Expedition 321: Pacific Equatorial Age Transect (PEAT II)

21 June 2009

Site U1338 Summary

Site U1338 (PEAT-8D, 2° 30.469'N, 117° 58.178' W, 4200 m water depth) was sited to collect an 18-3 Ma segment of the PEAT equatorial megasplice, and is located on ~18 Ma crust just north of the Galapagos Fracture Zone, 324 nautical miles (600 km) southeast of Site U1337. A seamount (3.7 km water depth) with surrounding moat is found ~25 km to the NNW of Site U1338, at the downslope end of the survey area. Originally a site (PEAT-8C) was chosen about 10 km from the seamount. However, an alternate PEAT-8D was selected and drilled uphill and further away from the seamount to avoid possible turbidites as were found near seamounts on Exp. 320 Sites U1331 and U1335. The recovered sediment column at Site U1338 represents a nearly complete and continuous early Miocene to Holocene sedimentary section.

Operations

Four holes were cored at Site U1338. At Hole U1338A, APC cores were taken from the seafloor to 221.2 m DSF (U1338A-1H to 24H) using non-magnetic core barrels with the Flexit core orientation installed. Flexit and steel core barrels were used from Core 25H-26H. In addition, five successful APCT3 temperature measurements were taken with Cores 5H, 7H, 9H, 11H, and 13H. XCB coring continued with Cores 27X through 44X. A small piece of basement was recovered in the core catcher of Core 44X.

At Hole U1337B, APC cores were taken from the seafloor to 188.1 m DSF (U1338A-1H to 20H) except for a short drilled interval of 2.5 m (from 235.6-238.1 m

DSF) to adjust the core breaks. Non-magnetic core barrels and Flexit core orientation system were used through Core 20H. Flexit and steel core barrels continued through Core 42H to a depth of 387.4 m DSF. Coring continued with three XCB Cores 43X through 45X to a depth of 416.1 m DSF. The basement contact was recovered in Core 45X. Three logging strings (triple combo, vertical seismic imager (VSI), and FMS-sonic) were deployed in Hole U1338B.

Hole U1338C was cored to recover sections that were missing from Holes U1338A and U1338B. APC cores were taken from the seafloor to 189.8 m DSF (U1338A-1H to 21H) using non-magnetic core barrels and the Flexit core orientation system. Flexit and steel core barrels were used through Core 44H to a depth of 396.9 m DSF. Coring continued through Core 47H to a total depth of 414.4 m DSF setting a new all time depth record for the APC.

Hole U1338D was primarily planned to recover a few “instructional” cores to be used during the upcoming expedition. Three APC cores were cut to a depth of 23.9 m DSF.

Lithostratigraphy

At Site U1338, approximately 415 m of nannofossil ooze and chalk with varying concentrations of diatoms and radiolarians overlie early Miocene seafloor basalt, and are divided into three lithologic units. Pleistocene through middle Pliocene sediments of Unit I are characterized by multicolored (various hues of white, brown, green, and gray) nannofossil ooze, diatom nannofossil ooze, and radiolarian nannofossil ooze that alternate on decimeter- to meter-scale. Light green and light gray nannofossil ooze with occasional darker intervals with abundant siliceous microfossils, notably diatoms, comprise the upper Miocene to middle Pliocene Unit II. Decimeter-, meter-, and tens of meter-scale color alternations in Units I and II are associated with variations in lithology and physical properties. Some of these color changes, as well as common mm- and cm-scale color banding, are not associated with compositional changes and likely reflect variations in sediment redox state. White, pale yellow, light greenish gray, and very pale brown nannofossil oozes and chalks dominate Unit III of lower to upper Miocene, although slightly darker green and gray intervals with larger amounts of siliceous microfossils remain present. Lower Miocene seafloor basalt (Unit IV) was recovered at the base of the sedimentary section.

Biostratigraphy

All major microfossil groups have been found in the ~415 m thick succession of Holocene to lower Miocene sediment bulge recovered from Site U1338. The calcareous nannofossils at Site U1338 are in general moderately preserved, but there are some intervals in which the preservation is good or poor. Nannofossil Zones NN4 to NN21 are present, indicating an apparently complete sequence. Planktic foraminifers vary from rare to abundant, with moderate to good preservation throughout most of the succession, but are absent or rare in a short interval in the late Miocene. Planktic foraminifer Zones PT1b (late Pleistocene) to M2 (early Miocene) are documented, with the exception of Zones PL4, M12, and M6. The radiolarian stratigraphy spans the interval from the uppermost part of Zone RN16-17 (late Pleistocene) to uppermost part of RN3 (early Miocene). The radiolarian assemblages show good to moderate preservation, except in the lowermost portion (early Miocene), which is barren of radiolarians. The high resolution diatom stratigraphy spans the interval from the *Fragilariopsis (Pseudoeunotia) doliolus* Zone (late Pleistocene) to the lowermost part of the *Craspedodiscus elegans* Zone (early Miocene). The diatom assemblage is generally well to moderately preserved throughout the recovered section; however, there are several intervals in which valve preservation becomes moderate to poor. The nannofossil, foraminiferal, radiolarian, and diatom datums and zonal schemes generally agree, with some inconsistencies. Benthic foraminifers occur continuously throughout the succession recovered in Hole U1338A, and show generally good preservation. The overall assemblage composition indicates lower bathyal to abyssal paleodepths. Marked variations in downcore abundance and species distribution reflect major changes in global climate linked to fluctuations in ice volume and re-organization of Pacific Ocean circulation during the Neogene.

Stratigraphic Correlation

Stratigraphic correlation provided a complete spliced record to a depth of approximately 260 m CCSF-A. Several gaps were seen between 280 and 360 m CCSF-A. Comparison of GRA density records with well logging density data suggests that no more than a meter of section was lost in any of the gaps. Correlation between the holes was broken again several times between 435 m CCSF-A and basement at 460 m CCSF-A. Growth factor for the correlation was 1.11. The linear sedimentation rate decreases from approximately 29 m/m.y. in the Miocene to 13 m/m.y. in the Pliocene-Pleistocene.

Paleomagnetism

Paleomagnetic measurements were conducted on archive half sections of 26 APC cores from Hole U1338A, 42 APC cores from Hole U1338B, and 47 APC cores from Hole 1338C. The Flexit core orientation tool was deployed in conjunction with all APC cores except for the deepest 3 cores of U1338C, and we conclude that the Flexit orientation data are generally reliable. Measurements of natural remanent magnetization (NRM) indicate moderate magnetization intensities (on the order of 10-3 A/m) for depth intervals of 0-50 m CSF-A, 280-225 m CSF-A, and 295-395 m CSF-A. Polarity reversal sequences of these intervals are provisionally correlated to the Brunhes to the upper part of the Gilbert Chron (0 to ~4 Ma), Chron C4An to C5n (~9 to 11 Ma), and Chron C5r to C5Br (~12 to 16 Ma) of the GPTS, respectively. Except for these intervals, remanence intensities after alternating-field (AF) demagnetization of 20 mT are reduced to values close to magnetometer noise level in the shipboard environment (~1x10-5 A/m). Magnetization directions are dispersed and not interpretable there. Sedimentation rates increase downcore from ~12 m/m.y. at the top to ~30 m/m.y. near the bottom.

Physical Properties

Physical properties measurements on whole-round sections and samples from split cores display a variation strongly dependent on the relative abundance of biosiliceous and calcareous sediment components at Site U1338. As at Site U1337, the general pattern is that intervals enriched in siliceous microfossils and clay display darker colors, lower grain density and bulk density, and higher porosity, magnetic susceptibility (MS), and natural gamma radiation (NGR). The variation of velocity is more complex in that it is dependent on both the wet bulk density and the sediment rigidity. These parameters vary independently with the variation in abundance of biosiliceous and calcareous components. The physical properties at Site U1338 also display cyclicity on multiple scales, a decimeter to meter scale and a scale with a spacing on the order of 10's of meters.

Lithologic Unit I at Site U1338 is characterized by low wet bulk density that decreases from 1.4 g/cm^3 near the seafloor to 1.2 g/cm^3 at the base of the unit, as a result of an increasing abundance of radiolarians and diatoms with depth. The grain density in Unit I and Unit II displays a greater variability than deeper at the site as a result of the greater variability in the abundance of biosiliceous and calcareous components. The average grain density for Units I and II is relatively low, 2.59 g/cm^3. The NGR signal at Site U1338 is characterized by a near seafloor peak that is somewhat lower than those recorded at the other PEAT drill sites, but it extends deeper and is marked by a double peak. Spectral reflectance measurements show that Unit I is characterized by lower L* and higher a* and b* values in the upper 25 m of Unit I. Below 25 m CSF-A, the sediment becomes lighter colored (L* increases) and more bluish green (a* and b* decrease).

Unit II is characterized by increasing wet bulk density with depth, down to approximately 175 m CSF-A. Below this depth, an increase in the abundance of siliceous microfossils produces a broad density minimum. The MS and NGR signals are low in Unit II, down to the depth at which the biosiliceous material increases in abundance. The interval of the broad density minimum is characterized by higher MS values that are roughly equal to those in the upper 25 m of Unit I. Unit II is lighter colored than Unit I (higher L*) and more blue (lower b*).

Unit III at Site U1338 is characterized by a higher and more uniform carbonate content, and as a result more uniform physical properties. Wet bulk density increases from roughly 1.5 g/cm^3 at the top of Unit III to 1.7 g/cm^3 at the base of the unit. Grain density varies over a narrower range in Unit III than it does in Units I and II and displays an average, 2.64 g/cm^3, nearer to that of calcite. Velocity, which through much of Units I and II is close to the velocity of water, displays a regular increase in Unit III, from ~1620 m/s at the top to ~1820 m/s near the base of the unit. The velocity gradient increases near the base of Unit III accompanying the transition from nannofossil ooze to chalk. MS is low from the boundary between Units II and III, at ~245 m CSF-A, to 300 m CSF-A. Below 300 m CSF-A, susceptibility again increase to values comparable to those in the upper part of Unit I. The variability of the NGR is lower in Unit III than in Unit II and remains uniformly low throughout the unit. Overall, Unit III is the lightest colored (highest L* values) unit at Site 1338. The transition from greenish gray to pale yellow is marked at ~385 m CSF-A by a shift to higher values of both a* and b*.

Downhole Logging

Downhole logging of Hole U1338B began after the end of APC/XCB coring to a total depth of 416.1 m DSF. Three tool strings were deployed in Hole U1338B a modified triple combo (that did not include a neutron porosity measurement), a FMS-Sonic combination, and a VSI seismic tool with a SGT-N gamma ray sonde. The modified triple combo and FMS-Sonic tool strings took downhole measurements of natural gamma ray radioactivity, bulk density, electrical resistivity, elastic wave velocity, and borehole resistivity images in the depth interval 125-413 m WSF (wireline depth below seafloor). The VSI seismic tool string measured seismic waveforms in a vertical seismic profile experiment that covered the depth interval 189.5-414.5 m WSF. Measurement depths were adjusted to match across different logging runs, obtaining a wireline matched below seafloor (WMSF) depth scale.

The downhole log measurements were used to define three logging units: Unit I (139-244 m WMSF) and Unit II (244-380 m WMSF) have average densities of ~1.45 and ~1.6 g/cm^3, respectively, that do not show any trend with depth, while in Unit III (from 380 m WMSF) density increases with depth reaching 1.7 g/cm^3 at the base of the hole. Resistivity and P-wave velocity follow a pattern similar to that of density throughout the logged interval, suggesting that the major control on these physical properties are variations in sediment porosity. Both resistivity and density measurements show a small-scale peak at 280 m WMSF. This peak at 280 m WMSF is clearly visible in the borehole resistivity images as a high-resistivity layer 16 cm thick, and it corresponds to a chert layer that has only been recovered as rubble in the cores. The natural gamma ray measurements are low throughout (~4 degrees API), but do show a pronounced high at the seafloor due to a local increase in uranium concentration.

In the VSP experiment, the arrival time of a seismic pulse was measured from the sea surface at 14 stations. Together with the travel time to the seafloor, the VSP measurements are the basis for a travel time-depth conversion that allows seismic reflectors to be correlated to stratigraphic events. Downhole temperature measurements and thermal conductivities of core samples were combined to estimate a geothermal gradient of 34.4°C/km and a heat flow of 33.6 mW/m^2 at Site U1338.

Geochemistry

A total of 118 interstitial water (IW) samples were collected from Holes U1338A and U1338B, 43 using the whole-round squeezing approach and 75 by Rhizon sampling. The chloride ion concentration (not corrected for Br^- contribution) varies slightly with depth and is generally within the range of 555 to 565 mM. Alkalinity increases slightly downhole from around 2.7 mM at the sediment/water interface to peak slightly above 4 mM at 140 m CSF-A. A monstrous dissolved manganese peak of 150 µM at 10 m CSF-A is captured by the high resolution IW sampling and is remarkably similar to that observed at Site U1337. These peaks are more than 10 times greater than the highest dissolved manganese concentrations encountered on Expedition 320. Lithium concentrations decrease from ~26 µM at the surface to a minimum of ~3 µM around 250 m CSF-A before increasing sharply with depth to seawater values at the base of the section. The interstitial water strontium profile is a mirror image to that of lithium except the decrease from the peak of 400 µM at 200 m CSF-A is punctuated by a sharp drop of >100 µM between ~260 and 290 m CSF-A. The lithium and strontium profiles indicate seawater circulation in the basement as their values tend toward seawater values near the basement.

$CaCO_3$ concentrations range between 26 and 88% with substantial variability in the upper 273.31 m CCSF-A, corresponding to the alternation between calcite and opal production in the upper two lithological units. Below 273.31 m CCSF-A (lithological Unit III), calcium carbonate contents become generally high and stable between 66 and

91% compared with the upper part of the stratigraphic column. In the upper ~ 230 m CCSF-A, the TOC content is generally high and variable ranging between 0.09 and 0.46%, whereas below ~230 m CCSF-A the TOC content is less than 0.09%. The downhole TOC variability is most likely related to lithological changes with higher TOC being found in the more biosiliceous intervals.

The interstitial water and bulk sediment samples reflect large variations in the sediment composition resulting from shifts in carbonate versus opal primary production. The large scale redox state and diagenetic processes of the sediment column are related to the overall changes in sediment composition. The interstitial water chemistry points to seawater circulation in the basement while the basement itself appears to exert little influence on the geochemistry of the sediments and interstitial waters.

Highlights

Color changes; lithology and redox state

Smear slide analyses and visual core descriptions show that many of the decimeter-, meter-, and tens of meter-scale color variations in Units I and II to some extent relate to changes in lithology. We suspect, however, that some of these color variations, notably the transitions between pale green and pale yellow lithologies are controlled by sediment redox state, similar to those recorded at Sites U1331 through U1337 and earlier work in the Equatorial Pacific Ocean (e.g., Lyle, 1983).

Magnetic susceptibility is relatively low in the light gray and light brown intervals in Unit I and for most of Unit II. A significant decrease in the intensity of the magnetic signal in Unit II suggests dissolution of magnetite resulting from intensified microbial Fe reduction. In the lower part of Unit III, a sharp downcore transition from green to yellow is not associated with any other lithological change, does not occur at the same stratigraphic level between holes and thus should not be considered as an equivalent time horizon. While pore water Fe concentrations reach 6 to 7 μmol/liter in the green interval, Fe is absent below the transition to yellow and brown. Although some of this signal may be affected by seawater contamination during XCB drilling in Hole U1338A, all available information suggests that the lowermost color change represents a redox front.

Occurrence of diatom-rich layers

Unit II at Site U1338 is mainly composed of nannofossil ooze with relatively high abundances of biosiliceous components, notably diatoms. The relative abundance of diatoms is lower than that at Site U1337 and the record lacks laminated diatom ooze intervals ("diatom mats") such as observed at Site U1337. However, cm- to sometimes 1–2 m thick diatom nannofossil ooze layers containing abundant specimens of the diatom *Thalassiothrix* spp. are occasionally interbedded with nannofossil ooze (e.g., ~126.2–127.1 m CSF-A and ~231.8–234.3 m CSF-A in Hole U1138A, and ~127.3–128.0 m CSF-A and ~233.8–234.8 m CSF-A in Hole U1338C). Units II and III also contain significant amounts of pyrite, particularly in diatom-rich intervals in Unit II (e.g., U1338B-14H, 19H–21H, 26H, 28H–29H, 32H–41H). In addition, the middle part of Unit III contains thin intervals of abundant pyrite-filled siliceous microfossils (e.g., Core U1338B-33H-4, 58–66 cm and U1338B-35H-5, 76–82 cm). These diatom rich layers, pyrite nodule occurrences, and pyrite-rich siliceous microfossil layers in Units II and III are associated with high TOC content, suggesting a relation between the abundance of diatoms in the sediments, sediment redox-state and the production or preservation of organic carbon.

References

Lyle, M., 1983. The Brown-Green Color Transition in Marine Sediments: A Marker of the Fe(III)-Fe(II) Redox Boundary. Limnology and Oceanography, 28(5), 1026-1033.