Oligocene through the early Miocene (24-16 Ma) at a temporal resolution of 5 kyr. In the same time interval, a magnetic polarity stratigraphy can be unequivocally correlated to the geomagnetic polarity timescale (GPTS), thereby providing direct correlation of the isotope record to the GPTS. In an initial age model we use the newly derived age of the Oligocene/Miocene boundary of 23.0 Ma (Shackleton et al., 2000) revised to the new astronomical calculation of Laskar (2001) to recalculate the spline ages of Cande and Kent (1995). We then tune the site 1090 oxygen isotope record to obliquity, assuming a 7.2 kyr phase lag, using the new astronomic solution of Laskar (2001). In this manner we are able to refine the ages of polarity chrons C7n through C5Cn.1n. The new age model is consistent, within one obliquity cycle, with previously tuned ages for polarity chrons C7n to C6Bn from Shackleton et al. (2000), rescaled to the new astronomical solution of Laskar (2001). For early Miocene polarity chrons C6AAr through C5Cn, our obliquity-scale age model is the first to allow a direct calibration to the GPTS. The new ages are also close to, within one obliquity cycle, to those obtained by rescaling the Cande and Kent (1995) interpolation using the new age of the O/M boundary (23.0 Ma), and the same middle Miocene control point (14.8 Ma) used by Cande and Kent (1992). Thus we have confidence in the orbitally tuned age model and the refined GPTS calibration for the late Oligocene through early Miocene.

U11B-0009 0830h POSTER

Model for the Establishment of Modern Atolls during the Mid Brunhes MIS 12 to MIS 11 Sea Level Transgression in the Maldive Archipelago (Equatorial Indian Ocean)

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The Maldive archipelago consists of 22 main atolls characterized by a marginal rim surrounding a lagoon commonly less than 50-60 m deep, though some lagoons reach depths of more than 80 m. The overall evolution of the carbonate system in the Maldive Archipelago clearly shows that the slow subsidence of hypothetical volcanic edifices buried under the atolls cannot explain their typical ringed morphology. On the contrary, the atolls in the Maldives, as most likely the majority of the modern atolls, are probably young (less than 0.5 My old) carbonate edifices. Our research in the Maldives was developed based upon the interpretation of two Elf-Aquitaine and Royal Dutch Shell MCS grids, groundtruthed by ODP Site 716 and two deep exploration wells. Several seismic profiles across the modern atoll margins clearly illustrate a shift from middle Miocene-early Pliocene sigmoid lateral margin progradation of flat-topped carbonate banks to late Quaternary bank top vertical aggradation evolving into the modern atoll physiography. This well-marked transition is first illustrated by a regionally observed initial downward shift of the depositional system dated at 3.0-2.5 Ma. This downward shift of onlap and subsequent deposition in sedimentary wedges below the early Pliocene bank margins are explained by a late Pliocene-early Pleistocene (3.0-0.5 My) gradual sea level regression tied to the onset and successive expansions of major continental ice sheets in the northern Hemisphere. This regression is clearly defined in several Pliocene-Quaternary high resolution benthic isotope records, best proxy for ice volume variations in the past 5 My, at ODP sites such as 659, 677, 846, and 849.The early Pliocene flat-topped carbonate banks, exposed for about 2.5 My in the late Pliocene and early Pleistocene, were fully re-flooded for the first time at the glacial MIS 12 to interglacial MIS 11 transition. This sea level transgression is unique by its highest amplitude among the multiple sea level transgressions in the past 5 My and by its occurrence directly after a 2.5 My-long sea level regression The unique character of the MIS 12 to MIS 11 sea level transgression is clearly shown in the Karner et al. stack of six tropical high resolution 18-O records (five of them are from ODP Sites 659, 664, 677, 846, and 849) from the Atlantic and eastern Pacific oceans. In conclusion, the atolls in the Maldives and probably most of the modern atolls are very young, less than 0.5 My old, edifices. Early Pliocene flat topped bank remained mostly exposed and were karstified during a late Pliocene to early Pleistocene 2.5 My.-long sea level regression. This karst morphology served as substratum and, therefore, template for the atoll development first during the unusually high amplitude MIS 12 to MIS 11 sea level transgression. Subsequently the successive exposures and floodings related to the series of late Brunhes, 120 m high amplitude, sea level transgressions and regressions, enhanced the initial mid Brunhes ring-shaped morphology, so typical of the modern atolls observed in the Maldive Archipelago.

U11B-0010 0830h POSTER

A New Automated Technique for the Construction of More Accurate Composite Depth Scales and an Analysis of Core Deformation in Different Sediment Types

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A composite depth section reconstructs a continuous record of the sediment at a drilling site by splicing together cores from different holes; its corresponding composite depth scale describes the correlation of the sediments between holes. Both are important tools for analyzing the sediment recovered from a drilling site. The standard splicing technique for creating composite depth sections does not correct for distortion within cores, so that a sedimentary feature may have a slightly different composite depth in each hole. Additionally, the splicing technique often results in composite depths which are $\sim$10% greater than recorded drill depths. A new automated compositing technique aligns features between holes and prevents the artificial increase in composite depth. The results of this technique are compared with the traditional composite depth scale. Additionally, the new technique allows for analysis of the deformation and extension that occurs in cores during the drilling and extraction process. This study describes typical core deformation and its effect on calculated sedimentation rates for the carbonate and siliceous sediments of ODP Leg 138 and the terrigenous-dominated pelagic sediments of ODP Leg 154. Preliminary results indicate that cores from Leg 138 are stretched by more than 5% and those from Leg 154 by nearly 3%. For both legs, extension is greatest in the top half of cores, but variability in deformation may increase toward either end of a core.

U11C MCC: 3001-3003 Monday 1020h

Union Tutorials II

Presiding: **R L Wesson,** U.S. Geological Survey**; J T Snow,** University of Oklahoma

U11C-01 1020h INVITED

Mars: A Scientific Revolution in the Making?

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The planet Mars has always been an object of fascination for scientists and the public alike, in part because of a never-ending set of enigmas it has always presented. Today, international spacecraft-based exploration of Mars has been reinvigorated, in part thanks to the discovery of meteorites bearing carbon-based molecules from Mars, as well as a consequence of the remarkable suite of discoveries made by NASA's Mars Global Surveyor and Odyssey orbiter missions. Indeed, in little more than the past 6 years, the underlying paradigms for how Mars has operated as a dynamic silicate planet since its time of formation have been recast, rethought, and revolutionized on the basis of the ongoing observations of the Global Surveyor and Odyssey. The current view of Mars is so rapidly evolving that one can offer only generic statements as to what is unambiguously understood. What can be said is that scientists are now viewing Mars as an inner planet for which the history of water, climate variability, and of the entire interior are complex, dynamic, and inadequately explored. A series of robotic spacecraft missions are presently enroute to the red planet in an aggressive attempt by scientists from NASA, ESA, the Japanese Space Agency, and many other international partners to re-examine the history of water, explore atmospheric loss mechanisms, explore the shallow subsurface, investigate the hydrological cycle, and even to begin exploration for the molecular building blocks of life. Because the state of scientific understanding of Mars has been changing so rapidly, it has been suggested that a scientific revolution is underway. This Union Tutorial will highlight current thinking about Mars on the eve of the most intensified robotic exploration of any planet other than the Earth's Moon, in the history of humanity. As has been said, perhaps too often, at least in terms of science, "Mars rocks".

URL: http://mars.jpl.nasa.gov

U11C-02 1120h INVITED

Temporal and Spatial Scaling in the Earth Sciences

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The *AGU Focus Group on Nonlinear Geophysics* began in 1998, focusing on the general area of nonlinear and complex geophysical systems, with an emphasis on developing the mathematical, theoretical, numerical, experimental and observational tools to understand and simulate the dynamics of these systems. Nonlinear geophysics is fundamentally the application of nonlinear and/or stochastic partial or total differential equations to geophysical problems. Some key concepts and philosophies related to *Nonlinear Geophysics* include fractals, multifractals, chaos, nonlinear waves, solitons, turbulence, cascades and vortex dynamics, scaling, critical phenomena and nucleation, time series, and self-organizing systems. Scaling in both time and space is an underlying attribute of many of these concepts, and is included in a majority of talks presented by the general *Nonlinear Geophysics* community at AGU. The purpose of this one-hour union tutorial will be to introduce students and experienced researchers alike (particularly those outside of the general area of nonlinear geophysics) to some of the basic concepts, techniques and examples surrounding temporal and spatial scaling in the Earth Sciences. As many are familiar with the idea of spatial scaling in the Earth Sciences (e.g., the concepts of fractals and self-similarity that approximately the same pattern repeats itself at many different scales in nature), ideas of spatial scaling will be briefly introduced, with the majority of the talk concentrating on temporal scaling. This tutorial will include 40' 'lecture' + 15' for questions/comments. Key terms will be introduced and defined (e.g. self-affine, persistence), some of the major techniques used will be briefly described (e.g. Hurst, Fourier-Analysis, Semivariograms, Wavelets), and throughout, examples and applications to the Earth Sciences will be used. Concepts and techniques will be presented from an intuitive perspective, without the use of extensive mathematics. A reference list for further reading will be available and a power-point version of this presentation will be available via the *AGU Nonlinear Geophysics* website. Finally, a secondary purpose of this tutorial will be to highlight major advances made in the general area of *Nonlinear Geophysics* and to summarize, from a non-mathematical perspective, the major focus and highlights of related sessions at this conference. A prepared handout will be available with this information.

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U12A MCC: 3001-3003 Monday 1340h

The Contributions of 20 Years of Scientific Ocean Drilling II

Presiding: **K Becker,** Rosenstiel School of Marine and Atmospheric Science, University of Miami**; M F Coffin,** Ocean Research Institute, University of Tokyo

U12A-01 1345h

Tales of Two LIPs: Kerguelen/Broken Ridge (Indian Ocean) and Ontong Java (Pacific Ocean)

Scientific Parties

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The Kerguelen Plateau/Broken Ridge (KP/BR) and Ontong Java Plateau (OJP) are among Earth's largest igneous provinces (LIPs), with crustal volumes of 2.5 and 5.7 x 10^7 km^3, respectively. Recent investigations, culminating in ODP Leg 183 to KP/BR, and Leg 192 to OJP, have revealed significant differences between the two. The Kerguelen hotspot has been active since at least 120 Ma. KP/BR contain microcontinental fragments. Upper crust of KP/BR is structurally complex, and although dominantly tholeiitic basalt, it includes basalts to rhyolites. Nearly all of the drilled upper crust formed subaerially, and subsequently subsided beneath sea level at rates comparable to those of typical oceanic crust. In contrast to KP/BR, OJP is entirely oceanic, includes no continental material, and cannot be linked to any hotspot track or currently active hotspot. It formed instantaneously, in a geological sense, at $\sim$120 Ma, together with flood basalts in

older neighboring oceanic basins. OJP's upper crust is structurally relatively simple, and is homogeneously tholeiitic. To date, all rocks drilled on the plateau and sampled from obducted OJP sections in the Solomon Islands formed underwater, and subsequent lithospheric subsidence was either minimal or erratic. OJP is characterized by a low velocity mantle root extending several hundred kilometers into the asthenosphere that is interpreted as chemically, not thermally, anomalous. This root appears to deflect normal Pacific Ocean asthenosphere around it, and thus seems to be rigidly coupled to OJP crust. Extant plume theory explains neither KP/BR nor OJP. Plume models predict massive flood volcanism roughly coeval with continental breakup, yet the onset of voluminous KP/BR magmatism post-dated separation of India and Antarctica by at least 10 million years. Plume theory also predicts short-lived (approximately 1 Myr) plume head volcanism followed by long-lived (10-100 Myr) plume tail volcanism, yet peak magma output of the Kerguelen hotspot lasted approximately 25 Myr. Plume models predict major lithospheric uplift approximately coeval with voluminous magmatism, and subsequent plateau subsidence at rates similar to normal oceanic lithosphere, but the main OJP was never above sea level and has experienced only slight or erratic ensuing subsidence.

U12A-02 1405h

First Results From Hole 1256D - a New Ocean-Crust Reference Hole Drilled in Fast-Spread Crust During ODP Leg 206

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Sampling a complete section of oceanic crust has been a long term objective since the inception of scientific ocean drilling. Recovery of in situ ocean crust is imperative to understand igneous accretion and the complex interplay between magmatic, hydrothermal, and tectonic processes, as well as a means for calibrating remote geophysical observations, especially seismic and magnetic data. Only by drilling a complete section of upper crust formed in a simple tectonic setting can the processes operating at normal mid-ocean ridges be understood. Leg 206 completed the initial phase of a planned multi-leg project to drill a complete in situ section of the upper ocean crust that will eventually extend through the extrusive layer and sheeted dikes and into gabbros. Drilling was conducted at Site 1256 (6.7N, 91.9W), which resides on 15-Ma oceanic lithosphere of the Cocos plate that was created by superfast seafloor spreading (220 mm/yr). Given the inverse relationship that exists between spreading rate and depth to axial magma chambers, it should be possible to reach gabbros on a second leg to this site, at depths $<$ 1400 m sub-basement. On Leg 206, we installed a reentry cone with a 16-inch-diameter casing string that extends into basement in Hole 1256D. Beside coring the 250 m of sediment and 88.5 m of basement in pilot holes (Holes 1256A, B, and C), we cored 502 m sub-basement in Hole 1256D. The basement section consists of massive and sheet flows with subordinate pillow lavas, hyaloclastites, and rare dikes that are capped by more evolved, ponded massive flows up to at least 75-m thick. The lavas have N-MORB compositions and exhibit typically slight, low-temperature alteration effects, with little oxidation. The capping sequence found at the top 100 m of basement is chemically and magnetically distinct, remarkably unfractured, and the great flow thickness requires existing abyssal-hill topography, all suggesting deposition at least 5 km from the axis. The low proportion of pillow lavas ($<$10%) indicates typically rapid lava emplacement, consistent with thermal-model predictions of less than 1-km vertical thickness of the dike zone. A complete suite of geophysical wire-line logs confirmed that Hole 1256D is in excellent condition, open to its full depth (752 m below seafloor), and ready for future deepening into the sheeted dikes and gabbros early in the next phase of ocean drilling.

U12A-03 1425h

Ocean Drilling Program Contributions to the Understanding of the Deep Subsurface Biosphere

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Tantalizing evidence for microbes in oceanic basalts has been reported for a few decades, but it was from rocks cored on Ocean Drilling Program (ODP) Leg 148 in 1993 that the first clear-cut evidence of microbial invasion of ocean basalts was obtained. (Work on ODP legs, starting with Leg 112 in 1986, had already revealed the presence of significant microbial biomass in sediments.) In 1997 ODP created the Deep Biosphere Program Planning Group to promote the investigation of the microbiology of the ocean crust. In 1999 ODP built a microbiology lab on the JOIDES Resolution, and used the lab that year (Legs 185 and 187) to test the amount of microbial contamination introduced into rocks during drilling and to establish cultures from cored basalts. These experiments have been repeated on several legs since then. The development of CORKs has permitted long-term sampling of subseafloor fluids, and microorganisms have been recovered from CORKed holes. Thus, ODP made it possible for the scientific community to address major questions about the biology of the igneous crust, such as, (1) What microbes are present? (2) How abundant are they? (3) How are they distributed? DNA from basalts and subseafloor fluids reveal what types of organisms are present. Cell abundance and biomass have been estimated based on cell counts and on organic content of basalts. Surveys of basalts in DSDP/ODP repositories indicate that microorganisms are ubiquitous in the igneous crust. Microorganisms are found in rocks that are close to 100° C. They are found as deep as 1500 m below the sea floor, and in rocks as young as a few years and as old as 170 million years. Because of the vast size of the habitat, microorganism, even if present in small numbers, could be a significant fraction of the Earth's biomass. In a short time ODP contributed to advances in our understanding of the oceanic subsurface biosphere. Answers to other significant questions such as: (1) How do the microorganisms live?, (2) What impact do subsurface microorganisms have on the surface biosphere? (3) And, what roles do the subsurface biosphere play in element cycling? will be answered by future drilling. The International Ocean Drilling Program (IODP) is in the enviable position of providing support to address these key questions about the Earth's subsurface biosphere.

U12A-04 1445h

Trace Elements in Interstitial Waters: From Carbonate to Siliceous Environments

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Similarities in the characteristics of depth-profiles of major constituents in IW from boreholes drilled during DSDP and ODP cruises indicate that the same set of diagenetic reactions controls porewater compositions at many sites. Depending largely on sediment deposition rates porewater profiles are dominantly mediated by alteration of volcanics (basalts of layer II or volcanic matter dispersed throughout sediments) or by reactions involving sulfate reduction and methanogenesis (e.g., Gieskes, 1981). Largely as a result of analytical diffulties, however, trace elements in IW have generally not received the attention that has been afforded to major species. Trace element concentrations, particularly those in non-diffusional profiles, although also governed in part by the main diagenetic reactions taking place in the sediment column, also reflect the existence of localized reaction zones. This is particularly true in sediments where episodic changes in the depositional regime lead to the isolation of pockets of highly reactive material. Such reaction zones can then exert a more dominant control on the trace element composition of IW. In this contribution we will compare and contrast profiles of various trace elements (e.g., Sr, Li, Rb, Cs, Fe, Mn, and selected transition metals) determined in IW recovered from passive and active continental margins, carbonate platforms, and pelagic settings.

U12A-05 1505h

Fluid pressure transients and mechanical coupling in decollement zones

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Accretionary wedges syn-sedimentary decollements are low friction fault zones and generally lie in the aseismic portion of the subduction plane updip of the seismogenic zone. Understanding the role of fluid migration and fluid pressure has been an important target of ODP, with legs 110 and 156 on Barbados accretionary wedge and legs 131, 190, 196 on Nankai accretionary wedge. In both settings, arguments based in great part on microstructural observations suggested pore pressure cycling. Logging while drilling data also indicate that decollements can keep a high water content in spite of the generally compactive nature of the deformation observed at the micro-scale. Theory and modeling show that high pore pressure fronts may propagate spontaneously along a decollement under certain conditions, which include a strong dependency of permeability on pore pressure. However, there are important differences between the Barbados case and the Nankai case. In Barbados, pore fluid chemistry indicates transient fluid migration along the decollement from a smectite diagenesis fluid source at depths. On the Nankai Muroto transect, smectite diagenesis occurs in the trench and there is no clear fluid migration signal at decollement level. This suggests that pressure cycling may occur without significant horizontal flow along the decollement. A conceptual model is proposed in which transient fluid pressure transfer from the underthrust sequence to the decollement and pore pressure in the decollement are controlled by the stress state in the underthrust sequence. Studies of anisotropic physical properties indicate strong decoupling at the decollement level and suggest an extensional state of stress is maintained in the underthrust sequence. Slip along the decollement increases the extensional stress in the underthrust sequence at the tip of the slipping zone and promotes fluid flow into the slipping zone.

U12A-06 1525h

Twelve Years of Results from ODP Subseafloor "CORK" Hydrogeological Observatories

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The CORK ("Circulation Obviation Retrofit Kit") sealed-hole observatory was developed 12 years ago by ODP engineers and scientists to investigate in-situ hydrogeological state and processes, through long-term measurements of in-situ temperatures and pressures and sampling of in-situ fluids. CORK capabilities have been expanded recently to allow monitoring and sampling in multiple isolated horizons. To date, 18 CORK hydrological observatory sites have been established in ridge crest, ridge flank, and accretionary prism settings. Observations at these sites have provided precise constraints on the primary driving forces for, and thermal consequences of, sub-seafloor fluid flow caused by thermal buoyancy and tectonic consolidation. Deep in accretionary prisms, high formation pressures have been observed, confirming that plate boundary faults possess little strength. In young ocean crustal settings, surprisingly low lateral temperature and pressure gradients have been documented, implying that the extrusive upper oceanic crust permits efficient transport of fluid, heat, and solutes over distances of many kilometers. CORK observations have also revealed pressure variations and associated fluid flow resulting from co-seismic plate deformation and from tidal, oceanographic, and barometric loading of the seafloor. The characteristics of the formation response to seafloor loading provide constraints on formation elastic and hydrological properties, and allow quantitative estimates of crustal strain to be made from pressure transients related to tectonic events. Strain events have been observed up to 250 km away from several seismic dislocations along subduction, transform, and seafloor spreading plate boundaries.