Expedition 320: Pacific Equatorial Age Transect (PEAT I)

30 April 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., 2001b; 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 U1336A, 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. A hard layer at 120-140 m prevented achieving a full stroke during coring (Core 1336A-14H and Core 1336B-16H). XCB cores (Cores U1336A-22X to 35X) were taken from 184.8 to 302.9 m at 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.

The sedimentary section at Site U1336 is composed of an ~300 m-thick nannofossil ooze and chalks of middle Miocene through early Oligocene age. They are divided into three lithologic units. Unit I (0-74.54 m CSF-A) consists of Miocene nannofossil ooze with varying amounts of radiolarians, foraminifers, diatoms, and clay as minor constituents. The physical properties, including magnetic susceptibility, b* and L* reflectance, and GRA bulk density all represent higher amplitude variability throughout Unit I. $CaCO_3$ contents are also variable, ranging between 48 and 90%.

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. Greenish gray mm-scale color bands are present below 120.86 m. $CaCO_3$ contents are relatively constant in Unit II and typically greater than 85%.

The dominant lithologies of Unit III (189.5 to 299.6 m) 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 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. $CaCO_3$ contents remain above 88% in the chalk layers. Igneous basement was not recovered at Site U1336. Lithological descriptions of this site are based only on sediments recovered in Hole U1336A. A second hole (Hole U1336B) was cored to 174.01 m CSF-A at this site during Expedition 320. Cores from Hole U1336B were left onboard to be split and described by Expedition 321.

Light-dark cycles in the nannofossil oozes of Unit I are associated with variations in the relative amounts of accessory lithologic components within the nannofossil oozes, including clay, radiolarians, and diatoms, and also higher amplitude variations in the physical properties including L*, b*, MS, and GRA bulk density.

Light greenish gray sediments are recovered just as they were at Sites U1334 and U1335, and persist for about 250 m CSF-A before shifting to white and pink. Magnetic susceptibility drops to near-zero throughout the light greenish gray interval. Unlike other sites drilled during Expedition 320, discrete mm- to cm- scale color bands frequently occur within the interval where Fe reduction has occurred in Units II and III.

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 (see “Biostratigraphy”). They provide a coherent, high-resolution biochronology through a complete sequence. Calcareous nannofossils are moderately well preserved throughout the succession and there appears to be a complete sequence of nannofossil zones from NN6 (middle

Miocene) through NP22 (lower Oligocene). Planktic foraminifers are present throughout the succession ranging from Zones M1 through O1. They are abundant and well preserved in the Miocene, and less well preserved in the Oligocene. The radiolarian biostratigraphy at Site U1336A spans the interval from just above the RN6 – RN5 boundary (middle Miocene) in Core U1336A-1H to the uppermost part of RP22 (upper Oligocene) in Core U1336A-19H (Section U1335-19H-CC, ~170.3 m CSF-A). Below this level the sediments are barren of radiolarians. Above this level the assemblages tend to have moderate preservation, with intermittent intervals of good preservation in RN3 and RN4 (lower to middle Miocene). This down-section decrease in preservation and ultimate disappearance of the radiolarians below about 170 m CSF-A appears to be associated with dissolution of the biogenic silica. However, the nannofossil, radiolarian, and planktic foraminiferal datums are in good agreement except the dissolution interval of radiolarians. Benthic foraminifers are present through most of the section and indicate lower bathyal to abyssal paleodepths.

The Oligocene/Miocene boundary marker of the base *Paragloborotalia kugleri* (23.0 Ma) occurs between Section U1336A-16H-CC and Sample U1336A-17H-2, 38-40 cm (142.96 m CSF-A), while calcareous nannofossil event top *Sphenolithus delphix* is recognized at 145.9 m CSF-A between Samples U1336A-17X-2, 90 cm and U1336A-17X-4, 90cm. Top *Sphenolithus delphix* is placed just prior to the Oligocene/Miocene boundary, and the boundary exist between the both occurrences.

Paleomagnetic measurements were conducted on archive half sections of 21 APC cores from Holes U1336A and the magnetic susceptibilities and masses of 138 discrete samples. The natural remanent magnetization (NRM) measurements above ~80 m CSF-A in Hole U1336A indicate moderate magnetization ($1x10^{-3}$ A/m) with a patchy, but generally weak viscous isothermal remanent magnetic (IRM) coring overprint. Between ~80 and ~160 m CSF-A is a zone of diagenetic alteration within the greenish gray core interval, in which sediments effectively have no remanence or have been entirely overprinted during the coring process. Below ~160 m CSF-A polarity reversals are present but the inclinations are steep (up to 80°) indicating that the drilling overprint was not effectively removed during demagnetization.

The magnetozones in the upper ~80 m CSF-A correlate well with the biostratigraphic framework. At the top of Hole U1336A, magnetozones in Cores U1336A-1H and 2H tentatively correlate with the interval from the base of C5Ar.3r through to the base of C5ABn. Core U1336A-3H contains one polarity interval, corresponding to polarity Chrons C5ACn and C5ADn, but Chron C5ACr was not identified. Core U1336A-4H includes Chrons C5ADr, C5Bn and the top of Chron C5Br occurs at the base of U1336-4H and terminates at the base of Core U1336A-5H. Below Chron C5Br the correlation with the GPTS is relatively unambiguous through to Core U1336A-9H which contains the upper portions of Chron C6n. Between ~80 and ~160 m CSF-A the magnetization of the sediment deteriorates below analytical noise level within the greenish gray core interval as observed at Site U1335. Below ~160 m CSF-A a reversals pattern is discernable and tentatively correlate with Chrons C6Cr through Chron C7An.

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 CCSF-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. Hole U1336B was analyzed only by the whole round multisensor track and natural gamma radiation detector. The physical property data for Hole U1336B have not been filtered for drilling disturbances.

MS measurements correlate well with the major differences in lithology of Site U1336. MS values are highest in Unit I with high amplitude and frequency variations from 5 to 30 $x10^{-5}$ SI. In Unit II, they decreases from ~10 to near 0 $x10^{-5}$ SI. There is a slight increase in the amplitude and frequency of the variation in Unit III. The highest natural gamma radiation are present at the seafloor (~56 cps) and, rapidly decrease with depth in Unit I, and then are very low (2 cps) in the Unit II.

Velocities are between 1480 to 1500 m/s in Unit I and between 1480 and 1530 m/s in Unit II. At ~176m CSF-A velocities begin to increase rapidly into Unit III, from

1530 to ~1960 m/s at 208 m CSF-A. The remainder of Unit III shows high frequency and high amplitude variation averaging 1910 m/s in this more lithified interval.

Wet bulk densities are lowest in Unit I (1.4-1.7 g/cm^3) sediments which contain a large amount of clay, radiolarians, diatoms, and then increases slightly and is more uniform (~1.7 g/cm^3) in Unit II. In Unit III wet bulk density becomes variable deeper than 180 m, averaging 1.9 g/cm^3. Grain density variations match changes in lithology. At the top of the section grain density is at 3.0 g/cm^3 and falls rapidly, reflecting clay-rich sediments which grade rapidly into nannofossil ooze. Grain density averages 2.7 g/cm^3 for most of the succession (varying from 2.6 to 3.0 g/cm^3); this reflects the dominance of carbonate material through the succession (calcite = 2.70 g/cm^3 grain density). Porosity is highest in Unit I, varying from 65 to 80%, and decreases gradually toward the base of Unit II to a 55 to 60% at ~184 m CSF-A. In Unit III, porosity ranges from 45 to 60%.

Thermal conductivity decreases from 1.2 to 1 W/K·m through Unit I, with a minimum conductivity of 0.91 W/K·m at 31 m CSF-A. The values of Units II and III increase from 1 to 1.4 W/K·m. Below 183 m CSF-A thermal conductivity decreases by increased core disturbance by XCB coring.

Spectral reflectance corresponds to pronounced lithologic and diagenetic changes. In Unit I, L* values are lowest (50-80%), and display high amplitude variations that due to minor lithologic changes. Values in Unit II are higher and more uniform, and slightly lower and more variable in Unit III. Variations in b* (blue-yellow) decrease abruptly below 92 m depth.

Hole U1336B cores were not split during Expedition 320, the position of coring disturbances is unknown and the construction of a spliced section for sampling purposes had to be postponed. MS and GRA density were used for correlating between Holes U1336A and 1336B. Features in these data are well aligned between Holes U1336A (84 m CSF-A) and U1336B (84 m CSF-A) down to a depth of ~94 m CCSF-A. Below 94 m CCSF-A the correlation between the two holes becomes challenging without additional split-core data, and a single spliced record was not assembled at this point. A growth factor (GF) of 1.13 is calculated by linear regression for the top 94 m CCSF-A of Site U1336, indicating a 13% increase in CCSF relative to CSF depth.

A standard geochemical analysis of porewater, organic and inorganic properties

was undertaken on sediments from Site U1336. 22 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 and iron have a broad peak in the depth range from ~25-120 m CSF-A, and below 100 m CSF-A, respectively. An increase of iron millers a decrease in manganese. 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 very 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, and GRA bulk density. These high sedimentation rate and cyclic 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 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., 2001b; 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 pore water 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 Fe and Mn pore water may be related to 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 down-section and disappear below Core U1336A-19H. Instead, they sediments contain several chert fragments. Some inferred chert layers occur around120-140 m CSF-A prevented the 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 porcellainite 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, 2008b). This site will provide information on chert formation in the equatorial Pacific regions.

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