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MARGINS

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Why MARGINS?

MARGINS Steering Committee

Margins are where the action is. Continental margins are the Earth's principle loci for producing hydrocarbon and metal resources, for earthquake, landslide, volcanic and climatic hazards, and for the greatest population density. Despite the societal and economic importance of margins, many of the mechanical, fluid, chemical and biological processes that shape them are poorly understood. Progress is hindered by the sheer scope of the problems and by the spatial-temporal scale and complexities of the processes. To overcome these obstacles, the MARGINS community has identified the outstanding scientific problems in continental margins research and the MARGINS Program (a research initiative supported by the US National Science Foundation) is promoting research strategies that redirect traditional approaches to margin studies.

The MARGINS Program seeks to understand the complex interplay of processes that govern continental margin evolution. The objective is to develop a self-consistent understanding of the processes that are fundamental to margin formation and evolution. The MARGINS approach involves concentration on several study areas targeted for intense, multi-disciplinary programs of research in which an ongoing dialogue among field experiment, numerical simulation and laboratory analysis researchers is axiomatic. The plan is to investigate active systems as a whole, viewing a margin not so much as a "geological" entity of divergent, translational or convergent type, but more in terms of a complex physical, chemical and biological system, subject to a variety of influences. The processes that fundamentally govern the evolution of margins include lithospheric deformation, magmatism and mass fluxes, sedimentation, and fluid flow. The goal of the MARGINS Program is to provide a focus for the coordinated, interdisciplinary investigation of these processes.

On the following pages we describe five fundamental Scientific Problems to be studied (p.2), outline the common Research Strategies (p.3), and present four focused Research Initiatives (p. 4-6). Broad community input at three thematic workshops in 1991-1993 attended by over 120 researchers defined the scientific problems and research strategies. With this input, the MARGINS Steering Committee produced an Initial Science Plan 1996 that presented notional experiments for the scientific objectives. They deliberately eschew description of "place" but outline the scope and nature of process-oriented experiments that could be applied at any suitable location. Even so, hard choices had to be made to frame an initial science plan of achievable scope. Three parallel planning efforts further influenced and refined the MARGINS implementation plan that we presented to NSF in 1997: the 1994 JOI-USSAC workshop on Recycling Processes and Material Fluxes at Subduction Zones, the 1995 International Lithosphere Program workshop on Dynamics of Lithosphere Convergence, and the 1996 NSF Future of Marine Geophysics (FUMAGES) meeting.

Interesting and productive science is now being done on continental margins without benefit of the MARGINS program so, "Why MARGINS?" and "If MARGINS, then why focus on only a few areas?" MARGINS came into existence because of a community perception that continental margin science can benefit from increased communication and cooperation of scientists making different types of observations, doing different types of experiments, and explaining observations with different models and simulations. MARGINS proposes to foster much larger, more interdisciplinary experiments, albeit in relatively few areas due to resource limitations. Our science is currently advanced by small groups of investigators making observations at sites best suited for their particular type of observation. This approach diffuses effort and the opportunity to compare diverse data types in a single locale.

MARGINS does not seek to eliminate or replace single investigator proposals that fall outside MARGINS sites. MARGINS instead wants to see a mix of smaller globally distributed experiments and a few larger, carefully chosen, multidisciplinary experiments. MARGINS is committed to involving a broad cross-section of investigators in any focused study area and to rapidly distributing the resulting data. This will provide a vehicle for individual researchers to undertake laboratory and theoretical studies, or piggy-back field experiments, that are reinforced by a greater range of samples and observations than would otherwise be possible.

In This Issue

Scientific Problems

from the Initial Science Plan, 1996

Low-strength Paradox of Lithospheric Deformation

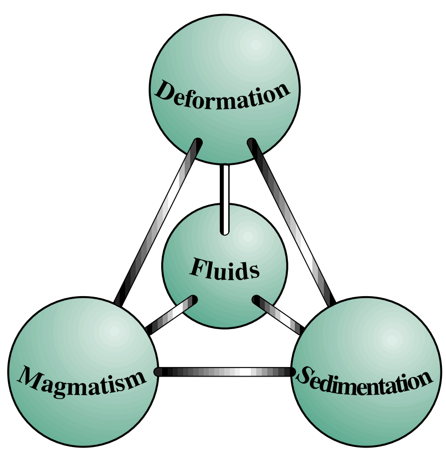
Very large fault structures (subduction thrusts, major transforms and perhaps normal detachments) accommodate a major component of strain at continental margins and produce nearly all the most destructive earthquakes. However, these structures move at resolved shear stresses far smaller than those expected to cause failure and we currently lack a viable theory to account for them. The apparent low-strength property of large faults may be corollary to an even more fundamental issue. When lithospheric strength (the integrated "yield stress envelope") and tectonic forces are compared, we find that the forces available are insufficient to rupture the lithosphere. Although mechanisms may exist that allow a strong lithosphere to be deformed by weak forces through concentration of stresses into narrow regions, those mechanisms are not yet understood. Similarly, the mechanical factors that control the rupture size and frequency of earthquakes are not understood.

Strain Partitioning During Deformation

Mounting evidence suggests that strain measured at the surface by geological techniques may be significantly different from that inferred to have taken place in the lower crust and upper mantle from geophysical observations. One explanation is that the rheology of the lower crust is viscous and weak relative to mechanically strong layers above and beneath. This "jelly-sandwich" model of lithospheric rheology allows upper and lower crust to behave essentially independently of one another, and provides appealing explanations for some problems.The jelly-sandwich rheology, however, remains little more than plausible conjecture and even a basic description of how the lower crust and upper mantle behave during deformation remains incomplete.

Magma Genesis and Crustal Recycling

Models of mantle flow, melt generation, and melt migration for margin settings have lagged behind those for mid-ocean ridges due to the more complex boundary conditions and uncertainties about the relative roles of subducted and upper plate material. Tracing and balancing mass, volatiles, and energy across a convergent margin holds promise to address the poorly understood mechanisms of thrusting and seismicity, the cycling of crustal material through the subduction zone, and the magmatic fluxes that ultimately lead to continental crust formation. Although subduction magmatism has long been thought of as the primary mode of continental growth, it is becoming clear that very large volumes of magma are brought to the Earth's surface in so-called Large Igneous Provinces in intra-plate and divergent margin settings. We lack a theory that can adequately explain the spatial and temporal aspects of melt generation and migration needed to account for even our most basic observations.



Stratigraphic Preservation of Geologic Events

Continental margins are the Earth's principal loci of sedimentary accumulations and contain one of the best preserved records of global sea-level variations, climatic fluctuations, lithospheric deformation, ocean circulation, geochemical cycles, organic productivity and sediment supply. Margins, therefore, record the variations in the solid earth-ocean-atmosphere system essential to evaluating models for today's global changes. Margin sediment prisms are also the principal low- to moderate-temperature chemical reactors that produce massive mineralogical changes in basin sediments, resulting in most of the world's oil and gas reserves and mineral deposits. The complex and dynamic interplay of processes responsible for the erosion, transport, accumulation and preservation of margin sediments is poorly understood.

Fluid Fluxes

Large-scale fluid circulation is the most important chemical transport mechanism within margins. Geochemical processes such as diagenesis and metamorphism, and deformation processes such as stick-slip faulting versus creep, are strongly controlled by the rate of fluid flow, fluid composition and the rate of rock-fluid interactions. Flow driving mechanisms include compaction, compression, and thermal and gravitational circulation. Water/rock/organic matter interaction changes fluid composition and, by altering rock porosity and permeability, creates a feedback mechanism affecting fluid pathways and flow rates. These fluid flow and diagenetic processes represent important contributions to the global geochemical inventory. Many of these mechanisms, their rates, and the fluid pathways are still largely unknown.

Research Strategies

from the Initial Science Plan, 1996

Achieving MARGINS research objectives will generally require new experimental approaches, including:

Developing Multidisciplinary Case Studies

One goal of the MARGINS Program is to coordinate a community consensus on a small number of in-depth, multidisciplinary case studies carefully designed to address one or more scientific objectives. We expect these experiments to be three-dimensional in nature, with the size of the study region, the duration of the experiment, and the suite of instrumentation employed to be determined by the processes to be studied. The study areas may be on land, under sea, or crossing the boundary. These case studies require commitments from investigators and funding agencies for extended and diverse experimentation. Each case study will involve field experiments well-integrated with appropriate laboratory studies and theoretical modeling exercises, to relate new observations to relevant physical-chemical-biological processes.

Focusing on Active Systems

One corollary of the process-based, systems approach is that it is most useful to study active systems, as opposed to their fossil counterparts. Once a system is no longer active, it becomes more difficult to completely characterize the boundary conditions and the *in situ* states of the materials in the system. Furthermore, one or more of its characteristics have usually changed, and paleoconditions may be difficult to infer from the rock record. Investigations of inactive systems will be undertaken as a route to understanding processes in currently inaccessible parts of active systems; for example, the deep roots of a fault zone or volcanic complex.

Studying Whole Systems

An important aspect will be to adopt a whole system approach, rather than targeting a particular physical or chemical component in isolation. In designing the in-depth case studies, it will be important to define *a priori* the dimensions, boundary conditions, principal rock and fluid components, physical and chemical states of the system. Field, lab and modeling studies should be interpreted jointly by teams of geologists, geophysicists, and geochemists to characterize the coupled dynamic components as an integrated system.

Establishing the Scaling Relations

It is extremely difficult for any study, whether it be field-, laboratory-, or computer-based, to cover simultaneously more than 3 orders of magnitude in length or time scales. However, finding solutions to some of the major scientific questions posed above requires understanding the operation of processes over many orders of magnitude. Therefore the MARGINS Program will include nested experiments that cross both length and time scales.

Including Comparative Global Studies

While the emphasis in MARGINS will be on a few in-depth case studies, more global and satellite studies will be necessary for the purpose of making informed choices on the sites for some case studies. Furthermore, the additional sites will permit testing the generality of quantitative and conceptual models derived from the case studies in regions where some of the system parameters are different.

Establishing Event Response Strategies

Having made a commitment to studying active systems, it will be necessary to develop a strategy of event response, since even "active" systems may be only intermittently active.

"To understand the complex interplay of processes that govern the evolution of continental margins."

Check out our website:

www.soest.hawaii.edu/margins

Science Initiatives

MARGINS Steering Committee

The MARGINS Steering Committee presented an implementation plan to NSF in January and October 1997 that focuses on four initiatives. Further refinement of this plan is anticipated as the science evolves.

Rupturing Continental Lithosphere

The mechanisms that allow continental lithosphere to be deformed by weak tectonic forces are not understood, nor is the manner in which strain is partitioned and magma distributed. These processes control the fundamental margin architecture and hence the location and magnitude of resources and geologic hazards. One way to solve these problems is to focus a comprehensive investigation on faulting, strain partitioning and magma emplacement at sites of active continental rifting where there is a lateral transition to initial seafloor spreading (Fig. 1). The along strike variation will provide a spatial proxy for temporal variability. The effects of, and consequences for, hydrous fluids and sediments will be included in these integrated observational, laboratory and modeling experiments. The objectives are to:

1. Determine the local and regional states of stress, the distribution and rate of strain, the pressures and temperatures, and the physical and chemical properties of rocks and fluids associated with a well-imaged and seismically active low-angle normal detachment (the extreme case of the weak fault paradox). Measurements of these *in situ* parameters made by drilling, instrumenting and long-term monitoring will be used to determine how such faults move at resolved shear stresses far smaller than those expected based on laboratory observations and Coulomb rheologies.

2. Determine the spatial and temporal distribution of strain by (i) mapping the geometry and offset of faults, (ii) inverting and modeling the stratigraphic and structural record to resolve the history of strain variation and its control on topography/erosion/deposition, (iii) using seismic, gravity/geoid and geothermal methods to obtain an integrated sum of the deformation and a measure of the ductile thinning of the lower crust, and (iv) evaluating the heterogeneity of the continental lithosphere prior to rifting.

3. Determine the pattern of mantle flow, the extent of melt generation, and the style of melt migration and emplacement during continental rifting and the early stages of seafloor spreading by imaging with seismic and electromagnetic methods an active rift-spreading transition, by measuring the heat flow distribution, and by analyzing the chemistry of magmas emplaced in these regions.

Rupturing Continental Lithosphere

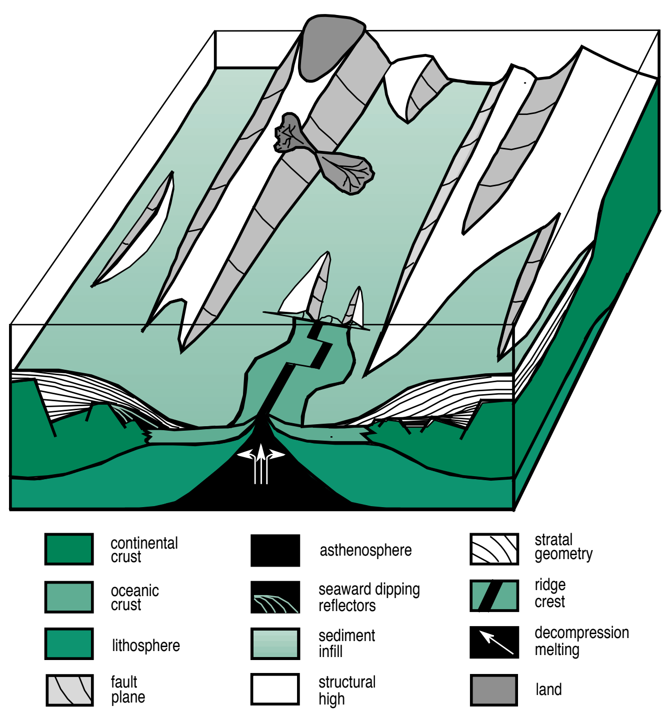


Fig. 1. 3-D representation of the transition from active continental rifting to initial seafloor spreading. MARGINS strategies to understand the processes that rupture continental lithosphere include (i) image, drill, instrument and monitor an active low-angle normal fault, (ii) 4-D, 4-component seismic studies of fluid migration and strain variation, (iii) invert structures and stratigraphy for strain history, (iv) invert geophysics for total deformation, (v) 3-D seismic, electromagnetic and heat flow studies of mantle flow, melt generation and migration in the rifting-spreading transition, (vi) geodetic and reef studies of horizontal and vertical kinematics, (vii) studies of magma chemistry and core complex P-T history, (viii) laboratory studies of material rheologies, and (ix) computer models of dynamic processes.

Seismogenic Zone Experiment

Subduction zone megathrusts produce the largest and potentially the most destructive earthquakes and tsunamis on our planet by shear along converging plate boundaries. Despite the societal and economic importance of great earthquakes, little is known about the seismogenic zone that produces them. A shallowly dipping subduction zone thrust provides a large fault surface, partly seismic and partly aseismic, that is accessible to study by a combination of selective drilling and extensive ongoing monitoring using passive and active seismology and geodesy. It lies within a forearc where sediments undergo compaction, lithification, and dehydration reactions as they underthrust at a low angle. Therefore, the processes and products that control the partitioning of strain, the flow of water and other volatiles, the formation and behavior of faults, and the onset of seismic slip are all relatively accessible (often at depths less than 8-10 km) to geophysical imaging and direct sampling/monitoring. This experiment represents an opportunity to address primary MARGINS objectives related to the mechanics of seismic and aseismic faulting in a new, comprehensive, and aggressive manner.

The objectives of the Seismogenic Zone Experiment (SEIZE, Fig. 2) are: 1) to measure stress and strain across a seismogenic subduction margin, 2) to determine the nature and fluxes of the fluids and solids throughout the forearc, 3) to establish the relationships between earthquakes and the geometry and mechanical state of faults, and 4) to determine the inter-relations between the above and thermal structure, lithification and intrinsic rock strength. In concert with the data acquisition, SEIZE investigators will conduct laboratory experiments and formulate testable quantitative models of how the subduction cycle works, including the complex interactions among the various chemical and mechanical processes. Testing these models through deep riser drilling into the seismogenic zone is a prime goal of SEIZE. This experiment is also the first priority defined by the July 1997 international Conference on Cooperative Ocean Riser Drilling (CONCORD). The investigators will need to observe active tectonic, seismic, and geochemical processes that occur from milliseconds to decades, and document their accumulated geologic record. These characterizations will help define the conditions and materials that control earthquake cycles and improve evaluation of natural hazards.

Seismogenic Zone Experiment (SEIZE)

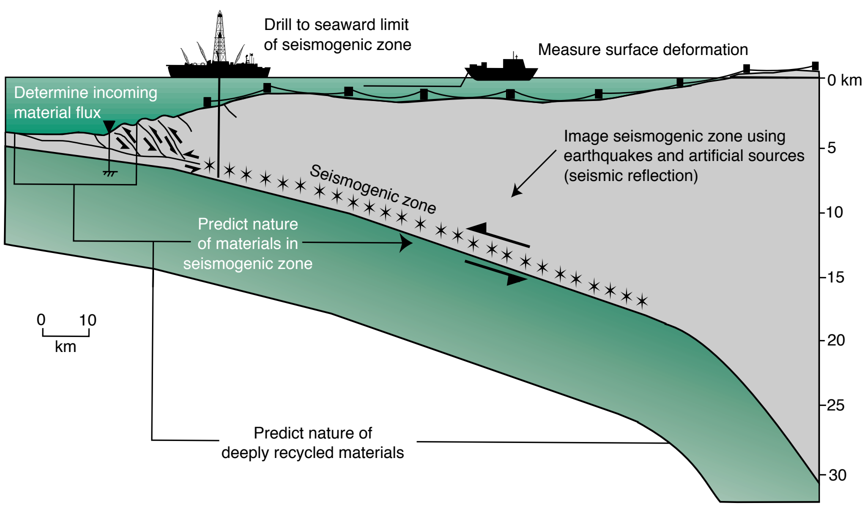


Fig. 2. Cross-section of a convergent margin forearc showing elements of the Seismogenic Zone Experiment. This experiment seeks to define the conditions and materials that control earthquake cycles and processes on subduction zone megathrusts. In addition to the observational strategies depicted in the figure, SEIZE investigators will conduct laboratory experiments and formulate testable quantitative models of how the subduction cycle works, including the complex interactions among the various chemical and mechanical processes. Testing these models through deep riser drilling into, and monitoring of, the seismogenic zone is a prime goal of SEIZE.

Subduction Factory

At convergent margins (Fig. 3), raw materials (sediments, oceanic crust and upper mantle) are fed into the "subduction factory" where many processes (including dewatering, metamorphism, melting) under changing physical and chemical conditions shape the final products (magma, volatiles, ore deposits, new continental crust, recycled materials) with some environmental consequences (hazardous seismicity, explosive volcanism, noxious and greenhouse gases). In practice, it has been difficult to investigate processes and estimate fluxes through the "factory" owing to poor constraints on the volumes of magmas, fluids, and volatiles produced. The approach here is to implement an interdisciplinary study of this problem at a margin having characteristics that optimize study of volatile cycling and crustal growth, and where geological and geophysical measurements will constrain ongoing processes in real time.

Some major questions to be answered include:

1. What fraction of subducted volatiles (H_2O, CO_2) are returned to the oceans and atmosphere, stored in crustal rocks, and subducted to the deep mantle? Does subduction of carbonate lead to enhanced volcanic CO_2 fluxes to the atmosphere?
2. What is the rate and mechanism of continental growth at convergent margins? How do forcing functions such as convergence rate, volatile input and upper plate structure control magma production rates and composition?
3. How much continental material is recycled to the deep mantle? After processing through the subduction factory, are residual slab compositions suitable sources for mantle plumes?

Subduction Factory

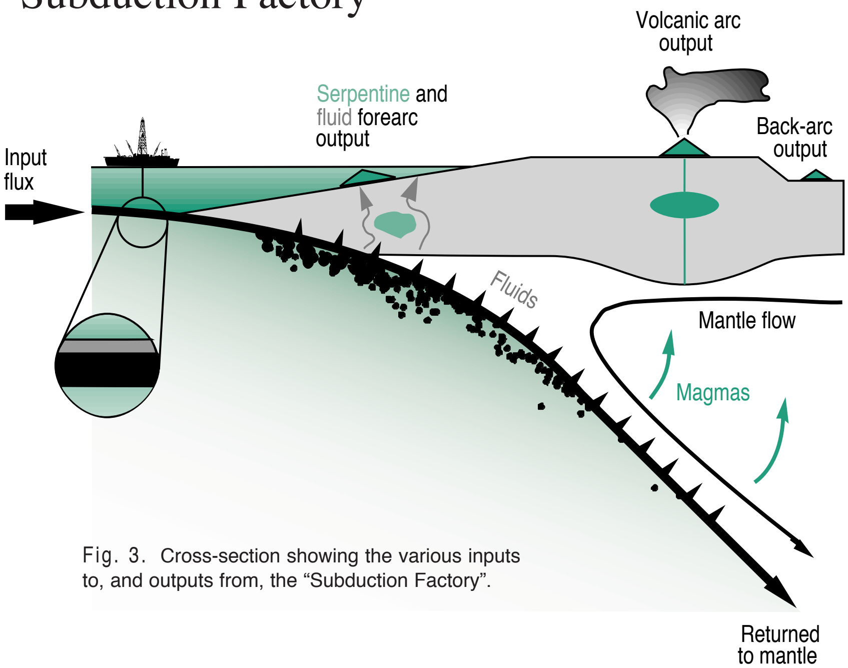


Fig. 3. Cross-section showing the various inputs to, and outputs from, the "Subduction Factory".

Sediment Dynamics and Strata Formation

Understanding the processes that form and modify continental margin stratification at all scales, and the events that trigger those processes, is key to unlocking the encrypted record of earth-ocean-atmosphere system history produced by the convolution of lithospheric deformation, sea-level variations, climate fluctuations, and fluid fluxing. This initiative seeks to identify a small number of natural laboratories where large-scale, interdisciplinary experiments, involving field, laboratory and theoretical components, can be designed and implemented (Fig. 4). These experiments will achieve the following:

1. Determine the timing, spatial distribution, and causes of stratal discontinuities in the context of depositional and erosional processes, which will allow us to evaluate the interrelations among tectonic subsidence/uplift, landscape erosion, sediment supply/compaction, physiography, climate, oceanography, and eustasy in the formation of stratigraphy.
2. Clarify the scaling relationships among physical processes operative on various spatial and temporal scales, their control on the formation of sedimentary signatures (e.g., "event" strata), and how such strata are preserved in the longer-term stratigraphic record.
3. Investigate the fluid flux through the integrated stratigraphic-structural-thermal-chemical margin system, in order to understand how fluids act as the primary coupling agent of the physical and chemical processes controlling sediment transport, deposition, burial, and diagenesis.

Implementation

MARGINS has initiated a series of workshops at which site selection and experiment development occur in a forum open to the interested scientific community. The first of these open workshops was held in June 1997 by the SEIZE community and convened by Greg Moore, Tom Shipley, Casey Moore, and Miriam Kastner (see report, p. 7). A follow-up meeting organized by Eli Silver and Marino Protti and specific to Costa Rica - Nicaragua was held at the fall AGU meeting (see report, p. 9). Julie Morris will convene a Subduction Factory workshop this June (see report, p. 20). The MARGINS Steering Committee is planning future workshops and theoretical institutes to further the sedimentology, rheology and deformation objectives.

We envision that the four science initiatives outlined above could be carried out in five or six geographic areas of focused, interdisciplinary investigations. Recent and nascent advances in global positioning, seismic data acquisition, scientific drilling, seafloor observatories, remote sensing and sampling, computational simulations, and laboratory measurements of rock physical and biogeochemical properties provide exciting prospects for major scientific advances from coordinated, interdisciplinary MARGINS research programs in the next decade.

Sediment Dynamics and Strata Formation

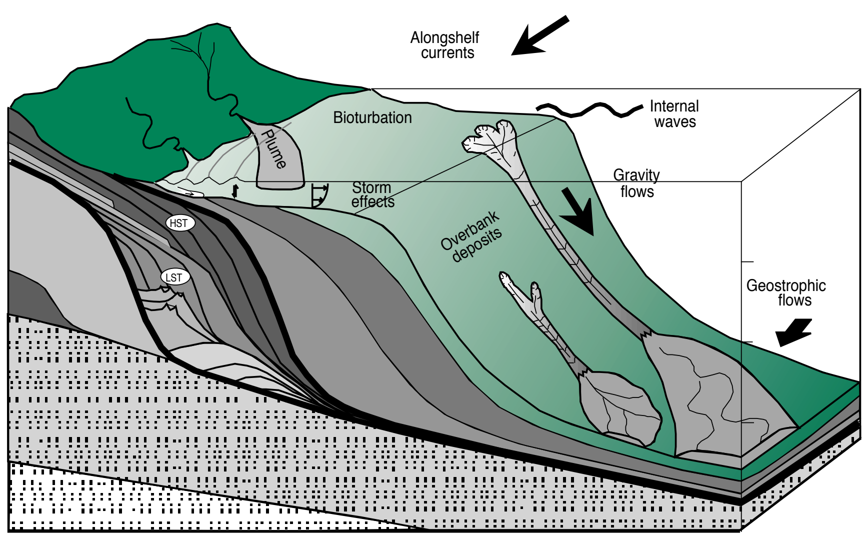


Fig. 4. 3-D sketch of sediment dynamics and strata formation on a continental margin.

The Seismogenic Zone Experiment (SEIZE)

Greg Moore[1] and Casey Moore[2]

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Most of the world's great earthquakes and tsunamis are initiated in the zone of underthrusting, or seismogenic zone, of subduction zones. Fifty earth scientists (including 18 from outside the U.S.) gathered in Kona, Hawaii during the week of June 2, 1997 to discuss approaches to understanding the seismogenic zone. The workshop, sponsored by JOI/USSAC and NSF/MGG, started with an informal evening poster session followed by a day of talks focused on important issues relating to future Seismogenic Zone Experiments. The remaining day and a half consisted of spirited discussions of the key elements of potential SEIZE field study areas.

The workshop built on a 1995 conference on the same topic sponsored by the International Lithosphere Project, and outlined the goals of a seismogenic zone experiment: SEIZE seeks to understand the relationship between earthquakes, deformation, and fluid flow in this environment. SEIZE will address the following questions: 1) What is the nature of an asperitie? 2) What are the temporal relationships between stress, strain, and fluid composition throughout the earthquake cycle? 3) What controls the up-and downdip limits of the seismogenic zone? 4) What is the nature of a tsunamigenic earthquake zone? 5) What is the role of large thrust earthquakes in mass flux?

SEIZE will proceed by focused investigations combining earthquake seismology, seismic reflection imaging, and geodetic studies in and around a limited number of seismogenic zones. Sampling the incoming material combined with laboratory experiments and modeling will be used to predict the nature of the fault rock in the seismogenic zone. Waveform models of the seismic images will be used to predict physical properties of the seismogenic zone. Deep riser drilling will be used to test these models, lead to a better understanding of our questions about the seismogenic zone, and calibrate techniques for monitoring changes in fault zones during the earthquake cycle. Seismogenic zones selected for focused study must have historic earthquake activity, be imagable by seismic reflection, be geographically accessible, and ultimately be penetrable by drilling. At the SEIZE workshop, application of these criteria to candidate localities targeted areas off the Japanese Islands (Nankai Trough and Japan Trench) and Central American (Costa Rica and Nicaragua) for SEIZE programs. The extraordinary infrastructural investments, the immediate societal relevance, the seismic imaging possibilities, and the drilling potential in the Japan area require focus there. Central America, especially Costa Rica, offers exceptional opportunities for seismic and geodetic monitoring, can be imaged and drilled, and contrasts geophysically with the Nankai Trough locality in Japan. Japan Trench and Nicaragua have generated tsunamigenic earthquakes warranting investigation. Investigations in the Nankai Trough in Japan will have direct application to understanding the societally relevant, currently quiescent but paleoseismically active Cascadia seismogenic zone of the Pacific Northwest.

Landward of the Nankai Trough, sediments underthrusting the accretionary prism can be traced into the seismogenic zone on existing 2-D seismic reflection images; therefore, the material properties of the seismogenic zone are predictable. The seismogenic zone here lies within the planned capability of the OD 21 riser drilling ship. The Japan Trench and the Nicaragua Trench have produced tsunamigenic earthquakes, with shallow seismogenic zones worthy of study; as these tsunamigenic seismogenic zones are within the drilling capability of the JOIDES Resolution, they can be investigated in the near future. In the Japanese Islands the large number of seismic stations both on land and underwater, the extensive GPS network, and an abundance of other available data provides overwhelming scientific investment that a SEIZE program can build on. Both the Japanese and Central American regions have active scientific communities that can develop strong SEIZE efforts; success in proposal-writing by these groups will narrow SEIZE activities. As the prime localities become clearer, various inter-related and piggy-back studies can be quickly initiated to achieve the desired focus. Focused scientific activities at prime SEIZE localities will have immediate transfer to other convergent margins.

The full SEIZE report is available at http://www.soest.hawaii.edu/moore/seize/report.html. The Nankai Trough subsection of the report is reproduced below, followed by a report of the subsequent workshop on the Costa Rica and Nicaragua seismogenic zone.

Nankai Trough

Seismicity

The Nankai Trough subduction zone of southwestern Japan is a vigorous seismogenic zone with recent great earthquakes in 1944 of Ms = 7.9 and 1946 of Ms = 8.0. Recent great events, high thermal gradients and the reflective plate boundary combine to make Nankai Trough a particularly good margin for a large-scale integrated study of seismogenic processes.

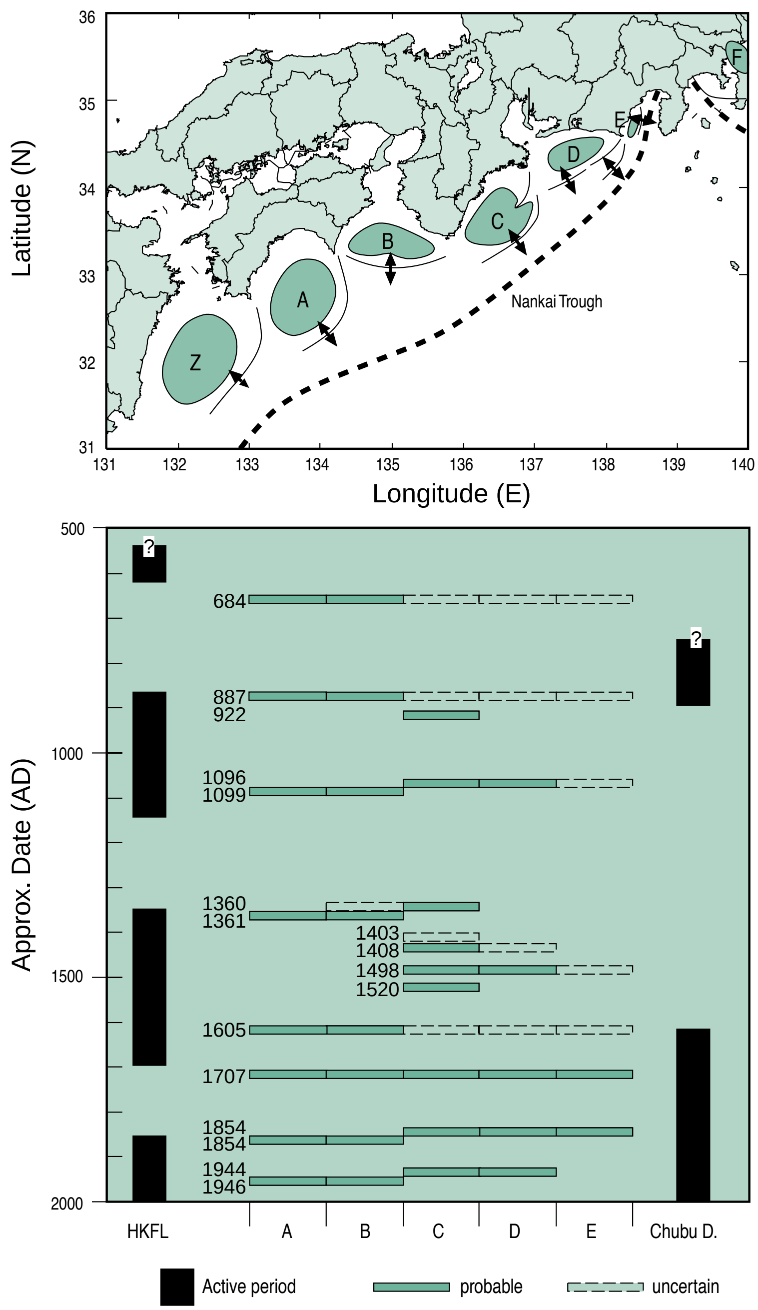

Fig. 1. Map of earthquake rupture zones and chart of historical earthquake activity in the Nankai Trough area of Japan.

The historical record of great earthquakes extends from 684 AD. The recurrence interval is now approximately 100 years, and a northeastern segment not ruptured by the 1944-46 pair of earthquakes is a potential candidate for the next major event. The 1944 and 1946 events are well-studied (Fig. 1). Level-lines before and after rupture provided data on surface deformation that combined with tsunami data have been modeled to define the regions of co-seismic slip. Modern geodetic programs are well-established indicating that seismic coupling is high.

Seismic Imaging

Seismic reflection images from the Nankai Trough are classic in illustrating a fold and thrust system (Fig. 2). Image quality of the decollement plate boundary also is exceptional; the top of the down-going plate, and usually the Moho, can be traced from the Shikoku Basin to at least the shelf edge. The reflection associated with the plate boundary remains above the water bottom multiple well into the updip portion of the seismogenic zone, producing an exceptionally high quality reflection, a unique setting. Direct waveform inversion could establish how fault zone physical properties vary between the updip aseismic zone and the deeper seismogenic zone. This could also lead to repeat studies by 4-D seismic reflection to examine changes in fault properties during the earthquake cycle.

Drillability

Previous ODP drilling has shown that the sedimentary sequence, at least at the toe of the trench, is readily drillable. A 1300 m hole was completed with excellent core recovery. The shallowest updip limit of the seismogenic zone is approximately 3 km below the seafloor where the water depth is 4 km. Within the OD21 water depth limit of about 2.5 km, a 7-8 km deep hole would be required to reach the seismogenic zone. Other targets on out-of-sequence faults, that root in the seismogenic zone, could provide targets of intermediate depth suitable for deep JOIDES Resolution drilling.

Present Data

Because of the history of destructive earthquakes in Japan, the seismological community has both long-established and new modern seismometer arrays. There is a long history of geodetic surveys throughout the region and a recently installed large-scale permanent GPS program (over 1000 instruments throughout the Japanese islands). There is also a long-established tsunami (tide-gauge) program. Extensive swath mapping and side-scan data exist on all offshore areas as well as 2-D seismic surveys. A combination of BSR mapping and heat flow probe data provide an unusually complete representation of the margin heat flow and demonstrate the high thermal gradients associated with the young crust. Active OBS experiments have produced successively higher quality velocity models of much of the offshore area. Three DSDP/ODP drilling legs provide a data set for assessment of the incoming sedimentary section and updip aseismic portion of the fault. Data from drilling and related geophysics have been used to develop some of the best models of fluid flow and deformation kinematics. The Shimanto Belt onshore Shikoku is a Cretaceous to Miocene analog of the modern accretionary prism.

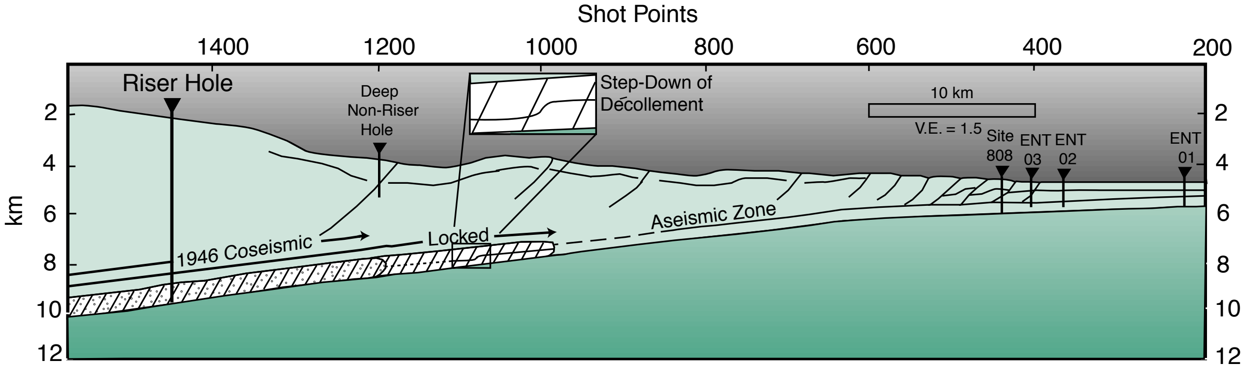

Fig 2. Cross section of the seaward portion of the Nankai Seismogenic zone showing past shallow (ODP Leg 131; Site 808) and possible future deep riser drilling localities (after 1997 SEIZE and CONCORD workshop reports). ENT 01-03 are proposed future ODP Drill sites.

Several additional ODP drilling proposals for shallow drilling in the region are currently in review. A 3-D MCS and OBS data acquisition program is proposed for 1999 to provide further regional coverage along the Nankai margin.

Infrastructure and logistics
There are well placed onshore networks of geodetic and seismic stations, and a strong community of seismologists interested in subduction zone scientific problems. Significant expansion of efforts related to earthquake research is underway in Japan. A key element is the recent installation of cables to a series of seismometers offshore to collect data with a geometry that is essential to more precisely define the updip limit of the seismicity. These are the first permanent installations, and the first that will allow proper geometries for location and characterization of the seaward (updip) sections of the fault zone.

The Nankai Trough is less than one day steaming time from Tokyo. A rapid event response program is already in place. The weather is fine, except for typhoons during August-November.

Nature of Subduction
The plate convergence rate of 3-4 cm/yr. is sufficient to result in great earthquakes. This margin is accreting clastic sediments deposited on the young Shikoku Basin. Resulting high thermal gradients produce a relatively shallowly dipping subduction zone.

The Costa Rica-Nicaragua Seismogenic Zone (CRiNiSEIZE)

Eli Silver

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Overview: Previous international workshops have stressed the importance of understanding the mechanics of the seismogenic zone in subduction environments, and the SEIZE meeting recommended Costa Rica-Nicaragua as one of two highest priority regions for focused studies. Following these recommendations, a group of approximately 55 experts in different fields gathered to briefly review what is known, followed by discussion of what needs to be done to understand this process. The goals were to better define the nature of the seismogenic zone, to prioritize potential scientific studies, and to organize international teams to focus on different aspects of the structure and behavior of the seismogenic zone in Costa Rica and Nicaragua. It is expected that proposals for research will be generated from these teams. In part, this work is a first step in the preparation for deep riser drilling into an active seismogenic zone. The workshop, held December 7th in San Francisco, was supported by JOI Inc., NSF International Programs, and MARGINS.

A broad section of the geosciences community is keenly interested in focusing on the problem of the contrasting seismogenic behavior illustrated by the Nicoya and Nicaragua segments of the Middle America Trench. An integration of geodesy, active and passive seismology, geochemistry, laboratory studies, modeling, and both JR and riser drilling holds the promise of a much fuller understanding of the seismogenic process. Integration of effort will also result in minimizing the cost/benefit ratio of carrying out these large science programs.

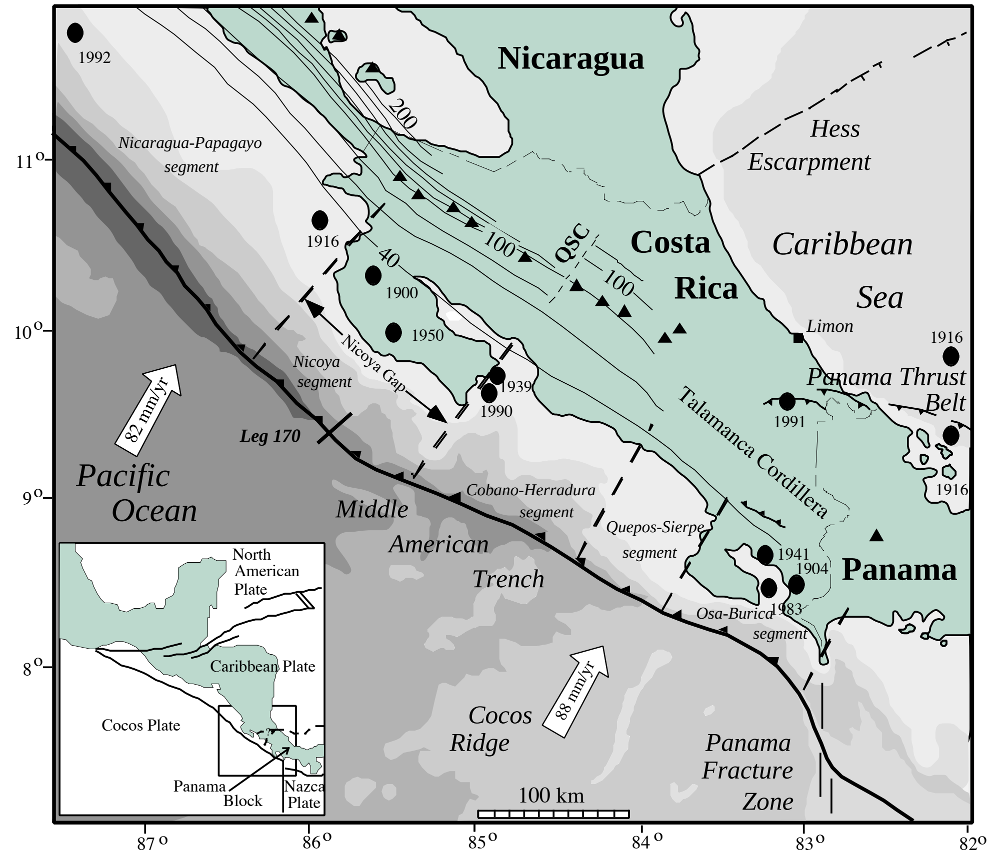

Fig. 1. Tectonic setting of southern Central America and the geometry of the top of the Wadi-Benioff Zone (from Protti et al. 1995). Isodepth contours are at 20 km intervals, starting at 40 km. Filled triangles = active volcanoes; and filled circles = location of large (magnitude>7.0) earthquakes that occurred in this century. The Nicoya Gap separates the rupture zones defined by the aftershocks of the 1990 and 1992 earthquakes. Darker shades of gray show greater depth. Each shade increment is 1000 m.

Seismology

The major objective is to define the seismogenic zone, with a focus on the updip edge, for both the Nicoya section of Costa Rica and the tsunamigenic zone of Nicaragua. The experiment would consist of instrumenting the two corridors, covering an area of about 80 km x 40 km in each region. The study will require about 30 three-component OBS offshore plus another 20 land recorders to extend the arrays to cover the full width of the seismogenic zone. This design will allow acquisition of fault zone trapped waves and reflected or converted waves as well as achieving the primary objective of obtaining accurate earthquake locations and focal mechanisms for microearthquakes. The instruments would be spaced 10-15 km apart, giving 1 km resolution. The array would be deployed for at least six months, first offshore and onshore of the Nicoya peninsula, then off Nicaragua.

It is also important to study older, large earthquakes that have occurred in these regions to address the question of what are asperities. There seems to be a close correspondence between the Costa Rica - Nicaragua differences and those along strike off Sanriku in northern Japan: rougher seafloor generates tsunami earthquakes and smoother seafloor generates larger earthquakes.

Crustal Structure

Studies are needed to advance our understanding of (1) the nature and history of interplate slippage and coupling, in particular as linked to the geometry of the interface, and (2) the physical and fluid processes and mechanical state of material involved in the passage or storage of ocean floor sediment along the interplate boundary underlying the Nicaragua and Costa Rica margins. Suggested experiments include:

1) Identification and location of underthrusting and underplated sedimentary bodies by active (seismic reflection and refraction) and passive (receiver function inversion of earthquake seismicity) imaging of Nicaragua, the Nicoya Peninsula of Costa Rica and the margin immediately adjacent which has been deeply eroded by underthrusting seamounts and seamount chains.
2) Specific studies to resolve the structure and interplate fabric of that part of the Nicaraguan margin known to spawn tsunami earthquakes.

3) Mapping of the along-strike and cross-strike shape of the interplate boundary underthrusting the Nicaragua and Costa Rica margins.
4) Specific studies to identify and image subducting seamounts beneath the Costa Rican margin, in particular beneath the south eastern area of Nicoya Peninsula, the nucleation area of a large magnitude earthquake in 1990. Linked onshore studies are needed to related offshore data to inferences of block faulting along the Costa Rican coast.
5) Specific offshore geophysical experiments to identify what is “special” about the Nicoya margin with respect to its behavior as an area of strong interplate coupling.

The specific studies identified call for a combination of onshore and offshore investigative techniques. These include coastal studies to unravel the history of vertical and block tectonism (in particular with respect to questions of crustal underplating and the passage of subducted seafloor relief) and the chemistry of late Cenozoic and older arc volcanic rocks. Onshore installation of seismic stations and GPS monuments are essential and needed to compliment offshore arrays of OBS and OBH instruments, established to listen both passively and actively.

Offshore studies necessarily require the gathering of both high-power and high-resolution seismic reflection profiles and wide-angle reflection and refraction data via ocean-bottom instruments. Long-lived ocean bottom arrays are needed to understand the nature of interplate slippage and upper plate strain release. 3-D seismic reflection shooting will be needed as specific target areas are identified concerning seismogenic processes, asperities, and settings. Heat flow data is required for the Nicaragua margin and incoming plate. All of these studies are focused to identify offshore scientific drilling sites at which physical, chemical, fluid, and tectonic information can be obtained from the seismogenic zone directly.

Geodesy

Geodesy will play a primary role in the determination of interplate slippage and upper plate strain release. Geodetic measurements have successfully described the locked zone along interplate thrusts in Japan and elsewhere, though a continuing problem is the inability to obtain geodetic data closer to the updip edge of the locked zone. Costa Rica allows much better coverage of this zone than most places because of the fortuitous location of the Nicoya peninsula, located far out over the forearc. Additionally, the morphology of the margin allows submarine geodetic experiments, potentially providing unprecedented constraint on the updip edge of the locked zone.

A number of geodetic experiments are ripe for initiation. Continuous GPS stations should be emplaced on Cocos and San Andres Islands. The GPS array in Costa Rica should be significantly expanded and densified, to be able to separate local effects (such as post seismic strain from the 1992 Nicaragua Earthquake) from longer term elastic deformation on the seismogenic zone. Four to six marine geodetic arrays should be placed on the seafloor seaward of the Nicoya peninsula to tightly constrain the location of the updip edge of the locked zone. Eventual installation of a buoy system would provide continuous monitoring.

Borehole strain measurements are important as well for understanding the deformation above the locked zone. Vertical motions might be monitored in the subsurface by use of inverted echo sounders, which need to consider changes in the temperature and salinity of the water column for their effects on acoustic velocity. However, such instruments do not need to be corrected for drift, as do pressure sensors. The proximity to the trench makes the offshore an excellent region to install an instrumented bottom cable for long-term monitoring of strain, seismicity, and geochemistry. Onshore programs include borehole strain, leveling, and additional continuous GPS stations.

Along-strike variability between Costa Rica and Nicaragua is of very high interest in this program. The group recognized that Nicaragua will not necessarily be an equal recipient of all the studies being carried out in Costa Rica. One difference is the presence of the Nicoya peninsula of Costa Rica which extends far over the seismogenic zone. However, an expanded GPS network in Nicaragua would be essential for understanding some of the differences between the two regions.

Geochemistry

Geochemistry will play a central role in: (1) understanding the smectite/illite transition (that may control the updip limit of seismicity); (2) providing chemical fingerprints, geothermometers and geobarometers for tracing subduction components; (3) determining sources of fluids (by studying fluid flow through the decollement and downdip reactions such as serpentinization); and (4) establishing volcanos as flow monitors of subducted sediments and basement (by using tracers such as ^{10}Be, B, Ba, La, U, Th, etc).

Integrated experiments to determine and monitor geophysical, geochemical and hydrological parameters for Costa Rica and Nicaragua would include:

1) Drilling reference sites at least 300 m into oceanic basement to understand fluid sources.
2) Drilling CORKed holes through the decollement to find the rate of fluid flow and fluid pulsing, both off Costa Rica and in the tsunamagenic zone off Nicaragua.
3) Designing and building chemical fluid samplers.

4) Drilling for the arc history (10 Ma) as a long term flow monitor of subduction inputs/outputs.
5) Laboratory studies of the smectite/illite and serpentine phase transitions.
6) Volcano tracer studies to discriminate relative inputs of carbonates, hemipelagics and basalt. Use of ^{10}Be proxies for older history.

Modeling and Laboratory Studies

The goal of modeling is to obtain realistic estimates of the role of pore pressures in the seismogenic zone. The approach for Costa Rica includes:

1) Creation of a 2-D model of the drilling transect that accounts for the current geochemical and physical property data. The output of the model would include estimates of pore pressures that are possible in the seismogenic zone and fluxes of chemical species. This type of model can be used to explore the importance of basement flow and permeability, the time frame of transient flow relative to the earthquake cycle, and the effect of underplating. It can also be used to perform sensitivity analysis to formulate sampling strategies prior to future drilling.
2) Creation of a 2-D plan view or a 3-D model to look at the time of drainage of pockets of pore pressure.

Measurements needed to support new modeling efforts include:

1) Continuous pore pressure estimation with depth in boreholes.
2) Geochemical lab experiments for reaction kinetics between 150° and 350° C and for the quantity of water released.
3) Frictional and rheologic properties at realistic temperatures and pressures for carbonates, serpentines and mafics.
4) Lab measurements and borehole logs to relate seismic properties to physical properties.
5) 3-D seismic data and seafloor vent flow monitoring.
6) Cross-hole tomography to define the regional distributions of porosity and physical properties using closely spaced drill-holes could be carried out with wireline reentry methods. ODP drilling using drill-in casing has the ability to penetrate well into the deformed Costa Rica forearc prism, where first results from ODP Leg 170 suggest this unit is related to onshore geology, not to incoming Cocos plate material.

Reference

Protti, M., Guendel, F., and McNally, K., 1995. Correlation between the age of the subducted Cocos plate and the geometry of the Wadati-Benioff zone under Nicaragua and Costa Rica. *In* Mann, P. (Ed.), Geologic and Tectonic Development of the Caribbean Plate Boundary in Southern Central America. *Spec. Pap. Geol. Soc. Am.*, 295: 309-326.

Platforms for Shallow Water Drilling

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Platforms for shallow water drilling that complement the strengths and capabilities of the JOIDES RESOLUTION are required to address fundamental questions about continental margin development and evolution. One of the major objectives of margin studies is to assess the morphologic and stratigraphic response of continental margins and sedimentary basins to environmental forcing functions acting over a variety of scales. Sampling and imaging strategies spanning entire margins, from shallow water to deep, are required for understanding the links between fundamental physical processes and the formation of the preserved stratigraphic record.

Rapid advances in technology have greatly improved the accuracy and precision with which we can navigate and seismically image the sea floor and sub-bottom horizons. Coring technology available to the research community has not kept pace with these geophysical advances, however, especially in shallow-water environments. Hole stability in, and core recovery of, unconsolidated sediments remains poor, which greatly limits our groundtruthing/correlating capability. Hole stability problems caused by thick unconsolidated sands encountered on the New Jersey continental shelf during ODP Leg 174A highlight the need for additional platforms to operate in shallow water environments (< 75 m) that can efficiently penetrate, sample, and log deeper into the sedimentary succession. The COMPOST meetings (COMmittee on POST 98 Drilling) likewise concluded that the scientific community needs access to technology that will increase the penetration and core recovery of ODP's drilling platform(s). New coring and downhole logging technology developed for industry offers exciting prospects for continuously coring and logging unconsolidated sediments in diverse environments including the continental shelf and slope.

Climatic studies will also benefit from additional shallow-water drilling platforms. Most open ocean sediment cores cannot be used to resolve short period climate change, and records from most corals and varved sediment sequences are too short to resolve millennial-scale changes. Every ocean basin is rimmed by continental margins, most of which have long histories of exceptionally high rates of sediment accumulation (10 -100's cm/1000 yrs). High resolution paleoclimate studies at these locations could complement the records of corals, bivalves, and varved sediments. Continental margins as a whole have been grossly underrepresented in studies of paleoclimate, because high terrigenous flux has been viewed as a liability rather than an asset. With shallow-water drilling platforms and chemical analysis using sensitive instruments, it is possible to recover high resolution series of paleoclimate proxy data. In addition, samples recovered from shallow-water drilling will prove essential for correlating marine and terrestrial climatic data.

Recognizing all of the above, a shallow-water drilling workshop entitled MarineCAM (Marine Coring at Margins) was held at Lamont-Doherty Earth Observatory on May 1 and 2, 1997. The workshop was funded by the JOI/USSAC and the Office of Naval Research (ONR). The main objective of the meeting was to examine state-of-the-art industry drilling and logging technology for shallow-water environments (<500 m) in order to determine if these tools could accommodate the needs of the scientific community. A total of 28 scientists and 6 representatives from 4 offshore engineering companies attended (Alpine Geophysical, Fugro-McClelland Marine Geosciences, Inc., Rosscore, and Warren George, Inc.). Three general approaches were presented for shallow-water sediment sampling and logging: (1) vibra-coring, (2) push/percussive/rotary coring, and (3) *in situ* geotechnical monitoring without coring (Table 1). In this article, we provide a brief summary of these three sampling and logging approaches and outline the costs associated with the different technologies.

Table 1: MarineCAM Options

downhole device	typical platform	WD, m	mbsf	~costs[4,5]
VIBRACORES				
pneumatic vibracorer	mid-size ship of opportunity	0-75	10[1,2]	4-8
electric vibracorer	mid-size ship of opportunity	0-1500	10[1]	4-8
lt-wt electric vibracorer	small ship of opportunity	0-5000	10[1]	2-6
PUSH/PERCUSS/ROT				
lt-wt push/percuss/rot corer	small portable barge	5-30	30[1]	4-6
push/percuss/rotary corer	portable barge[3]	6-30	100	15 / 250 / 500[a]
"	self-elevating barge	6-100	1000+	30 / 1,200 / 2,000[b]
"	oil field jack-up	20-100	1000+	>>?1,000 total
"	anch'd mid-sized ship w/ pool[3]	6-300	650	30 / 500 / 1,000[b]
"	Dynamic Positioning-DP ship[3]	100+	650	75 / 1,000 / NA[b,c]
GEOTECH LOGGING				
geotech measurements	anch'd mid-sized ship w/ pool[3]	6-100	70[1]	30 / 500 / 1,000[b]
"	DP ship w/pool[3]	100+	70[1]	75 / 1,000 / NA[b,c]

[1] limited by stiff clays + thick sands
[2] "could be increased to 50 mbsf or more" - *K.Moran*
[3] need seafloor reaction mass
[4] $K/day vibra-coring includes mob/demob, ~3-6 cores/day
[5] wireline coring based on 100 mbsf, 30 days on site (~9 - 100 m cores):
 [a] $K/day not incl mob from east coast US / $K east coast US ops[6] / $K west coast US ops[6]
 [b] $K/day not incl mob from Gulf of Mexico / $K east coast US ops[6] / $K west coast US ops[6]
 [c] west coast US ops only if ship available from SE Asia or China
[6] mob/demob costs only

Vibracoring is accomplished by using a cable to lower a corepipe to the seabed and vibrating it into the sediment with a submerged motor. The pipe and motor assembly is vertically stabilized in one of several ways, and must be deployed and retrieved for each core. This technique is weather-sensitive during launch and recovery from a floating vessel because of its size and the need for a crane or amovable frame. Vibracores can be acquired in virtually any near shore setting except where high energy surf precludes safe operation. The deep-water limit is determined by ship stability and by the type of vibrating motor: pneumatic and hydraulic systems are practical to about 75 m water depth, while electric systems can continue to 750 and perhaps to 1500 m. Depth of penetration and degree of core disturbance are controlled in part by the frequency and amplitude of the applied vibrations. Vibracore penetration and quality can be severely limited by thick sand and more importantly, stiff silts and clays. Nevertheless, penetration of difficult horizons can be accomplished by offset vibracoring and washing down or "jetting" without sampling through the horizon with continued core recovery beneath it. The practical penetrations for all types of existing vibracores are in the range of 10-20 m subbottom.

Push/percussive/rotary coring spans a large range of operating settings and costs. The basic approach applies a constant load or percussive impulse from above the sea surface that drives a core pipe into the sediment. With increasing induration of the sedimentary succession, operations switch to a top-drive motor that rotates a drill bit and cuts into the formation. As water depth and desired depth of penetration increase, progressively more robust systems can be used to reach 1000's of meters below seafloor (mbsf) in 100's m of water. Several sampling techniques are available for push/percussive/rotary coring. The low end of push/percussive/rotary coring begins with a lightweight system typically operated from an anchored platform, which is limited to waterdepths of less than 30 m because of its weather sensitivity. Depending on the substrate, samples can be recovered to 30 m sub-seafloor. A modular, portable barge system can be assembled on-site; its operating depth is limited by weather sensitivity, and the size/buoyancy of the barge governs the depth of seafloor penetration. Typical estimates for the modular barge system are up to 30 m water depth and 100 m subbottom penetration. Increased sea worthiness and mobility make ships more versatile platforms than floating barges. Mid-sized, anchored vessels with coring through a center well can recover samples to 650 mbsf in water depths up to 300 m. A dynamically positioned ship increases the operating water depths to 700 m, again with penetration to 650 mbsf. A jack-up platform can be used instead of a ship to lower legs to the seafloor, raise the platform out of the water, and isolate the drill rig from wave motion. These platforms begin with small, towed barges that are recommended for 6-20 m water depths; they can hang enough pipe to core to 500-1000 mbsf. Larger, self-propelled jack-up barges can work to 100 m water depth and core to 1000 mbsf. Oil field jack-ups complete this group of platforms, operating in water depths up to 100 m with penetration capabilities of well over 1000 m. Regardless of size, however, all jack-ups are uniquely weather sensitive during jack-up and jack-down operations.

The third approach collects a suite of *in situ* measurements of sediment properties but fails to recover any samples. These tools record any of several geotechnical engineering properties typically used to determine bearing load capacity before placing structures directly on the seafloor. Because of the cm-scale resolution, high reliability, and downhole continuity of these data, workshop participants agreed this information could be a valuable asset to push/percussive/rotary coring. The tools discussed were cone penetrometers, vane shear devices, pressuremeters, and packers. Measurements can be performed in undisturbed sediment 3 m or less ahead of the bottom hole assembly while either continuously pushing the device into the seabed, or in a “measure - advance - measure” mode. Data are stored downhole and downloaded to a top-side computer when the tool is retrieved. Typical properties extracted from these measurements include pore pressure, permeability, shear strength, present stress field, and proxies for sediment density and composition. These devices can be used to 3000 m water depths or more. Their sub-bottom window of applicability is determined by sediment induration; typical applications to 70 mbsf were described. Each can be deployed from the same platform that acquires push/percussive/rotary cores, i.e., a floating barge, ship, or jack-up. Whatever the platform, however, a seafloor “reaction mass” is needed to stabilize the bottom assembly and to isolate it as much as possible from platform motion at sea level.

The relatively affordable costs and the large variety of appropriate platforms ensure that vibracoring is within reach of expected scientific budgets. Furthermore, pre-site characterization needed for 10-20 m penetrations is far more modest than for deeper sampling operations. The jump in cost and operational complexity between vibracoring and push coring poses a significant challenge to meeting a variety of scientific goals. The only route to >20 mbsf samples discussed at the workshop is to hire specialized companies. Daily costs begin at $15K and continue upward to more than $100K (Table 1). Contractors estimated that mobilization costs for these platforms deployed to either the east or west coast of the US would range from $250K to $2M. Obviously, every effort will be needed to reduce these costs by either sharing mobilization with other interests, waiting for a ‘platform of opportunity’ that is transiting through a given study area, or defining scientific programs that are in areas close to where these platforms are already deployed.

ODP could provide managerial benefit to coring at margins. For example, the recently formed Drilling in Shallow Environments Program Planning Group could help to: a) formulate precise scientific objectives; b) maintain a schedule of platforms of opportunity; c) recommend site surveys for pre-coring site evaluation; and d) ensure proper sample distribution and archiving at one of the ODP core repositories. Participants left the workshop with renewed confidence that the time had come for coordinated coring at margins. The potential rewards in this virtually untapped geologic archive are very large, but so are the costs for reaching those goals.

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Drilling Input to the Mariana-Izu Subduction Factory: ODP Leg 185

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The rumblings and emissions at convergent margins mark the inner workings of the Subduction Factory (Fig. 1). Raw materials — seafloor sediments, hydrothermally altered oceanic crust +/- forearc material — are fed into the Subduction Factory at deep sea trenches. The output products — fluids, metalliferous deposits, serpentine diapirs, volcanics, continental crust, gases, organic material, back-arc seafloor — emerge from the Factory on the upper plate. The Subduction Factory is thus an unusual factory. We can see what goes in and what comes out, but the Factory itself operates deep in the earth, hidden from view. We can try to recreate the pressure and temperature conditions of the Factory in the laboratory, and we can measure its properties by remote imaging. But direct sampling of input and output material provides many of the constraints on the constitution and operation of the factory. For example, mass balancing the input and output fluxes through the factory measures the efficiency of production. How much of the H_2O, CO_2, metals and other elements (K, Th, Be etc..) that enters the subduction zone emerges back out through the volcano? The answer to this question bears not only on the partitioning processes in the Subduction Factory but also on the balance of material between crust and mantle. The balance of mass is directly related to crustal growth (through volcanic arc accretion) and destruction (through sediment subduction to the mantle), while the chemical balance affects the chemical evolution of the crust and mantle. Thus mass balance across the subduction zone is relevant to the evolution of the whole Earth and will help constrain fundamental problems related to the composition of continental crust through time, the sources of metals and organic material for the formation of economic deposits, and the origins of mantle plumes by recycling of oceanic crust into older mantle reservoirs.

The only way to measure directly the input to the Subduction Factory is to drill the seafloor adjacent to trenches. The ODP, since 1988, has set as one of its goals the quantification of subduction fluxes. Leg 123, on old Indian Ocean crust approaching the Sunda Arc, was one of the first drilling legs with objectives to quantify the input fluxes of sediment and altered basement approaching a trench (Plank and Ludden, 1992). More recently, Leg 170, seaward of Costa Rica, aimed to determine mass balances within the accretionary wedge, as well as input fluxes to constrain forearc fluid and volcanic output. This Leg was successful in providing several reference sites of the incoming sedimentary section (but not the basement), and in demonstrating that all of the oceanic sediments are subducted under to toe of the accretionary prism. Apart from these and a few other convergent margin Legs, very little drilling has been dedicated to measuring subducted inputs; most input studies have had to bootleg information from existing holes of opportunity (e.g., Plank and Langmuir, 1993; 1998; Rea and Ruff, 1996).

ODP Leg 185, which is scheduled for April - June, 1999, is the first drilling leg whose primary focus is subduction mass balances; in this case the objective is to drill the input to the Mariana-Izu Subduction Factory (Fig. 2). Leg 185 will involve two deep water sites, one seaward of the Mariana trench (existing ODP Site 801C) and one seaward of the Izu-Bonin trench (proposed Site BON-8A). Previous drilling has already provided sections through the sedimentary layer approaching the Mariana trench. Drilling during Leg 185 will provide samples of some of the remaining input fluxes to the subduction zones: the upper 300-500 m of altered basaltic crust at 801C, and the sediments (500-600 m) and upper 300-400 m of basaltic crust at BON-8A (Fig. 2).

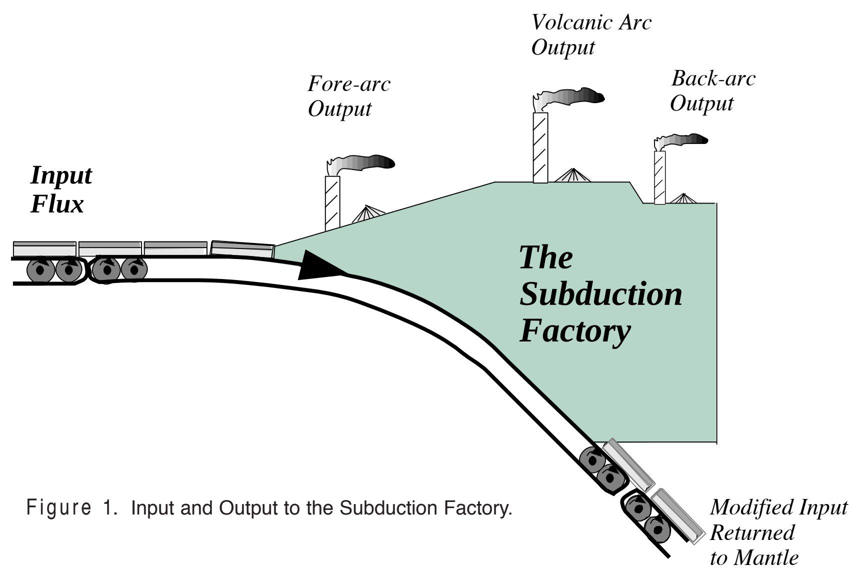

Figure 1. Input and Output to the Subduction Factory.

Why Mariana-Izu?

There are thirty or so active subduction zones where one could observe the Subduction Factory at work. Why do we choose the Mariana-Izu margin? The first reason is that significant progress has already been made on measuring many of the fluxes. Fore-arc sites of fluid outflow (serpentine seamounts) have already been drilled (Leg 125; Fryer, 1992), and are the subjects of intensive, on-going inquiry. Through drilling, primarily during Leg 129 (Lancelot and Larson, 1990), we already have samples of the sedimentary components being subducted at the Mariana trench. The volcanic arcs and back-arcs are among the best characterized of intra-oceanic convergent margins, both in space and time (Legs 125 and 126; Gill et al., 1994; Arculus et al., 1995; Elliott, et al., 1997; Ikeda and Yuasa, 1989; Stern et al., 1990; Tatsumi et al., 1992; Woodhead and Fraser, 1985; Hochstaedter et al., 1990; Stolper and Newman, 1994). And here the problem is simplified because the upper crust is oceanic, so upper crustal contamination is minimized. Sediment accretion in the fore-arc also is non-existent (Taylor, 1992), so sediment subduction is complete.

Primary Goal 1: Why are the Mariana and Izu Volcanic Arcs Chemically Distinct?

Despite the simple oceanic setting and the shared plate margin, there are still clear geochemical differences between the Mariana and Izu arcs. One example is in the Pb isotopic composition of the two arcs (Fig. 3). While the Mariana arc forms a mixing trend almost perfectly coincident with the average subducting sediment and the average upper basalt at Site 801C, the Izu arc forms a distinct trend between different mixing end-members. By drilling the sediment and basalt at Site BON-8A, we can directly test if the Izu trend results from mixing of the distinct crustal components subducted there. Another feature of the Izu volcanics is their extremely depleted character; they are anomalously impoverished in many subduction tracers, such as Ba, Sr and Th, with respect to the Marianas basalts and indeed most arc basalts worldwide. This depletion occurs despite a larger sediment section (based on seismic profiles) than that subducted at the Mariana trench. Drilling at BON-8A will demonstrate whether this large Izu section is actually impoverished in trace elements, leading to low elemental fluxes into the Izu trench. If not, then the cause of the depletion is not the input flux, but in the workings of the Subduction factory.

while a very poor estimate exists for the alteration flux in the basement section. Only 63 m of Jurassic MORB were drilled at Site 801C, providing too little material to estimate the alteration flux. While we clearly won't drill through the entire 6 km of oceanic crust during Leg 185, we do anticipate sampling through the upper

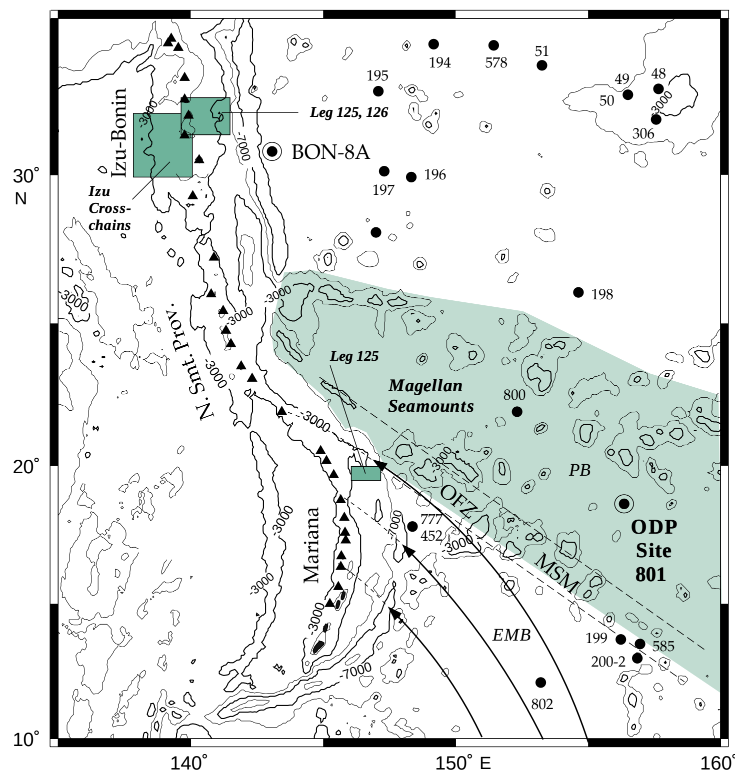

Figure 2. Map of the Western Pacific and Mariana, Izu-Bonin, and Northern Mariana Seamount Province volcanic arcs. Sites BON-8A and 801C are sites to be drilled during Leg 185 (April-June, 1999). Filled circles are existing drill holes; most drilling prior to Sites 800-802 failed to penetrate the complete sedimentary section and/or had poor recovery. Filled triangles are active volcanoes. Shaded seafloor includes Pigafetta Basin (PB) and Magellan Seamount Province, where alkalic Cretaceous overprint predominates. Ogasawara Fracture Zone-Magellan Seamount Flexural Moat (OFZ-MSM) after Abrams et al. 1992 (their Fig. 2). Curves are instantaneous trajectories for the Pacific plate relative to the Philippine plate, after Seno et al. (1993). Dashed curves are continuation of trajectories beneath the arc.

Primary Goal 2: What is the Mass Balance of Various Tracers Across the Mariana and Izu Subduction Zones?

With information in hand, it is possible to calculate many of the input and output fluxes for a few chemical components through the Mariana subduction zone. We consider here a preliminary flux balance for K_2O (Fig. 4). A consistent estimate of the sediment K input flux comes from Sites 800 and 801 (Plank and Langmuir, 1998), oxidative alteration zone, which based on other sections of the oceanic crust, lies in the upper 200-300 m and contains the lion's share of alkali and other trace element budgets. At this point, our crude estimates for the alteration flux are based on the upper 500 m at Site 417/418, in the Atlantic (Staudigel et al., 1996), and on 10% inter-pillow (K-enriched) material at 801C (Castillo et al., 1992). The other input fluxes are igneous — the original igneous K flux in the basalt, well known from MORB studies, and the Cretaceous overprint, well known from previous drilling throughout the western Pacific. The seafloor subducting into the Marianas proper is that of the East Mariana Basin, which contains off-axis Cretaceous tholeiitic flows, as sampled at Site 802 (Fig. 2). Thus, the input fluxes include two that are ultimately "continental" in origin (sediments and alteration phases in the oceanic crust) and two that are ultimately "mantle" in origin (basaltic MORB and Cretaceous overprint).

The output fluxes include fluid effluent in the fore-arc and volcanic effluent in the arc and back-arc. The Mariana arc and back-arc basin are both well sampled and analyzed, and form the basis for the output fluxes. While forearc fluid chemistry has been determined (Mottl 1992), the fluxes are highly model dependent; they are estimated here from the maximum water loss from the subducted sediment during clay mineral breakdown. Further work on the unique fluids found in the Marianas forearc serpentine seamounts will help to refine this flux, but these preliminary calculations suggest that it may be minor for K and many other tracers (Ba, Be, Th, etc.). This preliminary flux balance provides some initial insights into the efficiency of the Mariana Subduction Factory, and reveals where the major uncertainties lie. If we ignore the igneous MORB and Cretaceous basalt contributions as no net gain from the mantle perspective, then the continental K inputs and outputs may be remarkably closely balanced across the subduction zone (100% recycling efficiency). This would mean that all the continental K that enters the trench is cycled back to the continents via arc and back-arc volcanism, and that there is no net change of K in the mantle as a consequence of the plate tectonic cycle. The balance hinges critically, however, on the magnitude of the basement alteration fluxes. Current estimates are poor, and the actual flux balance could still go either way. Drilling through the upper oxidative zone at 801C can dramatically improve the key flux in the Mariana mass balance: the alteration flux. Drilling both the sediments and oceanic crust at BON-8A will then provide an independent mass balance at the Izu margin.

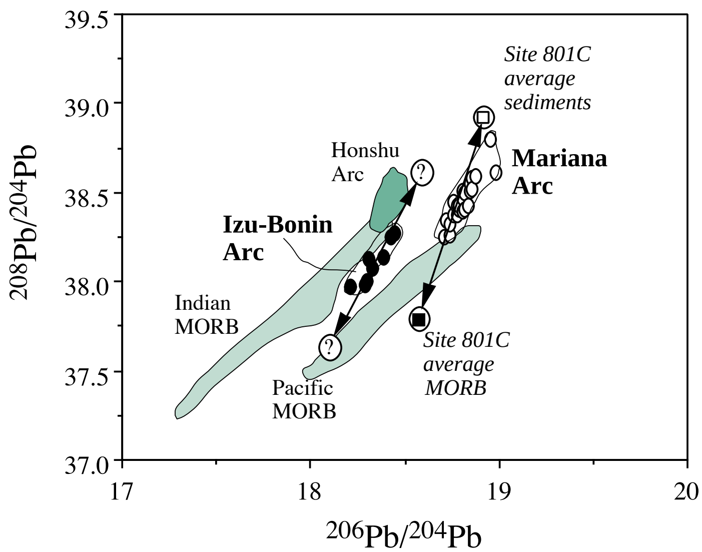

Fig. 3. Contrasting Pb isotopic composition of Mariana (open circle) and Izu-Bonin (solid circle) arc volcanics. Mariana volcanics form a mixing trend (arrow), almost perfectly coincident with mixtures of ODP 801C sediment (open boxes) and basalt (solid boxes) averages. Drilling at BON-8A will test whether Izu-Bonin arc trend (arrow) is consistent with different subducted material than for the Mariana. Modern Indian MORB, Pacific MORB and Honshu arc shown for reference. Data sources: Elliott, et al. (1997); Gill, et al., (1994); Plank and Langmuir (1998); Castillo, et al., (1992); Gust et al. (1997).

Primary Goal 3: What Style of Alteration Characterizes the Oldest Oceanic Crust?

At 165 Ma, the basement at Site 801C is the oldest *in situ* oceanic crust yet drilled. Thus, the value of deepening 801C is independent of the subduction zone problem itself — it is a critical end-member in crustal aging studies. In particular, further drilling at 801C would provide a valuable complement to the extensively-studied young (6 Ma) Pacific section at Site 504B. At present we really don't know the bulk composition of altered crust and how it varies, despite its importance in mass balancing subducted fluxes and global volatile budgets. Real heterogeneities exist that remain to be quantified, but this does not decrease the value of drilling old Pacific crust, however. We need to drill deeply into basement in a matrix of well-characterized end-member sites (fast vs. slow spreading and hot vs. cold crust) in order to develop models that will enable us to predict the spatial distribution of seafloor alteration. If spreading rate and age have anything to do with seafloor alteration, then 801C is a valuable end-member to test the importance of these variables. Deep drilling at 801C will constitute an important part of the matrix of seafloor alteration parameters: 801C - fast and old; 504B - fast (sort of) and young; 417D, 418A - slow and old; and 395A - slow and young.

Site 801C

Although located almost 1000 km from the Mariana trench, Site 801C is the most promising site for penetrating Jurassic MORB in the region. Throughout much of the Pigafetta and East Mariana Basin (Fig. 2), "basement" consists of Cretaceous flows and sills that overlie the "normal" Jurassic crust. Because these Cretaceous units have already been sampled by Leg 129 drilling, the remaining goal is the MORB section. Hole 801C is the only location where Jurassic-aged material has been reached in a reasonable amount of drilling time, and that material should be essentially the same as what is now being subducted at the Mariana trench (which is only ~ 15 Ma younger than crust at 801C; Abrams et al., 1992). The drilling strategy is to deepen 801C at least another 350 m to

~ 940 mbsf, with the specific site objectives being: a) to provide alteration flux estimates for mass balance studies (Goal #2 above), b) to provide an end-member of old-fast crust for aging studies (Goal #3 above), c) to test models for the origin of the Jurassic Magnetic "Quiet Zone."

Site BON-8A

Site BON-8A is approximately 60 km east of the Izu-Bonin trench, where the plate surface is broken by normal faults as it bends into the subduction zone. Avoiding some of this complexity, BON-8A is located on the top of a fault block in flat lying sediments. BON-8A should provide us with samples of the largely pelagic sediments from the region. Of the approximately 600 m of sediment, we anticipate 150 m of pelagic clay and volcanic arc ash above 450 m of mid- to Early Cretaceous cherty porcellanites and chalks. The basement should be Early Cretaceous MORB (135 Ma), with the upper 300 m of extrusives containing the oxidative alteration zone. The drilling strategy is to core the 600 m sediment section and at least 300 m of the basement, with the specific site objectives being: a) to contrast crustal budgets here with those for the Marianas, in order to test whether along-strike differences in the volcanics can be explained by along-strike variations in the crustal inputs (Goal #1 above), b) to provide a flux mass balance independent of the Mariana mass balance (Goal #2 above), c) to provide constraints on the Early Cretaceous paleomagnetic timescale, d) to provide constraints on mid-Cretaceous CCD and equatorial circulation fluctuations.

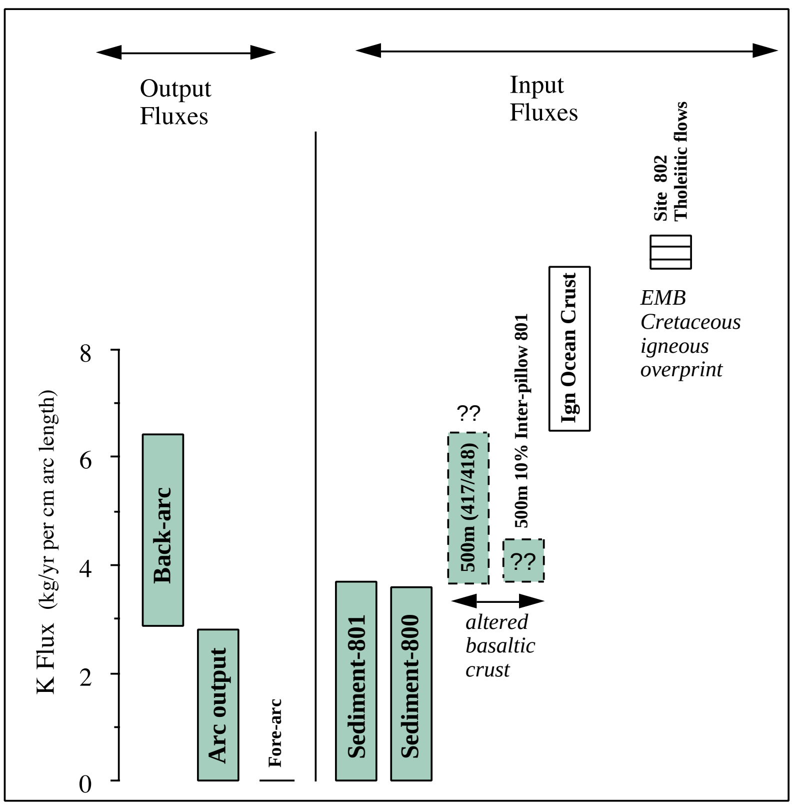

Fig. 4. Estimates of potassium (K) Input and Output fluxes for the Marianas subduction zone. Height of bar gives the flux for each parameter (scale on the left); bars are placed side-by-side to show competing estimates (as for Site 801 vs. 800 sediment) and are stacked to show cumulative input (on the right) and output (on the left). Shaded bars represent "continental" fluxes, unshaded bars are pristine igneous fluxes. Note that continental inputs and outputs may be very closely balanced, however the balance depends critically on the real alteration fluxes for Site 801C, which can only be constrained by further drilling. Cretaceous overprint given for the East Mariana Basin (EMB); lines show fluxes resulting from different layer thickness (100, 250, 400 m).

What Will We Find Out?

Drilling during Leg 185 will a) test whether along strike variations in the Mariana-Izu arcs originate in the along-strike variations in crustal inputs to the two subduction zones, b) provide the best constraints to date on the mass balance of fluxes through the Subduction Factory, c) determine the effects of age and spreading rate on seafloor alteration fluxes, and d) help to guide our continuing efforts to study the Subduction Factory, as this MARGINS Science Initiative progresses.

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SUBDUCTION FACTORY WORKSHOP

La Jolla, CA
June 7-9, 1998

Convergent margins are sites of extensive exchange of mass and energy between the asthenosphere, lithosphere, hydrosphere and atmosphere, with profound implications for the evolution of Earth's surface and interior. Major societal consequences derive from this exchange, in the form of earthquakes and tsunamis, hazardous explosive volcanic eruptions and associated climate modification, but also formation of ore deposits, fertile soils and new continental crust.

The National Science Foundation, Joint Oceanographic Institutions and the MARGINS Program are sponsoring an interdisciplinary workshop to discuss the most important science to be tackled in subduction zones, to identify the optimal place(s) for a focused, interdisciplinary experiment and to generate proposals to the National Science Foundation and the Ocean Drilling Program. Convergent margins are places where subduction zone processing of the incoming and overlying plates affects fluid flow, interplate seismicity, mantle melting and crust formation, the Earth's volatile cycle, mantle evolution, ore formation, and volcanic hazards and climate modification. Workshop participants will cover the entire spectrum of subduction zone science: theoretical, experimental, analytical and field oriented geophysics, petrology, low and high temperature geochemistry and volcanology.

Some spaces at this small (<50 participants) workshop are available through application, due by April 1, 1998. Funding is available to partially defray travel expenses for U.S. participants. Further information on application procedures and the workshop itself is available on the web at:

http://epsc.wustl.edu/admin/people/morris/factory.html

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DEVELOPMENT OF NON-VOLCANIC RIFTING IN CONTINENTAL MARGINS AND BACK-ARC BASINS: A COMPARISON OF EVIDENCE FROM LAND AND SEA

Geological Society Lecture Theatre in Burlington House, Piccadilly, London
September 16-17 1999

The objective of the meeting is to bring together those who are studying non-volcanic rifted continental margins both at sea, using geophysics and samples provided by scientific drilling, and on land, where subsequent tectonics has exposed pre-rift and syn-rift rocks. Potentially, this unusual combination will allow the observations and scientific hypotheses of the two, frequently independent, scientific communities to be merged to the greater benefit of both parties. Speakers will come from both the national and international communities. Talks will include both invited and uninvited presentations. Maximum total number of talks will be 24 (ca. 30 minutes each). Half-day or whole-day poster sessions will be encouraged.

Topics to be covered:
ODP drilling on non-volcanic rifted margins (e.g. Legs 149 and 173, West Iberia; Leg 180, Woodlark Basin).
Petrological, geochemical and microstructural investigations of basement cores.
Mapping of exposures of rifted rocks on land (e.g. Alpine exposures of Tethyan margins, islands surrounding Woodlark Basin) and associated petrological, geochemical and structural investigations.
Seismic velocity and magnetic structure of rifted continental margins and marginal basins.
Tectonics of rifted margins and marginal basins from seismic profiles and (P,T, t) histories and structures of cores.
Tectonics of rifted margins and marginal basins from mapping on land (e.g. Alpine exposures of Tethyan margins, Papua New Guinea)
Finite element modelling of rift development
Modelling of decompression melting

Co-ordinators-Organizers: N. Froitzheim (Basel), B. Taylor (Hawaii), R.B. Whitmarsh (Southampton), R.C.L. Wilson (Milton Keynes)
For more information, please contact: *The Geological Society Conference Department*
e-mail: harrisona@geolsoc.org.uk (Amanda Harrison)
Tel: 00 44 (0) 171 434 9944

OCEAN DRILLING FORUM 1998

Edinburgh, United Kingdom
September 19-22, 1998

Programme
Saturday 19th Sept:
Fieldtrip to Ballantrae ophiolites, S W Scotland; leader Phil Stone,
Sunday 20th Sept:
Day off in Edinburgh (Self-guide geological tour available)
Monday-Tuesday 21st-22nd Sept:
Programme of talks and posters

Invited Talks
THEME A: CONTINENTAL MARGINS
North Atlantic Rifted Margins:
R. Whitmarsh, (U.K.)
North Atlantic Volcanic Rifted Margins:
H.-C. Larsen* (ESF)
Mediterranean Basins: M. Comas (ESF)
Slope stability: P. Weaver (U.K.)

THEME B: RESOURCES
Gas hydrates: J. Mienert (Germany)
Beep Biosphere: J. Parkes (U.K.)
Hydrothermal Processes and
metallogenesis: Y. Fouquet (France)
Organic-rich sediments (Sapropels):
J. Rullkotter (Germany)

THEME C: EARTH'S INTERNAL PROCESSES
Spreading Ridge Processes: M. Cannat (France)
Subduction Processes: P. Huchon (France)
Arc-back arc systems: J.-Y. Collot (France)
Large Igneous Provinces: D. Weis (ESF)

THEME D: EARTH'S EXTERNAL PROCESSES
Sea-level change: C. Betzier (Germany)
High Resolution Stratigraphy: E. Jansen (Germany)
Glacial History: J. Thiede (ESF)
Climate Change: N. Shackleton (U.K.)

Current research will also be presented as posters which represent a very important part of the meeting.

For information, contact:
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Joint Convenors:
Alastair Robertson and Julian Pearce

DEEP SEISMIC PROFILING OF THE CONTINENTS AND THEIR MARGINS

Platja d'Aro Conference Centre, Barcelona, Spain
September 20-25, 1998

The Institute of Earth Sciences of the National Research Council (CISC) and the University of Barcelona, on behalf of all Institutions supporting the Spanish ESCI seismic programme, encourage you to attend this biennial meeting on deep profiling and structure of continents following in sequence Cornell/1984, Cambridge/86, Canberra/88, Bayreuth/90, Banff/92, Budapest/94 and Asilomar/96.

Scientific Programme
We invite submission of papers dealing with deep reflection profiling techniques and results that constrain the structure, composition and tectonics of the continental lithosphere. Special topics to be emphasized are:

Intra-Continental collisions.
Rifts, basins and extensional provinces.
Active/passive continental margins.
Transects and syntheses: seismic signatures of Precambrian shields, Alpine versus Variscan orogens in Eurasia,....
Integrated multidisciplinary studies (wide-aperture seismics, earthquake tomography, magnetotellurics,...)
Modeling constraints on lithospheric evolution: lower crust and mantle processes.
Imaging 2-D and 3-D heterogeneities and anisotropy.
Seismic techniques: new developments.
Drilling and reflectivity.
Seismic reflection applications to natural resources and environment.

Both oral and poster contributions are encouraged. Following the principle of these meetings and to stimulate a workshop-like environment, no parallel sessions are planned. Posters are considered a fundamental part of the meeting. They will be on display for the entire period of the symposium, and significant time will be dedicated to poster sessions. Moreover, there will be evening open discussion sessions.
A symposium volume will be published with scientific papers arising from the meeting.

Accomodation and Registration Fees
Estimated costs are about 13000 Pts/person/day in a single room, and 10000 Pts/person/day in a shared double room. Prices include accomodation, all meals and taxes. (Current exchange rate: 150 Pts = 1 US $). Attendance will be limited to about 250 persons. Full registration fee for the symposium payable in advance estimated to be 30000 Pts. This includes the abstract volume, coffee/tea during breaks, participation in all social events (icebreaker party, mid-conference excursion and dinner, final banquet), etc. Shuttle service to Barcelona airport will be assured at the beginning and end of the meeting. Sponsoring funds will be allocated to subsidize registration for students, and for scientists from less-favoured countries.

June, 15, 1998 is the deadline for Abstract Submission, Registration for Symposium and Accomodation at normal (reduced) rates.

Sponsored by ILP, and IASPEI

Meeting contact address:
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Personal Profiles

Andreas Aichinger, Scientific Asst.

Born and raised in Germany, my geology studies took me to the Julius-Maximilians-Universitaet Wuerzburg in 1984. There I received my pre-diploma. From 1986-1987 I spent a year abroad at the University of Hull (UK). Back in Germany I studied at the Christian-Albrechts-Universitaet Kiel where I graduated under the supervision of Prof. Dr. Joern Thiede. My diploma thesis constituted two parts, field mapping and laboratory analysis. I mapped Miocene to recent (Tortonian to Quarternary) sediments from the Mediterranean "salinity crisis" in Sicily, Italy. In the laboratory I worked on a core from the Greenland Sea representing sediments from the last 423,000 years to establish an oxygen isotope stratigraphy and to decipher clim-atic changes in this region. At GEOMAR I wrote my Ph.D thesis on "Development of the mid-Norwegian shelf between 64-65 degree N and 6-8 degree E during the Tertiary: Sedimentology and subsidence analysis". Prof. Dr. Joern Thiede was the supervisor and PI in the "Rifted-sheared margins: Evolution and environment" project. As a part of this project, the German-Norwegian Geoscientific Co-operation Phase II, detailed sedimentological investigations of Tertiary age cuttings from four wells of the Halten Terrace (mid-Norwegian shelf) were completed as was a subsidence analysis. This was a collaborative effort with Statoil and the University of Oslo and Tromsø (Norway). The investigations consisted of grain size analysis, component analysis, and determination of TOC and carbonate content. Accumulation rates were calculated and seismic lines were interpreted in order to get a 3-D understanding of the sedimentology of the study area through time.

In November 1997 I joined the MARGINS Office as the Scientific Assistant to the chairman of the MARGINS steering Committee. I oversee the day-to-day operations of the MARGINS Office, write, edit and distribute this semi-annual newsletter, working group reports, and meeting minutes. I also develop material for the MARGINS website and database and, with the help of Steffi, oversee national meetings logistics, travel arrangements and on-site support.

Steffi Rausch, Administrative Asst.

I was born and raised in the Washington DC metropolitan area. In 1995, I completed my B.S. in Mathematics and Education from the University of Maryland, but chose to pursue a computer career thereafter. After living in Santa Cruz, California for two years and traveling around the world teaching the Army computer skills for their improved recreational facilities, my journeys brought me here to Hawaii on the island of Oahu. Since September of 1997, I have been working for the MARGINS Office. My goal as Administrative Assistant is to continually improve the communication and support services of the MARGINS Office. I maintain our website and produce this newsletter. Other responsibilities include budget management, logistical and travel arrangements for meetings, document production, preparation of materials for meetings, as well as assisting Andreas. In the meantime I enjoy listening and learning about continental margins from the experiences of my geoscientist co-workers.

The deadline for submission of articles to be included in our next Newsletter is:

August 1, 1998

Send via e-mail or the post.

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