# OCEAN DRILLING PROGRAM

# LEG 199 SCIENTIFIC PROSPECTUS

# PALEOGENE EQUATORIAL TRANSECT

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This Scientific Prospectus is based on precruise JOIDES panel discussions and scientific input from the designated Co-chief Scientists on behalf of the drilling proponents. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-chief Scientists and the Operations Manager that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Science and Operations Committees (successors to the Planning Committee) and the Pollution Prevention and Safety Panel.

Technical Editors: Karen K. Graber and Lorri L. Peters

# ABSTRACT

The Paleogene Equatorial transect (Leg 199, Fig. 1, Table 1) will study the evolution of the equatorial Pacific current and wind system as the Earth went from maximum Cenozoic warmth to initial Antarctic glaciations. The drilling program will be primarily devoted to a transect along 56- to 57-Ma crust, old enough to capture the late Paleocene thermal maximum event in the basal, more carbonate-rich sediments. One drill site (Site PAT-8C) will also be drilled on 40 Ma crust to collect a near-equatorial sediment sequence from the middle Eocene through the late Eocene transition to glacial conditions in Antarctica. If the plate tectonic model we used for paleopositions is approximately correct, Site PAT-8C is at the equator at 40 Ma.

Because the Pacific plate drifts north with time out of the high productivity equatorial region, Paleogene equatorial sediments are overlain by a thin Neogene section of red clays. The youngest biogenic sediments to be drilled will be early Miocene in age. The lack of Neogene sedimentation minimizes burial diagenesis; essentially the entire Paleogene sediment section should be recoverable by advanced piston coring.

The Leg 199 transect extends from a paleolatitude of about 11°N to about 5°S and encompasses anomalously thick early Eocene sediments deposited as much as 8° north of the Paleocene equator. The transect will collect continuous sediment sequences to document the evolution of the equatorial current system, equatorial surface-water and deep-water temperature variations, wind patterns, and productivity in the late Paleocene and early Eocene. In addition, one site will specifically be drilled to study the changes in equatorial circulation associated with the transition from the late Eocene to the early Oligocene to the ice-house world.

Leg 199 drilling will accomplish, in addition to its primary objectives, the following goals:

1. Collection of continuous sequences of Paleogene sediment to improve Paleogene biostratigraphy and to tie this stratigraphy to paleomagnetic chronostratigraphy;
2. Better constraints on the late Paleocene and early Eocene equatorial position using paleomagnetic and micropaleontologic indicators;

3. Linkage of seismic stratigraphy from the site survey to sediment chronostratigraphy to extend the Neogene equatorial Pacific seismic stratigraphy (Mayer et al., 1985, 1986; Bloomer et al., 1995) back in time;
4. Locate the transition between Asian and American dust sources to understand the primary structure of the Paleogene wind field;
5. Provide primary geochemical information needed to understand the widespread formation of Eocene cherts;
6. Provide important data to make an early Paleogene mass balance of carbonate and opal burial and to track the Eocene movement of the carbonate compensation depth (CCD) in detail; and
7. Collect basal hydrothermal sediment sections for study of hydrothermal activity in the early Paleogene.

## BACKGROUND

The complex system of equatorial currents is one of the most persistent and clear traces of wind-driven circulation in the oceans. In the Neogene, the unequal hemispheric thermal gradients have pushed the Intertropical Convergence Zone (ITCZ) north of the equator and given rise to a narrow band of equatorial upwelling as well as an equatorially assymetric zonal current system. The high productivity associated with the equatorial upwelling results in a high rain of biogenic debris to the seafloor within 1.5°–2° of the geographic equator, with peak values restricted to an even narrower zone. In the Pacific Ocean, this biogenic rain has built a mound over geologic time of almost pure calcareous and siliceous sediments stretching along the equatorial region and reaching a thickness of over 500 m (Fig. 2).

The central equatorial Pacific is unique in the world's oceans because the path of plate motion carries this linear trace of equatorial upwelling and productivity northward with time (van Andel, 1974). There are two clear implications of this northward plate motion: (1) the thickest part of the equatorial mound of biogenic sediment is displaced several degrees to the north of the equator and (2) sediments deposited a few tens of millions of years ago have moved completely out of the region of high sediment flux. This movement into regions of very low sediment accumulation (or even erosion) puts Paleogene equatorial sediments within the reach of the Ocean Drilling Program's (ODP) advanced piston corer (APC)/extended core barrel (XCB) technology. For the most part, the sediments have never been subject to strong burial diagenesis and can be cored easily with little disturbance by APC. Time intervals notorious for extensive chert formation (e.g., the middle Eocene) are more likely to contain only oozes because they have never been deeply buried.

## PREVIOUS DRILLING

Nearly 30 years ago, Deep Sea Drilling Project (DSDP) rotary drilling and coring of the central Pacific equatorial mound of sediments (e.g., DSDP Legs 5, 8, 9, and 16) established the general pattern of equatorial sediment accumulation and plate migration through the Neogene and late Paleogene (e.g., van Andel et al. 1975; Leinen, 1979). However, the rotary coring technology available to these very early legs could not provide undisturbed sections or complete recovery and was utterly defeated by middle Eocene chert layers encountered in some of the more deeply buried sections. Thus, even the broad outlines of equatorial sediment accumulation in the middle Eocene and older sediments remain poorly defined. The complete recovery of undisturbed and largely unaltered sections in a transect of the Pacific Paleogene sediments has yet to be accomplished.

## THE SCIENTIFIC PROBLEM

### Early Paleogene Warm Climates

We know that the climate of the very early Paleogene was markedly different from that of the rest of the Cenozoic. The very warm temperatures (~12°C) estimated for high latitudes and deep waters, as well as the relatively stable temperatures of the Eocene tropical regions, have led us to confront the single greatest paradox of paleoclimate studies: if warmer high-latitude climates depend on enhanced wind-driven ocean currents or wind-carried heat and moisture to transport heat to the poles, how can this transport have been maintained under the weaker pole-to-equator thermal gradients? Such a scenario should give rise to weaker winds and diminished wind-driven transport. It is a paradox that has defeated most mathematical models of global climate. If the dynamics of Eocene climate can be understood, we will gain a fundamental understanding of the physics of Earth’s climate.

New data from the tropical oceans are necessary to define the climatic and oceanographic processes that caused early Paleogene warmth. Measurement of tropical sea-surface temperatures, for example, is an important way to distinguish between greenhouse-induced warming of the poles and warming by either atmospheric or oceanic heat transport. Data on winds and currents are needed to partition heat transport between atmosphere and oceans. Finally, the pattern of tropical wind and ocean circulation is a key element of global circulation. There are clear indications that these patterns may have been markedly different in the early Paleogene.

The Paleogene Equatorial Transect (Leg 199) will drill an early Paleogene transect across the world's most long-lived wind-driven current system, a system that contains the confluence of the Northern and Southern Hemispheric winds, and a system whose pattern, strength, and biogenic productivity is linked to global climate patterns.

The drilling of an equatorial transect will provide better and more continuous records of sea-surface and abyssal temperatures with which to assess stability of the water column and the magnitude of heat transfer out of the tropics. Changes in sea-surface temperature, plankton communities, and paleoproductivity across the transect will also provide important data concerning ocean circulation and the location and strength of the trade wind belts and ITCZ. The composition and rates of dust deposition will be used to locate both the ITCZ and the transition to the westerlies, whereas mass accumulation rates of biogenic debris will be used to assess the position and the strength of upwelling zones. Stable carbon isotope data will be used to assess nutrient flows in the water column and to constrain the global carbon cycle.

## CRITICAL INTERVALS

We have known for many years that the early Paleogene, particularly the early Eocene (~53 to 50 Ma), represents the most extreme long-lived interval of global warming witnessed on Earth since the well-documented mid-Cretaceous 'greenhouse' (e.g., Shackleton and Kennett, 1975). Yet, little is known about the number of constituent hyperthermals, the range of temperatures, or their effects on biotic evolution (Thomas and Zachos 1999). Similarly, whereas we know that the Eocene greenhouse period was followed by a long shift toward lower temperatures and ice sheet growth into the late Eocene and early Oligocene, the detailed history of these events and consequences for ocean circulation, carbon cycling, and biotic evolution are only vaguely understood. The late Eocene is also interesting from the perspective of the response of global climate and biodiversity to the history of large extraterrestrial impact events on Earth. Thus, the Palaeogene can be thought of as containing numerous 'critical intervals' that provide an excellent opportunity to improve our understanding of important paleoceanographic problems involving the dynamics of greenhouse gas release, warm climate stability, biotic turnover associated with extreme climate transitions, and extraterrestrial impacts. Below, we discuss three such intervals that have a particularly high chance of being recovered during Leg 199 drilling.

### The Late Paleocene Thermal Maximum

It is now well accepted that the Late Paleocene Thermal Maximum (LPTM) involved a substantial (~5°-7°C) warming in the Southern Ocean and subtropics, a 35%-50% extinction of deep-sea benthic foraminifers, and rapid perturbation to the global geochemical carbon cycle (e.g., Zachos et al., 1993; Koch et al., 1992). A growing body of evidence attributes these events to the massive release and oxidation of methane from the marine gas hydrate reservoir (e.g., Dickens et al., 1997; Katz et al., 1999). High-resolution stable isotope analyses (Bains et al., 1999) and orbitally tuned chronologies from sites in the Atlantic and off Antarctica (Norris and Röhl, 1999) suggest that carbon release occurred extremely rapidly (a fraction of a precession cycle). Thus, the LPTM may represent the best example in the geologic record of the response of the Earth ocean-atmosphere climate system to greenhouse warming on a time scale approaching that of the ongoing global anthropogenic experiment. Recent evidence in favor of elevated biogenic barium accumulation rates in deep-sea sites suggests that enhanced deposition of organic matter in deep-sea sediments may have acted as a negative feedback on atmospheric $CO_2$ levels and global temperatures to return Earth to average late Paleocene conditions (Bains et al., 2000). Whereas these new data support the methane hydrate hypothesis, considerable uncertainty remains about the mechanism and location of carbon release, the response of the CCD, and biotic overturn. Leg 199 presents a major opportunity to help improve our understanding of the chain of events. Results from the leg should prove particularly useful given the volumetric significance of the Pacific Ocean to geochemical mass-balance simulations (e.g., Dickens, et al., 1997) and the current paucity of LPTM records from the basin.

### Eocene/Oligocene Transition

The Eocene-Oligocene boundary represents an important point in the transition from the greenhouse world of the Cretaceous and early Paleogene into the late Paleogene-Neogene 'icehouse.' Attempts to estimate global ice volumes from deep-sea benthic $\delta^{18}O$ records have prompted very different conclusions as to the timing of the onset of the accumulation of continental-scale ice sheets. These range from the Early Cretaceous (Matthews and Poore, 1980) to the middle Miocene (Shackleton and Kennett, 1975). However, recent improvements in the stratigraphic resolution of the $\delta^{18}O$ record have led to suggestions that either the late Middle Eocene (~43 Ma) or the earliest Oligocene (~34 Ma) are better estimates of the greenhouse to icehouse transition (Shackleton, 1986; Miller et al., 1987, 1991; Zachos et al., 1994). Supporting evidence for this interpretation comes from oceanic records of ice-rafted debris, weathered clay mineral compositions, microfossil assemblages, and sequence stratigraphic analyses (Browning et al., 1996). Yet, the rarity of complete deep-sea sections across these intervals has limited our understanding of the dynamics of this important step to the modern icehouse world.

The Eocene-Oligocene transition is marked by a large rapid increase in the benthic foraminiferal calcite $\delta^{18}O$ record in earliest Oligocene time (Oi-1). This excursion was first ascribed to a 5°C temperature drop associated with the onset of thermohaline circulation but, more recently, Oi-1 has been associated with the onset of continental ice accumulation on Antarctica. Such confusion reflects the long-standing difficulty of separating the effects of temperature and ice on benthic $\delta^{18}O$. Recent application of an independent paleothermometry technique based on Mg/Ca in benthic foraminifers shows no significant change corresponding to Oi-1 (Lear et al., 2000). This result suggests that all of the $\delta^{18}O$ increase associated with Oi-1 can be ascribed to ice growth with no concomitant decrease in polar temperatures. This finding implies that the trigger for continental glaciation lay in the hydrological cycle rather than the carbon cycle. Specifically, it has been proposed that the opening of the Australian-Antarctic seaway in earliest Oligocene time might have enhanced the supply of moisture as snow to the Antarctica interior

(Lear et al., 2000). Yet, our most complete records of the Eocene/Oligocene boundary come from only two mid-latitude sites (DSDP Site 522, ODP Site 744). Leg 199 offers an excellent opportunity to generate low-latitude records of the Eocene-Oligocene transition and thereby fully evaluate the competing roles played by global cooling and ice-growth in the transition from the Cretaceous greenhouse into the Neogene icehouse.

### Late Eocene Impact Events

Widespread evidence now exists to support the occurrence of at least two large closely spaced extraterrestrial impact events on Earth during early late Eocene time. In particular, two large craters (order ~100 km diameter; Chesapeake Bay, North America and Popigai, Northern Siberia) have been proposed to explain impact-ejecta strewn fields that are documented in deep-sea sediments from around the world (e.g., Koeberl et al., 1996; Bottomley et al., 1997). Proxy records for fine-grained extraterrestrial dust (Helium-3 measurements) in correlative marine carbonate strata have been interpreted as evidence for a comet shower triggered by an impulsive perturbation of the Oort cloud (Farley et al., 1998). Intriguingly, unlike the more famous and pronounced precursor extraterrestrial impact event at Cretaceous/Paleogene boundary time, biostratigraphic studies indicate that the late Eocene impact horizons do not correspond to major extinctions among marine organisms. Only five radiolarian species appear to disappear from the record, accompanied by modest compositional changes in planktonic foraminifers and organic-walled dinoflagellate cysts (Sanfilippo et al., 1985; Keller, 1986). On the other hand, whereas little evidence exists in the literature for climate change across the Cretaceous/Paleogene transition, recent work has suggested that the late Eocene impact event was associated with a short-term (~100 ka), albeit modest (maximum 2°C) cooling event at high latitude (Vonhof et al., 2000). Leg 199 presents an ideal opportunity to study the climatic and biotic effects of impacts that were too small to precipitate global mass extinctions but were apparently large enough to have engendered global changes in climate.

## SPECIAL PROBLEMS AND OPPORTUNITIES

Paleoceanographic studies require good positional information for the best paleoenvironmental interpretations. For intervals older than the Pleistocene, sites must be backtracked by a plate tectonic model to locate drill sites with respect to important geographic features. For Leg 199, it is important to locate the equator in the early Eocene and Paleocene with respect to each of the drill sites.

We backtracked positions of the proposed drill sites by using a model in which hotspots have remained fixed with respect to the Earth's spin axis. The hotspot reference frame we used was Gripp and Gordon (1990) for 0- to 5-Ma Pacific hotspot rotation pole and Engebretson et al. (1985) for older poles. Because the hotspots may have moved, the drill sites may be systematically mislocated (Tarduno and Cottrell, 1997). In addition to the possibility of hotspot motion leading to inaccurate paleopositions, there is also significant disagreement between plate reconstructions using hotspots and those following global plate circuits and controversy over whether hotspots have moved or whether plate reconstructions are incomplete (e.g., Acton and Gordon, 1994; Cande et al., 1995; Tarduno and Cottrell, 1997). There is an additional concern that true polar wander (the shift of Earth's rotation pole through time) (Besse and Courtillot, 1991, Steinberger and O'Connell, 1997) may have caused a shift in the position of the equator over time. This presents both a problem for designing the leg and an opportunity to improve the Pacific plate tectonic model by paleomagnetic studies on Leg 199 recovered cores.

We have already combined seismic reflection data from the EW9709 site survey with the Neogene seismic stratigraphy of Mayer et al. (1985, 1986) to determine that the early Miocene equator was about 2° farther south than predicted by the backtrack model we used (Fig. 3) (Knappenberger, 2000). This illustrates the necessity of locating the equatorial position in the Paleogene.

To deal with the uncertain location of the late Paleocene equator position, we have proposed drill sites that adequately cover possible major errors in latitude. The proposed drilling transect spans a paleolatitude range of more than 16° around the estimated hotspot equatorial position, from 5°S to 11°N.

The span of drilling latitudes presents an opportunity to use paleomagnetic techniques to constrain this important plate tectonic problem. The Leg 199 paleomagnetic studies will complement Leg 197 (Motion of the Hawaiian Hotspot During Formation of the Emperor Seamounts: a Paleomagnetic Test) objectives and will provide further constraints on Pacific plate motion. Paleomagnetic determinations over the same time period during Leg 198

(Exploring Extreme Warmth in the Cretaceous and Paleogene: a Depth Transect on Shatsky Rise, Central Pacific) when combined with Leg 199 data will be used to better define Paleogene poles of rotation for the Pacific plate.

Estimated equatorial crossings of Sites PAT-6 (~22 Ma), PAT-17 (~29 Ma), PAT-9 and PAT-8 (~41 Ma), and PAT-10 (~50 Ma) all should occur within the APC section and should be useful for paleomagnetic analysis. In addition, the more northern drill sites (Sites PAT-12, PAT-19, PAT-13, PAT-15, and PAT-26) will provide an array of paleomagnetic data spanning an additional 13° in latitude that should also have good paleomagnetic profiles contained in the APC section of the sediment column.

## COMPARISONS BETWEEN SEISMIC PROFILES AND DRILLING

The site survey cruise (EW9709) continuously collected data along two transects of the northern tropical Pacific. Segments of these transects are combined to reconstruct two cross-sections: one at ~40 Ma (late middle Eocene) and the other at ~56 Ma (late Paleocene) (Fig. 1). These transects were planned to follow the 57-Ma (Chron An25r) or 41-Ma (Chron An18r) ridge crest (where carbonate sediments will be better preserved). They span the time of maximum warmth and extend through the cool down of the "hothouse world" into the time of initial Antarctic glaciation. We chose the crustal age to be ~1 m.y. older than the age of the first sediments of interest to avoid sediments with the largest hydrothermal component.

The collection of high-resolution seismic reflection data along the two EW9709 transects has given us valuable insights into the character of Paleogene deposition in the equatorial region and has led us to speculate that the patterns of sediment accumulation and biogenic flux were markedly different in the early Paleogene (Moore et al., 1999). We have correlated the seismic signature of the equatorial Pacific section in data collected during our recently completed cruise with that developed by Mayer and his co-workers (Mayer et al., 1985, 1986; Knappenberger, 2000). This correlation is based on the seismic character of the reflections themselves and is checked against the age of surficial sediments recovered in piston cores during our cruise (Figs. 4, 5) and in nearby DSDP drill sites. The seismic stratigraphy of Mayer et al. (1985,

1986) covers the Pleistocene to the uppermost Oligocene. We have tentatively extended this stratigraphy to the base of the sections imaged in our transects.

Our extension of this seismic stratigraphy and the exact ages of the reflecting horizons we have identified await verification by drilling. However, assuming that the stratigraphic horizons and the ages we have assigned to them are even approximately correct, we can make a few rather startling observations:

1. The equatorial mound of the lower Miocene sediments (as defined by Mayer et al., 1985) can be clearly seen in the seismic data; however, the "upper-middle Eocene" (M-E1) and "middle-early Eocene" (E1-acoustic basement) sedimentary packages show a very different pattern: (a) the M-E1 package shows only a hint of thickening in the equatorial region and (b) the E1-basement package actually appears to be thicker 5°-10° north of the hotspot-estimated positon of the equator than it does at the equator.
2. Cores taken on cruises to the tropical North Pacific, DSDP Site 40, and Site PAT–13C, have recovered middle Eocene radiolarian oozes at hotspot-estimated paleolatitudes of 7°-8°N. Throughout the Neogene and into the Quaternary, sections at comparable paleolatitudes are typically devoid of siliceous microfossils or contain only sparse, highly corroded specimens.
3. Given that our assigned ages are approximately correct, the accumulation rates of sediments in the thicker lower Eocene sections of the 56-Ma transect are similar to average accumulation rates calculated for Neogene and Quaternary sections.

These observations, if substantiated by the proposed coring, require a new oceanographic paradigm for the tropics of the early Paleogene. Our stratigraphic interpretations must be verified by drilling; however, if they prove to be approximately correct, they will necessitate a revolution in our thinking about wind-driven circulation and productivity in the tropical oceans during times of extremely warm climates. The sections recovered at Leg 199 drill sites will help to establish the patterns of biogenic sediment flux, the distribution patterns of planktonic assemblages, the accumulation patterns, size variation, and sources of wind-blown dust, and the isotopic compositions of benthic and planktonic (deep- and shallow-living) organisms. With these data we should be able to develop a clearer understanding of tropical atmospheric and oceanic circulation during the extremely warm climate of the early Paleogene.

## ANCILLARY BENEFITS OF DRILLING

In addition to the main focus of the proposed ODP leg discussed above, there will be important other benefits derived from the recovered sediment sequences.

1. Complete recovery of sections using multiple holes and APC/XCB coring techniques should vastly improve Paleogene biostratigraphy and chronostratigraphy. It will form a critical element in determining Paleogene mass accumulation rates.
2. The linking of seismic stratigraphy and the chronostratigraphy provided by the recovered sections will complement and extend the seismic stratigraphy developed by Mayer et al. (1985, 1986) and Bloomer et al. (1995). This will permit the development of a broad regional view of equatorial deposition currently constrained only by the extent and quality of seismic data coverage.
3. We should be able to map the latitudinal position of the change over through time between dust sourced from the Americas and that sourced from Asia. This, together with the pattern of dust flux and grain size variations, is likely to be a valuable independent check on models of Paleogene atmospheric circulation (Rea, 1994).
4. Although we have selected sites to minimize encounters with chert layers, it is unlikely that we will avoid them altogether. The recovery and logging of sections containing chert and comparisons to equivalent intervals without chert at other sites will be an important step toward a better understanding of the pervasive occurrence of these cherts in the early and middle part of the Eocene. Coring and logging data, together with material recovered in this drilling transect, will provide important information on the timing and geochemical nature of these cherts.
5. Because the equatorial Pacific is the major region of carbonate burial and an important region of biogenic silica burial in the abyssal Pacific Ocean, the transect will be important to develop the Paleogene mass balance of biogenic sediment components. Important new data will also be gathered to understand the shallow Eocene CCD and whether production or dissolution was most important in shaping the change in the Eocene CCD with time. The data will also be used to study to what extent the Eocene silica cycle was different than modern conditions.

6. Because each site is planned to terminate in the uppermost basaltic basement, we will sample the basal hydrothermal-rich sediments. Study of these sediments will give important data about the strength of hydrothermal input to global mass balances.

## PROPOSED SITES

The following sites and alternates are proposed for drilling during ODP Leg 199. One site, Site PAT-13C, will be drilled during Leg 200 if time becomes available. The locations of drill sites in this prospectus are the most current and reflect minor corrections in site location from the Pollution Prevention and Safety Panel (PPSP) document (Lyle, 2000) caused by a correction for the difference between the common depth point (CDP) position and the ship's position.

### North of Molokai Fracture Zone (PAT-15)

Site PAT-15D will be used primarily to define the shift in the ITCZ through the Paleogene by following the change in aeolian dust composition and flux through time. It will also help define North Equatorial Current and North Pacific subtropical gyre processes, although the probable lack of carbonate above the lower Eocene will preclude high-resolution paleoceanographic studies. Site PAT-15D will also be highly important to test whether there was significant motion of the Hawaiian hotspot with respect to the Earth's spin axis during the early Cenozoic. At 56 Ma, the backtracked location based upon a hotspot reference frame (Gripp and Gordon, 1990, for 0- to 5-Ma Pacific-hot spot rotation pole; Engebretson et al., 1985, for older poles) should be about 11°N, 117°W. At 40 Ma, the site was located at about 16°N, 121°W. If significant hotspot motion or true polar wander occurred since 57 Ma (Petronotis et al., 1994), this drill site could have been much nearer to the equator.

### Between Molokai and Clarion Fracture Zones (PAT-26, PAT-13, and PAT-19)

Site PAT-26 was chosen because, based upon the seismic stratigraphy of seismic reflection data acquired on EW9709, it is near the thickest section of lower Eocene sediments along the 56-Ma transect (Moore et al., 1999). This site is relevant to understanding the processes that caused higher sediment accumulation, a sign of elevated paleoproductivity. We will be particularly interested in this drill site if the paleoequator proves to be significantly north of the position estimated by the hotspot reference frame. Site PAT-26 will also be used to define tropical circulation in the Paleogene and the shift in ITCZ in the Paleogene and Neogene.

Site PAT-13C will be drilled during Leg 200, if time becomes available, and will be used primarily to define tropical current structure and sedimentation in the early and middle Eocene, although the lack of carbonate above the lower Eocene will make it difficult to perform high-resolution paleoceanographic studies. It will also help define the shift in ITCZ through the Paleogene by following the change in aeolian dust composition and flux through time. One of the important discoveries of the site survey cruise is the presence of an almost pure biogenic sediment, a middle Eocene radiolarian ooze, deposited when the site was more than 8° north of the paleoequator as defined by hotspots. This type of deposition has no analog in modern sediments and appears to be an important feature of the middle and early Eocene. Part of the objectives of drilling will be to better understand the conditions that formed the radiolarian ooze. We also want to understand whether the hotspot reference frame has moved with respect to the spin axis. At 56 Ma, the backtracked location based upon a hotspot reference frame was 8°N, 109°W. At 40 Ma, the site was located at about 10°N, 113°W.

Site PAT-19A will be important to define the North Equatorial Current/North Equatorial Countercurrent boundary and it will help define the middle and late Eocene CCD. It will also better define the extent of the middle Eocene radiolarian bloom noted at Site PAT-13 and DSDP Site 40 and will be used to define the shift in ITCZ through the Paleogene by following the change in aeolian dust composition and flux through time. At 56 Ma, the backtracked location based upon a hotspot reference frame was 5°N, 106°W. At 40 Ma, the site was located at about 8°N, 111°W. If the Hawaiian hotspot has moved significantly with respect to Earth's spin axis (Petronotis et al., 1994), this drill site would have been in a near-equatorial position.

### Between Clipperton and Clarion Fracture Zones (PAT-8, PAT-17, PAT-9, PAT-10, and PAT-12)

Site PAT-8C is the only top priority drill site on the 40-Ma transect. Both it and Site PAT-9D were at the equator at 40 Ma based upon fixed hotspot backtracking. Site PAT-8C will be used to define equatorial circulation and upwelling from the middle Eocene through the Eocene/Oligocene boundary. Its primary role will be to monitor equatorial upwelling and evolution of the South Equatorial Current. It will also be used to monitor bottom waters generated in the Antarctic and changes in CCD through comparisons with Site PAT-9D. At 40 Ma, the backtracked location was 0°N, 107°W based upon a hotspot reference frame. The site passed below the CCD in the middle lower Miocene.

Site PAT-17C will be used to study equatorial ocean circulation from the late Paleocene to the late Eocene including deep-water flow and properties and will help define the CCD during the Eocene-Oligocene transition and near the Oligocene/Miocene boundary. Based on the piston core from the site survey, Site PAT-17C passed below the CCD in the lower Miocene. At 56 Ma, the backtracked location was 5°S, 107°W based upon a hotspot reference frame. At 40 Ma, the site was located at about 2°S, 113°W. Site PAT-17C crossed the equator at 29 Ma. If there has been significant southward movement of the Hawaiian hotspot relative to the Earth's spin axis in the early Cenozoic, this site will be important to determine the magnitude of that motion. PAT-17C passed below the CCD in the middle lower Miocene.

Site PAT-9D will be used to define early Eocene equatorial circulation during the early Cenozoic thermal maximum and to study the evolution of equatorial circulation as the world cooled. It will also be used to study equatorial ocean circulation in the middle and late Eocene including deep-water flow and properties and will be used to define the CCD during the Eocene-Oligocene transition. One of the high priorities of drilling will be to compare Site PAT-9D to Site PAT-8C. Both were on the equator at 40 Ma, but Site PAT-9D was about 1100 m deeper. They will best illuminate CCD changes in the middle Eocene through the Oligocene. At 56 Ma, the backtracked location was 3°S, 109°W based upon a hotspot reference frame. At 40 Ma, the site was located at about 0°N, 114°W.

Site PAT-10B will be used to define early Eocene equatorial circulation and study how ocean circulation evolved as the world cooled from maximum Cenozoic warmth. It will also be used to study equatorial ocean circulation in the middle and late Eocene, including deep-water flow and properties, as well as define the CCD during the Eocene/Oligocene transition. At 56 Ma, the backtracked location was 1°S, 110°W based upon a hotspot reference frame. At 40 Ma, the site was located at ~2°N, 115°W, and it should have crossed the equator at ~50 Ma. The site's near-equatorial position in the early Eocene will be important to define the strength of equatorial upwelling and define the evolution of the South Equatorial Current. Site PAT-10B will be important to define whether there has been significant southward movement of the hotspots with respect to the spin axis prior to 40 Ma.

Site PAT-12C will be used to define the northern boundary of the South Equatorial Current and to define the extent of upwelling at the early Eocene equator. It will also help define tropical current structure and sedimentation in the middle and late Eocene as well. Site PAT-12C will also be used to monitor bottom waters generated in the Antarctic and changes in CCD through the Paleogene. At 56 Ma, the backtracked location based upon a hotspot reference frame was 1°N, 111°W. At 40 Ma, the site was located at ~4°N, 116°W. Because of its position, Site PAT-12C will also help to monitor the position of the ITCZ in the late Eocene and perhaps early Oligocene. Finally, Site PAT-12C will be important to define whether there has been significant southward movement of the hotspots with respect to the spin axis prior to 40 Ma.

## DRILLING STRATEGY

The eight high-priority sites are summarized in Tables 1-3 and shown in Figure 1. Additionally there is another high-priority site, Site PAT-13C, that will be drilled during Leg 200 if time becomes available. The proposed drilling program consists of two northwest to southeast transects. The western transect includes the following proposed sites, from north to south: Sites PAT-15D, PAT-12C, PAT-10B, PAT-9D, and PAT-17C. The eastern transect includes proposed sites, from north to south: Sites PAT-26, PAT-19A, and PAT-8C. The proposed transects are designed to provide a reconstruction of Paleogene paleoceanography and paleoclimatology by coring and logging a late Paleocene-early Eocene latitudinal transect across the equator and a depth transect at the equator during the middle to late Eocene.

The APC/XCB will be used to core to basement to meet the leg objectives. Ideally most of the sites should be double- to triple- APC cored. However, and because of time constrains, the present minimum coring program consists of (Tables 2, 3): single APC and XCB at Sites PAT-15D and PAT-10B; double APC and single XCB at Sites PAT- 26, PAT-19A, PAT-12C, and PAT-9D; and triple APC and single XCB at Sites PAT-8C and PAT-17C.

Tensor core orientation will be used at least in one hole at each of the proposed sites.

If drilling conditions are favorable and time becomes available during the leg, we will use this time to extend the present minimum coring/logging program to double and/or triple APC sites using as a guide the priorities expressed in Table 3.

Additionally, one of the high-priority sites, Site PAT-13, will be drilled during Leg 200, if time becomes available.

## LOGGING PLAN

Downhole logging provides continuous measurements of geophysical parameters, which can be used to assess the physical, chemical, and structural characteristics of the formation. Where core recovery is poor, downhole logs are often the most reliable source of information; where core recovery is good, log data can be correlated with core data to produce more detailed and emphatic results.

During Leg 199, a great deal of information will be obtained from the in situ downhole physical property data. Density measurements will be crucial for calculating acoustic impedence values, and neutron porosity data will be particularly valuable for identifying intervals of high-porosity radiolarion ooze. Density and porosity results may also be useful for delineating the extent of hydrothermal activity toward the base of the sedimentary section, which will be characterized by high concentrations of iron and manganese. The downhole natural gamma-ray and density values will be correlated with comparable analyses from the multisensor track (MST), which will enable the precise depth matching of cored sections.

A major objective of logging during Leg 199 will be to use the downhole sonic data in conjunction with the density results, and check shot surveys where necessary, to obtain a velocity profile, a time/depth model, and synthetic seismograms. These results will be compared with the regional seismic sections to interpret the origin and geological significance of the major reflectors.

Downhole measurements, in particular taken by the Formation MicroScannner (FMS) and the new high-resolution (~0.1 m) Lamont Multisensor Gamma tool (MGT), will be useful for cyclostratigraphic analysis of continuous Paleogene sequences. Logs will also be invaluable for determining the position of chert layers, which are likely to occur in the lower part of the boreholes and will be difficult to recover in the core. Chert horizons show up exceptionally well as resistive stripes on FMS images.

The plan is to run the triple combo, MGT, and FMS-sonic toolstrings at the three deepest penetration sites: PAT-8C, PAT-17C, and PAT-9D. Time permitting (Table 3), these toolstrings will also be run at Site PAT-26 (~0.8 days). There is also the possibility that check-shot data will be acquired at some of the deeper logged sites, with the priorities being Sites PAT-8C (~0.6 days) and PAT-17C (~0.6 days). Less extensive logging operations may be performed at some of the shallower sites.

## SAMPLING STRATEGY

Sampling guidelines and policy are available at the following web site URL: http://www-odp.tamu.edu/publications/policy.html. The sample allocation committee or SAC (co-chiefs, staff scientist, and ODP curator onshore and curatorial representative on board ship) will work with the entire scientific party to formulate a leg-specific sampling plan for shipboard and postcruise sampling. Modification of the sampling strategy during the leg must be approved by the co-chiefs, staff scientist, and curatorial representative on board the ship.

In some critical intervals (i.e., LPTM, Eocene/Oligocene, Oligocene/Miocene, Eocene impact events) there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling, a higher sampling density, reduced sample size, or continuous core sampling by a single investigator. A coordinated sampling plan may be required before critical intervals are sampled.

During Leg 199, we hope to be able to sample at <5-k.y. resolution to obtain records of biological and physical oceanography at temporal resolutions adequate to resolve orbital-forcing cycles. Given low regional sedimentation rates (~1-3 cm/k.y.), the high temporal-resolution sampling required, and the operational reality of obtaining deeply buried sections across a transect of water depths indicates that in special circumstances we may require high sample density and volume to achieve the primary paleoceanographic, paleoclimatic, and paleomagnetic cruise objectives. Sample volumes must be large enough to ensure adequate numbers of planktonic and benthic foraminifers for biostratigraphic and stable isotopic/trace element studies and will depend on the exact nature of the sediment recovered. This is not meant as a blanket statement for heavy sampling of all cores. In fact, every effort will be made to stay within sample guidelines by first attempting to assemble consortia scientists to develop plans to attack these problems with the most efficient use of samples and/or by encouraging scientists to work on time slices or a subset of sites (as high-resolution sampling of all core at all sites will result in an unreasonably large number of samples to be analyzed by any individual scientist for the scientific results).

Because there are only a limited number of people available for sampling at sea and to minimize sediment waste, we plan to conduct low-resolution sampling at sea and save most of the high-resolution sampling for a postcruise shore-based sampling party. Low-resolution sampling will be carried out onboard ship to conduct shipboard description/characterization of the sediments, to facilitate pilot studies, to identify sections requiring high-resolution postcruise sampling, and to provide samples for studies that do not require a high temporal resolution. High-resolution sampling at sea will typically be limited to provide sufficient samples to work on until the shore-based sampling party takes place. All shipboard scientists will participate in shipboard sampling according to a shift schedule.

Most high-resolution sampling will be done approximately four months postcruise at a sampling party at the Gulf Coast Core Repository (Texas A&M University). However, the SAC may decide to sample the upper few cores on the ship because high-porosity sediments could be disturbed during transport to the core repository. Samples that need to be frozen or sealed for shore-based analysis also must be taken on board.

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