the rate at which velocity increases with depth increases, ultimately reaching a value of approximately 2,200 m/s at 290 m CFS-A, near the base of Hole U1336A.

Special Task Multi Sensor Logger (STMSL) data were collected at 5-cm intervals from Hole U1336B and compared to the Whole-Round MultiSensor logger (WRMSL) data obtained at 2.5-cm resolution from Hole U1336A during Expedition 320. Features in the magnetic susceptibility and GRA density are well aligned between Holes U1336A and U1336B down to a depth of ~94 m CCSF-A. Below 94 m CCSF-A the magnetic susceptibility signal drops to very low values but the density data are good enough to sustain a correlation to Core U1334B-14H-4, 122 cm. At this point (138.50 CCSF) sediments recovered in both holes are disturbed.

Paleomagnetic reversals were used to calculate the average linear sedimentation rates (LSRs) for the upper 74 m of the section at Site U1336 on the CCCSF-A depth scale. Below 74 m CSF-A only biostratigraphic datums were used to calculate the average LSRs. The LSR at Site U1336 decrease from 15 m/m.y. in the upper Oligocene to 12 m/m.y. in the lower Miocene and stay relatively constant at 9 m/m.y. in the remainder of the section.

A standard geochemical analysis of porewater, organic and inorganic properties was undertaken on sediments from Site U1336. Twenty two interstitial whole-round water samples from Hole 1336B were analyzed. Chlorinity values have a distinct increase from ~555 to ~570 mM in the uppermost 40 m CSF-A, potentially reflecting the boundary condition change from the more saline ocean at the last glacial maximum to the present. Alkalinity is relatively constant at values >2.5 mM in the upper 110 m CSF-A, with a pronounced decline to 1 mM by 170 m CSF-A. Sulfate concentrations decrease with depth to values as low as 22 mM. Dissolved phosphate concentrations are ~5 µM at ~9 m CSF-A, decreasing to values ~1 µM by ~15 m CSF-A. Dissolved manganese has a broad peak in the depth range from ~25-120 m CSF-A, and dissolved iron appears then peaks below 100 m CSF-A. The increase of dissolved Fe occurs where Mn decreases downhole. Concentrations of dissolved silicate increase with depth from <400 to 800 µM, but do not reach saturation with biogenic opal.

Highlights

1) Miocene sedimentary section and cyclic sedimentations

One of the highlights from Site U1336 is the recovery of a thick Miocene carbonate section from the central equatorial Pacific, one of the high priority objectives of the PEAT program. We recovered the complete early Miocene sequence (~9 m.y. duration) in a ~110 m thick section, with a sedimentation rate of 12 m/m.y. and the middle Miocene sequence (4.5 m.y. duration) in a ~45 m thick with a sedimentation rate of ~21 m/m.y. These high sedimentation rates will facilitate the study of paleoceanographic processes at unprecedented resolution for the equatorial Pacific.

The obvious variations of both color and biogenic composition within nannofossil oozes represent cyclically changing fluctuations of CCD and upwelling intensity during the middle Miocene through early Miocene. The variable lithology also results in the variations of many petrophysical signals of physical properties including L*, b*, MS, natural gamma radiation, and GRA bulk density. These high sedimentation rate cyclically-deposited sediments will facilitate the study of paleoceanographic processes at unprecedented resolution for the equatorial Pacific.

2) Oligocene/Miocene (O/M) transitions and depth transects

Site U1336 was planned as part of a latitudinal transect for early Miocene age slices and the PEAT Oligocene/Miocene (O/M) depth transect in conjunction with Sites U1335 (PEAT-6C) and U1337 (PEAT-7C). The Miocene sequence at these sites includes the critical intervals of the Mi-1 glaciation and middle Miocene ice-sheet expansion (Holbourn et al., 2005; Zachos et al., 2001; Pälike et al., 2006b). The dominant lithologies of nannofossil ooze and chalk at Sites U1336 and U1335, with better preservation of calcareous microfossils than any other site drilled during Expedition 320, will allow us to achieve the prime objective for this coring site.

The O/M transition at Hole U1336A occurs in very homogeneous nannofossil ooze within the alternations of white and light greenish gray ooze. The same alternating sequence is observed above the O/M transition in Site U1334. The biostratigraphy reveals that the O/M boundary exists between 142.96 m CSF-A and 145.9 m CSF-A at Site U1336; this will allow the high-resolution study of this critical interval.

3) Geochemical front

Site U1336 recovered an interval of greenish gray carbonates that exhibit a distinct Mn increase and elevated Fe porewater concentrations with similar characteristics as geochemical alteration fronts at Sites U1334 and U1335. At Site U1336, this zone is about ~200 m in thickness. The paleomagnetic signal was very weak in most parts of this section (80-160 m CSF-A). High dissolved Fe and Mn in pore water is probably caused by changes in the oxidation state in the sediments. The oxidation-reduction reactions are likely fueled by enhanced availability of organic carbon in overlying and underlying sediments zone. This site may provide the opportunity to study organic matter degradation.

Site U1336 migrated from south to north through the equatorial belt of high productivity. Based on paleo-latitude reconstructions, these geochemical alteration fronts can be mapped to similar equatorial positions between Sites U1334 and U1335, roughly between the equator and ~4º N.

4) Chert formation in the early Oligocene

The sequence at Site U1336 includes barren intervals of radiolarian fossils and many thin intercalated chert layers and fragments. The radiolarians decrease in preservation downsection and disappear below Core U1336A-19H. Instead, they sediments contain several chert fragments. Some inferred chert layers occur around120-140 m CSF-A and blocked APC penetration. Below ~190 m CSF-A, various colored chert layers and fragments occurred within the cores. The chert frequently contains foraminiferal tests, reflecting diagenetic process of dissolution and reprecipitation of the biogenic silica.

The dissolution of biogenic silica is the source of porcellanite and chert, and on crust less than 65 Ma in age, almost all cherts in the Pacific lie less than 150 m above basement. Although we have not recovered basement rocks at this site, the sediments became hard, lithified limestones, and the drilled section is probably close to basement. The dissolution of silica in the basal sedimentary section is likely associated with the circulation of warm hydrothermal waters in the upper oceanic crust that extends into the lower sediments where they are cut by fractures and faults (Moore, 2008a,b). This site will provide information on chert formation in the equatorial Pacific regions.

References

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