Source to Sink Workshop

Neal Driscoll and Charles Nittrouer

A four-day meeting funded by NSF and JOI was held at Lake Quinault, WA, on Sept 28-October 1, 1999 to create the science plan for the MARGINS sedimentology and stratigraphy community. The science plan will suggest important directions for future research, recommend strategies for accomplishing this research, and will consider candidate sites for detailed interdisciplinary studies in light of the site criteria accepted at the workshop (and described below). The science plan is expected to provide a blueprint for taking geomorphologic, sedimentary and stratigraphic processes to a substantially higher level of understanding. The research goal is to discern the relationships among processes relevant to sediment production, transport, accumulation, and preservation on margins at multiple temporal and space scales, from turbulence to tectonics and from sedimentary fabric to sequence stratigraphy and basin analysis.

Margins constitute material dispersal systems that convey water, sediment and associated chemicals from the continent to the sea via rivers, aquifers, mass movements and turbidity currents. The various parts of this system are typically in a state of flux at geological time scales. Temporal and spatial evolution of margins involve strong interactions between the various zones of the sediment dispersal system. Understanding and predicting these changes requires empirical knowledge of the linkages and feedbacks between the components. At present, we have some understanding of the individual units constituting margins, but little ability to link them interactively in a quantitative and predictive way. The MARGINS program was conceived on the premise that significant improvements in both understanding and predictive ability can be obtained through the pursuit of these linkages. A 10-year program of concerted research based on a group philosophy, and fully integrating field, experimental and modeling elements should allow for a major breakthrough toward achieving this predictive ability. The intertwining of sediment flux, morphodynamics and stratigraphy offers an unprecedented opportunity for research synergism.

Criteria for "Focus" Sites

The meeting employed a systems approach to examine coupled land and ocean environments (from mountain tops across shorelines to abyssal plains) and because site selection is an integral part of the MARGINS strategy, substantial discussion was devoted to producing a list of important criteria. The following list of site criteria was agreed upon at the workshop. All of these criteria are deemed important, but not mandatory - that is, failure by a site to meet one or more criteria would not necessarily disqualify it from consideration.

Natural factors for selecting a site:
• Strong forcing that produces strong signals
• Active sedimentation spanning source-to-sink environments
• Active transfer among environments
• Closed system
• High-resolution stratigraphic record
• Presence of carbonate environments
• Significant differences between the two sites

Human considerations for selecting a site:
• Background data and scientific infrastructure
• Manageable logistics
• Definable, preferably small, anthropogenic influence
• Societal relevance
• Potential to leverage resources for research

These criteria are explained below. An overarching goal of the Source to Sink research program is to increase our understanding of the roles that climate, tectonics, and eustasy play in shaping Earth's surface and stratigraphic record. This goal is best achieved by focusing on research areas where these factors exert strong control on evolution of the Earth's surface. Areas experiencing rapid uplift and vigorous atmospheric forcing yield large amounts of sediment, often during catastrophic events. Unraveling the complex interplay of processes and interpreting their history is easier to achieve when various landforms and sedimentary layers can be clearly associated with distinct events arising from strong forcing.

The MARGINS sedimentology/stratigraphy program offers an unparalleled opportunity to blend the skills and expertise of the terrestrial and marine communities. To foster maximum interaction, a site should bridge as many different physiographic environ-
ments as possible in going from source to sink. Ideally, a research program will build insight into the dispersal system that transfers particles from mountain tops to abyssal plains.

A guiding principle of this program is that the key to the past lies in the present. Through study of active processes comes understanding of landforms and strata at the Earth’s surface. Because this MARGINS program seeks understanding of material transfer from source to sink, sites should, at present, have active transfer among: hill slopes, river valleys, coastal plains, continental shelves, slopes, rises and abyssal plains.

An important metric of understanding source-to-sink transfer in a basin is the accuracy of sediment budgets. Unexplained sources and sinks of sediment confound sediment budgets and thus should be avoided. Closed systems are ones in which all of the major sources and sinks of sediment can be investigated and quantified, and these systems would be best suited for mass-transport studies.

A high-resolution stratigraphic record extending back to glacial stage 5e (125ka), and preferably farther, will provide a history of glacial/interglacial cycles and eustatic sea-level fluctuations. Given the mandate to understand the effects of climate and eustasy on the evolution of the Earth surface, a record of at least this length is vital.

Carbonate components are found mixed with siliciclastic sediments in most marine settings, and in some cases dominate the flux of material to the seabed. The factors that control this mixed siliciclastic/carbonate system need to be understood and quantified. Historically, attention has been drawn to the separation between the two sediment types. This has led to the division between carbonate and siliciclastic specialists, who rarely interact to examine the entire system. This is counterproductive, because carbonate material provides unique geochronologic constraints, chemical signals, sea-level information, and other insights.

The selection of sites that are significantly different from each another will provide the most insight into processes affecting the Earth’s surface and stratigraphic record. With only two sites to study, the group agreed that environments as different as possible should be selected; e.g., steep versus gentle surface gradients, short versus long dispersal systems, wet versus arid environments, rapid versus slow tectonic uplift.

The ability to understand past, rare, sediment-transporting events is helped markedly by historical data. Quantitative information about rainfall, stream flow, sediment discharge, ocean waves, and winds are all desirable. Aerial photographs, digital models, and remotely sensed data also would aid this MARGINS effort. Going hand-in-hand with historical data is a well maintained data infrastructure. Continuing observations of the above variables as well as easy access to the data would benefit the research.

Manageable logistics focus the attention of scientists on research rather than on the details of completing it. Sites should, for example, be accessible by many scientists and be politically stable. The host country should have trained scientists willing to participate in and augment the proposed research.

Many river systems around the world are so affected by human activity that the transfer of material is anthropogenically dominated. To maintain societal relevance, it would be wrong to eliminate sites with an anthropogenic signal. Rather, the impacts should be quantifiable and should not overwhelm the natural processes.

A large part of the Earth’s population lives in river valleys and coastal regions, therefore the proposed research has an enormous potential to strengthen the scientific basis of land-use strategies, as well as those used to protect coastal wetlands and fisheries. Likewise, research into catastrophic events will assist risk assessment and hazard mitigation. The final criterion is the potential for leveraging resources to undertake research. If the work could be conducted in an area hosting other active research programs, both efforts would benefit.

"Allied" study sites - One or two of these will be identified because they provide a unique opportunity to investigate a process relevant to, but not accessible in, the "focus" sites.

Site Selection
Focus sites will be chosen based on the consensus of opinions given by e-mail and at the Town Meeting in light of the criteria identified at Lake Quinault. Only two of the seven candidates will be selected as "focus" sites. It is important to note that the candidate sites not selected for the "focus" study areas cannot then be classified as "allied" sites. On the basis of the above site criteria, the workshop participants identified the seven areas listed below to be evaluated by the community as potential "focus" sites. Participants at the workshop either volunteered or nominated the appropriate researchers to provide succinct site descriptions, which illustrate how the sites meet the criteria accepted at the workshop. The objective is to give the community enough information to evaluate the site in light of the criteria. For the two sites ultimately selected, very detailed descriptions will be presented at workshops next year.

- Brazos-GoM: Mike Blum, John Anderson
- SW Japan: Gary Parker, Mike Underwood
- New Guinea: Bill Dietrich, Steve Kuehl
- New Zealand: Basil Gomez, Craig Fulthorpe
- Nicaragua: Ray Torres, Sam Bentley
- Santa Monica: Tom Dunne, Bill Normark
- Taiwan: Niels Hovius, Neil Lundberg

Allied site for glacial processes:
- SE Alaska: Bernard Hallet, John Jaeger

MARGINS Web Site and AGU Town Meeting
In November a draft of the conceptual plan, site criteria, and descriptions of the 7 potential study locations will be available on the MARGINS web site http://www.soest.hawaii.edu/margins and we will solicit e-mail input from the community. A Town Meeting will be held at AGU on Monday evening, December 13 at 5:30-8:00 pm in Room 120 of the Moscone Center. The documents will be discussed and, based on input at the Town Meeting and from e-mail responses, a consensus will be reached regarding focus areas for coordinated research studies.

Meeting and from e-mail responses, a consensus will be reached regarding focus areas for coordinated research studies.
Kirk McIntosh, $425,668  
Eli Silver, $148,118 (3 years)  

Structure of the Nicaragua/Costa Rica Subduction Zone: A Framework for the Subduction Factory and Seismogenic Zone Initiatives

Around the world there is tremendous variation in seismogenic character of convergent margins and in the geochemical character of the associated volcanic arcs. This may be expected due to the wide range of upper and lower plate composition and thickness and variation of subduction parameters such as slab age and convergence rate. Because arc geochemistry and seismogenic patterns associated with the subduction system of Nicaragua and Costa Rica show along-strike variations comparable to those worldwide, we propose to investigate the nature of this variability along this margin with a single subducting plate and gradually changing subduction parameters. The Costa Rica segment of the margin has been well studied by seismic reflection and refraction techniques, swath bathymetry, and ODP drilling on Leg 170, but in contrast, the Nicaraguan margin is poorly studied. Only one MCS profile is present on the Nicaraguan trench slope and a single block of swath bathymetry has been collected. The sparse data we presently have suggest that structural and stratigraphic differences are a significant reason why these two margins develop such different subduction processes. For example, fault block rotation on the subducting plate may lead to particularly efficient sediment subduction and may also enhance the tsunamigenic potential of the Nicaraguan margin segment. However the extent of this type of basement structure, as well as the importance other factors, is unknown due to lack of data. Thus, we propose to acquire, process, and interpret an extensive MCS survey supplemented with three selected refraction profiles and additional Hydrosweep swath bathymetry. We will use these data to document variations in the subducting Cocos plate structure and stratigraphy and the effects of these variations on the upper (Caribbean) plate. Ultimately these data will help identify how factors, such as Cocos plate fault block rotation, fault throw, and stratigraphy affect structural deformation styles in the upper plate that control sediment accretion, subduction, or erosion, processes which are critical to gradients in arc geochemistry and seismogenic characteristics.

This project will directly support many goals of the Subduction Factory Initiative of the MARGINS program in Central America. In particular, we will document sediment fluxes into the system, we have a good chance to identify accretionary or erosional processes at shallow depths, and we hope to identify factors influencing the efficiency of sediment subduction. Similarly, our investigation of the Cocos Plate, its interaction with the upper plate (especially the plate boundary fault zone), and determination of margin velocity structure will directly benefit the SEIZE Initiative (Seismogenic Zone Experiment). The science plans of both these initiatives picked Costa Rica/Nicaragua as a highest priority area and call for extensive seismic reflection and refraction surveying to provide the critical framework for subsequent interdisciplinary investigations.

This project will involve international collaboration with scientists from Nicaragua and Germany and it will build on ongoing programs in the area. A German research vessel, R/V Sonne, will be in this area in fall 1999 to investigate crustal thickness variations of the Cocos plate along the Costa Rica segment and crustal structure of the Nicaraguan forearc near the coast. One of us (McIntosh) will participate in that project and work with a portion of the refraction data acquired. We emphasize...
that the work we propose here, although complementary, does not in any way duplicate ongoing work, and, with the planned MCS data, provides the key element for further interdisciplinary research.

Kevin Brown, $64,564 (1 year) Benthic Flux Study across Costa Rica Margin

This project will be used to determine how leaky the upper plate of the Costa Rica subduction system is based on the patterns of diffuse fluid expulsion through the forearc. Ultimately these data can be used to make numerically based predictions about the fluid pressure regime on the subduction thrust as well as place important constrains on the overall mass balance of \( \text{H}_2\text{O} \) in the system. This Costa Rica study presents a unique opportunity to undertake a combined deployment of 14 OBS/flux meter combinations and another 8 autonomous benthic flux meters across the subduction system. The flux meters are designed to measure slow to moderate diffuse aqueous flow rates from 0.1 mm/y to ~15m/year. This would be the largest attempt to date to obtain a transect of direct measurements of diffuse surface fluid expulsion patterns across a subduction system and can be accomplished at moderate extra cost given the location of the proposed Dorman et al. OBS study. In many respects, the Costa Rica margin may present an ideal target for this type of flux meter study because the main fluid fluxes may be escaping via moderate to slow diffuse regional flow (i.e. outside of a narrow out-of-sequence-thrust region). There are also a series of well delineated tectono-hydrogeologic provinces that can be contrasted to determine their relative significance in terms of their contribution to the overall advective mass balance and vertical constraints supplied by ODP Leg 170 and 3D seismic reflection data. In addition, the study area includes regions of disseminated gas hydrates and we be will be measuring the diffuse flow that could be feeding their development. The large numbers of flux measurements involved are necessary because lateral changes and variability in fluid expulsion patterns is to be expected. The hydrogeologic processes occurring within the Costa Rica system are highly relevant to both Subduction Factory and SEIZE program objectives.

Tim Dixon $306,483
LeRoy Dorman $410,788
Susan Schwartz $362,679 (3 years)

Imaging the Seismogenic Zone with Geodesy and Seismology: Two Land-Ocean Transsects Across Costa Rica and the Middle America Trench

We propose two geodetic and seismic transects across the Middle America Trench and Costa Rica, immediately above the seismogenic interface between subducting Cocos and overriding Caribbean plates. We will use GPS, leveling, and three-component digitally-recording seismometers on land, and Ocean-Bottom Seismometers (OBS) offshore. Our goal is to map the three-dimensional distribution and nature of the seismogenic zone (the locked or partly locked plateinterface that generates large or great earthquakes), for comparison to candidate processes (e.g., sedimentary diagenesis, metamorphic reactions) that may control the distribution of seismicity and plate coupling. Geodesy outlines the locked or partly locked portion of the plate interface by measurement of strain accumulation, and are particularly sensitive to the percentage of locked slip and the down-dip extent of the seismogenic zone. Seismology outlines the portion of the plate interface that generates microseismicity (not necessarily the same portion outlined by geodetic data), and given the OBS coverage can also outline the up-dip extent. This ability to "image" the seismogenic zone with combined and closely coordinated geodetic and seismological data is enhanced in regions like the Nicoya and Osa Peninsulas because of the close approach of local coastline to the trench axis (60 km for Nicoya, and only 30 km for Osa!). This unique geography allows us to deploy precision instrumentation immediately above and close to essentially all of the seismogenic zone, giving one of the first complete transects above the most critical part of a subduction zone, namely the part that generates large or great earthquakes and tsunamis.

OBS (solid circles) and flowmeter (unfilled diamonds) positions deployed in 1999; a second deployment will be made in 2000
Michael Carr/Mark Feigenson, $117,437 (2 years) The Slab Component in Central America: Isotopic Evidence for both Hydrous and Silicic Fluxes in Nicaragua

The Subduction Factory Initiative of the MARGINS Program strives to understand fluxes through volcanic arc systems. Specific goals include uncovering what regulates the production of magma. Our work will address this goal by clarifying the nature of the slab fluxes in Central America. We recently discovered unusual trace element systematics in lavas from Central America. The data are best explained by mixing between two end-members, thus there are at least two fluxes to identify. The sediment section, subducting beneath Central America, also has two end-members: a lower carbonate ooze and an upper hemipelagic mud. These lithologies have hugely different trace element signatures and, in general, the chemical signatures of the sediments match up with the two end-members seen in the lavas. We identify the origin of the two geochemical end-members as the subducted sediments, but how do sediments become fluxing agents that trigger melting and volcanism? Do they move into the mantle as hydrous fluids or as melts? Our proposed project can answer half of the latter question by employing very precise isotopic measurements. The Sr-Nd isotopic data for Central American lavas define an array apparently involving the same end members seen in the trace element data. The far more precise isotopic data have the potential to severely restrict interpretations once sufficient data are available. The geometry of the isotopic mixing lines for Central America is such that a flux from the upper, hemipelagic sediments can be a melt but can not be a hydrous fluid. To establish this, we plan to expand the data set, which at present is too sparse to allow us to state this as a firm conclusion.

Phil Gans/Andrew Calvart, $159,391 (2 years) Neogene Evolution of the Costa Rican Arc

The Costa Rican segment of the Central American volcanic arc is a superb natural laboratory to investigate processes related to arc magmatism. The chain of active stratovolcanoes in Costa Rica is the latest "snapshot" in a prolonged history of arc volcanism that dates back to at least the early Miocene. One of the main limitations to understanding the subduction factory in Costa Rica is the fact that pre-Holocene arc history is poorly known. We propose to conduct detailed geologic mapping and a comprehensive 40Ar/39Ar geochronological investigation of Miocene to Pleistocene volcanic sections from throughout Costa Rica with the goal of better establishing the space-time-composition-volume patterns of arc volcanism. The sort of questions and problems that such a database will help address include: Where was the active arc at various times in the past? What are the time-volume-composition relationships for Costa Rican volcanism? What is the nature of the plutonic roots to the Costa Rican arc and how do intrusive volumes and compositions compare to coeval volcanic rocks? This data base will shed important new light on how continental volcanic arcs evolve and on the relationships between various subduction parameters (convergence rate, age of slab, sediment flux) and output products (magma volumes and chemistry) in arc environments.

Harold Tobin, $83,473 (2 years) Experimental Investigation of Décollement Zone Mechanics and Consolidation State, North Barbados Ridge and Nankai Accretionary Prisms

In recent years, a model for the physical state of active accretionary prism décollement zones (the up-dip plate bounding fault, including both seismic and aseismic portions) has emerged, describing them as narrow, mechanically very weak faults, with high pore pressure, both brittle and ductile structures, greatly enhanced permeability relative to adjacent sediments, and episodic pulses of updip fluid flow. These observations have led to the suggestion that an essential element of décollement zone mechanics is natural hydraulic dilation of fractures. This model has been based in very large part on successes in seismic reflection imaging of the northern Barbados Ridge décollement zone, and the interpretation that fluid-rich zones are responsible for distinctive reflections. However, recent drilling data from this margin discount the likelihood of fracture dilation, favoring instead inhibited consolidation of patches of the fault zone in the seismic survey area. This finding, if correct, removes an important piece of evidence cited in support of the fault dilation model, and may significantly alter our understanding of fault mechanics in this setting. Several apparent paradoxes and conceptual questions are raised by this model, including these specific questions: Mechanically, how can high-porosity (75 to 80% water by volume) weak zones be maintained within a very high strain shear zone? What limits do such zones place on the integrated effective stress history in an evolved décollement? To address these questions, a suite of experiments will be conducted in a high-pressure sealed ring shear device. The Sandia National Lab Geomechanics Dept device is capable of taking samples through anticipated stress and pore pressure conditions comparable to and much deeper than sampled décollements at Barbados and Nankai. These experiments will explore the hypothesis that high strain and retained high porosity can coexist in these décollements, and document the necessary stress paths to achieve this state, as well as the expected structural fabrics. Artificial analogs and natural samples representative of the décollement lithologies at Barbados and Nankai, will be subjected to high shear strains through a variety of stress paths, pore pressure regimes, and strain rates. Porosity evolution, microstructures formed, and dynamic elastic properties (seismic wave velocity) will be documented.

Larry Ruff, $51,680 (1 year) Interaction between Earthquakes, Stress, Temperature, and Fluid Flow in the Seismogenic Zone

The PI will develop a physical-thermal-fluid model of the seismogenic zone that not only includes constraints from seismology but also from fluid flow that can modify both the stress and thermal state. He will explore a spectrum of models for fluid expulsion from the subducted crusts and its effect on the temperature regime. The objectives of the work are in accord with the overall scientific objectives of the Seismogenic Zone initiative of the MARGINS Program that seeks to understand the temperature structure and the flow regimes in the seismogenic zones.
Derrill Kerrick, Jamie Connolly & Dave Eggler, $308,010 (3 years)
Quantification of Metamorphic Decarbonation and CO₂ Degassing in Subduction Zones: Implications for Fluid Fluxes, Volatile Recycling and the Global Carbon Cycle

Funds are provided for the computation of high-pressure phase equilibria of carbonate-bearing subduction zone lithologies. High pressure experimental studies of selected key equilibria will constrain the computations of phase equilibria and will reduce errors arising from uncertainties in thermochemical data and equations of state. This will enable the PIs to track carbon dioxide expulsion with progressive depth in subducted slabs and thus track the evolution of carbon dioxide in forearcs, subarcs and at depths beyond subarcs. This study will contribute to the MARGINS program objectives by shedding light on how volatiles are balanced across convergent margins and ultimately to the role of subduction in carbon-dioxide recycling and the global carbon cycle.

Charles Nittroer, $70,000 (1 year)
From Source to Sink: MARGINS Science Plan for Sedimentology and Stratigraphy

Funds are provided to hold a community workshop of sedimentary geologists to generate a science plan for the sedimentology, geomorphology and stratigraphy aspects of the MARGINS initiative. The workshop will identify important new directions for the future of sedimentary research and recommend strategies for accomplishing those goals. Cooperative interdisciplinary studies will be a focus of the workshop. A four-day meeting is planned, where 80 scientists will gather to produce the science plan for NSF and the MARGINS community.

Lui-Heung Chan, $177,869 (3 years)
Lithium Isotope Compositions of Volcanic Arc Lavas: a Study of Processes and Fluxes in Subduction Zone

Funds are provided to extend the use of the Lithium proxy to the arc systems. The objectives are to determine the isotopic variation of Lithium in lavas as a function of the nature of subarc mantle, the extent of modification by subduction components, the mass transfer processes and the physical conditions of the subduction environment. In addition, sediment flux carried by the down-going plate will also be estimated to assess lithium recycling at the convergent margins. Samples from the Cascadia, Aleutian and Tonga-Kermadec Arcs will be analyzed.

Brian Taylor, $115,137 (2 years) MARGINS Theoretical and Experimental Institute: Inside the Subduction Factory

Funds are provided to hold a MARGINS theoretical and experimental school where the subduction zone will be the topic of a 4-day short course followed by a 1-day workshop. The short course will support the emerging multi-disciplinary study of the subduction zone and focus on the geochemical and geodynamic processes at intermediate depths (50-150 km), a region where mass transfer plays a fundamental role in the evolution of subduction zones. A steering committee will select the speakers and attract participants. Funds will pay for full or partial travel of about 65 participants, although a total of 100 participants are expected.

Brian Taylor, $117,760 (2 years) MARGINS Theoretical and Experimental Institute: Rheology and Deformation of the Lithosphere at Continental Margins

Funds are provided to hold a MARGINS' Theoretical and Experimental Institute where "Rheology and Deformation of the Lithosphere at Continental Margins" will be the topic of deliberations. Communication between experimentalists and theoreticians is essential to design experiments to address the broader implications raised by macroscopic field observations on the one hand, and small-scale laboratory findings on the other. The institute will foster cross-disciplinary inquiry into rheology and deformation of the lithosphere. It will consist of a 4-day short course followed by two days of discussions during which a science plan will be fleshed out for the Rupturing Continental Lithosphere initiative. The funds will pay for full or partial travel of 50 participants to the workshop, but the total number of attendees are expected to be as much as 95 scientists from various subfields of geology and geophysics.

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**Fall AGU MARGINS Town Meetings**

Moscone Center 5:30 - 8:00 pm

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At convergent margins, seafloor is fed into the subduction zone, mixed with mantle, and transformed into volcanic, fluid and gas products on the over-riding plate. This recycling process that takes place in the “Subduction Factory” is difficult to observe directly, but is clearly illuminated using chemical tracers. By mass balancing the tracers, and measuring the fractions that occur between them, we can begin to understand how the factory works and affects earth evolution. The Mariana-Izu-Bonin margin, one of the focus regions of the MARGINS Subduction Factory Initiative, has a lot to offer tracer recycling studies. The volcanics are well studied; sediment subduction is virtually complete; the upper plate is oceanic and therefore largely transparent to magma assimilation; and there is a wide aperture of output products on the upper plate, from serpentine seamounts in the forearc to zero-age basalts in the back-arc. The missing component to the recycling equation, however, has been the sedimentary and basaltic input on the incoming Pacific plate. The aim of Leg 185 of the Ocean Drilling Program was to core two sites in Mesozoic crust in the western Pacific, and so determine inputs into the western Pacific subduction factory (Fig. 1).

The results of Leg 185 will bear directly on two of the three thematic objectives of the MARGINS Subduction Factory Initiative: 1) forcing functions on factory
output, 2) volatile cycle through the factory, and 3) mass balance. Forcing functions include convergence vectors, thickness of the upper plate, slab temperature, and sediment transport to depth. The Izu-Mariana margin is an excellent area to examine forcing functions because of the large geochemical signal along-strike in the volcanic arc. Leg 185 will test whether the arc signal is a function of variations in sediment input along-strike. In addition to addressing forcing functions, Leg 185 will also provide critical new data for the volatile cycle. A major part of the volatile emissions (H2O and CO2) from arc volcanics derives from the basaltic portion of the downgoing plate, and yet this volatile input is virtually unknown for any convergent margin. Results from Leg 185 will demonstrate how alteration zones and carbonate veins are organized in ancient fast-spreading crust, and so enable the first estimates for H2O and CO2 contents of the upper oceanic crust near a subduction zone with which to compare directly to volcanic and fore-arc volatile outputs.

After a ten-day transit from Hong Kong in April of 1999, Leg 185 re-occupied Hole 801C off the Marianas (Fig. 1). The hole was first drilled during Leg 129, which tagged 50 m of Jurassic basement, at ~170 Ma, the oldest oceanic crust ever drilled. Formed at fast spreading rates, Site 801C is a valuable Mesozoic analog to the modern East Pacific Rise. During Leg 185, the hole was deepened to nearly 500 m into basement, making it the sixth deepest drill site into normal oceanic crust (> 900 mbsf). This site represents the first deep basement penetration near a subduction zone, and will provide an unparalleled opportunity to evaluate the amount of CO2, U and H2O supplied by the altered basaltic crust to the Subduction Factory.

The main objective at the other site, ODP Site 1149, was to penetrate through the sedimentary section and > 50 m into the Early Cretaceous crust entering the Izu-Bonin trench (Fig. 1), and so provide the first samples of the crustal inputs to the Izu-Bonin subduction zone. More than seven previous DSDP attempts in the greater Nadezhda Basin, a 1000 x 1000 km region east of the Japan and the Izu-Bonin islands, had failed to penetrate through the resistant cherts at 50-150 m below seafloor (mbsf). Leg 185 was successful in drilling through a thick section of chert and porcellanite (~ 250 m), as well as > 130 m into volcanic basement, at some of the greatest water depths and total drill string lengths (> 6300 m) attempted by deep sea drilling. Although recovery of the chert section was low (< 15%), logging of the section was successful in providing the first complete profile of the sedimentary section being subducted at the Izu-Bonin trench.

Aside from achieving the basic operational objectives and “bringing home the rocks” for extensive geochemical analysis, Leg 185 made the following discoveries:

**Punctuated Alteration - A Characteristic of Fast-Spreading Crust?**

In contrast to the decrease in oxidative alteration that occurs with depth at other sites in the oceans, the MORB basement at Site 801C is punctuated by discrete zones of alteration between intervals of minimally altered basalt. These discrete zones occur adjacent to ocherous, Fe-Si-rich, low temperature hydrothermal deposits, and near breccias probably related to near-axis faults. Away from these alteration zones, fresh basaltic glass occurs abundantly, demonstrating the spatially heterogeneous nature of seafloor alteration. Hole 801C is the only site ever drilled into fast-spreading crust, and so this organization of alteration zones near hydrothermal deposits and faults may be the hallmark of fast spreading crust. In order to quantify the visual descriptions, ground-truth the logs, and determine the timing of alteration events, a common set of samples of Site 801C basement lithologies has been taken for all geochemical investigations. This communal sampling strategy is a novel move for the drilling program, and will lead to an unprecedented geochemical data set with which to constrain subduction recycling models (including over 40 major and trace elements, as well as Pb, Nd, Sr, Os, Hf, Li, B, Be, Cl, S, Se, C, N, O and H isotopes).

**Contrasting Sediment Input to the Mariana and Izu Subduction Zones**

Having cored for the first time through the entire sedimentary section subducting at the Izu-Bonin margin, Leg 185 enables comparison of the inputs to the Mariana and Izu arcs. In contrast to the East Mariana and Pigafetta Basin sediments subducting at the Mariana trench, the Nadezhda Basin sediments lack a mid-Cretaceous volcanioclastic section, and contain more siliceous and carbonate-rich biogenic material due to its longer passage beneath zones of high biological productivity. Shorebased geochemical studies of communal samples will demonstrate the extent to which these different sedimentary histories can be traced to the volcanic output from the two arc systems. For example, does the sedimentary and basaltic input on the incoming plate provide suitable Pb isotope mixing end-members for the Izu arc volcanics, or are other mantle and upper plate sources required? Does the extensive biogenic section in the lower half of Site 1149, which is highly depleted in alkali elements, contribute to the low alkali content of the Izu arc?

**Mesozoic and Cenozoic Pelagic Sequences**

The equatorial paleolatitude history of Site 1149 during the mid-Cretaceous, combined with a predictable subsidence history, is ideal for testing variations in the Cretaceous CCD. Site 1149 sediments also record a well-developed metalliferous sedimentary profile, which documents clearly the decreasing influence of hydrothermal plume precipitation with distance from the ridge. High sediment accumulation rates (~ 30 m/Ma) and the mineral composition of the youngest sediments suggest that Site 1149 was in the reach of the Asian dust plumes after the early Pleistocene.

**Mesozoic Pacific Basaltic Glass**

Fresh basaltic glass recovered from both Sites 1149 and 801 provide pristine samples of the igneous liquid that forms Mesozoic Pacific crust. These are valuable samples that record mid-ocean ridge processes, mantle composition and mantle temperature at a time preceding the Cretaceous superplume event in the Pacific.
Rapid Polarity Alternations during the Jurassic Magnetic Quiet Zone

Hole 801C Jurassic basement records up to six geomagnetic reversals. Not only are there several reversals, but some sections preserve gradual changes in the magnetic field direction from one polarity interval to the other. Thus igneous basement at 801C was extruded at a time of rapid polarity alternations of the geomagnetic field. These data may provide an explanation for the Jurassic “Quiet” zone in a series of superposed flows with opposite polarity, essentially canceling out one another. The presence of fresh basaltic glass at depth in 801C will also provide suitable material for paleo-intensity studies, to test the hypothesis that the Jurassic Quiet Zone was a time of low geomagnetic field intensity.

The Deep Biosphere

Leg 185 was the first ODP leg to invest a significant effort in carrying out microbiological contaminant tests, equipping a microbiology laboratory, and establishing techniques for core handling of biological samples. Contaminant tests using perfluorocarbon and fluorescent microsphere tracers demonstrated that sediments cored with the APC showed less susceptibility to contamination than RCB coring. In fact, several APC core interiors were entirely free of contaminants, and both APC and RCB core interiors were free of the microsphere tracers. These tests, which demonstrate that biological contamination can be assessed and surmounted, pave the way for establishing ODP as a new platform for microbiological studies. Leg 185 samples are being used to start culturing experiments in various media at both atmospheric and in situ pressure, and to begin shorebased DNA extraction and community characterization. Several glass samples from Site 801C show textural evidence for microbial alteration and invite the intriguing question of whether there is still microbiological activity in 170 Ma volcanic basement.

For more on Leg 185, see:

Steiner, M., and Leg 185 Shipboard Scientific Party, 1999. Finally! Origin(s) of the Jurassic Quiet Zone (JQZ), AGU Fall Meeting.

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MARGINS Rheology & Deformation
Theoretical & Experimental Institute

Snowbird, Utah, 23-28 January 2000

**Day 1**  
R. Buck (Macroscopic models of continental deformation: Theoretical aspects)  
J. Jackson (Relations between velocity fields and faulting on the continents)  
G. Axen (Continental example: Basin & Range)  
L. Ruff (Limits of the seismogenic zone)

**Day 2**  
N. Kusznir (Strain partitioning across passive continental margins as functions of space and time)  
D. Sawyer (FEM models for lithospheric extensional deformation: Application to the N. Atlantic margins)  
R. Hyndman (Thermal and rheological modeling of the subduction interface)  
S. Willett (FEM modeling of compressional systems: boundary flux and rheological effects on convergent orogens)

**Day 3**  
F. Chester (Internal structure and slip mechanisms of continental faults)  
C. Scholz (Field and laboratory observations and the low-strength fault paradox)  
C. Marone (Relationship between laboratory observations of faulting and seismic observations)  
D. Olgaard (Relationship between the mechanics of overthrusting and metamorphism)

**Day 4**  
J. Tullis (Rheology of the crust)  
D. Kohlstedt (Role of water and melts on upper mantle viscosity and strength)  
B. Evans (Role of fluid pressure in modifying crustal and upper mantle rheology during deformation)

**Days 5&6**  
Rupturing Continental Lithosphere Workshop
We successfully installed two seafloor borehole sensor packages immediately above the plate boundary of the Japan Trench seismogenic zone. Each sensor string measures strain, tilt, and seismic signals. These were installed to become the first subduction seismogenic zone observatories.

The main scientific objective of ODP Leg 186 (June 21- Aug 15, 1999) was to establish seafloor borehole observatories to monitor strain and seismic activity continuously and ultimately to understand how plate motion is accommodated across a subduction zone (MARGINS NL #3). We know that normal earthquake slips within the seismogenic zone can explain only 1/4-1/3 of the plate motion. Figure 1 shows where the sites are located. Site 1150 is within a seismically active zone, whereas Site 1151 is within an aseismic zone. We still do not understand why such difference exists despite the similarity of the tectonic setting and seismic velocity structure, although a recent OBS study suggests that the acoustic impedance contrast may be different between the 2 zones (Fujie, 1999). We report here what was accomplished during ODP Leg 186 for the observatories and during the subsequent ROV (remotely operated vehicle) operation.

Site 1150
The array of emplaced instruments from bottom to top consists of 3-component strainmeter (< $10^{-11}$ strain resolution) newly developed for this project, 3-component broadband PMD sensor, 2-component tiltmeter (< 10 nanoradians resolution), and 3-component CMG-1 sensor. These sensor specifications are not compromised and state-of-the-art. A 3-m long “stinger” pipe with centralizers was attached to the strainmeter bottom. The remaining sensors were attached to a specially designed pipe (“X-mas tree”) which was connected to the top of the strainmeter. The strainmeter bottom was set at 1120 m below seafloor. This was decided based on core descriptions and logging data, which indicated relatively constant and higher density and P-wave velocity. The sensor string is hung from the re-entry cone all the way down by 4.5” casing pipes, so that the length is precise and the cementing path is secured. Figure 2 shows the assembly schematically. The operation required 4 cables to be attached to the casing pipes as we lowered down the instruments and to be terminated at the seafloor and connected to MEG, which combines all the signals from 4 sensors and digitizes (24-bit) and streams to the data recorder. We designed MEG to be replaceable by ROV, so that the connectors are all underwater mateable.

After cementing the borehole package from the drill ship, the seafloor package was sent down using the logging cable guided by the drill pipe. The seafloor package (PAT) is a platform (about 3.5 m in diameter and 2.6 m in height) that houses Sea-Water batteries (18 W capability), and a data recorder (72 GB). After viewing the successful emplacement of PAT, the drill pipe was disconnected just above PAT and recovered. Because this operation could not be carried out simultaneously with the instrument lowering operation, PAT and MEG were not electrically connected.

Site 1151
The strainmeter installed at this site is a volumetric strainmeter, as we assumed the deformation mode might be simpler than at seismically active Site 1150. This site is...
located about 50 km south of Site 1150. The installation depth of the strainmeter was 1097 mbsf. The target depth is shallower than at Site 1150, but is in a more competent rock environment.

**Contingencies**
This type of operation is unthinkable without contingencies at any moment of many steps to follow. At Site 1150, we lost one hole because the casing pipe while casing the hole broke and some sections fell into the hole. We encountered constricting hole condition and had great difficulty inserting the string down to the aimed depth. When we eventually completed Site 1150 operation, we were so far behind the schedule that the second site operation seemed impossible. However, the weather stayed calm and learning from the very first experience plus a better hole condition made it possible to complete 2 holes as planned. We hardly had to sacrifice other scientific objectives.

**ROV Operation**
The mission of NT99-12 cruise of R/V Natsushima of JAMSTEC (Sep. 2-10) was to connect the electrical cables between PAT and MEG, so that the system would start running. ROV DOLPHIN-3K capable of diving to 3000-m water depths was used since the sites are 2180 and 2700 m deep. In essence, the ROV operation was quite successful, however the operation required more than just connecting cables because of some electrical problems.

**Site 1150**
DOLPHIN first dived to check the surroundings of the seafloor assemblies. The platform diameter was barely large enough for DOLPHIN to touch the outer rim without bumping onto the center casing hanger. On second dive, DOLPHIN pulled out a dummy receptacle from the top of MEG, pulled out the link cable from its parking position on PAT and inserted onto the plug. This took about 40 minutes. The system was designed so as not to start until 20 minutes after connection. To check if the startup is successful, an instrument (BOB) that sits on the data recorder (SAM) can communicate with sensors through MEG via infra-red communication link. At the top of BOB there are many LEDs to indicate the system condition for the ROV video to see. BOB also has RS232 connection to communicate and get data. We could confirm the startup of the system, but soon afterwards, the windows of the BOB cracked and ceased operation due to water leakage. Because of this window problem and a concern for total power consumption, which may need to be improved, we recovered SAM. SAM is designed to be liftable by ROV. We recovered about 8 hours of data, which indicated there was some malfunctioning of MEG so that only seismic signals looked excellent. We left the site without re-inserting SAM. We will upgrade SAM and MEG and replace them on our next mission.

**Site 1151**
The relative position between MEG and PAT could not be pre-determined. At this site, ROV operation required the cable to go around the center longer distance than at Site 1151. Fortunately, this posed little problem and also, the BOB windows did not crack at this site. We left the site after confirming the system start with SAM in operation. We expect that the hard disk would fill up after about 1 year of continuous recording.

**Summary**
The installation by the drill ship and the seafloor operation of ROV went quite successfully at both sites. At this moment, we only have a very small amount of data retrieved. But the borehole seismic data look promising. On our next visit, we will recover at least several month-long data from Site 1151. We hope to re-start Site 1150 system as well after some modifications. After confirming the health of the sensor packages, we will try to connect them directly from shore by fiber-optic cables for real-time monitoring. We are now entering the era of seafloor observatories in operation where active processes are taking place.

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**Fig 2.** Schematic of the seafloor and borehole installation for Hole 1150D. The reentry cone is installed and the casing cemented in. The instrument string is coupled to 41/2-in casing pipe and to the hanger/riser. This is inserted into the hole using the drill string. Cement is pumped through the instrument string and up into the cased part of the hole. The battery frame is then lowered onto the reentry cone, and the hanger/riser is then decoupled from the drill string. mbrf = meters below rig floor, TD = total depth.
Offshore and coastal oil and gas seeps have been known for decades in hydrocarbon provinces and have been important in guiding exploration. Over the last 15 years submersibles and remotely operated vehicles discovered numerous fluid seep sites along the continental margins around the world resulting in an explosion of research in this area (Fig. 1). Fluid seeps range from the oil and gas dominated systems, as mentioned above, to more water dominated systems with dissolved hydrocarbons, carbon dioxide, nitrogen, and hydrogen sulfide, to brine dominated systems commonly derived from subsurface salt (Fig. 2). The discovery that chemicals in seep fluids support organisms (Fig. 3) that live off the chemical effluents electrified groups studying life in extreme environments, including the early earth and other planets. Fluid seeps also form precipitates (Figs. 2, 4, 5) at the surface and in the subsurface, affect the surface geomorphology of continental margins, and influence water and air quality.

This growing body of information indicates that seep phenomena are not restricted to hydrocarbon provinces but are a fundamental feature of the geohydrologic system of continental margins (Fig. 1). Fluid seeps, both terrestrial and submarine, record the flux of fluids from the earth’s lithosphere to the atmosphere and hydrosphere. The overall impact of seepage on cycling of chemicals between the earth, oceans, and atmosphere is unknown, but could significantly contribute to the supply of greenhouse gases. The importance of seeps fostered a symposium, fieldtrip, and workshop on "Fluid Seeps on Active Continental Margins" at the AAPG Pacific Section Meeting. Supported by the Energy Institute at the University of California, the meeting conceptualized as a west coast, active continental margin meeting. However it drew earth scientists from across the US and from Germany, France, Russia, New Zealand, Japan, Norway, and Turkey, and served as a forum for the development of a plan for the global analysis of fluid seeps.

MARGINS email list effectively publicized the meeting and assisted in attracting international participation. This meeting explicitly attempted to foster cooperation between the academic scientists studying seeps and industrial communities studying hydrocarbon migration.

The meeting consisted of a field trip (Garrison et al., 1999), a symposium (AAPG, 1999), and workshop (http://www.UCEI.berkeley.edu/UCEI/). The field trip examined modern examples of seep precipitates and fauna as recovered by The Monterey Bay Aquarium Research Institute from Monterey Bay (Figs. 4, 6). These materials were compared to Miocene examples of precipitates from the stratigraphic record near Santa Cruz and linked to probable Miocene bituminous intrusions in the same formation (Fig. 5).

The symposium updated participants on the ongoing global studies of seeps; see (AAPG, 1999) for abstracts of the papers presented. A number of groups showed geophysical imaging, geochemical sensing (sniffing) data, and direct observations indicating evermore evidence for the
expanded distribution of modern seeps worldwide (Fig. 1). Both talks and posters related seepage and associated gas hydrates to geomorphic features of continental margins, including pockmarks, brine pools and landslides. New results presented by a German-Russian consortium studying the Sea of Okhotsk were especially revealing. Reviews of results from the North Sea and Gulf of Mexico provided the view of seepage phenomena in areas being actively explored for hydrocarbons. Several presentations showed evidence for large accumulations of precipitates at the surface, including carbonates, sulfates, and gas hydrates. Several papers showed that seeps bleed large quantities of methane into the oceanic water column, altering water chemistry. Monitoring studies by a UC Santa Barbara group showed that lowered reservoir pressure in production wells reduces rates of gas seepage, and reduces the localized air pollution. Monitoring by Scripps scientists revealed complicated patterns of fluid transport from sediment to the water column and visa versa. However, the question of how much seep gas reaches the atmosphere globally remains a point of contention because of limited flux measurements and the belief that much gas may dissolve in the water column. US Geological Survey scientists presented geochemical results that traced seep hydrocarbon migration paths and demonstrated that some beach tar balls come from natural sources in areas not known for surface seepage of hydrocarbons. Researchers showed that biological communities at seeps are sensitive recorders of the chemistry of fluid flow or of seep derived chemicals in the water column. Echoing the theme of the field trip, several talks emphasized that seep-related biological communities and precipitates are extensive in the stratigraphic record and provide unparalleled detail on the geometry, structural control and evolution of seep systems.

The field trip and symposium provided a context from which a workshop group conceptualized the key areas for concentration of future research. The workshop report is at http://www.UCEI.berkeley.edu/UCEI. Determining the flux of fluids from the earth into the oceans and atmosphere emerged as one of the most important research goals of this workshop. This endeavor requires extensive surveying of continental margins, establishing observatories, and calibration of remotely sensed images in terms of geomorphology, biology, fluid chemistry, and fluid flow rate. Once the distribution of, and flux from, seeps is known earth scientists will have to ascertain how the fluids interact with and alter the rocks below and affect the overlying hydrosphere and atmosphere. Evaluating fluxes and understanding fluid interactions will allow estimation of the influence of fluid seeps on biological resources and on the chemistry of the ocean and atmosphere, as well as the role of seeps as geological hazards. In addition to the major question of their flux, seeps offer exciting opportunities for fundamental research on microbiology and biological control of mineral formation. To understand the dynamics of seeps earth scientists need to study their subsurface plumbing, measure the pressure and density variations that may drive them, and model the fluid flow. Careful studies of seeps in ancient rocks are necessary to evaluate their influence on the geologic and paleontologic record.

Achieving effective cooperation between academic and industry groups is a difficult but potentially rewarding objective. For example, fluid seeps of all kinds directly reflect fluid migration and offer clues to the understanding of the principles of hydrocarbon migration. Industry studies of microseepage of light hydrocarbons demonstrate that associated precipitation and mineral alteration can signal significant accumulations of hydrocarbons at depth (e.g., Saunders et al., 1999). This type of industry perspective has to be brought to the ongoing academic studies of fluid seeps at continental margins. Conversely, results from the academic studies need to be carefully considered by industry scientists both involved in exploration and hazard surveys. Exploration and production activities produce a wealth of surface and shallow sub-surface data that could profitably analyzed by the academic community (e.g., Schumacher and Abrams, 1996). This analysis in turn might provide valuable information to further industry goals. Academic researchers
hope that "win-win" cooperative programs can be assembled in which academic groups obtain access to the extensive industry survey data and in turn provide results that are both valuable and timely.

References

Fig 5. Bedding plane exposure of carbonate seep structures in upper Miocene outer shelf deposits near Santa Cruz CA (Fig 6). Note similarity of cylindrical structures to examples from Monterey Bay (Fig. 4). Width of view about 8 m. Photo courtesy of Bob Garrison.

Fig 6. Map of Monterey Bay region showing the locations of major fault zones and fluid seep localities. Note localities of ancient seepage features (Fig 5) near Santa Cruz. Green lines are active faults, dashed where inferred. Black lines are inactive faults. S.G. F.Z. and M.B. F.Z. indicate San Gregorio and Monterey Bay fault zones, respectively. Image created my Norman Maher, Monterey Bay Aquarium Research Institute. © Monterey Bay Aquarium Research Institute, 1999.

MARGINS Steering Committee

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Committee members serve three years terms, on average.

Nominate yourself or your colleagues (with their permission) by sending a two-page curriculum vitae to the MARGINS Office.

Appointments are made by the Chairman, on the advice of the steering committee.
Meetings

AGU Fall Meeting 1999
Moscone Convention Center, San Francisco, California, December 13-17, 1999
- see Town Meetings announcement on p. 6 -

MARGINS Theoretical & Experimental Institute:
Rheology & Deformation of Lithosphere at Continental Margins
Snowbird, Utah, 23-28 January 2000 (see p. 9)

The Nature and Tectonic Significance of Fault Zone Weakening

Penrose Conference on Volcanic Rifled Margins

Geoscience 2000 Program
Manchester, England, April 17-20, 2000
- Hazards on Continental Margins
- Structural Architecture of Rifed Continental Margins
- Subduction Zone Diet

9th Deep Seismic Profiling of the Continents and their Margins
Ulvik, Norway, June 18-23, 2000

MARGINS Theoretical & Experimental Institute:
Inside the Subduction Factory
Eugene, Oregon, USA, August 20-25, 2000

For more information on these announcements visit our web site:
http://www.soest.hawaii.edu/margins/Meetings.html