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In This Issue:

ODP Leg 205 Explores Active Fluid Flow Across the Costa Rica Convergent Margin to Investigate the Subducton Factory and Seismogenic Zone

LEG 205 SHIPBOARD SCIENTIFIC PARTY
Julie Morris, Heinrich Villinger, Adam Klaus, Dawn Cardace, Peter Clift, Valerie Chavagnac, Toshio Hisamitsu, Miriam Kastner, Marion Pfender, Demian Saffer, Cara Santelli, Burkhard Schramm, Liz Screaton, Evan Solomon, Michael Strasser*

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The character of the incoming plate subducting at convergent margins and the processes affecting it as it passes below the shallow forearc may play a major role in the nature and extent of hazardous interplate seismicity as well as the magnitude of volcanism and the chemistry of lavas produced in the overlying volcanic arc. The fate of incoming sediments and ocean crust, and of their associated volatiles, as they pass through the shallow levels of a subduction zone (0-50 km depth) has profound effects on the behavior of the seismogenic zone, which produces most of the world's destructive earthquakes and tsunamis. Fluid pressure and sediment porosity influence fault localization, deformation style and strength, and may control the updip limit of the seismogenic zone (e.g., Scholz, 1998; Moore and Saffer, 2001). Fluids within both fault zones and sediments underthrust at the trench affect early structural development and are a key agent in transport of chemical species. The mineralogy and chemistry of any subducted sediments and their dehydration reactions during subduction may affect the physical properties of the deeper subduction interface and, hence, downdip limits of the seismogenic zone.

The escape of fluids to the surface from the downgoing plate at depth may support a deep biosphere, contributes methane and higher hydrocarbons for gas hydrate formation, affects seawater chemistry for selected elements, and is intimately linked to deformation, faulting, and the evolution of the décollement. The distillation and loss of some volatiles and fluid-soluble elements from the shallow slab record reactions and processes within the seismogenic zone. They also play a central role in the supply of residual volatiles to the deeper Earth and change the composition of the slab delivered to the depths of magmatism beneath volcanic arcs. Processes operating in the shallow subduction zone thus affect the way the slab contributes to continent-building magmatism, explosive volcanism, ore formation and, ultimately, the evolution of the mantle through time. The subduction signature recorded in the chemistry of arc volcanics constrains the nature and sometimes the volume of the sediments transported through the seismogenic zone to the depths of magmatism. The arc thus acts as a flow monitor for the transport of sediments to depths greater than those that can be drilled or imaged seismically.

Sailing from Acapulco Mexico on September 13, 2002, a team of international scientists joined co-chiefs Heiner Villinger (University of Bremen, Germany) and Julie Morris (Washington University USA) and Ocean Drilling Program (ODP) Staff Scientist Adam Klaus aboard the JOIDES Resolution (See Fig. 1). Leg 205 was intended to investigate active fluid flow in both the subducting plate and along the decollement zone offshore of the Nicoya peninsula (see Fig. 2). A primary goal of the cruise was to install long term sea floor observatories (CORK-IIs) to monitor and sample fluid flow for a period of ~5years.

Central America is a focus area for the U.S. MARGINS program, and is also under intensive study by German scientists. It is an important area for studies related to MARGINS Seismogenic Zone and Subduction Factory initiatives for several reasons. As one of the few modern arcs subducting a carbonate-rich sedi-

Figure 1. Photograph of shipboard science party for Leg 205 in front of re-entry cone. Standing rear: Matthias Haeckel, Paola Vannucchi. Standing Center: Evan Solomon, Marion Pfender, Burkhard Schramm, Liz Screaton, Valerie Chavagnac, Julie Morris, Demian Saffer, Heiner Villinger. Kneeling: Michael Strasser, Dawn Cardace, Peter Clift, Cara Santelli, Moe Kyaw Thu, Toshio Hisamitsu. Seated front: Adam Klaus. Not shown: Miriam Kastner.

ment section, Central America permits study of CO_2 recycling through a subduction zone.

A large body of work also shows that there are differences in seismicity and arc magmatism along the length of the Central American margin that appear to correlate with changing sediment dynamics along strike. The Nicoya section of the Costa Rica margin appears to have Mw = 7 or greater earthquakes at a 40- to 50-year recurrence interval, with the last such event in 1950 (Guendel, 1986). Coupling between the downgoing and overriding plates is estimated from Global Positioning System (GPS) data to be 40%-60% (T. Dixon, pers. comm., 2001) and appears to start ~15 km arcward of the trench. Nicaragua is characterized by a greater frequency of magnitude 7 or larger earthquakes, including the 1992 tsunamogenic earthquake. In detail, the updip limit of seismicity appears to be at ~ 20 km depth north of the fracture zone trace shown in Figure 2 and at ~10 km depth to the south (Newman et al., 2002).

There are also significant changes in volcanism between Nicaragua and Costa Rica, with an offset in the volcanic chain just north of the northernmost Nicoya peninsula (Fig. 2). In Nicaragua, the arc-trench gap is 180-190 km and the volcanoes lie approximately 180-200 km above the Waditi-Benioff Zone of the downgoing slab. In Costa Rica, the arc-trench gap narrows to ~165 km and the seismic zone is approximately 120-130 km below the volcanoes (Protti et al., 1994). Nicaraguan volcanoes tend to be smaller than those of Costa Rica; when averaged over the last 100-130 ka, magma production rates (compiled in Patino et al., 2000) are much lower in Nicaragua than Costa Rica being ~14 and 44 km^3/km arc length per million years, respectively. In the chemistry of the arc volcanics, ^{10}Be data, radiogenic isotopes, and trace element studies of Nicaragua lavas (Reagan et al., 1994; Patino et al., 2000) suggest that the entire sediment section is subducting to the depths of magma generation, producing in the lavas a strong signature from the hemipelagic sediments at the top of the incoming sediment section. In contrast, the Costa Rican lavas have a much lesser sediment signature, little contribution from the uppermost hemipelagic sediments of the incoming plate, and a proportionally larger contribution from the basal carbonate section.

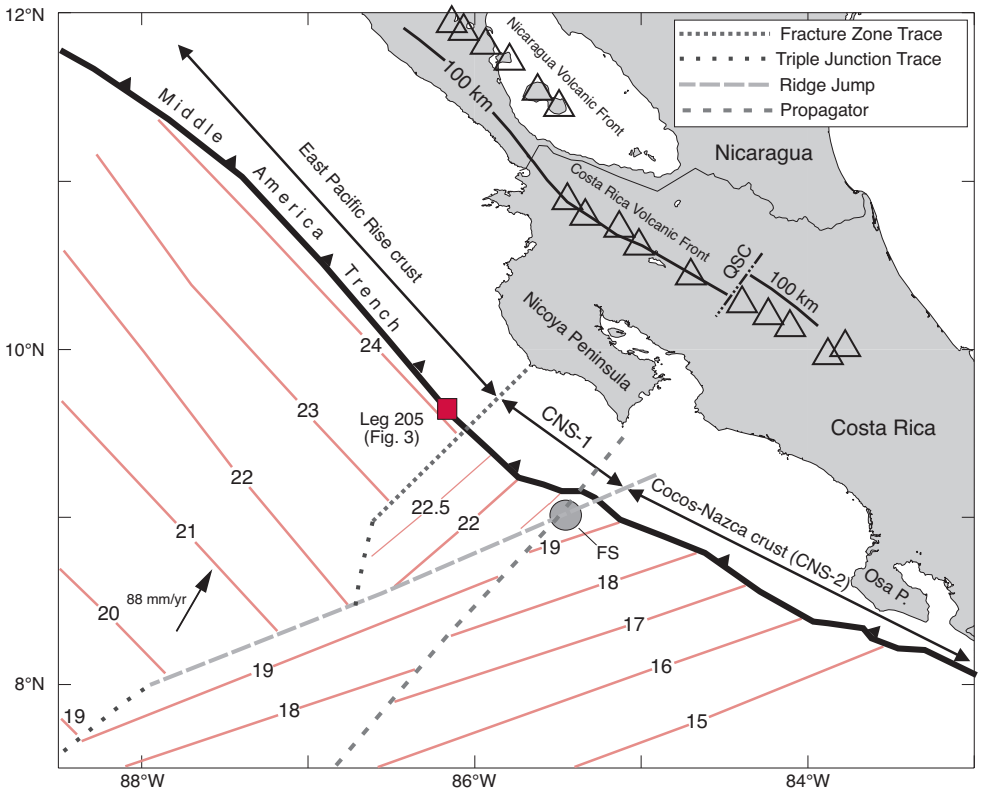

Figure 2. Leg 205 Costa Rica drilling area (red box) and isochrons derived from seafloor magnetic anomalies (Barckhausen et al., 2001). Numbers indicate crustal age in million years. Tectonic boundaries, convergence direction and rate (arrow; de Mets et al., 1990) as well as arc volcanoes (triangles) are shown. Note offset in volcanic arc between Nicaragua and Costa Rica. FS = Fisher Seamount, QSC = Quesada Sharp Contortion.

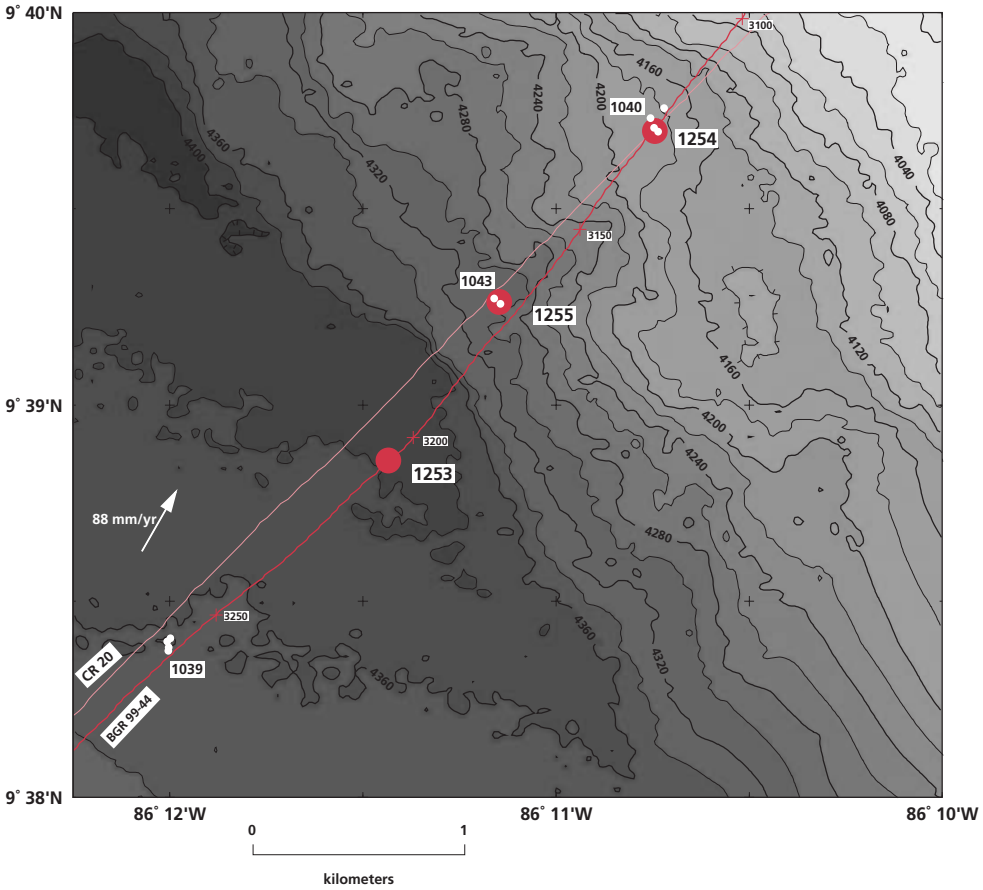

Figure 3. Bathymetric map of the Leg 205 drilling area showing Leg 205 (Sites 1253-1255) and 170 (Sites 1039-1043) drill sites. Location of seismic lines are shown by the red (BGR-99-44; C. Reichert and C. Ranero, pers. comm., 2001) and white (CR-20; Shipley et al., 1992) lines. Numbers along the BGR 99-44 seismic line are shotpoints. The white arrow gives the convergence direction and rate (88 mm/yr; de Mets et al., 1990). Location of map is shown in Fig. 2; bathymetric contours are in meters.

Science objectives for Leg 205 (see Fig. 3) translated to two primary foci, both related to seismogenic zone and subduction factory questions. The first was to characterize and monitor two of the three hydrologic systems inferred from Leg 170 drilling (Kimura, Silver et al., 1996): in the igneous section of the subducting oceanic plate and across the decollement zone. The second was to determine the igneous and alteration history of the uppermost part of the down going plate at reference Site 1253, along with the inferred distribution of fracture permeability in the core and borehole. During Leg 205, we carried out targeted coring and logging at the reference Site 1253 on the incoming oceanic plate, and installed a CORK-II. Inboard of the deformation front, we cored a thrust fault within the prism and the decollement zone at Site 1254. Attempts to install a CORK II at this site failed, due to a combination of operational problems and hole conditions. A CORK-II was successfully installed in the decollement zone at Site 1255, 0.4 km inboard of the deformation front.

Figure 4. CORK HEAD. The "CORK" head is the last piece to be attached above the screen, packer, and casing. The head contains the pressure sensors and data loggers. It also has valves and a data port that can be operated by a submersible or remotely operated vehicle. The "CORK" head will fit into the reentry cone on the seafloor to seal, or "cork", the borehole; the sensors will be down in the sealed hole beneath it.

In the vicinity of Site 1253, both heat flow data and the chemistry of porefluids sampled from deep sediments suggest that there is extensive flow of cool fluids in the basement of the incoming oceanic crust, created at the East Pacific Rise at ~ 24Ma. Heat flow in the Leg 205 vicinity (Langseth and Silver, 1996, TICOFLUX I and II, METEOR Cruise 54-2) averages about 30 mW/m^2, about 1/3 of the expected value from lithospheric cooling (Stein and Stein, 1992) and increase to an average value of about 110 mW/m^2 south of the Fracture Zone Trace (See Fig 1). Plates north and south of the FZT have approximately the same age so one would expect them to show similar average heat flow. That the crust north of the FZT is significantly cooler implies that a substantial amount of its heat is probably being removed by fluid circulation within the crust. The more recent cruises show a complex distribution of local heat flow highs and lows within each region, which provide information for eventual detailed modeling of the flow systems and their driving forces.

Pore fluid chemical profiles determined shipboard also suggest extensive fluid flow at depth beneath reference Site 1253 on the incoming plate. Variations in Ca, Sr, Li, H_4SiO_4 and SO_4 concentrations in porefluids sampled from calcareous sediments at depth were observed at Site 1253. In all cases, concentrations in

basal sediments change towards values typical of modern seawater (Morris, Villinger et al., 2003). Similar patterns for Leg 170 samples are also observed; $^{87}Sr/^{86}Sr$ isotopic compositions for Leg 170 samples (not yet available for Leg 205) deviate from values expected from the paleo-seawater curve and trend towards modern seawater compositions at depth (Silver et al., 2000).

At Site 1253 on the incoming plate, we cored 230 meters, including ~170 m within two igneous units, where the upper is a 30 m thick sill with sediments above and below. We also logged up to 150 m, primarily in the lower igneous section, and installed a CORK II long-term seafloor observatory. The lower igneous unit may be an exceptionally thick sill composed of multiple intrusions, or a series of often thick and slowly cooled lava flows of oceanic crust created at the East Pacific Rise, similar to those encountered on ODP Leg 206 (Teagle, Wilson et al., 2003). Core descriptions showed that the section is more extensively altered and fractured below about 510-513 mbsf, while logging results confirm greater fracturing imaged in the borehole walls.

A CORK II was installed at Site 1253, with temperature probes and osmotic fluid and gas samplers at 497-504 mbsf and also at 512-519 mbsf (See Fig. 4 and 5, and Jannasch et al., 2003). Pressure monitoring is within the upper OsmoSampler zone, and above the packer at ~453 mbsf. The osmotic samplers (Teflon tubing for fluid analysis and copper tubing for gas analysis) use osmotic membrane pumps to recover borehole fluids that are pushed progressively further along the sampling coils with time. Submersible dives in 2004 (to be led by Miriam Kastner, Earl Davis and Heiner Villinger) will recover the osmotic samplers and install a new set designed to operate for ~4 years. The dives will also recover and replace temperature loggers and download pressure data from the CORKs. An Alvin dive in November 2003, by Keir Becker, showed the CORK installation to be operational. Ideally,

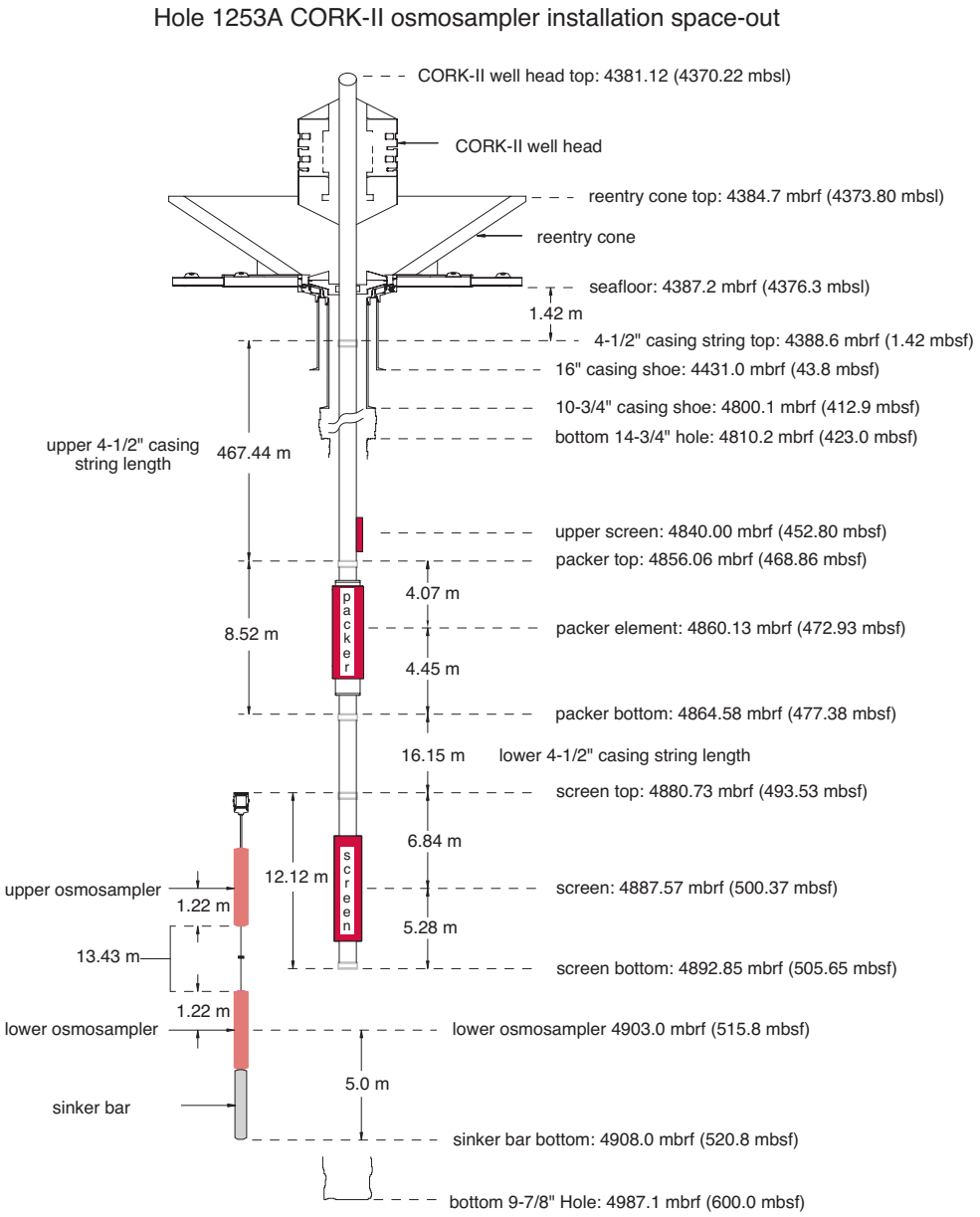

Figure 5. Fig. 5) Schematic for Hole 1253A CORK-II installation showing subseafloor depths for osmotic water samplers, screens, packers, and casing strings. This figure is not to scale.

upon recovery in 2004, the pressure and temperature loggers will show borehole recovery from drilling perturbations and the fluid and gas compositions will show transition to seawater compositions modified by water:rock interactions.

Inboard of the deformation front, drilling at Site 1254 in the prism cored through a thrust fault zone at ~197-219 mbsf and the decollement zone at 338-365 mbsf. Despite drilling disturbance it is possible to see that deformation, particularly brecciation and brittle shearing, generally increase downward in both zones, but with concentration of shear along specific horizons. Anomalously high concentrations of thermogenic hydrocarbons (including ethane, pentane and hexane) in the gases and sediments, and unique pore water chemistry (elevated Li and Ca, decreased K) are seen within both fault zones, indicating advection of exotic fluids, possibly along sandy horizons showing brittle fracture within

the fault zones. The porefluid geochemistry suggests that some fraction of the fluids derived from regions with temperatures >90-100 ℃, or possibly higher. The base of the décollement lies within the uppermost part of the underthrust section at Site 1254, as opposed to between the prism and underthrust sediment at Leg 170 Site 1040, 50 m away. Several attempts were made to install a CORK-II at Site 1254, twice into the decollement zone, and once into the shallower thrust fault. All failed due to a combination of operational difficulties and hole conditions.

At prism Site 1255 ~0.4 km inboard of the deformation front, we carried out very limited coring to identify the decollement zone and installed a CORK-II into the plate boundary fault. The base of the decollement was placed at 144 mbsf and corresponds to the lithologic boundary between prism and underthrust sediments. The chemical signature of deeply sourced fluids was observed just above the decollement, but is weaker than at Site 1254. The CORK-II was installed successfully, with the packer centered at 129 mbsf and the Osmo-Sampler centered at 140 mbsf, along with a temperature logger and pressure monitoring screen. This deployment also included an Osmo-flow meter located below the Osmo-Samplers for fluids and gases (Jannasch et al., 2003). Injecting iodate, Rb and Cs at a constant rate into the incoming fluids, which are also sampled osmotically, their concentrations in the analyzed fluids will constrain flow rates. With flow rates and fluid compositions, it should be possible to determine fluxes of elements such as B, Li, U, K, Ca out of the downgoing plate. With a central injection port surrounded by four sampling ports, it may also be possible to elicit information about flow directions. This installation was also visited by Alvin in November 2002 and is fully operational.

For additional information, the reader is referred to the Preliminary Report for Leg 205, currently available on the ODP website: **www-odp.tamu.edu/publications/prelim/205_prel/205toc.html**.

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From the Chairman's Desk: Spring 2003

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It seems only a short time ago that our "baptism by fire" was upon us as we frantically organized the Puerto Vallarta and Sharm el Sheik workshops while assembling the Lamont MARGINS Office. That was 3 years ago and on the 9 May, 2003, we bade farewell to Joan Basher as she and her husband Reid prepared to move to Geneva, Switzerland. Olaf Svenningsen and I (on behalf of the Steering Committee) wish them well and thank Joan for her good kiwi wit and hard work for the MARGINS community over the last 3 years — it was much appreciated. The dismantling of the Lamont MARGINS Office has begun.

The Fall-Spring period of 2002-2003 has been extremely busy for the MARGINS Office, with the running of a number of important workshops and theoretical institutes and preparing a series of files and documents to help with the transition of the MARGINS Office from New York to Saint Louis. The transition will occur over a three-month period between July and September, with the Saint Louis office taking full control of the MARGINS Office on the 1 October, 2003. Efforts are also underway to publish all of the revised, revamped, and updated science plans. Although the science plans are clearly dynamic documents, NSF considers it important to publish the these documents, both to define the present-state and successes of each initiative, but also to provide documents for internal NSF purposes and funding issues.

I would also like to thank Chuck Fisher and his RIDGE 2000 staff (Liz Goehring, Sharon Givens, and Patty Nordstrom) for their invitation and hospitality during the recent R2K steering committee meeting in Whistler, Canada, 17-18 April, 2003. The task was to give an overview of the MARGINS program, discuss the procedures of how the MARGINS community selected focus sites, and the database aspirations of the MARGINS program. Given the significant overlap between MARGINS and RIDGE database requirements, such a meeting is very important in opening dialogue and exploring common links and goals between the two programs.

The MARGINS Budget

The FY03 budget for MARGINS was $6.15M and while this number is a slight increase compared to last year's budget, the growth of the MARGINS budget remains slow and out of proportion compared to the cost of the excellent science being proposed. The situation will be exacerbated during FY04 as RCL-northern Red Sea and S2S-Waipaoa compete for funds, along with the other focus sites, as they attempt to generate the necessary geological and geophysical frameworks for their subsequent research. NSF-EAR has restated its goal to be an equal fiscal partner in the MARGINS program and hopefully with their new injection of funds this year, their goal may be realized in 2003-2004. An extra $0.75M-1M input to the annual MARGINS budget would be a very welcomed addition. The present proposal success ratio within MARGINS in the last round was 40%, with proposals being funded in all initiatives. I am very happy and proud to announce that proposals were funded in the northern Red Sea RCL focus site for the first time, a momentous event given the immense political instabilities generated by the Iraqi war and recent terrorist activity within Saudi Arabia. Congratulations to Gomaa Omar, Daniel Stockli, and Robert Reilinger.

A first major step of MARGINS towards education and outreach was established this year by the successful implementation of the MARGINS post-doctoral fellowship scheme. We are very pleased to announce the awarding of three fellowships in our first year. Details of the proposed work and general information about the successful applicants are presented later in this newsletter (page 19).

I would also like to take this opportunity to clarify the "rude awakening" experienced during FY02, the first year where MARGINS had significant ODP-related shipboard programs, when $1.4M of our budget was spent on ship operations as opposed to being dedicated to research activities. In general, University-National Oceanographic Laboratory System (UNOLS) ship operations are paid for by NSF-Ship Operations. Any proposal using a non-UNOLS ship, such as for example, a small Australian or New Zealand vessel for coastal research, the ship costs need to be included in the proposal budget. However, for those MARGINS proposals funded (or partly funded) by NSF-ODP, then ship costs are borne directly (or proportionately) by the MARGINS program.

Marine Mammals and the MARGINS Program: An update

Following the shock to the marine scientific community over the court injunction that brought academic seismic work to a near halt late last year, there is particularly good news to report in terms of the issues involving the Marine Mammals Protection Act (MMPA), the R/V Ewing, and the lawsuit between the National Science Foundation and the Center for Biological Diversity (CBD). In short, the lawsuit has been settled, at least for the short term, and is the subject of a detailed article by Jim Yoder in this issue of the MARGINS newsletter (page 14). The settlement will allow NSF-funded researchers to continue to use seismic sources aboard the R/V Ewing, the key US research vessel for the field of ma-

Figure 1. The Anatahan eruption, a 40,000' ash cloud, on May 10, 2003. Photo courtesy of Allan W. Sauter.

rine seismic research. This is very welcomed news for the MARGINS program.

Event Response Plans

The MARGINS program, having made a commitment to studying active systems, has always recognized the importance of having a strategy for event response, since even "active" systems may be only intermittently active. The earth sciences community had contingency plans in ready to respond to volcanic eruptions and earthquakes. Other events relevant to MARGINS for which response strategies are required include major storms that modify the sedimentary environment on continental shelves, and floods that alter the shape of rivers, deltas, and landforms. However, to date, such natural events, and thus event responses, had not presented themselves within the timeframe of either the Hawaii or Lamont offices — but that was all about to change!!

Anatahan volcano erupted at about 9:00 GMT on May 10, 2003. The eruption was observed from a small ship deploying seismographs for the MARGINS Mariana Subduction Factory project (Doug Wiens, Chief Scientist). A helicopter sent out by the CNMI emergency management office reported an ash cloud reaching to about 40,000 ft. The eruption continued on May 12. The island was visited by the SubFac team on May 6 and there were no indications of an eruption at that time.

Based on budget information from Doug Wiens and recommendations from the SubFac community, the MARGINS Office organized an event response plan for volcanologists Toby Fischer (UNM) and David Hilton (UCSD) and geophysicists Allan Sauter and Juan Camacho to visit Anatahan to deploy a telemetered seismometer, repair the SubFac project seismometer, and collect ash, flows, pumice, and bombs from the Anatahan eruption.

Figure 2. Our intrepid SubFac researchers. Front left to right, Toby Fischer, David Hilton, and Juan Camacho.

The telemetering of seismic data to the ship was imperative and essential to conducting on-island operations in addition to determine the eruptive state of the island. From the ship, the group set up the COSPEC instrument and conducted a traverse through the plume. The telescope was oriented vertically and the ship made a north-to-south transect through the volcanic plume at a distance of about 1.5 km from shore. Once the Anatahan samples arrive on the US mainland, an intensive analysis program has been organized by Jim Gill, Julie Morris and Terry Plank. An AGU Fall 2003 special session is being arranged to present the volcanologic, geochemical, and petrologic analyses of the Anatahan samples and the tectonic implications of the seismic data collected during the eruptions.

The MARGINS Steering Committee

Two people rotated off the committee during the Fall, 2002 semester. The committee would like to take this opportunity to thank Marc Hirschman and Joann Stock for their unselfish contribution of time and effort to the steering committee and the Earth Scientific community. Marc and Joann both provided sound judgment and advice during the deliberation of a range of committee and community issues, most importantly on the fellowship and data policy documents. The committee also recognizes the significant contributions Marc and Joann made to their communities (SubFac and RCL, respectively) by being co-authors on a number of workshop proposals and taking the lead on contributing and revising their respective science plans. We are indebted to both of them for their untiring efforts.

Data Management of MARGINS Geologic Data, with Emphasis on Efficiency, Quality Control and Data Integration

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Summary

Data management is more than a safekeeping and then retrieval of the original data. The strongest benefits from management of geologic data will accrue to MARGINS when the many separate datasets can be combined and used to create integrated datasets at a wide range of spatial temporal scales, for purposes that stretch across disciplines, and that are convenient for researchers to use. The data need to be usable, not just available.

The Idea of Integration

The data collection methods which are used by investigators in the marine geological science programs of MARGINS are diverse. They have to be, because they investigate the range of known geologic processes in many different settings, for geologic materials from liquid to soft sediment to rock, in biogenic/volcanic/terrigenous settings, and for a range of ultimate project goals. Many different collection devices have to be used, and many descriptive and measurement technologies are employed. But this diversity presents challenges for the management of the data; not so much in the data storage and retrieval (which is conceptually straightforward in spite of attribute diversity), but in the issue of bringing this data into a form where integrated scientific products can be made. By integrated science products, I mean datasets that can be merged without intensive manipulation, large and useful information sets formed by combining smaller datasets, and visualizations / grids that are readily importable into applications like GIS.

Integration of data sets is a prime reason why we wish to have data management systems. (i) It allows us to merge datasets for a greater common benefit. Data from many small campaigns becomes useable at spatial scales, time ranges and resolutions different from those of the original studies - a goal which is key to the earth-system research goals of programs like MARGINS. And the data can be 're-purposed'.

(ii) Data which is integrated in one convenient-to-use form, can also help individual studies - for instance to develop sampling strategies, provide the environmental context of a local experiment, and enable the validation of models.

Integration of data is also a key to NSF's important goals of encouraging cooperative and inter-disciplinary science (NSF 2002), growing and exploiting synergies in research, and forwarding results to the community at large — especially to education. European science planners express the need to make integrated data available as a "provision of essential services", like a nourishment of science or supply of water and electricity to a town. In both views geologic data from MARGINS ought to be freely and conveniently available to scientists of sister disciplines (geophysicists, ecologists, biochemists, oceanographers) and also to community educators and decision makers.

The State of Play

Unfortunately, geological data has resisted digital integration while other sciences have streaked ahead in joining their results to global scale models and community debates about the environment. The Smith and Sandwell (1997) bathymetry compilation brought an earth sciences dataset into use in a multitude of other fields, (e.g., into biodiversity informatics; OBIS, Ocean Biogeographic Information System, **www.iobis.org/**). The World Ocean Atlas (Levitus et al. 1994) is another integration that has immense application through science. Both these, however, were built largely of machine derived, relatively well disciplined data — like data from bank ATM's.

By contrast, scientists still face a dauntingly complex and time consuming task just to merge the geologic datasets from successive expeditions in one region. Digital data integrations of say, descriptive and measured observations, of laboratory and probe device datasets, or across neighbouring terrigenous and carbonate systems are hardly ever made — even though MARGINS is intended to discover and address big-scale, long-epoch factors of the earth's geobiosphere.

How difficult it is for researchers to combine MARGINS type data, let alone integrate it, can be appreciated from visiting present online databases (e.g., AWI and MARUM 'Pangaea', **www.pangaea.de**/, Dittert et al. 2002; NGDC 'World Data Center for Marine Geology & Geophysics', **www.ngdc .noaa.gov/mgg/geology/geology.html**; LDEO 'PETdb', **petdb.ldeo.columbia .edu/petdb/**, Haxby 2002). These structures have commendable presentation, content of data, and software stability, but it would be very difficult for researchers to generate an integrated regional dataset from them for organic carbon values, sedimentation rates, or even grainsizes. High levels of skill in data manipulation would be required, levels which most research geoscientists do not have. In some systems data is rendered variously in columns of XY Z A, Z {XY} A, Z A{XY}, Z A1{XY} A2{XY} and other arrangements (where: XY is site location, Z subottom depth, A attribute, {} means implicit or held in metadata). There is variety also in the row arrangements, and vital details — like descriptions of the materials under analysis — are often held in a miscellany of metadata. To download and combine such data, investiga-

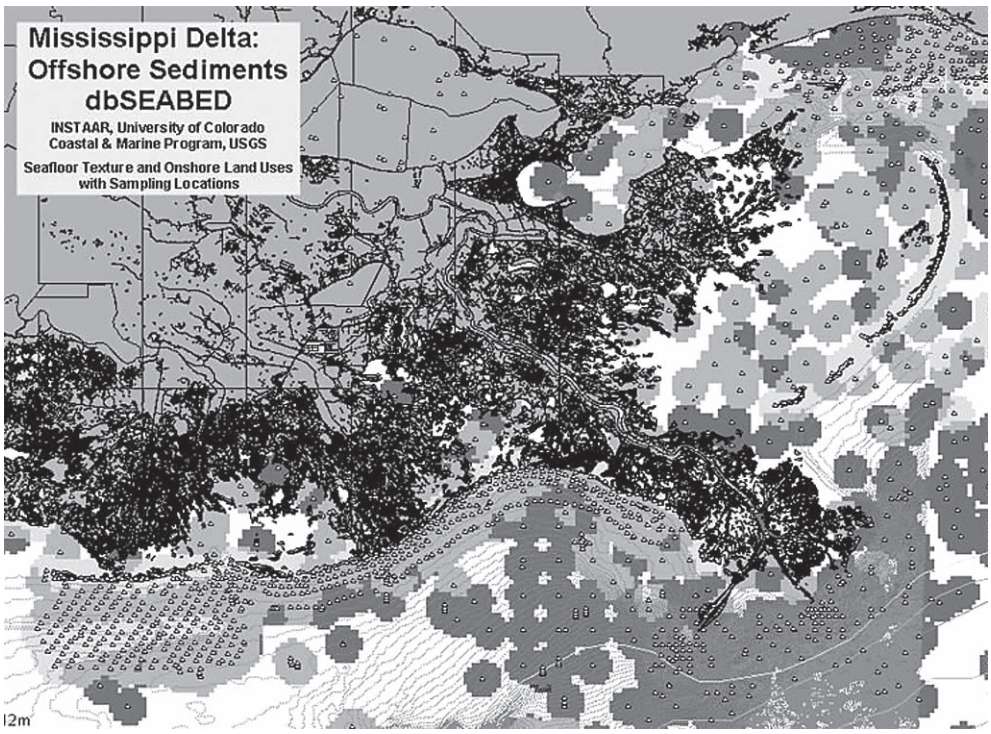

Figure 1. Interactive mapping of seafloor properties surrounding the Mississippi Delta - an integrated data management product highly relevant to MARGINS programs, especially Source to Sink. The full colour version is online (Jenkins et al. 2002). This coverage integrates over 26 datasets into a product that may be used easily by researchers and the public. The characteristics of marine sediments such as sand bars are visualized alongside onshore data layers that show land use, patterns of subsidence / flooding and geology.

tors will need to transpose tables, cut and splice rows/columns, merge in data held as metadata, sort on XY or Z and transform units. This will have to be done dataset by dataset, perhaps in each case with a complex combination of manipulations. Systems with this design - which may have thousands of datasets on one issue, like organic carbon - are not a great advance over a data warehouse where data in every conceivable form is stored and retrieved more-or-less as lodged by a multitude of independently-minded researchers.

Achieving Data Integration

Devising data management methods to overcome these problems and achieve full and rich integrations of geologic data is the focus of a long-term, multi-institutional project based at INSTAAR in the University of Colorado but also involving the USGS, NGDC and The Universities of Kansas and Sydney (Australia). This new approach to geologic data first performs orthodox data management requirements in the sense of storage and retrieval: it produces standard relational database (RDB) structures of the original data. But it does this within a process that also integrates the geologic data which then becomes ready-to-use in Geographic Information Systems (GIS) plotted as maps and sections, in RDB, and in many other applications. The process is mostly automated and has a range of quality control tools built in to that automation. Ready-to-use products include: large unified datasets to support statistical and other analyses; graphical core logs to superimpose on geophysical profiles; and spatially gridded values or parameters capable of being dynamically ported as inputs to numerical models. The system has accomplished detailed mappings of the US (Williams et. al. 2003) and Australian EEZ's, and holds nearly 1 million attributed samples worldwide. A significant feature of the system is that the fundamental 'raw' data is held in a primitive form, not in vendor-specific software, but in an ASCII tree-structured core-log format. Since that layout is commonplace in geologic data it is efficient for data import, and is readable by humans - a whole dataset at a time. The data is then brought into a relational database structure algorithmically. The efficiency of this structure for data import with quality control is extremely high. A key point is that rather than data being manually entered into tables, which is costly and prone to human error, this system minimizes human intervention on contributed datasets at import and can import in bulk. A second key point is that new datasets are immediately 'worked' — tested against automated quality filters and the outputs are made available immediately for visual inspection by attribute and location, and in comparison to nearby and overlapping datasets. Both the machine and human error detections are acted upon (corrected or flagged) in the basic data and in the metadata which is held directly with the data to which it refers.

A Great Divide Bridged

Probably the greatest divide in geological data has been that between measured numeric and descriptive word-based data. Whether we view ODP datasets or NOAA estuarine surveys, the bulk of data is still descriptive and word-based: grain counts, lithology, consolidation, odor, mesoscale structures, texture and fabric, etc. Word based data has many virtues relative to numeric, it is often more accurate (applies to whole of sample, not a small laboratory aliquot), is independent of technique (e.g., spans whole range of consolidations, shear strength instruments measure in certain ranges), and for facies is an extremely rich information source (e.g., biogenic components and

cements). The criticism of word data being more vague (less precise) than numerics is correct, but well proven mathematical techniques now exist to convert word data into numerics, using fuzzy set theory. This opens the way for splicing word based data in with numeric data - an exciting avenue for geological synthesis.

Although word-based data can be held in relational databases and queried, it has not been possible (or at least very expensive) to have an algorithmic parser set up inside these commercial software packages and applied to geologic data types with a geologic thesaurus. But we have built an algorithm which works very well on the primitive data, with accuracies comparable to those of laboratory grainsize measurement. This conclusion is based on calibrations using instances (samples) where numeric and word data are available for the same attribute (e.g., grainsize).

Data Mining

One of the great advantages of integrated databases is that fortuitous cases (like replicate and related measurements) in the bulk of data can be exploited to discover if there are internal relationships that can be used to improve the information arising from a database. This is data mining, where we learn about the parameter inter-relationships from helpful parts of the data sets, then apply inverse relationships to bring them into conformance. (Note that query operations no matter how complex, are not data mining.) For example, the moment, graphical (Inman, Folk and Ward) and engineering measures of grainsize and sorting which have divided geologic data can be reconciled in many cases - once relationships between them are established.

Uncertainty is not often reported in geologic data but is crucial if our results are to be taken up for decision making — in global change issues for instance. Data mining can also be used to find out, then attach uncertainty values to data. This may be done by comparing replicates or related values, as above, so that error analyses can be made. But even more importantly, integrated collections of quality controlled data provide exciting new opportunites for advanced statistical analysis of whole sedimentologic systems. Recently we obtained, in batch, measures of seafloor patchiness (spatial heterogeneity) across all zones of the US Atlantic continental margin from coastal to abyssal. Those results have two applications: (i) biologists now have a source of data from geosciences on marine habitat heterogeneity and which can be applied in landscape ecology and studies of adaptation, (ii) that geologists can attach quantitative spatial uncertainty values to interpolated maps and griddings as well as point measurements like cores.

Conclusion

The aim of data management is not only to safeguard public investment in data, but also to make that data available to address newly arising issues in science and society. The data must be integrated so that requests for geologic data can be met with timely, comprehensive and coordinated responses. Storing and echoing geologic data from relational databases or other structures is certainly data management, but the 'cudos will really only come when ready-to-use integrated products become publically available.

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MARGINS Theoretical Institute
The Seismogenic Zone Revisited — SEIZE 2003

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Subduction zones generate the world's largest and most destructive earthquakes, most of the world's tsunamis, and most of the world's explosive volcanoes. They are also the sites where much of the world's population is concentrated (the coastal zones) and, over geologic time, where most of the earth's continental crust and mineral resources are generated. NSF's MARGINS program includes the Seismogenic Zone Experiment (SEIZE) to study the shallow subduction plate interface that is locked and accumulates elastic strain, periodically released in large or great earthquakes. The scientific rationale for these studies was originally outlined in the SEIZE science plan, posted on the MARGINS website (**http://www.ldeo.columbia.edu/margins**), based on a workshop held in Hawaii in 1997.

SEIZE 2003

www.ldeo.columbia.edu/margins/SEIZE/ti03.html

The MARGINS program officially began in 1998, and has provided funding for focused studies in the Nankai Trough and Central America, and elsewhere. A re-evaluation of key science issues related to SEIZE based on this and other research, and planning for future studies, occured at the second MARGINS Theoretical Institute, held at Snowbird, Utah, Match 16-21, 2003.

Figure 1. The Theoretical Institute was held at the Cliff Lodge in Cottonwood Canyon, Snowbird, UT. The Wasatch Mountain Range offered a spectacular setting for the meeting.

78 researchers from 10 countries attended the institute. Formal presentations covered topics as diverse as the nature of subduction zone seismicity, seismic vs aseismic slip, fast vs slow rupture and tsunami earthquakes, geologic structure and physical properties of seismogenic zones, the role of fluids, permeability and pore fluid pressure, fluid chemistry, the impact of sediment-starved vs sediment-clogged trenchs, the nature and meaning of transient deformation events in subduction zones as recorded by GPS, and long term mountain building.

There was ample time for discussion of the formal presentations, and based on this, participants formulated a series of critical questions for future research:

1) What controls the overall distribution of seismic energy release during a subduction zones earthquake (up, down, and along strike). Is there one P-T-composition condition that defines the onset and down dip limits, or do these vary with material properties and fault geometry in the subduction system?
2) What are asperities, and do they have any long term significance? What controls the sometimes heteroge-

Figure 2. The Theoretical Institute registration and information desk was professionally run by Joan Basher, here awaiting participants arrival together with Brian Taylor, former MARGINS Chair.

neous distribution of locking patterns on the plate interface and subsequent variations of energy release on the seismic energy? Are asperities linked by common physical processes within the fault region or governed by separate, unrelated phenomenon? Do they vary in time, and if so, over what time scale?

3) What controls the rate of propagation and slip rates of earthquakes and the distribution of fast, slow, tsunamigenic, and silent earthquakes in time and space?
4) What is the nature of temporal changes in strain, fluid pressure and stress during the seismic cycle. Do these change gradually during the seismic cycle or are there transient interseismic phenomena that lead to strain and energy release at various times during the seismic cycle.

Figure 3. Scenes from the meeting (clockwise from upper left): Eli Silver opens a session for a full meeting room; Tim Dixon and Kevin Brown leading an afternoon discussion session; Chris Marone starts his presentation with musings over suitable (and unsuitable) acronyms for the SEIZE focus initiative, and; intense discussions during poster viewing.

A book to be published by Columbia University Press, consisting of review articles by leading scientists in the field and covering key SEIZE-related topics, in part based on presentations at the meeting, is planned for publication in 2004.

The MARGINS Office maintains a meeting website (URL below) with documents and information pertaining to the SEIZE 2003 Theoretical Institute. Most of the Powerpoint presentations from the talks, selected posters as PDF files, information about the progress of the publication of the book, a list of participants, and the abstract volume as a downloadable PDF document are among the information posted on the website. Below, the contents of the abstracts volume is printed. Please refer to the website for the most up-to-date information.

The SEIZE 2003 Theoretical Institute website
http://www.ldeo.columbia.edu/margins/SEIZE/ti03.html

Abstract titles from SEIZE 2003 (full texts available at website)**:**

- **Evolution of physical properties of the Nankai Trough plate-boundary thrust from the trench into the seismogenic zone inferred from 3-D seismic images** (Nathan Bangs, Tom Shipley, Sean Gulick, and the Nankai 3-D seismic working group)
- **Comparison of earthquake focal mechanisms and source processes between Nicoya and Osa Peninsulas, Costa Rica** (Susan L. Bilek, Heather DeShon, Susan Y. Schwartz, and Andrew V. Newman)
- **Issues and Opportunities in Seismic Reflection Imaging of the Sub-Continental Seismogenic Zone: Results of Reflection Modeling** (Larry D. Brown, and Amy Kwiatkoswki)
- **Coseismic, postseismic and interseismic deformation along the Kamchatka subduction zone** (Bürgmann, R., Kogan, M.G., Levin, V.E., Scholz, C.H., King, R.W., and Steblov, G.M.)
- **Measuring seafloor deformation across the Nazca/South America Plate convergence offshore Peru: Imaging the up-dip limit** (C. David Chadwell, Edmondo Norabuena, John Hildebrand, Fred Spiess, Tim Dixon, Seth Stein)
- **The evolution of the forearc Sandino basin: off Nicaragua sector of the Pacific convergent system** (Central America) (K. McIntosh, I. Ahmed, C. Ranero, B. Taylor, P. Costa Pisani and E. Silver)
- **Hydrodynamic Response of Subduction Zones to Seismic Activity: A Preliminary Study for the Costa Rica Margin** (Paula A. Cutillo, Shemin Ge, and Elizabeth J. Screaton)

- **Comparisons between seismicity and fluid flow behavior along the western Costa Rica margin** (Heather DeShon, Kevin Brown, Susan Schwartz, Mike Tryon, and LeRoy Dorman)
- **Seismic Attenuation in the Subduction Zone of Costa Rica** (LeRoy Dorman, Allan Sauter, Susan Schwartz, Heather Deshon, Andy Newman, Marino Protti, Sue Bilek, Ernst Flueh, Tim Dixon)
- **The Seismogenic Zone Along the Alaska-Aleutian Trench** (Jeff Freymueller, Chris Zweck, Steven Cohen, Sigrun Hreinsdottir, and Hilary Fletcher)
- **Along strike variability in the seismogenic zone and thermal models of subduction below the Nicoya Peninsula, Costa Rica** (Robert N. Harris, Andrew V. Newman, and Kelin Wang)
- **Secular, Transient and Periodic Crustal Movements in Japanese Subduction Zones, and Dynamics Underlying Them** (Kosuke Heki)
- **Images of Seamount Subduction Beneath Nankai Margin** (P. Henry, V. Martin, S. Lallemant, M. Noble, S. Kuramoto)
- **What We Know about Subduction Thrust Faults** (R.D. Hyndman)
- **Variations in Basement Topography and Sediment Thickness on the Philippine Sea Plate Subducting Along the Nankai Trough** (T. Ike, J-O. Park, G.F. Moore, Y. Kaneda)
- **Deformation in granular aggregates: Implications for strength of porous rocks and shear within fault zones** (Stephen L. Karner)
- **Comparative study on exhumed seismogenic faults and modern Nankai seismogenic megathrust** (Gaku Kimura, Arito Sakaguchi, Kohtaro Ujiie, Airaro Kato, J-O Park, Yujin Kiramura, Eisei Ikesawa, Masayuki Matsumura and Yoshitaka Hashimoto)
- **Very focused expulsion of pore fluid along the western Nankai accretionary complex detected by closely-spaced heat flow measurements** (Masa Kinoshita, Shusaku Goto, Sean Gulick, Hitoshi Mikada, KR02-10 Shipboard Scientific Party)
- **Continental deformation in the Central Andes controlled by changing subduction parameters and geologic inheritance** (Jonas Kley)
- **Partitioning of Seismogenic Strain in the Offshore Costa Rica Forearc** (Jonathan C. Lewis and Susan Bilek)
- **Seismogenic Strain at the Costa Rica Convergent Margin** (Jonathan C. Lewis and Allan Lopez)
- **Possible Forearc Sliver at the Lesser Antilles** (Alberto M. López and Seth Stein)
- **Fault Friction and the Transition From Seismic to Aseismic Faulting** (Chris Marone and Demian Saffer)
- **Characteristics of the Nicaragua convergent margin and their possible influence on seismicity and tsunami generation** (Kirk McIntosh, Imtiaz Ahmed, Eli Silver, Arnim Berhorst, Ernst Flueh, and Cesar Ranero)
- **Relationship of Fluids and Deformation at Seismogenic Depths: Structural Study of the Rodeo Cove Thrust Zone, Marin Headlands, California** (Francesca Meneghini, J. Casey Moore)
- **Evolution of a ductile shear zone in the down-dip continuation of the seismogenic zone** (Laurent G. J. Montési and Greg Hirth)
- **Factors Controlling the Frictional Strength of Sheet-Structure Minerals** (Diane E. Moore and David A. Lockner)
- **Summary of ODP Leg 190 results in the Nankai Trough** (G.F. Moore, Asahiko Taira, Adam Klaus)
- **Consolidation State and Overpressures Within the Underthrust Section, Nankai Accretionary Margin: Results of Uniaxial Reconsolidation Experiments** (Julia K. Morgan, and Maria V. S. Ask)
- **Splay Fault Branching Along the Nankai Subduction Zone** (Jin-Oh Park, Tetsuro Tsuru, Shuichi Kodaira, and Yoshiyuki Kaneda)
- **Mapping the plates interface from the trench to the maximum depth of the Wadati-Benioff Zone under Costa Rica** (Marino Protti, Victor González, Susan Schwartz, Andy Newman, Heather DeShon and LeRoy Dorman)
- **Seismic imaging of the megathrust in Central-Southern Costa Rica** (Cesar R. Ranero, Roland von Huene, Soenke Neben, Udo Barckhausen)
- **Relative relocation of intermediate depth seismicity: A double Wadati-Benioff Zone below the Central Andes** (Andreas Rietbrock, and Felix Waldhauser)
- **Contrasts in veining and faulting across the aseismic to seismic transition in a sediment-rich accretionary complex** (Christie Rowe, Eric Thompson, and J. Casey Moore)
- **Geophysical and drilling evidence implies that a thick sandwich(0.5->1.0 km) of sediment and detached continental margins material separates the upper and lower plates; So what does this mean for forearc seismicity and expected deep drilling encounters?** (David W. Scholl)
- **Evaluation of the Updip Limit of the Seismogenic Zone in Central Costa Rica** (S.Y. Schwartz, H.R. DeShon, and S.L. Bilek)
- **The Nankai Trough versus the Sagami Trough - from a viewpoint of dehydration** (Tetsuzo Seno)
- **The Cellular Shear Mesh of the Chrystalls Beach Accretionary Melange: Relevance to the Active Hikurangi Margin Subduction Thrust Interface** (Richard H. Sibson)
- **Composition of sediments on the incoming Cocos Plate, offshore Costa Rica** (Glenn Spinelli and Michael Underwood)
- **A Coupled Hydrological and Geomechanical Study of the Nankai Trough Earthquake Recurrence** (Eyal Stanislavsky, and Grant Garven)
- **Heat Flow and Flexure at Subduction Zones** (Carol A. Stein)
- **Deformation at plate boundaries and related thrust faults. A comparison of ODP drilling with onland studies what can we infer about the aseismic-seismic transition** (Paola Vannucchi, Cesar R. Ranero and, Don Fisher)

Update on Marine Mammals and Research Involving Air Guns

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As many of you know, the National Science Foundation was sued by the Center for Biological Diversity (CBD) regarding the use of air guns on board the R/V Ewing, a research vessel owned by NSF and operated by Lamont Doherty/Columbia University. The suit alleged that Ewing air gun operations during a MARGINS Program cruise in Mexico's Exclusive Economic Zone (EEZ) in the Gulf of California led to the stranding of two beaked whales off the coast of Mexico. Few facts related to the possible causes for the strandings were available at the time, nor established since. For example, the time of the strandings, and thus the location of Ewing in relation to the position of the whales when they were known to be alive, is unknown. The dead whales were examined by a NOAA-NMFS scientist (who by coincidence was vacationing at the stranding site), but a necropsy was not performed. Thus, there was no biological evidence to show one way or the other if the deaths were in any way related to exposure to acoustic energy. Nevertheless, the Center for Biological Diversity (CBD), a Tucson, Arizona-based environmental group alleged that the R/V Ewing's use of air guns caused the strandings.

In an effort to halt the cruise, CBD accused the Foundation of failing to comply with the National Environmental Policy Act and the Marine Mammal Protection Act (MMPA) and filed a complaint in Federal Court in San Francisco. In late October, the Federal Magistrate in San Francisco granted a temporary restraining order against the cruise, causing it to terminate prematurely. For several reasons (good reasons, in my opinion), Department of Justice (DOJ) and NSF attorneys did not appeal the ruling. A couple of months later, CBD amended the complaint to challenge all of the Ewing's cruises scheduled for 2003, adding violations of the Endangered Species Act (ESA). Shortly afterwards, DOJ and NSF attorneys, in consultation with NSF program staff, began negotiations with CBD. These negotiations led to a settlement by mid April, 2003.

NSF is pleased with the terms of this settlement, recognizing that the litigation could have continued for some time and been very disruptive to future Ewing cruises. The settlement, which formalizes procedures already in place, allows Ewing to conduct seismic research in 2003. It also preserves NSF's argument that the MMPA does not apply to NSF cruises in foreign EEZs. The Foundation agreed to consult under the MMPA and the Endangered Species Act (ESA) with the Office of Protected Resources (OPR), National Marine Fisheries Service (NMFS) in connection with three upcoming 2003 R/V Ewing cruises and apply for permits, if necessary. [Lamont had initiated discussions with OPR in early 2002, and at the time of the settlement, were already seeking environmental assessments for Ewing cruises planned in 2003.]

The settlement letter also commits NSF (and thus scientists working on the Ewing) to mitigation measures to reduce possible adverse impacts of air gun operations on marine mammals including marine mammal observers, observation of a safety radius, shut down procedures that provide that the air gun operations will be suspended if a marine mammal is observed within the safety zone and ramp up procedures for the air gun array. [Lamont had voluntarily implemented these procedures prior to the Gulf of California cruise.] In return, CBD agreed to dismiss the case and will not challenge any permits issued by NMFS for the Ewing's 2003 cruises.

So what does this mean for the future of NSF-funded seismic research and for investigators involved in such research?

In brief, NSF, Lamont and investigators involved with research involving air guns will continue measures adopted in 2002 to ensure the safety of marine mammals. Lamont will seek environmental assessments for future cruises involving air guns, submit the assessments to NSF and then NSF will submit them to OPR for an incidental harassment or small take authorization (permit) as defined under the MMPA and ESA. This process can take 3 months to 1 year, and thus has to be started well in advance of a research cruise. There are also costs involved which NSF has agreed to pay. As a Chief Scientist of a Ewing cruise, you should discuss this process, and what will be required of you, with the ship operations folks at Lamont as soon as possible once your grant is funded or cruise is scheduled. The process will likely take longer, and possibly require more extensive mitigation measures and marine mammal monitoring efforts, for cruises planned for coastal waters and other areas having high densities of marine mammals. It is also possible that letters of authorization will not be granted for some sensitive areas or for some areas during specific seasons of the year. The evaluation process also includes procedures for public comment (and legal challenges) which can also affect the length of time for a letter of authorization; in some cases perhaps taking much longer than 1 year.

NSF is also discussing other approaches to be compliant with the terms of the MMPA and ESA. We are expecting guidance soon from OPR that will help us with our future plans. For example, can we use a different set of procedures for projects involving only 1-gun or 2-gun arrays than those we describe

above for the stronger sound sources? Can we seek broader authorizations covering a certain class of operational scenarios or will we continue to seek authorizations on a cruise-by-cruise basis? We may also be affected by new legislation and by other cases currently pending in Federal Court. For example, Congress is currently considering changes to the MMPA and ESA legislation that might redefine the definition of harassment or make other changes. There are also important issues associated with the jurisdiction of the MMPA. MMPA was written before the Exclusive Economic Zone (EEZ) was defined. Most agree that the MMPA applies to the high seas but does not apply to U.S. ships working in the territorial seas of other countries. What about the EEZ (which extends out 200 miles from the coast)? Do U.S. scientists, and their foreign collaborators, need authorization from the U.S. Government to work on U.S.-owned research ships in the EEZ of other countries, or does each country have the exclusive right to regulate their own EEZ? NSF argues the latter; some others disagree; and the Federal Courts have not issued a definitive opinion. It is a difficult issue [Try asking, as I have, one of your foreign collaborators if they think the U.S. government has any jurisdiction in their EEZ. You will likely get an interesting response.]. The Division of Ocean Sciences realizes that this unresolved issue will affect some of our funded projects, and we are trying to work on practical solutions.

In summary, we are now working in a much more difficult legal environment and with considerable uncertainty as to what will and will not be possible. NSF is, however, committed to supporting research involving responsible use of air guns, as we believe the record shows that most, if not all, research projects can be done without harming marine mammals and without "meaningful disruption of biologically significant activities, including but not limited to, migration, breeding, care of young, predator avoidance or defense, and feeding."

1NRC proposed definition of Level B harassment, p. 69, "Marine Mammals and Low-Frequency Sound", National Academy Press, Washington, D.C. 2000, ISBN 0-309-06886-X, 146 pp.

New European Funding on Margins Research ~ The ESF-EUROMARGINS is on the way

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EUROMARGINS is a new activity of the European Science Foundation (ESF) that has as its principle focus the imaging, monitoring and modelling of the physical, chemical, and biological processes that are occurring in the passive continental margin.

Within the new ESF EUROCORES scheme 14 multinational projects with a total volume of more than 12 M Euros will be funded. These projects will cover topics ranging from the crustal "architecture" of conjugate volcanic margins, through studies of slope stability on glacier-fed and river-fed margins, to studies of carbonate mounds and deep-water coral reefs and their relationship to seafloor seepages in margins. Together, the studies target a significant portion of the world's passive continental margin system, including margins of the North Atlantic, Iberia, Mediterranean Sea, and the Red Sea.

The 14 funded proposals came from a range of 61 outline proposals of which 24 were asked to submit full proposals. These were received in March 2002 and subsequently internationally peer reviewed and assessed by an independent Review Panel. Following negotiations with funding agencies participating in the EUROMARGINS Programme all 14 recommended proposals could be funded.

The funding agencies that comprise the EUROMARGINS currently include ESF Member Organisations from Belgium, France, Germany, Italy, Norway, Portugal, Spain, Sweden, The Netherlands, and the UK. Links have been established with the international programme, Inter-MARGINS, and it is hoped that other nations of Europe, especially those with long coastlines, will join EUROMARGINS in the future.

It is expected that the Programme will become fully operational in the second half of 2003 when the Networking, hopefully with the support of European Commission funds, will be put into place.

Even though it is just at the beginning EUROMARGINS has already been a European success in that it has brought together research groups that had little previous history of collaboration, encouraged the support and mobility of young scientists, and promoted the sharing of expensive technologies such as ships, deep-tow and seafloor instruments.

The challenge for the future will be to use this success to address the main research themes of EUROMARGINS and, importantly, the links between them

EUROMARGINS is part of the ESF EUROCORES programme scheme. These programmes are designed to provide an effective and efficient collaboration mechanism at the multi-national level within Europe and to mobilise national funding in basic research to tackle issues that have European-wide relevance. Participating funding agencies jointly define a research programme, specify the proposal call, and support the

(Continued on page 20)

Funded MARGINS Programs 2003

These are the funded MARGINS Proposals for the fiscal year 2003. This information is also available at the awards database of the MARGINS web site at **www.ldeo.columbia.edu/margins/MARGINSawards.html,** together with abstracts of all NSF-funded MARGINS Projects.

Seismogenic Zone

NSF Award number 0304946

MARGINS Postdoctoral Fellowship: The role of sediment diagenesis and dewatering on fluid and heat flow, Costa Rica margin

Michael B. Underwood

University of Missouri, Columbia, MO

This award will support a MARGINS post-doctoral fellowship to examine how ubducted sediments affect fluid pressure, fluid flow patterns and frictional properties within subduction zones. This project will address two fundamental questions about the role of sediments in subduction zones: 1) how are diagenetic fluid sources partitioned between opal and smectite dewatering on the Costa Rica margin (and therefore how deep in the subduction zone is most of the fluid produced), and 2) how do along-strike variations in heat flow and sediment composition affect the patterns of diagenetic fluid sources, fluid pressures, fluid flow, and possibly the updip limit of seismicity within the subduction zone?

NSF Award number 0241482

Collaborative Research: Seismic velocity, compaction, andpore pressure in underthrust sediments, Nankai subduction zone

Demian Saffer[1], Gregory Moore[2], and Harold Tobin[3]

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2. University of Hawaii, Honolulu, HI
3.New Mexico Tech, Socorro, NM

Funds are provided to better constrain in-situ pore pressure, relationship between pore pressure and porosity and compaction state of sediments in the Nankai margin using existing 3-D seismic data. Pore pressure and compaction state of underthrust sediments may be a key control on fault behavior because the decollement localizes at the top of these sediments. The work will provide important information necessary for the drilling of the Nankai seismogenic zone under IODP.

Subduction Factory

NSF Award number0305292

A numerical investigation of the relative importance of different melting mechanisms at volcanic arcs

James Conder

Washington University, St. Louis, MO

Under this award, the PIs will use finite-element viscous flow models to study the different melting mechanisms likely to be occurring beneath volcanic arcs. The three main mechanisms to be studied are: flux melting from hydration of the mantle wedge from the subducting slab, decompression melting that occurs when a temperature-dependent mantle rheology is considered, and possible sediment melting at the subducting slab surface. Different arcs can have large differences in the amount of magmatic production and may also vary in the relative production of each melting mechanism. The PIs will investigate the various parameters affecting the production of each melting mechanism such as slab dip, subduction rate, subducting and overlying plate ages, etc. Some parameters will have a greater influence on one mechanism than another, leading to the possibility that the dominant melting mechanism could change from one arc to another, and affecting what is observed at real arcs.

NSF Award number 0305137

Quantification of metamorphic devolatilization in the subduction factory focus sites: implications to fluid fluxes, seismicity, and volatile recycling

Derrill Kerrick

Penn State University, University Park, PA

Because many hydrous marine sediments entering subduction zones lack CO_2 (i.e., lack carbonate minerals), dehydration would be dominant over decarbonation upon subduction. Under this funding, the PIs will compute subduction zone devolatilization for the major lithologic types of CO_2-free hydrous marine sediments: red clays, hydrothermal (ferruginous) clays, turbidites, and mixed lithologies, i.e., radiolaria/diatom oozes mixed with clays or volcanic ash, using a variety of constraints from ODP drill sites off the Izu-Bonin-Marianas and Costa Rica-Nicaragua. Because the carbonate content of altered basalts in the upper oceanic crust increases with age, the PIs will compare metamorphic devolatilization of oceanic metabasalts in subduction zones with Jurassic crust (e.g., Marianas) with those subducting late Cenozoic crust (e.g., Costa Rica), and will quantify the relative contributions of the various volatile-bearing assemblages and assess the depth distribution of volatile release. A primary goal of the proposed research is to quantify metamorphic devolatilization for the lithologies entering these subduction zones and to compare the results with the distribution of earthquake hypocenters and volcanic activity associated with each subduction zone.

NSF Award number 0305755

Melt inclusions in Izu arc lavas: examining slab-derived contributions to intra-oceanic arc magmas and the role of volatiles in the subduction factory

Adam Kent

Oregon State University, Corvallis, OR

Via a Japanese, American, and European collaboration, this study will analyze major, trace and volatile elements (H_2O, CO_2, S, Cl, F) and B and H isotopic composition in melt inclusions and lavas from the Izu arc using petrographic, electron microprobe, ion microprobe and laser-ablation ICP-MS techniques. Melt inclusions will provide primary constraints on the major, trace and volatile element contents and boron and hydrogen isotope compositions of primitive Izu arc melts, and this data will test and constrain geochemical, petrological, geophysical and thermal models for subduction in this region, one of the MARGINS program selected study areas, and elsewhere.

NSF Award number 0305218

Collaborative Research: Constraining the volatile and slab flux in the Izu-Bonin-Marianna margin using geothermal fluids, phenocrysts, and melt inclusions

Tobias Fischer[1], David Hilton[2], and Erik Hauri[3]

1. University of New Mexico, Albuquerque, NM
2. Scripps Inst. of Oceanography, La Jolla, CA
3. Carnegie Institute of Washington, Washington, DC

Under this award, the PIs will carry out an integrated study of volatiles in the Izu-Bonin-Marianas margin that includes the analyses of specific volatiles (H_2O, CO_2, Cl, S) and fluid soluble elements (Li, B, K, Rb, Ba and others) as well as their stable isotope (dD, $d^{11}B$, $d^{13}C$, $d^{18}O$, $d^{34}S$) systematics utilizing SIMS measurements of melt inclusions of recently erupted tephra. This data set will be complemented by CO_2 and He abundance and isotopic measurements ($d^{13}C$ and $^3He/^4He$) in erupted phenocysts and discharging volcanic and hydrothermal fluids. Additionally, the study will measure the complete gas composition and the N-isotopes of the hydrothermal fluids in order to determine the present-day total volatile flux from the entire arc through normalization to ground-based SO_2 remote sensing measurements. The combined data set will allow the PIs to quantify the slab flux in terms of volatile composition (melt inclusion data), the source of the slab flux in terms of oceanic basement, subducted carbonates or organic sediments (CO_2-He and N_2-He systematics), the present day volatile flux to the atmosphere from the slab and mantle wedge (SO_2 flux and volcanic gas compositions). The study addresses the flux and composition of volatiles into and out of the IBM system and the distribution of volatiles in the mantle and its geochemical evolution through time.

NSF Award number 0305564

Mantle dynamics of the Izu-Bonin-Marianna subduction system

Matthew Fouch

Carnegie Institute of Washington, Washington, DC

This study provides new constraints on mantle flow and dynamics within the Izu-Bonin subduction system through a combination of seismic observations and numerical modeling experiments. Results of this work are providing key information regarding mantle processes in convergent margins, including the means of mantle magma transport and the geometry of strain partitioning between tectonic plates and the sublithospheric mantle.

In this coupled approach, the following issues are being addressed specifically: 1) the 3-D distribution of upper mantle anisotropy and its implications for strain partitioning and mantle flow in the Izu-Bonin subduction zone; and 2) the interpretation of seismic anisotropy results, particularly their relationship to both mantle transport processes and the degree of coupling between tectonic plates and sublithospheric mantle.

The seismic component of the project involves shear wave splitting analysis for a unique set of shear phases, including local S, teleseismic SKS, and sS-S differential splitting. The Izu-Bonin region is particularly well-suited for the proposed seismic studies, as earthquakes generated in Izu-Bonin provide an excellent dataset of seismic phases that sample a broad portion of the study area. The availability of broadband waveforms of Izu-Bonin earthquakes have been recorded by many high-resolution seismographs and allows constraint of both lateral variations and the depth distribution of anisotropy for the Izu-Bonin system.

The numerical modeling component of the project involves calculation of 3-D models of mantle flow for a range of physical model parameters. To determine the relationship of mantle flow to the seismic anisotropy observations, flow models are being used to calculate predicted anisotropy using appropriate elastic parameter values from a range of deformation studies, and comparing the modeling results with the seismic anisotropy results.

Source to Sink

NSF Award number 0305688

Collaborative Research: Late Quaternary Siliciclastic and carbonate sediments and sediment fluxes on the slopes and basin floors of the Ashmore and Pandora troughs, Gulf of PNG

André Droxler[1], Samuel Bentley[2], and Larry Peterson[3]

1. Rice University, Houston, TX
2. Louisiana State University, Baton Rouge, LA
3. RSMAS, Miami, FL

Funds will be provided to investigate sedimentation processes in the mixed siliciclastic carbonate slope and basin environment in the Gulf of Papua as a part of the integrated source-to-sink experiment at the Fly River-Gulf of Papua

focus site of MARGINS. Through the use of detailed acoustic surveys and seabed and water column sampling the proposers will estimate sediment fluxes and transport pathways from the shelf edge and carbonate reef margins to the ultimate sinks of the Ashmore and Pandora troughs over the last interglacial cycle. The work will lead to an understanding of the history of sediment accumulation on the continental slope and the deep ocean for the mixed system as well as sediment fluxes and transport mechanisms by identifying timing and geometry of deposition in the Gulf. The ultimate objective is to develop a model for mixed carbonate-siliciclastic deposition.

NSF Award number 0305779

Collaborative Research: Developing a Quantitative understanding of Clinoform formation, Gulf of Papua

Neal Driscoll[1], Rudy Slingerland[2], and John Milliman[3]

1. Scripps Inst. of Oceanography, La Jolla, CA
2. Penn State University, University Park, PA
3. Virginia Inst. of Marine Science, Cloucester, VA

This is a project to study the processes of sediment transport and accumulation that lead to development of the clinoforms on the Gulf of Papua (GoP) continental shelf. Shelf clinoforms are the dominant components of continental-margin stratigraphy, but little is known about the processes that create them. By combining field research (seismic profiling and piston coring) and numerical modeling, quantitative understanding of mid-shelf clinoform development at geologic time scales can be developed. These studies will test the hypothesis that the predominant mechanism for creating the present-day clinoform morphology is across-shelf gravity flow of fluid muds, whereas underlying strata may have formed in different conditions in response to changing rates of sea-level rise and sediment supply.

Rupturing Continental Lithosphere

NSF Award number 0305480

Geodetic constraints on the kinematics and dynamics of active rifting of the northern and central Red Sea

Robert E. Reilinger

MIT, Cambridge, MA

This project uses the Global Positioning System (GPS) to measure active deformation along the rift margins of the Red Sea. The project is being undertaken in cooperation with partner institutions in Egypt, Saudi Arabia, Eritrea, and Sudan. The ultimate objective of this research is to understand better the dynamics of continental rifting The approach includes both continuously recording GPS stations installed along the rift and survey GPS observations to determine variations in deformation style along and normal to the rift system. The GPS results are providing new constraints on the mechanics of continental rifting thereby adding to our understanding of the basic forces driving continental deformation and the rheological character of the continental lithosphere. In addition, this project is helping to transfer GPS technology to the host-country partners and is providing quantitative information on plate motions and rates of strain accumulation that are directly useful for evaluating and mitigating earthquake hazards.

NSF Award number 0305692

Collaborative Research: Integrated thermochronological and structural investigation of the Saudi Arabian Red Sea rift margin: implications for the rupturing of continental lithosphere

Gomaa Omar[1] and Daniel Stockli[2]

1. University of Pennsylvania, Philadelphia, PA
2. Caltech, Pasadena, CA

The PIs will undertake a structural and thermo-chronological study of the Saudi Arabian Red Sea margin as a part of the MARGINS "Rupture of the Continental Lithosphere" initiative. This margin offers an exceptional opportunity to study the processes associated with continental rifting and how extensional strain is distributed in space and time. The PIs will employ apatite fission-track and (U-Th)/He thermo-chronology and structural mapping in the study area to achieve their objectives. The study will contribute to a more comprehensive understanding of the Red Sea rift and will form a part of the overall geological/geophysical work planned in this area under the MARGINS program. A close collaboration with the Saudi Geological Survey is envisaged.

NSF Award number 0305454

Collaborative Research: Upper Mantle Structure beneath the Gulf of California

Jim Gaherty[1] and John Collins[2]

1. Georgia Tech, Atlanta, GA
2. Woods Hole Ocean. Inst., Woods Hole, MA

In this experiment, which is part of the NSF Margins initiative on Rifting Continental Lithosphere, the investigators are deploying 18 wide-band ocean bottom seismographs (OBS) in the Gulf of California for a period of 15 months. These seismographs are recording naturally occurring seismicity (over 200 moderate and large earthquakes) from around the globe. Using these seismic recordings, the investigators are constructing images of the mantle beneath the Gulf and the surrounding region, providing a means to evaluate the degree to which mantle processes control lithospheric rupture and the initiation of seafloor spreading in the Gulf of California. The experiment is focused on two questions that are particularly important for achieving the goals of the Rifting Continental Lithosphere initiative: (1) Is the upper-mantle directly underlying Gulf of California extension anomalously hot? (2) To what extent do North-South variations in extensional

(Continued on page 20)

MARGINS Post-Doctoral Fellows 2003

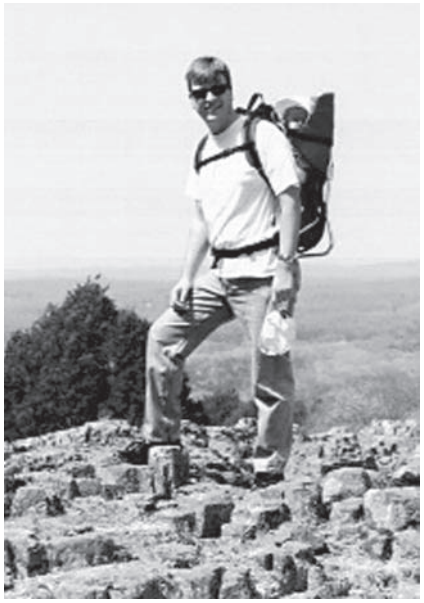
Beginning this year, the MARGINS Program is funding a number of post-doctoral fellows, both within the special MARGINS Post-Doctoral Fellowship Program and within the regular NSF-MARGINS program (cf. preceding pages). The MARGINS Office is proud to announce the names of the successful post-doctoral fellows: James Conder, Alison Shaw, and Glenn Spinelli — congratulations to you all. The MARGINS Office wishes them success in their post-doctoral research endeavors. Below, the three post-doctoral fellows introduce themselves and their projects:

James Conder
Washington University, St. Louis, MO

Working as a post-doc at Washington University has been a great opportunity to study geologic processes at volcanic arcs and back-arc basins and also to become involved with the MARGINS program. Previous and ongoing WashU seismic experiments at the Tonga and Mariana subduction zones have helped stimulate my interest in magma production and migration at these geologically important regions.

Growing up in Salt Lake City helped give me an appreciation for the outdoors and the many diverse, but interlinked, aspects of the natural and physical sciences. I discovered Geology as an undergraduate at the University of Utah, and worked for a year at a mining exploration company before heading to the East Coast for graduate school. Although my snowboarding skills severely atrophied after leaving the Wasatch Mountains, it has been an immensely rewarding experience, particularly because of the interaction with the many great people and discussions of interesting research I have encountered within the geophysical community.

While a graduate student at Brown University, I learned the value of combining different seismic observations with other methods, particularly numerical modeling, to understand mantle flow and melt processes. My research at Brown primarily focused on the Southeast Indian Ridge and the East Pacific Rise. One thesis chapter demonstrated with numerical models of mantle flow incorporating pressure- and temperature-dependent viscosity that asthenospheric flow driven from one side of the spreading axis to the other can account for the unexpected degree of asymmetry observed across the East Pacific Rise from the MELT experiment. Applying these same modeling techniques to understand the observed asymmetric seismic structure of the Lau back-arc spreading center led to the find that decompression melting should be expected beneath some volcanic arcs as the subducting slab viscously erodes the base of the overlying lithosphere. Models using temperature-dependent viscosity also predict slab temperatures >100 deg C warmer than isoviscous models. These observations put volcanic arcs in the interesting position of potentially having three possible



melting mechanisms for magma generation: wedge hydration, wedge decompression, and slab heating. As a MARGINS post-doc, I plan to use numerical models along with seismic observations to map out how the importance of each melting mechanism varies from arc-to-arc as the thermal structure and other governing parameters at subduction zones change.

Alison Shaw
Scripps Inst. of Oceanography, La Jolla, CA

After completing my undergraduate degree in geosciences at McGill University, I left the Great White North to pursue graduate studies in sunny Southern California at Scripps Institution of Oceanography. During the course of my Ph.D. research at Scripps with Dr. David Hilton, I had the opportunity to work on a MARGINS related project investigating the CO2 flux though the Central American Arc. Using He-C relationships in geothermal fluids (fumaroles, hot springs and geothermal well gases) collected from various volcanic centers along the arc, I was able to assess the provenance of the volcanic C output, allowing for an estimate of how much of the C input at the trench (as pelagic carbonates, organic C and altered oceanic crust carbonate) was recycled through the arc system. As a complement to my geothermal fluid arc

(Continued on page 20)

Glenn Spinelli
University of Missouri, Columbia, MO

I am excited to be starting a MARGINS post-doctoral fellowship this year. After spending most of my life near the edges of this continent (including growing up in New Jersey and attending grad school at the University of California, Santa Cruz), it seems natural to head to the heartland (Missouri) to study continental margins. After getting a B.S. at Penn State, I went to UC Santa Cruz where my research encompassed hydrogeology and sedimentology — ranging from groundwater seepage into San Francisco Bay and fluid seepage through sediments on the Juan de Fuca Ridge flank, to sedimentation patterns on northern California's Eel River margin. As a MARGINS post-doctoral fellow, I will further develop my interests in both hydrogeology and sediments by studying sediment dewatering within the Costa Rica margin subduction zone.

Sediments subducted off Costa Rica have high opal and smectite contents

(both contain a large amount of water that is expelled at moderate temperatures and pressures within the shallow subduction zone). Smectite dewatering has been shown to significantly affect pore fluid pressure and chemistry in the subduction zones of Barbados and Nankai. On the Costa Rica margin, opal dewatering provides another source of water during sediment diagenesis. Additionally, in Costa Rica, large along-strike variations in heat flow may lead to differences in the depth within the subduction zone at which the dewatering reactions occur. This has the potential to generate along-strike fluid pressure gradients and therefore margin parallel fluid flow within the subduction zone. Fluid pressure and fluid flow patterns in response to sediment dewatering in the subduction zone, in turn have implications for fault strength and potentially the location of the updip limit of seismicity.

This study will consist of two phases: a characterization of the sediments offshore Costa Rica (in cooperation with Mike Underwood at the University of Missouri), and modeling of sediment dewatering and fluid flow within the Costa Rica margin subduction zone (in cooperation with Demian Saffer at the University of Wyoming).

Continued from page 19, EUROMARGINS:

international peer review of the applications, with final funding decisions residing with participating national bodies. ESF acts as a catalyst by conducting the international peer review, offering project management, and by the "networking" of scientists who are involved in the individual projects.

For more information on EUROMARGINS please contact the ESF website at: **www.esf.org/euromargins**.

Continued from page 18, Funded Programs:

style correlate with upper-mantle velocity variations? The OBS deployment also provides the means to better characterize seismically active faults within the Gulf of California, improving the assessment of the natural hazards environment of the region. The Gulf of California OBS array builds two ongoing Margins-funded experiments: the NARS-Baja onshore broadband seismic array, and an active-source crustal survey. The ocean-bottom seismic data collected in this experiment will be available to any interested investigator 2 years following instrument recovery through the IRIS Data Management Center.

Continued from page 19, Alison Shaw:

studies, my postdoctoral research at the Carnegie Institution of Washington with Dr. Erik Hauri will focus on melt inclusions in recently erupted tephras from the Izu-Bonin-Marianas arc system. Melt inclusions are thought to represent pre-eruptive melts, and thus offer the exciting possibility to look at the composition of sub-arc partial melts. Since it is assumed that inclusions remain isolated after entrapment, they are thought to preserve the characteristics of primitive melts and are less influenced by magma chamber processes than erupted lavas. This study will be part of a collaborative volatile study of the arc using geothermal fluid data and remote sensing techniques, along with melt inclusions in mafic phenocrysts, to gain a better understanding of how volatiles are cycled through arc systems.

MARGINS Steering Committee highlights

Olaf M. Svenningsen

Lamont-Doherty Earth Observatory, 61 Route 9W, Palisades, New York 10964, USA

On March 27-28,2003, the MARGINS Steering Committee met at the National Science Foundation headquarters in Arlington, VA. The agenda included the following items (items covered in other places in this newsletter are indicated in brackets):

1. Welcome by the MARGINS Chair.
2. NSF Program managers' report on MARGINS and MARGINS funding (see From the Chairman's desk, page 6, and Funded Programs, page 16),
3. MARGINS Fellowships (see pages 19-20)
4. The marine mammals issue and ramifications for acoustic research and the MARGINS Program (editorial and Yoder)
5. Official OCE policy regarding proposals to work in politically senistive areas.
6. MG&G Databases, the MARGINS perspective
7. Review of the MARGINS program
8. MARGINS Science Plan publication
9. Meeting reports

Below are summaries of some of the more important discussions and decisions that are not covered elsewhere in this newsletter:

1. Two new and one old-new member were introduced and welcomed onto the committee: *Mark Reagan* of the University of Iowa and *Geoff Abers* of Boston University will both represent the Subduction Factory. *Julie Morris* of Washington University in St. Louis, MO is the new MARGINS Chair (see next page, Office News).

2. The MARGINS Funding situation is covered in the Chair's editorial on page 6.

3. 2003 is the first year of MARGINS Post-Doctoral Fellowships, and three fellowships were awarded by NSF. The MARGINS post-docs are presented on the preceding pages (19-20).

4. The impact of acoustic research on marine mammals, and the impact and status of the consequences of Gulf of California incident in September 2002, was discussed in detail. James Yoder, Director of Ocean Sciences at NSF, presented an update on the legal status of this issue (see page 14).

5. OCE Guidelines for Fleet Security (posted on NSF website, **http://www.nsf.gov/pubs/2002/nsf 02055/nsf02055_2.htm**). In summary:
   - PIs should consider regions of potential danger before submitting;
   - Where possible, cruises should be planned to avoid regions for which are not automatically insured through existing global coverage;
   - OCE currently advises reviewers and panelists not to introduce security issues as a review criterion;
   - Successful proposals to such areas will be held until determination is made regarding insurance and security;
   - NSF does not require operators to sail to region or port deemed unsafe (no insurance, no cruise support from NSF);

6. Davip Epp of NSF summarized data management efforts at NSF (see issue 9, Fall 2002, of the MARGINS Newsletter), and stated that NSF-MG&G reserves 8% of its budget for these purposes. Walt Snyder gave a presentation of the GEON project (**www.geongrid.org**) and its possible implications for MARGINS data management.

7. NSF will conduct a "midlife" review of the MARGINS Program in early 2004. The purpose is to review, not to evaluate, the program. The resulting report is intended to be a management tool for both the NSF and the MARGINS Office. For the review, documentation will be necessary, and one important component is the publication of all of the science plans (see next item). An overview of the history of MARGINS is necessary for the review and the Steering Committee was charged with producing this material. The review will be posted on the MARGINS website.

8. The MARGINS Science Plan/the science plans for the four initiatives will be published by the end of the summer of 2003. The final step in these preparations was the review of the SEIZE science plan after the SEIZE 2003 Theoretical Institute. The MARGINS Science Plan will be published before the Office moves to St. Louis in October.

9. A report from the *SEIZE 2003 Theoretical Institute* begins on page 11 of this issue. The *Source-to-Sink Town Meeting* held at the AGU 2002 Fall Meeting to present the revised science plan was attended by c. 80 people. The discussion at the town meeting was concerned more with *how* the science plan had been revised rather than its contents. The revised science plan was accepted by NSF Program Managers and the community.

MARGINS Office News

Olaf M. Svenningsen

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Website update

The MARGINS website has grown ever bigger and more complex, and this has necessitated an update, aiming to facilitate within-site navigation and accessibility. The update will be ongoing throughout the summer of 2003, but several important changes have already been made:

1. The navigation bar has been changed to include direct links to the various data pages available within the website.

2. The "About MARGINS" page has been expanded to four pages, covering; the MARGINS Program; the Steering Committee; the MARGINS Office, and finally the website. A sitemap (see Figure 1) has been added as graphic table of contents for the main pages and sub-sites of the MARGINS website.

3. The "Meetings" page has been changed, and instead of providing a long (sometimes very long) text list of upcoming meetings, each link now opens a separate page with information about one particular meeting. These pages have been designed to be printable directly from a web browser .

4. The within-site search engine has been complemented with two external science search engines.

5. Finally, but very important: Over the summer, many documents will be removed from the root directory of the website, which presently contains c. several hundred documents, making the website unnecessarily cumbersome to maintain. No documents will be removed, but the URL, or web address, to many documents will change, and bookmarks may have to be updated. Since the entire website will move to a different server in October, this is a suitable time to review you bookmarks anyway.

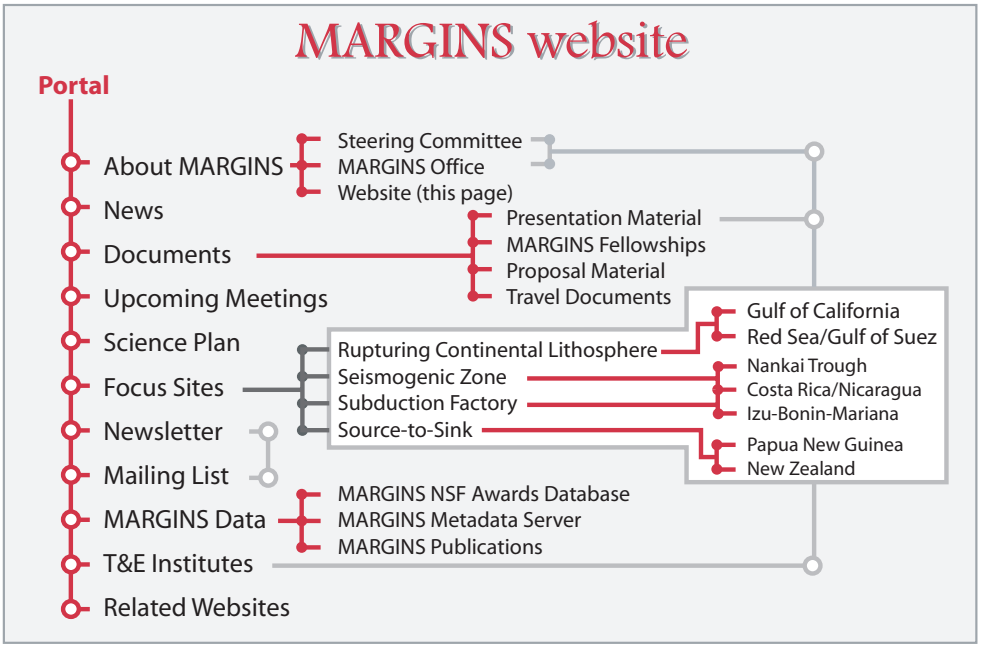

Figure 1. The recently posted new sitemap of the MARGINS website. Each label on this map is also a link to the different pages and sub-sites.

Where is the MARGINS Office?

Figure 2. View to the west of the Palisades Cliffs across the Hudson River from Hastings-on-Hudson, NY. Lamont-Doherty Earth Observatory and the MARGINS Office are perched on top of the cliffs. New York City is c. 15 miles to the south.

MARGINS Steering Committee

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This information is also posted on the MARGINS website, where it is continuously updated.

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LAMONT-DOHERTY EARTH OBSERVATORY
OF COLUMBIA UNIVERSITY

MARGINS

Newsletter No. 10, Spring 2003

Upcoming Meetings:

• Ocean Margin Research Conference
September 15-17, 2002 in Paris, France

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• The Geological Society of America 2003
Annual Meeting & Exposition
November 2-5, 2002 in Seattle, Washington

—

• AGU 2003 Fall Meeting
8-12 December 2003, San Francisco, California

—

More information about MARGINS-related meetings are posted on the Meetings page at the MARGINS web site:

http://www.ldeo.columbia.edu/margins

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