Drilling to Decipher Long-term Sea-level Changes and Effects

Abstract Volume

October 8-10, 2007; Salt Lake City, Utah

Sponsored by:
Joint Oceanographic Institutions
Integrated Ocean Drilling Program - Management International
International Continental Scientific Drilling Program
Drilling, Observation and Sampling of the Earths Continental Crust
Chevron Corporation
The Maldives archipelago is among the world's largest carbonate platforms, however, the geological evolution of this major shallow-water carbonate system is only poorly understood. The platform formed during the Cenozoic in a regime of high-amplitude sea-level fluctuations and global climate cooling, as well as palaeo-oceanographic change. The aim of the cruise NEOMA with the research vessel Meteor is to unravel the record of these changes in order to investigate the response of the platform to such processes. The better knowledge of these tropical carbonates will not only provide new data about the climate and palaeo-oceanographic evolution of the tropics, but also new models for the seismic stratigraphy of such bodies and sedimentological models for carbonate platform slope deposits. The project will also provide new data for the controversial discussion about the process of carbonate platform drowning and its controlling mechanisms, because on the Maldives, reef atolls and drowned atolls coexist.

Our research relies on seismic profiling and direct sampling of the sea floor. A high-resolution seismic grid in the NW of the platform, which is designated to complement industrial seismic grids imaging the deeper part of the succession (upper Miocene and older), will trace the position of the platform rim through time. This will allow to decipher the reaction of the platform to the sea-level and palaeo-oceanographic changes. The slope of the platform will be analyzed in detail in order to trace the configuration of the peri-platform deposits, i.e. to investigate the occurrence of canyon incisions and lobe systems. Seismic profiles crossing a drowned part of the platform (Fuad Bank) and an adjacent atoll (Ari Atoll) will provide data about the internal geometries of these bodies and the topography of the pre-drowning surface. A chronostratigraphic model for the platform evolution will be ensured by positioning seismic lines in such a way that ODP Leg 115 Site 716 is crossed.

Sea-floor sampling (grab samples and shallow cores) will be performed along shallow to deep transects. This will allow to determine the carbonate sediment types in the active atoll system and on the drowned bank. Gravity coring of the platform slopes will be used to unravel the response of this tropical carbonate depositional system to Holocene sea-level and palaeo-oceanographic change. These sedimentological studies are of special interest because up to the present day no systematic studies on the modern sediments and facies of the Maldives exist.

NEOMA will provide extensive site survey data sets for future IODP drilling on the Maldives.
Mediterranean Sea Level Changes and Climate: Inferences from Late Miocene Reef Corals

Thomas C. Brachert, Institut für Geowissenschaften
Regina Mertz-Kraus, Institut für Geowissenschaften
Markus Reuter, Institut für Erdwissenschaften
Karsten F. Kroeger, Geoforschungszentrum Potsdam

Stratigraphic distributions of clastic sediments and carbonates are generally used to infer relative sea level changes, however, clastic – carbonate transitions may also reflect changes in hinterland topography and freshwater discharge from changing climate. An example is the Mediterranean, whose sedimentation patterns are governed by local climate and northern Africa drainage related to changes in monsoon intensity (teleconnection) on astronomical time-scales.

We analysed shallow water sedimentary systems of Late Miocene age from the island of Crete (southern Greece) in the eastern Mediterranean with regard to the imprint of relative sea level change, sea surface temperature (SST), and hydrological balance. Stratigraphic architectures allow separating of 3rd and 4th order sea level changes superimposed on a long-term relative sea-level rise known from other records. Lithologically, the 3rd order early Tortonian highstand is represented by clastics, the late Tortonian and early Messinian highstands preferentially by carbonates. However, instead of this pattern being solely a reflection of a long-term (2nd order) relative sea-level rise, palaeobotanical data indicate to substantial long-term climatic drying and, therefore, imply diminishing sediment and freshwater discharge as modifiers of sediment dynamics and stratigraphic architecture.

Annual growth rates in massive Porites (reef coral) used as a proxy of SSTs imply constant long-term eastern Mediterranean SSTs over the late Miocene, however, do not rule out potential SST coolings during lowstands of sea level, because the completeness of the sedimentary record at sea level lowstands is hard to be inferred from small sedimentary basins. However, despite constant SSTs, subannually resolved stable isotope series ($\delta^{18}O$) from massive Porites (pristine aragonite preservation), reveal significant changes in average annual stable isotopic seawater composition between depositional sequences, and are more negative in corals from lowstand deposits (coarse marine clastics) than from highstand sediments (coral reefs). Such a signature represents a clear contradiction to attempts of tuning sea-level curves to global $\delta^{18}O$ records and climate variability. We infer, therefore, a substantial overriding effect of freshwater discharge/evaporation over ice-shield-related global $\delta^{18}O$ seawater compositional variability and global temperature within the eastern Mediterranean. Although the long-term coral-$\delta^{18}O$ trend over the late Miocene is in accord with the palaeobotanical data (and depending on the age model with deep sea $\delta^{18}O$), our coral stable isotope data document superimposed high-frequency variability of the hydrological balance on astronomical time-scale. In addition, on subannual time-scales, trace element compositional variability in Porites documents pronounced winter rainy seasons during wet intervals (clastic sediments), which is in good agreement with global climate models. Therefore, detailed analyses of coral faunas with regard to annual growth rates or stable isotope composition ($\delta^{18}O$) and trace element compositions has the potential in revealing essential additional information as to fully understand the geological record of relative sea level fluctuations.
Sea Level History and Regional Climate of the Beringian Arctic Gateway

Julie Brigham-Grette, University of Massachusetts Amherst
Beth Caissie, University of Massachusetts Amherst
Neal Driscoll, Scripps Institution of Oceanography
Jenna Hill, Scripps Institution of Oceanography
Lloyd Keigwin, Woods Hole Oceanographic Institution
Mei Cooke, Woods Hole Oceanographic Institution
Jeff Donnley, Woods Hole Oceanographic Institution

Late Cenozoic glacial and interglacial sea level change uniquely imposed on the Bering Strait region some of the most radical changes in paleogeography documented in the Northern Hemisphere. Today the broad region of Beringia, including western Alaska and eastern Siberia, is split by the Bering Strait and the broad continental shelves of the Bering and Chukchi seas. During the Last Glacial Maximum (LGM) however, when sea level was lowered by ~125m, Beringia was a vast land bridge stretching nearly 1000 km from north to south separating the Pacific and Arctic Oceans.

Following the transition from a forested Arctic in the middle Pliocene to the first major glaciation of the northern hemisphere, glacial and marine deposits found interbedded along the coasts of Alaska and Chukotka record a number of critical transitions in the evolution of Northern Hemisphere climate. Glacial periods across much of Beringia during the early and middle Pleistocene were at least an order of magnitude more extensive than during the Last Glacial Maximum (LGM) for reasons that remain unclear.

During interglacial periods seas repeatedly flooded the Bering Strait, rapidly changing the configuration of coastlines, altering regional continentality, and reinvigorating the exchange of water masses between the North Pacific, Arctic Ocean and North Atlantic. Since first submergence about 5-5.5 million yrs ago (Marincovich and Gladenkov, 2001) this marine gateway experienced the penetration of warmer water masses from as far south as northern Japan to as far north as the Beaufort Sea (Brigham-Grette and Carter, 1992). During the last interglacial (MIS 5e) the winter sea ice limit was as much as 800 km further north than now, and summer sea ice in the Arctic Ocean may have been periodically absent (Brigham-Grette and Hopkins, 1995). Treeline across much of Alaska and nearby Chukotka was hundreds of kilometers further north, notably eliminating tundra across Chukotka to the Arctic Ocean (Lozhkin and Anderson, 1995).

Changes in sea level repeatedly influenced Beringian climate and the nature of oceanic communication between the Pacific and the Atlantic, but the exact role of the ocean in controlling Beringian climate, especially east-west contrasts is unknown because so little is known of the sea level history, sea ice history, and shifting water masses in the surrounding seas. For example, the history of relative sea level is very poorly known, but is likely to have differed from low latitude eustatic sea level because of tectonic and possible glacial-loading effects. Sea surface conditions such as ice extent, temperature, and salinity are likely to influence the climate through albedo effects, heat exchange, and humidity, but there are almost no high-resolution proxy data for these properties in the Chukchi Sea.

Our ongoing research and results from a 2002 cruise (USCG Healy02; Keigwin et al., 2006) highlight the need for additional coring transects in Hope Valley and Barrow Canyon to establish a relative sea level history as well as high-resolution climate record north of Bering Strait. Additional CHIRP seismic data we hope to acquire across the inner shelf will constrain the onshore-offshore drainage and provide critical site survey information for a possible IODP Chukchi Sea drilling proposal. In the future we propose to conduct a follow-on cruise that will acquire much needed cores and seismic reflection data to test ideas about the changing climate, deglacial freshwater dispersal out of the Arctic via the Bering Strait, and its relationship to relative sea level changes over time, especially since the LGM but also during the last few glacial cycles. The proposed research will build on the research initiated on the Chukchi Shelf in 2002.
Early Cenozoic Glaciation: Exploring the Paradigm of an ‘Ice-Free’ Middle Eocene

Caroline Dawber, University of Cambridge
Aradhna Tripati, University of Cambridge

The onset of the Cenozoic ‘greenhouse-icehouse’ transition is poorly constrained, with the Middle Eocene often considered the intermediary ‘doubthouse’ phase. Most benthic foraminiferal oxygen isotope (δ¹⁸O) reconstructions typically assume ‘ice-free’ conditions during this period. However, the occurrence of high-frequency sea-level change of tens of meters in the sequence stratigraphic record, is best explained by glacio-eustacy (e.g. Browning et al., 1996). To explore the paradigm of an ‘ice-free’ Middle Eocene, we discuss a high-resolution record of seawater δ¹⁸O from Ocean Drilling Project (ODP) Site 1209 in the northern tropical Pacific Ocean. The new seawater δ¹⁸O record for Site 1209 indicates two major glacial episodes occurred at ~44.8 and 42.7 Ma, with excursions of greater than 1‰. The amplitude of these excursions necessitate the presence of ice in the southern and northern polar regions at these times, consistent with other records of seawater δ¹⁸O (Tripati et al., 2005) and ice-rafting debris (Moran et al., 2006). We also evaluate the seawater δ¹⁸O-sea-level calibration accounting for potential biases arising from carbonate ion concentration, Cenozoic ice δ¹⁸O composition and additional ice storage as a result of glacio-eustatic sea level fall.
Palaeogene Sections of the Isle of Wight: A Possible Target for Future Drilling to Investigate Glacio-eustatic Sea Level Changes Across the ‘Greenhouse-Icehouse’ Transition?

Caroline Dawber, University of Cambridge
Aradhna Tripati, University of Cambridge
Andy Gale, University of Portsmouth
Steve Hesselbo, University of Oxford
Conall MacNiocaill, University of Oxford

The Palaeogene strata of the Isle of Wight, situated of the Southern coast of England, provide valuable insights to past sea-level changes. During the Palaeogene, the island was a peripheral part of the Hampshire-Dieppe basin. Extensive outcrops across the island form a depth transect which can be correlated on the basis of magnetostratigraphy and nannofossil biostratigraphy. Dramatic facies changes are observed in the well-exposed sections at Alum Bay and Whitecliff Bay. High-resolution lithostratigraphy and faunal analyses are required to resolve the frequency and amplitude of sea-level change during the Palaeogene. We present preliminary lithofacies data and faunal analyses from the expanded Bartonian section at Alum Bay. The data indicate multiple episodes of major, local sea-level change, with at least two regressive-transgressive sequences on the order of tens of meters during the Middle Eocene. Magnetostratigraphy places the age of the sea-level changes during the late Middle Eocene in Chron 18r and C18n2n. Future chemostratigraphy may facilitate correlation with sea level cycles recorded at other localities and the open ocean oxygen isotope curve.
Coring of the cool-water carbonate mounds on the Great Australian Bight uppermost slope during ODP Leg 182 confirmed their biogenic origin, and established a clear connection between episodes of mound growth and sea level cyclicity. Mound faunas are dominated by a diverse suite of bryozoans, together with coralline algae, echinoid spines, and benthic foraminifers, in a mudstone to packstone matrix. AMS and U/Th dating and the oxygen and carbon isotopic record derived from benthic foraminifers and bryozoans demonstrate that mound growth was restricted to glacial episodes when sea level was low. Mound accumulation was relatively rapid (30-67 cm/k.y.) and locally punctuated by firmgrounds and hardgrounds. Increased upwelling during sea level lowstands promoted active mound growth, in contrast to the thin mud accumulations that draped inactive mounds during highstands.

An additional objective of the Leg 182 drilling program was to attempt to determine whether coring of this cool-water carbonate depositional system could provide information to refine the global sea level curve, in the same way that drilling results from warm-water, rimmed and unrimmed carbonate platforms have been used. In this respect, coring results did not provide any refinements to the existing understanding of past sea level history, and it is difficult to imagine how cores from such mounds might be used for this purpose in the future.
Future IODP Drilling Transect for Sea-Level Studies: Canterbury Basin, New Zealand
(IODP Proposal 600)

Craig S. Fulthorpe, University of Texas Institute for Geophysics
Hongbo Lu, Shell International

Scientific ocean drilling is a fundamental tool for sea-level studies, but it has yet to be applied to the extent envisioned by ODP-related planning groups well over a decade ago. These groups defined a drilling strategy to investigate stratigraphic development during the Neogene “Icehouse” period, when high-resolution chronological control is available and glacial cycles provide a well understood eustatic mechanism, calibrated by the oxygen isotopic record. This strategy involves drilling continental margin transects worldwide to evaluate global synchrony by inter-basinal correlation and to document stratigraphic responses in diverse tectonic and depositional settings, including both carbonate and siliciclastic systems. The value of this approach is that it allows evaluation of the relative roles of global (eustatic) and local forcing in controlling sedimentary architectures, in particular prograding clinoformal successions, in locations where extensive seismic coverage allows interpretation of local sedimentary processes using seismic geomorphology.

However, there are still only two ODP/IODP sea-level drilling transects that penetrate multiple clinoformal sequences: 1) the New Jersey margin siliciclastic, shelf-slope transect (Legs 150, 150X, 174A, 174AX, and future IODP Expedition 313), and 2) the Great Bahama Bank carbonate transect (Leg 166). The vital next step in the still-valid global approach is to drill distal analogs to both New Jersey and Great Bahama Bank.

The Canterbury Basin offers an opportunity to study the complex interactions among forcing processes responsible for the sequence stratigraphic record. High-resolution multichannel seismic (MCS) reflection profiles collected by R/V Maurice Ewing in 2000 (EW00-01 survey) reveal nineteen middle Miocene-Recent, regional, sequence-bounding unconformities (U1-U19). Correlation with oxygen isotopic records, using available industry well control, suggests eustatic control of sequence boundary timing. However, local processes have also strongly influenced observed sequence architecture. For example, in addition to clinoformal units, within which downslope sediment transport dominates, the shelf-slope sediment prism also contains at least eleven large, elongate sediment drifts, where along-strike transport by contour-following currents is the dominant process. These drifts were initiated near the slope toe and form deposits up to 1000 m thick, spanning multiple sequences. Agreement between sedimentation rate (estimated using sequence volumes) and tectonic convergence rates at the Alpine Fault indicates that tectonism has been the dominant control on sediment supply to the Canterbury Basin since ~11.5 Ma. In contrast, an early-middle Miocene (~15-11.5 Ma) peak in sedimentation rate correlates with low convergence rates and is instead mainly a response to global climatic and eustatic forcing. Variations in sequence geometry and seismic facies therefore reflect different combinations of local (currents, tectonics, sediment supply) vs. global (eustatic) controls.
The barri
er-island coastline of Florida’s east coast is the longes
test transgressive barrier coastline in the U.S., with a substantial portion underlain by the carbonate-rich Pleistocene Anastasia Formation, which acts to stabilize Holocene siliclastic barrier sediments. This environment presents an opportunity to explore the role of resistant antecedent topography on the development of Late Quaternary marginal marine facies. The Indian River lagoon (IRL) is a transgressive barrier island system along Florida’s central Atlantic coast proximal to Cape Canaveral. Four sites 80 km apart in the northern and central IRL were occupied for a 100-m-apart spatial vibracoring program of five cores per site. Based on textural properties, macrofauna, and radiocarbon dates, four major depositional units and environments were identified in the upper 3 m of Indian River Lagoon sediments: marine, brackish, lacustrine, and lagoonal. Pleistocene marine facies occur above and below current sea level, surrounding and underlying the Indian River Lagoon system, and thus form the highly variable antecedent topography within which Holocene lagoonal infilling has occurred. Brackish and lacustrine facies of the Indian River lagoon can significantly vary spatially within each site (e.g. stream channel, deltaic, and lacustrine). More importantly, they appear to be genetically unrelated between sites reflecting a unique relative sediment source for each site. The transition to a lagoonal environment represents marine inundation and is identified by the presence of a coarse pebbly shell lag in an organic rich sandy matrix, likely a marsh environment. Topographic differences, radiocarbon ages, and sharp northern facies contacts suggest an initially gradual inundation of marine waters in the southern region (later than ~ 6,200 cal ybp), followed by a more rapid inundation in the northern region (~ 3,500 ybp). However, with the exception of a coarse pebbly shell lag and pervasive bioturbation, the lagoonal facies do not appear to have developed a sedimentologic character that is unique to the lagoonal environment. Instead, continued localized fluvial depositional processes appear to have remained dominant. This facies succession represents a partial cycle of forced marine regression following the previous sea-level highstand, followed by subsequent transgression to the current sea level high stand. Sediments supplying these depositional environments are likely the detritus of adjacent Pleistocene barrier island (Atlantic Coastal Ridge) and lagoonal (Eastern valley) facies that exist in close geographic and topographic proximity. The limited tidal prism of the northern Indian River Lagoon has prevented any significant redistribution of the brackish deposits as is more common in mesotidal barrier island systems. The result is a stratigraphic sequence that is not consistent with the common facies models for transgressive barrier island systems.
Organic Matter Analysis: Dispersed organic matter in sedimentary successions is a composite record of organic productivity within the basin and in its provenance areas. Under a shelf setting where fluvial input is frequent and where the coastline is close, total characteristics of sedimentary organic matter from a piece of sediment, i.e., organic facies, can easily be a mixture of land-derived organic matter and marine-derived organic particles. As a result, if the diagenetic influence is regarded minimum, examination of the organic facies in sediments in a shelf setting will be an excellent source of paleoenvironmental information from both land and ocean. Stable carbon isotope ratios are strongly influenced by relative contributions of terrestrial or marine organic materials to the sediments.

Conclusion From Onshore Studies: We examined the Pliocene shelf sediments, which is distributed in the northern Japanese mainland along the northwest Pacific Rim. Basically, late Pliocene was a warm period, but global cooling was considered to start at 3.0Ma. Therefore, shelf sediment of this age might record the climate change from warm period to cooling stage.

The sea-level changes, which are inferred from facies analysis, coincided with the trend of the oxygen-isotope curve of 200 ky-400 ky cycles. Variations of total organic carbon content (TOC), total sulfur content (TS) and stable carbon isotope ratio ($\delta^{13}$C$_{org}$) well documented the changes of environmental conditions on the shelf. During warm period, the amount of river discharge was increased by frequent flood of rivers. Abundant land-derived organic matter was transported to the shelf. As a result, the ratio of land-derived organic matter was high and, TOC value increases upward in the warm period (3.75-3.5 Ma). While global cooling on set in about 3.5 Ma, the cooling of the ocean had increased the productivity of diatom. Therefore, the ratio of marine microfossil was high, and TOC value also increased in the early cooling period (3.5-3.35 Ma). The sea-level fall in the last cooling stage took place shallowing of the shelf after 3.35Ma. Coarse sandy deposits and abundant land-derived organic matter was frequently transported into the sea. As the result, high TOC value depended on the increase of land-derived organic matter in this stage. And the considerable variations in TS, TOC and $\delta^{13}$C$_{org}$ values are seen at cooling stage after 3 Ma.

Significance of Drilling on Offshore Area: This area is the most appropriate drilling site for testing the climate change in Pliocene age, because of the reasons as it follows:

1) Uninterrupted sedimentary sequence with high accumulation rate (more than 10 cm/kyr) provides us high-resolution continuous record from the late Miocene through the Pliocene.

2) As this area is within transitional region between warm and cold currents, it is the most sensitive for climate change and might monitor various climatic signals of high amplitude.

3) Because of the site location near the land, both land and marine signals can be obtained in the sediments. Land to ocean transect drilling will give us detailed information about the land-ocean linkage.
The Middle Cambrian Wheeler Formation in west-central Utah offers the opportunity to study sea level variations during an ancient greenhouse world. The Wheeler Formation consists of a succession of mixed carbonate and siliciclastic sediments deposited on a gently sloping ramp (the House Range embayment), a portion of the otherwise carbonate-dominated continental margin of western North America during the Middle Cambrian. Outcrop geophysical data (gamma ray spectrometry and magnetic susceptibility), calcite content, lithofacies, and biofacies are analyzed here and interpreted in a sequence stratigraphic context, to provide perspectives on two scales of sea level variations. The upper Wheeler Formation in the Drum Mountains, west-central Utah, is an ~85-m thick, 0.2-1.0 m.y. rock succession that begins with shallow-water oncolitic limestone, followed by transgression to a maximum flooding surface represented by deeper-water shales containing exceptionally preserved fossils with soft parts; this interval is followed by highstand deposition and regression to a capping, shallow-water stromatolitic limestone. This main lithologic interval is interpreted to represent most of a third-order sea level cycle. Superimposed on this probable third-order cycle are several higher-order cycles, one of which is a 5-m thick fluctuation from bracketing shallow-water, oncolitic limestones to deeper-water shale. The limestone lithofacies indicate water depths of 5-10 m, and the shale biofacies and lithofacies indicate deposition in deeper water below storm-wave base, possibly at ~30-50 m. Whereas the third-order cycle could be produced by either eustasy or a combination of subsidence and sedimentation, the higher-order cycles, indicating sea-level swings several times larger than decompacted sediment thicknesses, appear to require a eustatic origin.
The primary objective of the Ocean Drilling Program (ODP) Leg 194 was to evaluate the amplitude of the middle Miocene sea-level fall by drilling carbonate sequences deposited on the Marion Plateau, offshore Queensland, northeast Australia. The amplitude of the fall was determined by backstripping a surface defined by the top of what was interpreted as a highstand carbonate platform, and the base of a lowstand carbonate ramp. The backstripping estimate was refined by combining it with $\delta^{18}$O-based estimates, thus narrowing the range of sea-level fall.

Recently published Sr isotopes and larger benthic foraminfer data suggest that the shipboard assumptions regarding the stratigraphic relationship between the platform and slope drilling sites may not be correct. Here, we identify and characterize the lowstand facies in the distal slope of the carbonate platform and we reevaluate the stratigraphic relationship between the slope drilling locations and the platform. Specifically, we correlate drilling sites along the slope by using core and downhole log data, and we tie the platform to the slope sequences using the Sr isotope-based age model. The new integrated framework allows us to use the relatively well-constrained age model of the distal slope site to date critical sequences on the upper slope site.

Preliminary results show that the lowstand facies are characterized by condensed depositional facies, with abundant glauconite grains, fish teeth, and large terrigenous quartz grains. Condensed facies on the slope appear to have been driven by a reduction in the carbonate factory during eustatic lowstands. Furthermore, we show that the middle Miocene “lowstand” recorded by the Marion Plateau is a composite of at least two phases of successive sea-level falls, spanning the 13.5-11.7 Ma interval. These eustatic changes correspond to the oxygen isotope events Mi3 and Mi4-Mi5.

The new results constrain the timing of the middle Miocene sea-level fall recorded on the Marion Plateau. The observed link between $\delta^{18}$O and Marion Plateau sequences, consistent with results from the New Jersey margin transect, confirms that the sea-level fall observed was driven by glacio-eustatic variations. Because the newly recognized stratigraphic relationship between the slope locations and the platform is significantly different from the shipboard assumptions, we now need to reevaluate the estimate of the magnitude of the eustatic sea-level fall based on backstripping of the Marion Plateau sequences.
Tidal Erosion in a Transgressive Macrotidal Estuary

Toshiyuki Kitazawa, Shinshu University

This study shows outcrop- and regional-scale features of transgressive deposits and erosional surfaces in a macrotidal (tidal range > 4 m) estuary that is rarely presented in geological records. The solid subject is the Middle to Upper Pleistocene Ba Mieu and Thu Duc Formations exposed along the Dong Nai River, southern Vietnam. The Ba Mieu Formation was deposited during marine isotope stage (MIS) 7 to 6, and the Thu Duc Formation was deposited during MIS 5 (Kitazawa et al., 2006).

Kitazawa (2007) discussed the depositional environments and sequence stratigraphy of the two formations. Each formation is interpreted as a tide-dominated incised-valley fill composed of two packages: a transgressive, lower package of estuary and a highstand, upper package of delta. Estuary and delta are subsystems of an incised-valley system. The estuary package is characterized by a tidal ravinement surface (TRS), large mud clasts filling tidal channels, coarsening- and thickening-upward succession of reworked marine sands, and dominant landward sediment transport. The delta package is characterized by upward-convex tidal sand bars (Kitazawa and Tateishi, 2005), upward-fining succession terminated by fluvial deposits, and dominant seaward sediment transport. The Ba Mieu Formation is recognized as depositional sequence (SQ) 1 between sequence boundary (SB) 1 below and SB2 above. SQ1 was formed by a transgression-regression cycle during MIS 7. SB2 was formed by fluvial incision during the MIS 6 lowstand and is amalgamated with the TRS formed during transgression at the beginning of MIS 5. The Thu Duc Formation is recognized as SQ2 between SB2 below and SB3 above. SQ2 was formed during a major transgression-regression cycle of MIS 5.

The tidal range in the incised valley is estimated as 4-6.5 m (macrotidal) from the thickness of the tidal flat deposits. The most important features of the transgressive (estuary) deposits of the Thu Duc Formation are followings. (1) The lower sequence boundary (SB2) is amalgamated with TRS, and the incised-valley geometry is amplified. The TRS is not observed in the landward portions. This change is transitional and characterized by outcrop-scale interfingering of tidal sands and muddy tidal flat deposits. (2) The transgressive deposits thin seaward and are eroded away in the most seaward portions because of the tidal ravinement erosion. More than in 8-km length along the axis of the estuary, almost transgressive deposits lack estuarine muddy deposits. Only subtidal lag is preserved as the transgressive deposit instead of the muddy deposits.

Response of Late Cretaceous Migrating Deltaic Facies Systems to Sea Level, Tectonics, and Sediment Supply Changes, New Jersey Coastal Plan, U.S.A.

Andrew Kulpecz, Rutgers University
Kenneth G. Miller, Rutgers University
Peter Sugarman, New Jersey Geological Survey
James Browning, New Jersey Geological Survey

Paleogeographic, isopach, and deltaic lithofacies mapping of thirteen depositional sequences established a 35 myr high resolution (> 1 Myr) record of Late Cretaceous wave- and tide- influenced deltaic sedimentation. We integrate sequences defined on the basis of lithologic, biostratigraphic, and Sr-isotope stratigraphy from core with geophysical log data from 28 wells to further develop and extend methods and calibrations of well-log recognition of sequences and facies variations. This study reveals the northeastward migration of depocenters from the Cenomanian (ca. 98 Ma) through the earliest Danian (ca. 64 Ma) and documents five primary phases of paleodeltaic evolution in response to long-term eustatic changes, variations in sediment supply, the location of two long-lived fluvial axes, and thermoflexural basement subsidence: (1) Cenomanian-early Turonian deltaic facies exhibit marine and nonmarine facies and are concentrated in the central coastal plain; (2) high sediment rates, low sea level, and high accommodation rates in the northern coastal plain resulted in thick, marginal to nonmarine mixed-influenced deltaic facies during the Turonian-Coniacian; (3) comparatively low sediment rates and high long-term sea level in the Santonian resulted in a sediment-starved margin with low deltaic influence; (4) well-developed Campanian deltaic sequences expand to the north and exhibit wave reworking and longshore transport of sands; and (5) low sedimentation rates and high long-term sea level during the Maastrichtian resulted in the deposition a sediment-starved glauconitic shelf. Our study illustrates the widely known variability of mixed-influence deltaic systems, but also documents the relative stability of deltaic facies systems on the $10^6$-$10^7$ yr scale, with long periods of cyclically repeating systems tracts controlled by eustasy. Results from the Late Cretaceous further show that although eustasy provides the template for sequences globally, regional tectonics (rates of subsidence and accommodation), changes in sediment supply, proximity to sediment input, and flexural subsidence from depocenter loading determines the regional to local preservation and facies expression of sequences.
Late Cenomanian-Early Campanian Sea Level Change in the U.S. Western Interior: Eustatic and Tectonic Drivers

R. Mark Leckie, University of Massachusetts Amherst
Neil E. Tibert, University of Mary Washington

The western interior of North America was deformed into a foreland basin during Cretaceous time due to subduction, magmatism, and accretionary tectonics along the western margin of the continent. The foreland basin was episodically active throughout the Late Cretaceous as evidenced by volcanic ashfall deposits (bentonites) and temporally variable rates of sedimentation as depocenters subsided to accommodate thick sedimentary sequences or forebulge uplift resulted in condensed sections. High global sea level flooded the foreland basin to create the vast Western Interior Sea. The well-dated stratigraphic architecture of the margins and center of the basin preserve the interplay of tectonics, sedimentation, sea level and climate. Deciphering the global, or eustatic sea level from tectonically-driven changes in relative sea level in the western interior is a challenging proposition.

Several lines of evidence indicate that the second- ($10^7$ yr) and most, if not all, third-order ($10^6$ yr) cycles of sea level rise and fall are at least partially eustatic in origin. For example, the migration of warm water biota and associated lithofacies far northwards into the prairie provinces of Canada during major transgressions, as well as packages of carbonate-rich lithofacies representing transgressive episodes can be widely correlated from west to east across the seaway. However, the timing of sea level change in the U.S. western interior apparently is not synchronous with sea level cycles of the Russian platform (Sahagian, 1996) or the New Jersey coastal plain (Miller et al., 2003). In addition, the possible magnitude of sea level change in the western interior, based on coastal gradient analysis, exceeds the estimates based on the passive New Jersey margin. Are the discrepancies a function of age control and correlation, or do regional tectonics mask the global signature? The western interior foreland basin certainly was episodically more active at times, and differential basin subsidence and uplift played a major role in sedimentation, and probably ocean circulation and climate as well.

Many of the fourth-order ($10^5$ yr) carbonate-rich cycles can also be widely correlated. Are these eustatic in origin, or are they orbitally-forced climate cycles reflecting changes in evaporation and precipitation-runoff across the seaway, or could they be a consequence of shifting water masses due to subsidence and/or uplift in the foreland basin? Bentonite thickness and frequency in the western interior Cretaceous is a proxy for tectonic activity and data from the Colorado Plateau suggest elevated rates of volcanism and outgassing of CO$_2$ during late Cenomanian-early Campanian time. Very warm (>28°C) sea surface temperatures in the southern high latitudes (Huber et al. 2002) also support a model of greenhouse climate through the Late Cretaceous. These observations argue against a significant glacioeustatic control of sea level at this time. However, it is also difficult to reconcile a significant tectono-eustatic control on sea level, particularly at such high frequency.
Study of multiple basins with different tectonic and depositional histories is essential to understanding the relative roles of eustasy, tectonics and local sedimentary processes in generating and preserving continental margin stratigraphy. Seismic delineation of sequence geometries in 3D, followed by scientific ocean drilling, are both required if we are to develop robust criteria for interpreting the continental margin stratigraphic record. The strategy for using scientific ocean drilling to investigate stratigraphic development during the Neogene “Icehouse” period involves drilling passive continental margin transects worldwide. The objective is to drill and sample multiple margins for inter-basinal correlation to evaluate sequence-boundary synchronicity and stratigraphic responses in diverse tectonic and depositional settings, including both carbonate and siliciclastic depositional systems. Advantages of studying the Neogene are availability of high-resolution chronological control and existence of glacial cycles calibrated by the oxygen isotopic record, which provide a well understood eustatic mechanism. The margin transect approach allows the assessment of the relative roles of global (eustatic) and local forcing in controlling sedimentary architectures. This approach also allows us to examine prograding clinoform successions on margins where extensive seismic coverage enables the use of seismic geomorphology principles to evaluate the stratigraphic impact of local sedimentary processes.

Prograding Neogene clinoforms observed on the Australian Northwest Shelf (NWS) passive continental margin are predominantly clastic carbonate, with alternating siliciclastics. These clinoforms display similarities in seismic geometry and scale to coeval siliciclastic examples of this globally important stratigraphic architecture, including the New Jersey continental shelf and the Canterbury Basin (New Zealand). These architectural similarities exist despite differing lithologies and diverse forcing functions. The NWS is also an excellent carbonate analog to the Great Bahama Bank (ODP Leg 166). Before evolving into the modern platform, the Great Bahama Bank had a ramp-like to clinoformal geometry for most of the Neogene, corresponding well to present NWS geometry. The NWS differs from the Bahamas by exhibiting a siliciclastic component. Structural inversions exist on the NWS, but they are highly localized and should not interfere with using its multiple clinoformal successions to study the stratigraphic response to base-level change. Furthermore, a unique combination of commercial geophysical and geological data is available from the NWS: a large 3D multichannel seismic (MCS) volume, extensive grids of 2D MCS profiles, and exploration well data. These superb data will allow us to integrate classic sequence stratigraphic interpretation with seismic geomorphology to investigate the origins and evolution of these marvelously imaged clinoforms.
Comparative Analysis of Upper Palaeozoic Cyclothsms of Contrasting Tectonic Settings: Global vs. Regional Records of Sea-Level Change

Diethard Sanders, University of Innsbruck
Karl Krainer, University of Innsbruck
Spencer Lucas, Mexico Museum of Natural History and Science

Comparative analysis of co-eval cyclic successions deposited under glacio-eustatic sea-level changes, but in (a) a setting with active local tectonism, and (b) on a stable epicontinental platform has the potential to better discriminate controls on cyclothem development than by study within a single area. In the Late Carboniferous to Early Permian icehouse world, glacio-eustatic sea-level changes caused by waxing and waning of the Gondwanan ice shield resulted in deposition of cyclothsms of very large geographic extent. The objectives of research project P20178-N10 (Austrian Research Foundation) are the comparative study of architecture, composition and origin of (a) Lower Permian cyclothsms in the Southern Alps (Europe), deposited in an active tectonic setting related to rifting, with (b) Lower Permian cyclothsms in southern New Mexico (USA), accumulated on a stable epicontinental shelf. Comparison of cyclothsms accumulated in these different tectonic settings should allow for a better recognition of controls over cycle development and expression of cycle boundaries. In the Southern Alps (Europe), throughout an Upper Carboniferous to Lower Permian succession of stacked cyclothsms, both architecture and duration of cyclothsms change markedly up-section. The Upper Palaeozoic of the Southern Alps accumulated during early rifting related to the Alpine orogenic cycle. The vertical change in cyclothem style hence may result from a progressive influence of tectonism relative to glacio-eustasy. The Pedregosa basin of New Mexico (USA) accumulated under slow, steady subsidence in an epicontinental setting. The basin contains a Pennsylvanian to Lower Permian succession of cyclothsms of glacio-eustatic origin, but the Lower Permian cyclothsms to date are little documented. We intend to study in detail cycle architecture and how cyclicity changed over time. Potential controls over stratigraphic development shall be unraveled by comparative analysis of cyclothsms from the Southern Alps and from New Mexico.
Reconstructing the Stratigraphy and Sea Level Fluctuations at the New Jersey Margin: Predictions for Expedition 313

Michael S. Steckler, Lamont-Doherty Earth Observatory of Columbia University
Gregory S. Mountain, Lamont-Doherty Earth Observatory of Columbia University and Rutgers University

The New Jersey margin has been a focus of sea level studies for many years. The relative tectonic stability of an old passive margin, coupled with high sedimentation rates that have built well-preserved prograding clinoforms across the margin containing well-preserved, cosmopolitan fossils suitable for age control has made it an prime site for understanding the relationship between sea level fluctuations and sedimentary architecture. Previous drilling of the New Jersey Transect has taken place on the coastal plain and the outer shelf and slope. IODP Expedition 313 will drill three locations in the inner shelf, sampling early to middle Miocene strata. In order to contribute to the planning of this scientific program and test sequence stratigraphic models, we are developing detailed reconstructions of the growth of the margin and the role of sea level in sculpting the stratigraphic sequences. We are applying 2D backstripping the stratigraphy imaged by high-resolution multichannel seismic profiles to restore the geometry of the strata to the configuration that it had in the past. We remove the effects of tectonic subsidence, compaction and flexural loading by the sediments to remove the distortions that these processes cause. We are applying 2D backstripping the stratigraphy imaged by high-resolution multichannel seismic profiles to restore the geometry of the strata to the configuration that it had in the past. We remove the effects of tectonic subsidence, compaction and flexural loading by the sediments to remove the distortions that these processes cause. In this manner, the morphology of the clinoforms and geometry of the preserved strata can be evaluated. These reconstructions are now being used as the basis for forward modeling of the margin using SEQUENCE2D, an interactive program that simulates both the processes that create accommodation (tectonics, eustasy, flexural isostasy, compaction) and the depositional processes that fill it. Initial runs using a geometric model of deposition suggested sea level amplitudes of about 20 m and less than 40 m. In the newer version of the SEQUENCE2D, sedimentation is now calculated using a four-component moving-boundary formulation for determining the time-averaged cross-shelf sediment transport. Feedback between processes are captured using an interactive loop. We will present both backstripping reconstructions and forward models that estimate sea level amplitudes and their stratigraphic imprint at the New Jersey margin focusing on the inner shelf region to be drilled by Expedition 313.
High-resolution (20-250 Hz) multichannel seismic reflection data, totaling approximately 4620 line km, were collected in November-December 2004 (cruise EW04-12) on the inner shelf to slope in the Sandino forearc basin, offshore Nicaragua and Costa Rica. Approximate age constraints are provided by industry well data. The ultimate goal of the project is to identify and distinguish the Neogene stratigraphic signatures of both global sea-level change and local tectonism as well as to document how tectonic deformation is recorded in the stratigraphic record.

The Mesozoic basement is uplifted to the southeast as it nears the Cocos Ridge and becomes subaerially exposed on the Nicoya Peninsula. Immediately northwest of the peninsula, only a thin (approximately 0.2-0.4 s) layer of Neogene sediment overlies a prominent unconformity truncating basement. Approximately 50 km farther to the northwest, buried clinoforms that prograde northwestward, nearly perpendicular to the present shelf break, may record episodes of this uplift in the south. Similarly oriented clinoforms are also located still farther to the northwest and are associated with along-strike structural segmentation of the forearc basin.

In general, the basin thickens to the northwest, though some areas are locally uplifted. The northwestern area of the survey images a thick (> 4 s) forearc basin, where a series of angular unconformities truncate heavily faulted Cenozoic strata. Dip profiles show strata with steep basinward dips truncated by an angular unconformity near the seafloor at their landward ends. Continuing basinward, these strata are deformed by a series of approximately trench-parallel folds. Near the shelf edge, the sub-horizontal strata become clinoformal and the section is commonly cut by landward dipping normal faults. Beneath the slope, the faulted top of basement (margin wedge) is resolved, overlain by approximately 1 s of slope sediment. Faulting occurs within slope sediments and there is evidence of both buried and surficial slope failure. In addition, the slope is incised by both modern and buried canyons. A prominent bottom-simulating reflector (BSR), indicative of the presence of a hydrate layer, occurs on the slope throughout the survey area.

In spite of the tectonic deformation, regional unconformities occur within the forearc basin sediments. We hypothesize that these regional unconformities are the products of eustatic fluctuations. IODP drilling in the Sandino Basin will be required to fully test this hypothesis and verify the results of this study, but it appears to hold true in the Eel River Basin (northern California), a similar forearc basin setting where regional unconformities correlate approximately with the oxygen isotopic record and are distinguishable from unconformities of tectonic origin, which are localized around uplifted structures. If eustasy is revealed to be the dominant control on high-frequency sequence development even in the tectonically active Sandino Basin, the results would provide a model for determining the origin of unconformities throughout the stratigraphic record.
Carbonate Seismic Stratigraphy of the Gulf of Papua Mixed Depositional System: 
Neogene Stratigraphic Signature and Eustatic Control

Eugene Tcherepanov, Rice University
Andre Droxl, Rice University
Philippe Lapointe, Total
Kenneth Mohn, Fugro

This study integrates and interprets well, seismic, gravity, multibeam bathymetry datasets, and Landsat imagery to define the major controlling factors that influenced the evolution of the Gulf of Papua (GoP) mixed carbonate-siliciclastic depositional system. The Eocene-Miocene carbonate deposition in the GoP corresponds to the carbonate phase of the mixed depositional system evolution. Eustatic sea level fluctuations appear to be the most important factor that has influenced the depositional system development during that particular phase. Eustatic changes triggered the establishment of the carbonate system and then influenced the vertical and lateral accumulation, overall distribution of the carbonate sediments, and played an important role in the drowning and/or exposure of the carbonate platforms. Eustatic sea level fluctuations appear to be also at the origin of the sedimentary sequence geometries.

Major carbonate system development in the GoP was initiated during the Eocene. After that, subsequent to an early Oligocene hiatus, the carbonate system expanded its surface area, vertically aggraded, then systematically backstepped, and partially drowned during the late Oligocene (Chattian)-early part of the early Miocene (Aquitanian). During the late early Miocene (Burdigalian)-early middle Miocene (Langhian) the carbonate system continued its vertical growth (aggradation) in most of the platform areas, where it was able to keep up with sea level rise. In the middle Miocene (end of Langhian), the carbonate deposition shifted downward during a long-term sea level regression, exposing most of the early middle Miocene (Langhian) platforms. Following this downward shift, the carbonate production and accumulation remained active only during the late middle Miocene (Serravallian) in the northeastern part of the study area, and was characterized by four systematically prograding units. At the very beginning of the late Miocene (Tortonian), the Langhian platform tops were re-flooded, the carbonate system backstepped, and locally aggraded during part of the late Miocene, the early Pliocene, and part of the Quaternary. The influence of siliciclastic input, initiated during the late Miocene, became prevalent during the Quaternary.

This pattern of carbonate sequence geometries, referred to as the Oligocene-Neogene stratigraphic signature, is identical to the contemporaneous sedimentary patterns observed in pure carbonate systems around the world such as in the Maldives and in the Bahamas, and also in some siliciclastic systems (e.g., New Jersey continental margin). Since this identical sedimentary geometry pattern is observed in different locations around the world, the recognition of the Oligocene-Neogene stratigraphic signature in the GoP demonstrates that the depositional evolution of the carbonate system during the late Oligocene-Miocene, and the early Pliocene had to be dominantly controlled by eustatic fluctuations.
Recent advances in U/Th coral dating have the potential to produce a high-resolution sea-level record for the last 600 to 700 thousand years, from Marine Isotope Stage 17 to the present. Although highstand coral terraces that formed during interglacial and interstadial sea-level events are generally well exposed in areas of tectonic uplift, corals that grew during periods of lower sea level must be acquired by offshore drilling. Furthermore, the preservation of drowned coral reefs may be better than those that are uplifted and exposed to erosion. There are crucial gaps in our knowledge of sea-level change during the late Quaternary. Here I outline a number of critical sea level and climate change questions that may best be answered by drilling fossil coral reefs.
Early Cenozoic Sea Level Change: Insights From Pacific Records of Seawater $\delta^{18}$O

Aradna Tripati, University of Cambridge
Caroline Dawber, University of Cambridge
Jan Backman, Stockholm University
Harry Elderfield, University of Cambridge

Constraints on Earth’s glacial history come from the deep-sea oxygen isotope ($\delta^{18}$O) record. The growth of Antarctic ice during the early Cenozoic is modelled to have driven changes in seawater $\delta^{18}$O of up to 0.5‰ (DeConto and Pollard, 2003). Larger shifts in the mean $\delta^{18}$O of seawater therefore require some storage of ice in the Northern Hemisphere. In order to study the evolution of ice volume during the early Cenozoic, we developed high-resolution records of seawater $\delta^{18}$O for three sites in the tropical Pacific by combining new and published (Lear et al., 2004; Coxall et al., 2005; Tripati et al., 2005) records of benthic foraminiferal $\delta^{18}$O with Mg/Ca-based paleotemperatures. Deep Pacific $\delta^{18}$O records are the most representative of mean $\delta^{18}$O due to the size of the ocean basin. Fluctuations in carbonate ion concentrations during the time interval studied (Tripati et al., 2005) may have resulted in estimates of seawater $\delta^{18}$O that are biased by 0.1‰ (Elderfield et al., 2006), and thus we use 0.6‰ as a threshold value for Northern Hemisphere ice storage. The seawater $\delta^{18}$O reconstructions for Sites 1209, 1218 and 1219 show that several large (>0.6‰) shifts in seawater $\delta^{18}$O occurred throughout the middle Eocene to early Oligocene. The magnitude of variations in seawater $\delta^{18}$O necessitate the storage of ice in both the Northern and Southern Hemisphere at about 44.5 Ma, 42 Ma, 38 Ma, and after 34 Ma.

‘Clumped Isotope’ Thermometry in Benthic Foraminifera: A New Tool for the Accurate Reconstruction of Deep-Ocean Temperatures and Seawater $\delta^{18}O$?

Aradhna Tripati, University of Cambridge and California Institute of Technology
John Eiler, California Institute of Technology

The benthic oxygen isotope ($\delta^{18}O$) record is an archive of past deep-water temperatures and ice volume. The carbonate ‘clumped isotope’ thermometer provides a new technique for reconstructing temperature. It is based on the principle that the proportion of $^{13}\text{C}^{18}\text{O}$ bonds in carbonate minerals is temperature-dependent [1-3]. Unlike other temperature proxies, the clumping of heavy isotopes into bonds with each other is independent of the isotopic composition of the water in which the mineral precipitated. Abundances of $^{13}\text{C}^{18}\text{O}$ bonds in carbonates are determined by measuring $\Delta_{\text{cl}}$ values of CO$_2$ extracted from carbonate by acid digestion; $\Delta_{\text{cl}}$ values reflect enrichments, in per mil, of $^{13}\text{C}^{18}\text{O}^{16}\text{O}$ in product CO$_2$ relative to the amount expected by random chance.

We have measured the $\Delta_{\text{cl}}$ values of core-top benthic foraminifera and ostracods. Preliminary results show that multiple species with different ecologies exhibit the same temperature dependence as inorganic calcite [1]. In contrast to the benthic Mg/Ca thermometer [4], there does not appear to be a discernable influence of carbonate ion concentration on the $\Delta_{\text{cl}}$ composition of benthic foraminifera (e.g. a carbonate ion effect). Calibration data will be shown for several benthic foraminifera, including the epifaunal taxa *Planulina* wuellerstorfi, *Cibicidoides mundulus*, *Cibicidoides pachyderma*, *Hoeglundina elegans*, *Gyroidina* sp. and the infaunal taxa *Oridorsalis umbonatus*, *Melonis pompilioide*, and *Uvigerina* sp. Paired measurements of $\Delta_{\text{cl}}$ and $\delta^{18}O$ can potentially yield accurate and quantitative determinations of past temperature and seawater $\delta^{18}O$.

Ghosh, P., Adkins, J., Affek, H, Balta, B., Guo, W., Schauble, E, Schrag, D., and Eiler, J., 2006, $^{13}\text{C}^{18}\text{O}$ bonds in carbonate minerals: A new kind of paleothermometer,
Geochimica et Cosmochimica Acta, 70, 1439–1456.
A Proposal to Drill Drowned Corals Reefs Around Hawaii:
A Unique Archive of Sea-level, Climate Change, and Reef Response
Over the Last 500 kyr

Jody Webster, James Cook University
Christina Ravello, University of California, Santa Cruz
Christina Gallup, University of Minnesota
David Clague, Monterey Bay Aquarium Research Institute
Nicki Allison, University of St. Andrew
Juan Carlos Braga, University of Granada
Christopher J. Chiang, University of California, Berkeley
Charles Fletcher, University of Hawaii
Yasufumi Iryu, Tohoku University
John Pandolfi, University of Queensland
Willem Renema, Natural History Museum, Netherlands
Yusuke Yokoyama, University of Tokyo

Drowned coral reefs on rapidly subsiding margins, such as Hawaii, contain a unique and largely unexploited archive of sea-level and climate changes. The rapid subsidence ensures the unique potential to continually create accommodation space, thus generating greatly expanded stratigraphic sections compared to reefs from stable margins such as the Great Barrier Reef or Florida Margin, or uplifting margins such as the Huon Peninsula or Barbados. Moreover, these drowned reefs evolved mainly during different periods of Earth’s sea-level and climate cycles (i.e. glacial periods) that are not well sampled by reefs at stable and uplifting margins.

The links between eustatic sea level and global climate changes suffer from lack of appropriate fossil coral records over the last 500 kyr, particularly during the transitions into, during and out of the glacial periods. New coral data is needed to directly constrain the timing, rate, and amplitude of sea level variability over the last 500 kyrs. Such data will test Milankovitch climate theory, and assess controversial abrupt sea-level events (i.e., meltwater pulses) that occur on suborbital frequencies in concert with climate events occurring in the extra-tropics (i.e., Dansgaard/Oeschger (D/O) ice-core temperature Events, and Heinrich ice-rafted debris Events in North Atlantic sediment cores).

Identification of the factors and processes that control annual average global climate and seasonal and interannual climate variability in the subtropical Pacific is of equal importance. Earth history over the last 500 kyr reveals that the ‘dynamic range’ of climate change is much larger than in the instrumental record for the last century. Paleoclimate records from times when climate forcing, such as pCO2 and solar heating, were different than today will test proposed theories.

The drowned coral reefs around Hawaii grew and drowned episodically over the last 500 kyr and offer a truly unique opportunity to address these major scientific problems. Hawaii represents an ideal study location because: 1) the rapid subsidence is nearly uniform at 2.5-2.6 m/kyr over tens to hundreds of thousands of years; 2) Hawaii is distant from the confounding effects of large ice sheets and boundary ocean currents that can obscure sea level and paleoclimate records; and 3) an extensive database of bathymetric, submersible, ROV observations, sedimentary and radiometric data is available for these reefs. We propose to exploit the unique potential of this largely untapped record by drilling the succession of drowned reefs around Hawaii to 1) define the nature of sea level change in the central Pacific over the last 500 kyr; 2) reconstruct paleoclimate variability for the last 500 kyr and establish the relationship between the mean climate state and seasonal-interannual variability; 3) establish the geologic and biologic response of coral reefs to abrupt sea level and climate changes; and 4) elucidate the subsidence and volcanic history of Hawaii.
Quaternary Sea-Level Changes and River-Sea Interactions in the East China Sea

Shouye Yang, Tongji University
Hongbo Zheng, Tongji University
Congxian Li, Tongji University

The present day East China Sea (ECS) includes the continental shelf, Okinawa Trough and the Ryukyu Arc. The ECS continental shelf is one of the broadest in the world, with an average width of 500-600 km. In the Quaternary, especially during the postglacial period, this epicontinental shelf received a large amount of terrigenous sediment from two of the largest rivers in the world, the Yellow and Yangtze Rivers. The Yellow River, although the smaller of the two, has a very high sediment load, while the Yangtze delta extends to the 60 m isobath and supplies the major part of siliciclastic sediment to the ECS in the present day. Previous studies on the Quaternary stratigraphy of the Yangtze Delta revealed that the earliest weak marine transgression occurred in the early Pleistocene and the strongest ones took place in the late Quaternary. It is interesting to note that the marine transgression occurring in Marine Isotope Stage 3 has been considered to be stronger than those happening in Marine Isotope Stage 5 and the Holocene. The sediment source-to-sink history of the Yangtze River during the Quaternary is primarily controlled by neotectonic process, sea-level changes and East Asian monsoon evolutions. The development history of the Yangtze Delta during the Holocene is tightly related to the postglacial sea-level change. Nevertheless, the river-sea interactions during the Pleistocene remain to be clarified mainly because of the lack of long and continuous core record in the East China Sea.

The ECS is an integral part of the active continental margin of the West Pacific tectonic zone, and is bounded by Ryukyu Arc to the east, and Zhejiang-Fujian uplifted zone to the west. Two major Cenozoic basins extend NNE-SSW: the ECS Shelf Basin and the Okinawa Trough Basin, separated by the Diaoyudao Island uplift zone. The Shelf Basin comprises a number of near-parallel sub-basins filled by 6-14 km of Cenozoic marine and fluvial-lacustrine deposits, which fall into two groups separated by a low rise. From south to north, the western group consists of Pinghuxi, Nanri, Oujiang, Minjiang, Qiantangjiang and Changjiang sub-basins, and the eastern group consists of Xinzhu, Jilong and Xihu sub-basins. The long-term sea-level changes and resulting river-sea interactions were well recorded in these marginal basins. For this purpose we propose IODP drill sites in these basins of the East China Sea.