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Report on MARGINS Workshop: Interpreting Upper-Mantle Images

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Figure 1. Participants of the Interpreting Upper Mantle Images worksop, on the grounds of the National Academy of Sciences, Woods Hole, MA. Photo courtesy of M. Berwick.

Introduction

From May 19 to 21, 2006, approximately 70 scientists gathered at the Woods Hole Oceanographic Institution (WHOI) in Woods Hole, Massachusetts to discuss the role that seismic imaging can play in constraining the physical parameters of the upper mantle, specifically in the context of MARGINS Subduction Factory (SubFac) and Rifting Continental Lithosphere (RCL) Initiatives. Both SubFac and RCL include large seismic experiments with a main goal to establish the temperature and flow fields, as well as the distribution and extent of melting and H_2O, in the mantle. Volcanism occurs both in arcs and rifts, so a natural tie exists between igneous geochemistry, seismology, and rheology in these settings. The goal of the workshop was to bring new experimental and theoretical results to allow the analysis of these data sets in terms of the interpretation of physically meaningful parameters. Such analyses will be critical for integrating seismic data with other observations in any focus area synthesis.

The Interpreting Upper-Mantle Images (IMI) workshop was sponsored by the U.S. National Science Foundation through the NSF MARGINS Program. Woods Hole Oceanographic Institution provided the meeting venue and logistical support. Workshop conveners were Geoffrey Abers, James Gaherty, and Greg Hirth. Julie Morris (as MARGINS Chair) was instrumental in obtaining workshop funding, and Paul Wyer and Meredith Berwick from the MARGINS Office provided invaluable organization and support prior to the workshop, on site, and following the meeting. Additional information about the meeting, including participant list, technical program, and downloadable oral and poster presentations, is available at:

http://www.nsf-margins.org/IMI06/

Workshop philosophy and organization

To make progress in SubFac or RCL, it is necessary to constrain upper mantle properties in terms of bulk composition, temperature, water content, and melt distribution. Some key questions include: How much melt is present in situ within the mantle? What is the water content of the lithosphere and asthenosphere? How does subduction deplete or otherwise alter the residual mantle? How does melting occur beneath incipient rifts? Can we constrain the geometry and mechanism

Table 1. MARGINS geophysical projects for mantle imaging

PI	Project	Focus Area
Abers & Fischer	TUCAN broadband array	CentAm
Schwartz	SEIZE passive seismic array & followup	CentAm
Wiens & others	IBM broadband/OBS imaging	IBM
Wiens & Condor	IBM broadband analysis and modeling	IBM
Fouch	Anisotropy, geodynamic modeling	IBM
Chave	Magnetotelluric transect	IBM
Clayton	NARS-Baja broadband array	GoC
Gaherty & Collins	SCOOBA broadband OBS array	GoC
Nyblade & others	Saudi broadband network analysis	Red Sea
(Steckler & others)	(CAT/SCAN broadband/OBS array)	(Red Sea; relocated)

of melt focusing at spreading centers or arcs? Do low velocities below the Moho in both settings require melt to be present, or do they indicate compositional heterogeneity or something else? What defines the lithosphere-asthenosphere boundary, and where is it?

The seismological database needed for this task is rapidly building owing to new MARGINS-funded experiments (Table 1). At the same time, the laboratory community is making significant advances towards interpreting the influence of these variables and the fundamental physics behind their variation. However, much of this work has been done without significant interaction between the different communities. Even within communities, a lack of discussion has led to several first-order differences in opinion for what should be established physical relationships. There has been much need for a focused meeting of the minds on this subject, in order to cross-educate communities and to hash out differences.

To this end, the IMI workshop was designed specifically with the goal of encouraging cross-disciplinary discussion and interaction. The 2.5-day schedule focused on keynote speakers and extensive open discussion time (including poster presentations). The workshop began with two keynote presentations that introduced the range of science problems that can be addressed with mantle imaging in both SubFac and RCL focus sites (Wiens; Lizarralde). There were then two presentations that emphasized state-of-the-art imaging experiments focused on the presence of partial melt and compositional heterogeneity in the mantle (Forsyth; Nettles). These were followed by two presentations comparing theoretical and experimental results on anelasticity and seismic attenuation (Jackson; Cooper). Open discussion with the speakers and around posters rounded out the first day. The second day began with two keynote presentations on the constraints that petrology and electromagnetic imaging place on mantle properties (Hirschmann; Evans), followed by a pair of presentations on theoretical and experimental constraints on the influence of water and melt on seismic and electrical properties (Karato; Takei). The last two keynote talks of the day discussed the application of experimental results and geodynamic modeling (Faul; Billen), followed by another round of open discussion and posters. On day three, the workshop closed with two final presentations keying on the integration of seismology, experimental constraints, and geodynamic modeling in MARGINS settings (van Keken; Fischer), and an open discussion of critical experiments and future directions.

Summary of workshop discussion

Over the last few years, the explosion of datasets from dense deployments of portable broadband instruments, recorded on quiet high-dynamic range seismographs, has revolutionized our ability to extract information about the deep subsurface, with a vast toolkit of resources now available. At a minimum, seismic imaging provides estimates of spatial variations in Vp, Vs, and Qs. Recent studies have also extracted variations in $d\ln Vp/d\ln Vs$, Qp/Qs, the geometry of discontinuities and their impedances, anisotropy parameters, and frequency dependence of several observables. The importance of this wide spectrum of observations is that they are sensitive to physically meaningful variables in different ways. For example, Qs represents anelasticity in shear modulus, which is dominantly a function of temperature, somewhat a function of pore geometry and water content, and negligibly a function of major-element composition. On the other hand, the ratio Vp/Vs (essentially Poisson's ratio) has weaker temperature sensitivity but often is used to indicate pore geometry and presence of minerals with unusual physical properties in comparison with typical mantle minerals, such as quartz or serpentine.

Simultaneously, there have been several noteworthy advancements in theoretical and experimental constraints on seismic properties of mantle materials. First, improved thermodynamic analyses and petrological databases can be used to constrain both the phase proportions and mineral compositions in the upper mantle as a function of pressure and temperature. Combined with experimentally measured elastic properties, these analyses provide a critical baseline to use in evaluating the roles of temperature and pressure on seismic velocity. In particular, the temperature dependence of seismic velocities is controlled strongly by anelastic dissipation, and these effects have been recently quantified in the laboratory at geologically relevant temperatures, pressures and seismic frequencies. These experimental studies also demonstrate the importance of other variables on seismic velocity, such as grain size and melt content. While experimental measurements on the role of water on anelastic properties have not yet been conducted, theoretical analyses motivated by experimental observations on the influence of water on high strain creep indicate that seismic velocities in the mantle may be significantly lower under hydrous conditions. Experiments have begun to quantify the effect of water content on the dominant slip systems in olivine and the role of melt fraction on strain partitioning during deformation under partially molten conditions; these results provide new insight into the interpretation of seismic anisotropy.

Over the course of the workshop, presentations and discussions continually migrated to two major geodynamics questions that require a comprehensive integrated approach. The first was whether the range of seismic velocities observed in the upper mantle is effectively modeled using simple temperature dependence of solid-state peridotite, with partial-melt, composition, and/or water playing a role only in very localized regions beneath spreading centers, rifts, and/or arcs. The second was whether water-induced changes to the dominant olivine slip systems can explain seismic anisotropy observations within arcs. We summarize these discussions here; within this summary, **bold citations** by last name refer to keynote or poster presentations that are available on the meeting website:

http://www.nsf-margins.org/IMI06/

At what scale are melt, water, and/or composition important? There have been several recent papers that have argued that much of the velocity variation in the upper mantle is consistent with expected temperature variations in the upper mantle, with no need to call upon the effects of melt, composition, or water [*Faul and Jackson*, *2005*; *Stixrude and Lithgow-Bertollini*, *2005*; *Priestley and McKenzie*, *2006*]. These arguments combine well-calibrated thermal models of the upper mantle with experimental and theoretical estimates of pressure and temperature variation of seismic velocity and attenuation. The resulting predicted profiles of seismic velocity can be explicitly compared to observed velocity profiles. An example is shown in Figure 2, in which **Faul** argues that the observed deepening and increasing velocity of the seismic low-velocity zone with increasing seafloor age in the Pacific can be modeled using dry, solid-state peridotite. This notion was countered with examples from a variety of settings using a diverse range of observations: seismic velocity estimates suggesting the presence of melt beneath and substantially west of the East Pacific Rise (EPR) (**Forsyth**); electrical conductivity profiles indicating the presence of water in the asthenosphere beneath the EPR (**Evans**); evidence for velocity variations in back-arc and near-ridge settings that are too large to be purely thermal (**Wiens; Gaherty**); and evidence from seismic tomography and gravity that the upper-mantle composition is heterogeneous at the scale of continents and ocean basins (**Nettles**).

In detail there are several aspects of the predicted velocity/temperature relationships that require further consideration. All such predictions require extrapolation of experimental results to realistic grain sizes, but the kinetic basis and appropriate grain sizes for this extrapolation are uncertain. Also, the predicted velocity profiles have steep negative gradients in both *Vs* and *Vp* that are not generally observed in seismic studies of the uppermost mantle (e.g., Figure 2). Whether this is a shortcoming with the seismic models or the experimental predictions is unclear. What is clear is that the new experimental results, coupled with robust thermal models of the upper mantle, provide an excellent baseline for evaluating the underlying cause of velocity variations observed in MARGINS settings.

An interesting component of the discussion surrounding the relationship between temperature and seismic velocity is the increased recognition of the dominant role that seismic attenuation (denoted by its inverse, *Q*) plays in controlling observed velocities. In particular, at temperatures appropriate for the upper-mantle, much of the expected velocity variation is due to physical dispersion, i.e., the wavespeed variation produced by anelasticity. Anelasticity is strongly temperature dependent, but it is also sensitive to grain size (**Jackson**; **Faul**), water (**Karato**; **Cooper**) and melt (**Cooper**; **Takei**), and these effects are being mapped out experimentally. The remaining anharmonic effects are well known. The coupling suggests that in the ideal case, laboratory experiments can precisely describe the co-variation between velocity and attenuation for a given composition and physical state. These co-variations can then be compared to *in situ* estimates of velocity and attenuation in the mantle. *Faul and Jackson* [2005] take this analysis part way by utilizing laboratory estimates of *Q* and *Vs*, along with field estimates of *Vs*, to argue for a grain-

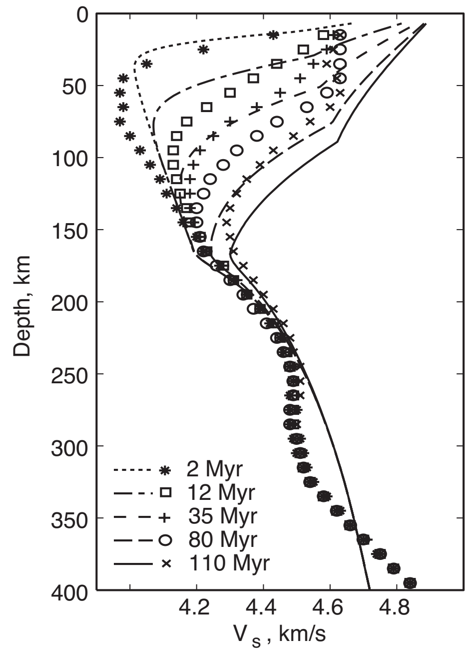

Figure 2. Comparison of observed and predicted shear velocity as a function of age for the Pacific. Symbols represent upper-mantle velocity models of Nishimura and Forsyth, while lines show velocities calculated for conductively cooling lithosphere from the fit to experimentally measured shear moduli. Figure courtesy of U. ***Faul****.*

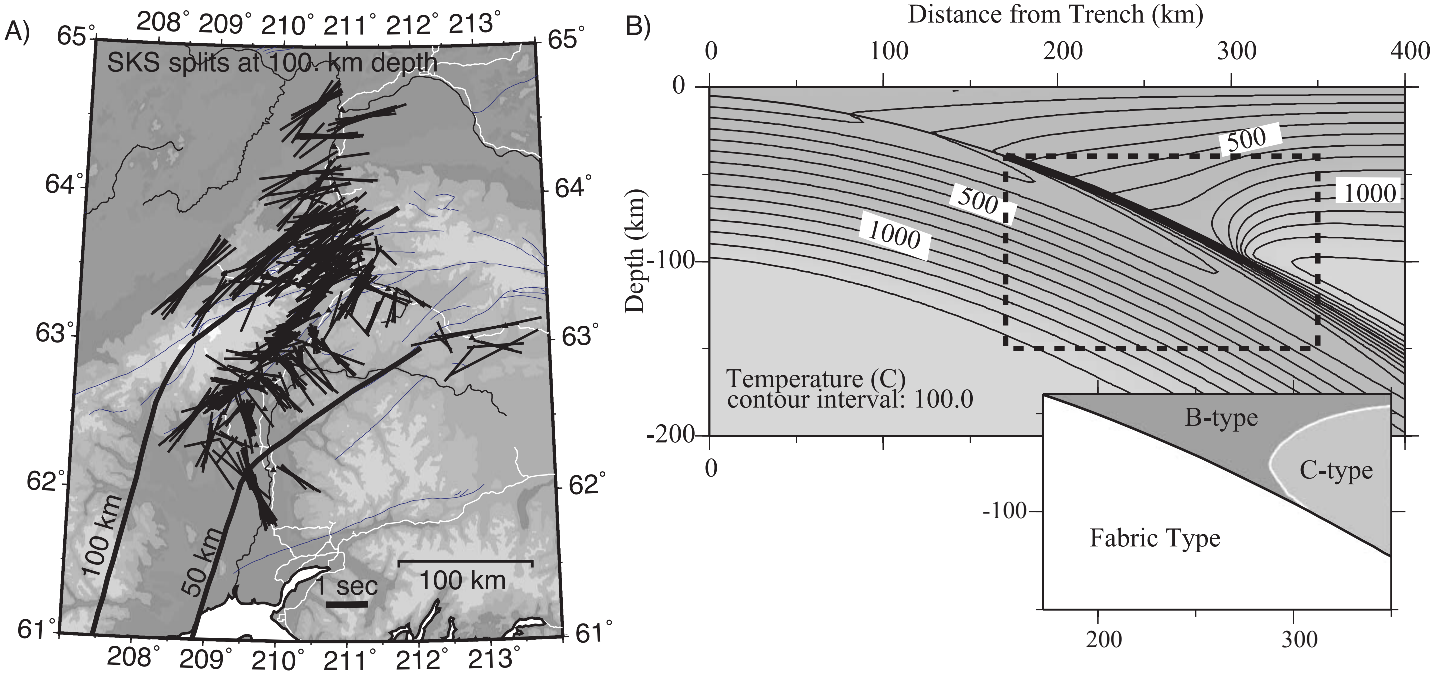

Figure 3. (a) Individual SKS-splitting observations from the BEARR array across the Alaska range, projected to 100-km depth. Approximate depth of the subducting slab is indicated by black contours. Sharp transition from arc-parallel to arc-perpendicular fast directions is observed at a slab depth of approximately 75 km. (b) Two-dimensional numerical model of temperature and fabric-type in the SubFac environment. Primary image shows temperature contours, with slab interface marked with a bold black line. Inset shows the region in dashed box, indicating fabric type in the nose just above the slab. In this model, stress and fluid content consistent with B-type fabric is restricted to a depth interval of 50-100 km, at a distance of 200-300 km from the trench. Location of B-type fabric is consistent with the transition observed in (a), but the 1-2 s split times in (a) appear too large to be consistent with this model. Additional models incorporating arc-parallel flow above and arc-perpendicular below the slab are being considered. Figures courtesy of D. Christensen and E. ***Kneller***.

size increase with depth in the Pacific asthenosphere. These constraints could be made stronger by incorporating geophysical measurements of upper-mantle *Qs* from the same region. **Wiens** presented a nice example of such an analysis. A major hurdle is that robustly quantifying upper-mantle *Q* remains a significant challenge (**Forsyth**; **Nettles**; **Dalton**); however, if velocity and attenuation can be robustly determined, the experimental constraints provide a powerful tool for unraveling the underlying cause of observed variations.

What can explain arc-parallel shear-wave splitting? Shear-wave splitting observations from subduction zones often exhibit a characteristic pattern of fast-wave polarizations, with a transition from roughly arc-parallel polarizations below the arc or forearc, to convergence-parallel polarizations further into the back-arc, although some arcs show different patterns (e.g., **Wiens**; **Fischer; van Keken**). Interpreted through the typical relationship between flow and fabric in dry olivine (i.e., fast seismic direction corresponds to the flow direction), these observations suggest arc-parallel upper-mantle flow that is difficult to explain using geodynamic models of subduction. An alternative has been suggested by **Karato** and co-workers, who found experimental evidence for a change in the dominant slip system in olivine under wet, high-stress conditions. Samples deformed under these conditions generate a "B-type" fabric that produces seismic fast directions roughly orthogonal to the dominant flow direction. This fabric thus can explain arc-parallel splitting observations with simple arc-normal convergent flow due to subduction.

Distinguishing between the slip mechanism active within SubFac and RCL regions provides a potentially powerful tool for evaluating underlying dynamics, as the B-type fabric exists in a very narrow range of water and stress conditions. Numerical models of subduction zones (**van Keken**) suggest that there is a small "nose" in the fore-arc corner between the slab and the overlying plate within which B-type fabric will be stable (Figure 3). The question is then whether the observations of arc-parallel splitting are consistent with the expected location of this wet, high-stress zone. If so, then the stress and water content within the arc can be tightly constrained by the anisotropy observations. If not, then alternative mechanisms are implied. Arc-parallel flow is one possibility, but apparent anisotropy due to shear-induced melt segregation has also been proposed (**Holtzman**). This latter mechanism may be particularly relevant for RCL (including Gulf of California, **Lizarralde**), but it might prove useful in interpreting splitting patterns from arcs as well.

At the workshop, observations broadly consistent with B-type fabric were presented from the Japan and Ryukyu arc (**Long**). New results from recent broadband deployments in the SubFac focus zones (Izu-Bonin-Marianas and Central America) are less consistent with this hypothesis. In particular, arc-parallel fast directions observed in Costa Rica and Nicaragua are not located in the expected region of the wet, high-stress nose (**Fischer**; **Abt**), and alternative explanations based on arc-parallel flow are being sought (**Behn; Kneller**). A similar conclusion was proposed for the Marianas, where a transition from arc-parallel to arc-perpendicular fast directions is observed, but the location of the transition appears to be well into the back arc (**Wiens**; **Pozgay**). Both of the latter results are preliminary, but it appears that the mechanisms controlling seismic anisotropy observations in arcs remain controversial.

Concluding Remarks

The MARGINS IMI workshop provided 2.5 days of spirited discussion on the use of seismic images to constrain critical physical and geodynamical processes in MARGINS focus areas. This report summarizes the goals and underlying issues addressed at the workshop. We cannot possibly address all of the topics discussed, however, and we encourage interested parties to access the meeting presentations for additional information. We emphasize that the confluence of new, high-quality observations from several MARGINS experiments, along with a new generation of experimental and theoretical results and modeling tools, makes this a very opportune time to address these problems. We hope that the discussions from the workshop will filter down through many communities, and form a basis for substantially improving our understanding of the deep earth.

References

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A MARGINS Interdisciplinary Mini-Workshop

MARGINS Interdisciplinary Mini-Workshop on the Izu-Bonin-Marianas Subduction Factory Focus Site

AGU Fall Meeting, 2006, Mon., 11 Dec., 6-8 pm, Salon A3, San Francisco Marriott

Conveners: R.J. Stern (U Texas at Dallas), Y. Tatsumi (IFREE/JAMSTEC), R.W. Embley (PMEL/NOAA), Y. Kaneda (Japan Continental Shelf Project)

Efforts to reach InterMARGINS and MARGINS-Subduction Factory science objectives in the Izu-Bonin-Mariana focus site have been enhanced by recent NOAA "Submarine Ring of Fire" investigations and the Japan Continental Shelf Project. Geoscientific studies in the region are being further stimulated by a set of IODP preproposals for drilling in the IBM arc system. These complementary efforts can be stimulated in turn by involving the MARGINS Subduction Factory community. This mini-workshop will inform the three communities of these efforts, solicit feedback, and explore possible synergies. The conveners also hope to present the status of a proposal for a future ~3 day MARGINS/IFREE Workshop to Integrate Subduction Factory and IODP Studies in the Izu-Bonin-Marianas Arc System.

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This mini-workshop shares its location with the MARGINS Middle America Subduction Zone mini-workshop following immediately after. Food and drink will be provided at both events.

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From the MARGINS Chair ~ Fall 2006

Doug Wiens, Interim MARGINS Chair, Washington University in St. Louis
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September 28, 2006

As I write this I have three days left in my term as interim MARGINS Chair, and I am pleased to report that the program is in good shape. The MARGINS Chair rotation from Julie Morris, who has become head of NSF-Ocean Sciences, temporarily to myself, and now to Geoff Abers of Boston University is going smoothly. This is largely due to the hard work of MARGINS Office Director Paul Wyer and Office Administrator Meredith Berwick, who have provided the continuity and institutional memory necessary for a smooth transition. We were fortunate to have the opportunity to visit with Julie during the September Steering Committee meeting in Washington DC; she seemed to be flourishing in her new position, although she said she misses the close interaction she developed with the MARGINS community over the past three years.

The two issues that have dominated much of the MARGINS Program discussion over the past few months are interactions with the ORION Program and the discussion about future directions for the Rifting Continental Lithosphere (RCL) Initiative. In both cases we opened web forums on the MARGINS website to allow input from the community. All the input was passed on to the Steering Committee during the September meeting; thanks to all of you who contributed input on these issues.

Much of the ORION discussion grew out of a request from the ORION STAC committee in April for the MARGINS Program to help provide guidance for two highly-rated responses to the Ocean Observatory Initiative (OOI) request for assistance (RFA) that involved MARGINS science at MARGINS focus sites. These were the buoyed observatory proposals for the Costa Rica seismogenic zone, coordinated by Kevin Brown, and the Mariana forearc, lead by Patty Fryer. Short descriptions of these programs were included in the Spring 2006 MARGINS Newsletter. Unfortunately, detailed budgeting and long term operations and maintenance cost estimates developed during the summer indicate that it is unlikely that OOI will be able to include either of these buoys within the initial program. Therefore the MARGINS Steering Committee decided there was little reason to prioritize these two projects at this time. However, we feel that the MARGINS community has learned a lot about the capabilities of seafloor observatories for advancing our science, and that seafloor observatories will be too important to ignore during the next decade.

There has also been a lot of discussion on the web forum and at the Steering Committee meeting about the future of the RCL initiative, after NSF made the decision to change the status of the Red Sea region to an "ancillary site," as detailed in the letter from Bilal Haq in the last newsletter. The community input and committee discussions indicate that it is not the right time in the program to be considering alternative RCL focus sites, and that the main MARGINS RCL studies will be undertaken in the Gulf of California – Salton Trough. There is some continued discussion that, although NSF will not fund seagoing work in the Red Sea, there may be some important questions that can be addressed within these limitations. Geoff Abers will discuss this subject in more detail at the MARGINS AGU reception and in a future newsletter.

The last half-year has also seen two highly successful MARGINS-sponsored workshops. The "Interpreting Upper Mantle Images" workshop was held at Woods Hole on May 17-19, organized by Greg Hirth, Geoff Abers and Jim Gaherty. The goal of the workshop was to bring together experimental, observational, and modeling communities to discuss how physical properties can be determined from upper mantle seismic images. Applications for the meeting ran far ahead of the conveners expectations, so the meeting size was increased somewhat from the initial proposal to accommodate all the interest. In the end, around 70 scientists participated in 2.5 days of talks and animated discussions. See the report in this newsletter for more details.

The MARGINS "Teleconnections Between Source and Sink in Sediment Dispersal Systems" Source-to-Sink Theoretical and Experimental Institute (S2S TEI) was just last week. Rudy Slingerland, John Milliman, Bill Dietrich and Lincoln Pratson organized the workshop around two successive venues separated by a field trip through the Eel River system in northern California. A little over 80 scientists from diverse disciplines gathered together to discuss ways to better understand the complex feedbacks that occur throughout source-to-sink systems. Keynote talks, panel discussions, poster sessions and breakout groups all contributed to this theme. Some participants stayed on for an optional extra half-day to review progress and goals in relation to the MARGINS S2S Science Plan. Geoff Abers and the Washington University MARGINS Office staff were joined at the TEI by the new Boston University MARGINS Office Administrator, Cary Kandel, enjoying her first interaction with the S2S community. Expect more about the meeting on the MARGINS website and in a future newsletter.

Well, it is almost time to "turn out the lights" on the Washington University office. We have really enjoyed the MARGINS presence here and have been delighted to help in this effort. In case anyone's still using the old MARGINS web address, now is the time to update to www.nsf-margins.org, which will carry through the move. Once again, I thank Paul and Meredith in particular and also our administrative and computer support staff for all their hard work to make the program run smoothly. Also, speaking of good things coming to an end, John Milliman has rotated off the Steering Committee as of this last meeting, and I thank him for his excellent service.

Geoff Abers is well underway in getting the Boston University office up to speed; Cary started her position early in September, and Geoff expects a new Office Coordinator to start soon. I wish them well, and look forward to seeing further progress as the MARGINS Program moves forward during the next three years.

MARGINS Steering Committee Highlights, Fall 2006

The MARGINS Steering Committee (MSC) met with visitors, 7-8 September, 2006, at NSF Headquarters, Arlington, VA.

1. Doug Wiens, Interim MARGINS Chair, welcomed new MSC members Steve Holbrook, University of Wyoming and Jim Gill (*in absentia*), University of California - Santa Cruz.
2. Bilal Haq, Program Director for Marine Geology and Geophysics and Coordinator for the MARGINS Program at NSF, welcomed and briefed the MSC on relevant NSF topics:
   - NSF-Ocean Sciences (NSF-OCE) rotations recently filled included Adam Schultz as a Marine Geology and Geophysics Program Director and Kevin Johnson as an Ocean Drilling Associate Program Director.
   - NSF-OCE continues to welcome cruise proposals and is maintaining a good award rate while working to alleviate ship time and cost pressures.
   - Although the Administration might increase NSF's budget for 2007, the main draws on any additional funds would likely be facilities and possibly ship time. Hence the 2007 MARGINS budget may not increase from 2006.

MSC discussion with NSF Program Directors considered opportunities for MARGINS to increase its appeal to NSF-Earth Sciences (EAR), especially mutually beneficial overlaps with the EarthScope Program. This theme continued in conjunction with EarthScope discussions later in the meeting. Similar advantages could continue to come from interaction with other major geoscience initiatives, such as ORION and IODP.

3. The MSC and NSF Program Directors discussed amendments to a draft MARGINS Program Event Response policy. This policy will be publicly released once a final version has been approved.
4. Kevin Brown, Scripps Oceanographic Institute and Patty Fryer, University of Hawaii, briefed the MSC on ORION Global Ocean Observatories and their potential applications in the MARGINS Central America and Izu-Bonin-Mariana Focus Sites. Kendra Daly, ORION Program Director, later gave her own briefing to the MSC regarding MARGINS-related opportunities in the ORION Program.
5. Lina Patino, NSF-EAR Assistant Program Director for EarthScope, briefed the MSC on the structure and progress of the EarthScope Program. She encouraged close interaction of the MARGINS Office and Steering Committee with the future EarthScope National Office. This office will be established for up to four years under an NSF Program Solicitation that closes on January 12, 2007:
   http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5618
6. Initiative subgroups updated the MSC on scientific progress in MARGINS Focus Sites.
7. Andrew Goodwillie of the Marine Geoscience Data System (www.marine-geo.org) at Lamont updated the MSC on developments in MARGINS database submission, content and access. A key step is to increase community awareness of the range of data now available through the MARGINS database. Community input on essential datasets for the database to host is welcome.
8. In the context of rising publication costs, the MSC discussed priorities for future MARGINS Publication Series volumes, including issues such as online availability, time to press and citation impact.
9. The MSC reviewed contributions from the MARGINS Rupturing Continental Lithosphere (RCL) online discussion forum. It was agreed that a new RCL focus site should not be added at this time. Until further notice, RCL will focus on the Gulf of California - Salton Trough, and completion of existing Red Sea projects. This topic will be discussed at the 2006 AGU Fall Meeting, and the MSC continues to consider how to proceed.
10. Workshops:
    - A report on the September 2006, MARGINS "Teleconnections Between Source and Sink in Sediment Dispersal Systems" Theoretical and Experimental Institute will appear in a future MARGINS Newsletter.
    - A report on the May 2006, MARGINS "Interpreting Upper Mantle Images" Workshop begins on the front page of this newsletter.
    - Proposals are in preparation for MARGINS co-sponsored Central America and Izu-Bonin-Mariana synthesis workshops.
    - MARGINS will co-sponsor a planned international data-sharing workshop in 2007.
11. Education and Public Outreach:
    - The MARGINS Education Advisory Committee continues to work on concepts outlined at the Spring 2006 MARGINS Steering Committee Meeting (MSC Highlights, *MARGINS Newsletter #16*, Spring 2006).
    - The second annual MARGINS Distinguished Lectureship Program received over 60 applications competing for an expected total of 12 tour stops in 2006-07. At time of writing, the selection process is ongoing. DVDs and streaming video of selected lectures from the 2005-06 series will be available soon through the MARGINS Office and website.
    - The MARGINS AGU Student Prize has been extended this year to highlight student participation at the MARGINS AGU reception (see p. 21).
12. The MSC considered proposals for MARGINS mini-workshops (see solicitation on p. 26, and MARGINS

See "Highlights" cont. on pg. 25

MARGINS, Rupturing Continental Lithosphere, Northern and Central Red Sea

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Introduction

The NSF MARGINS Program is designed to encourage the development of a systematic framework for integrating marine- and land-based geological and geophysical studies to further our understanding of the physical processes that characterize the boundaries between the Earth's lithospheric plates. The MARGINS Rupturing Continental Lithosphere (RCL) Initiative's main aim is a better understanding of the initiation of continental extension and its transition to ocean spreading, because many of the fundamental processes that govern continental rifting and that ultimately lead to rupturing of continental lithosphere and the birth of an ocean remain poorly understood. During the January 2000 MARGINS Theoretical and Experimental Institute and workshop on "Rupturing of the Continental Lithosphere" in Snowbird, Utah, the community formulated a science plan for the focused investigation of the geodynamic, mechanical, kinematic, thermal, and temporal evolution of two sites of active continental rifting to study the transition from continental extension to initial seafloor spreading, the Gulf of California and the northern and central Red Sea/Gulf of Suez rift system. It was anticipated that this integrated research effort at the focus sites will enhance understanding of the evolution of ocean basins and passive continental margins, with implications for lithosphere rheology, the dynamics of lithosphere – mantle interactions, and the geologic evolution of associated sedimentary basins that are commonly major source areas for oil and gas reserves.

At an organizational workshop and field trip for the RCL Red Sea focus site in Sharm el-Sheikh, Egypt, in March 2001, members of the scientific community met to formulate detailed scientific questions and strategies. One of the major objectives of this workshop was to provide a forum where the logistical requirements of working in the various countries bordering the Red Sea region could be discussed and researchers from the United States could meet and explore possible scientific collaborations with scientists from Egypt, Sudan, Jordan, Eritrea, and Saudi Arabia. Unfortunately, due to the current security situation and political climate in the Middle East, NSF decided that they could no longer consider U.S.-led marine geophysical experiments in the Red Sea at this tiime. The Red Sea has been re-designated as an "ancillary" focus area, indicating that while MARGINS will continue to encourage relevant research in this area, funding for future efforts must come from core NSF programs (see Comments from the Program Director, *MARGINS Newsletter #16,* Spring 2006). Discussion of this issue continues, see the Chairman's Report in this issue. In spite of this issue, a number of Red Sea projects supported under the initial phase of the Red Sea RCL Initiative have produced results that provide new constraints on rifting processes and lithospheric rheology and dynamics.

This series of articles presents the initial results of three MARGINS-supported geophysical studies of the Red Sea Rift. One study uses quantitative dating techniques to determine the geologic evolution of rifting and the subsidence history of the sedimentary basins that develop during the rifting process. A second study reports the initial results on crust and mantle structure beneath the eastern margin of the Red Sea and the Arabian shield from an analysis of seismic data from the Saudi Arabia National Digital Seismic Network. The third study uses geodetic techniques (predominantly GPS) to measure directly present-day deformations as a function of the stage of rifting (i.e., variations in style along strike). These studies are complementary in that the seismically constrained structure is the result of deformational processes observed with the GPS and inferred from basin analysis and rift flank exhumation and uplift. In addition, the geodetic results define present-day deformation while the seismic and quantitative geologic studies reflect deformation over geologic times – the relation between the deformations observed from these studies may provide another means of constraining the temporal evolution of rifting processes.

Tectonic Setting

The Red Sea Rift forms one arm of the Afar Rift/Rift/Rift Triple Junction, separating the Nubian and Arabian shields, the others being the Gulf of Aden separating Somalia and Arabia, and the more slowly spreading East African Rift that forms the Nubia–Somalia boundary (*Reilinger et al. 2006,* Figure 1, this newsletter). The separation of Arabia from Nubia initiated in the Miocene (~30 Ma; *Stockli et al., 2006,* this newsletter; *Reilinger et al. 2006,* Figure 1 inset, this newsletter), and involved counterclockwise rotation of Arabia relative to Nubia. This rotation, which continues to the present, results in increasing spreading rates and total extension from north to south, with the northernmost Red Sea being characterized by the early stages of continental breakup and the central and southern Red Sea having a well developed mid-ocean ridge and associated magnetic anomalies (e.g., *Chu and Gordon, 1998*). It is the variation in the stage of rifting along the strike of the Red Sea that makes it an ideal location to study the transition from rupturing continental lithosphere to full ocean spreading.

The Tertiary Red Sea-Gulf of Suez rift system is one of the best-exposed and studied examples of a continental rift. It provides both along-strike and across-strike views of the rifting process from distributed continental extension to the final rupturing of the lithosphere between the Arabian and African plates. Though much progress has been made in understanding the plate tectonic framework and modern strain field of this region, the transition from distributed continental extension to sea-floor spreading remains poorly understood. Specifically, our limited knowledge of how extensional strain is spatially and temporally distributed on the adjacent continental margins has made it difficult to adequately evaluate and test models for the dynamic evolution of this rift.

Several recent geodynamic models of rift geometries and evolution have relied heavily on data and concepts derived from the Red Sea rift system [e.g., *Bosworth et al., 2005* for summary]. The Gulf of Suez was the first rift system in which large-scale, long-axis segmentation into sub-basins and tilt domains by accommodation zones was clearly recognized, and has served as one of the premier examples demonstrating the interplay between extensional tectonism and sedimentation. Intracontinental rifting in the Red Sea began in the Oligocene and led to sea-floor spreading in the southern and central parts of the Red Sea in the Early Pliocene at ~4.5 Ma [e.g., *Bosworth et al., 2005*]. The margins of both the Gulf of Suez and Red Sea are bordered by large uplifted rift flanks that are actively undergoing erosion, exhuming basement rocks from >5 km depth [e.g., *Omar and Steckler, 1995*]. The flanks are asymmetrical, forming a steep escarpment facing the rift and a gentle backslope with decreasing elevation away from the rift. Growth of asymmetric rift flanks outside zones of large-magnitude lithospheric extension is a direct consequence of the crustal thinning and subsidence that occurs within rift systems [e.g., *Weissel & Karner, 1989*].

Ongoing studies

The articles presented here represent initial results from a selection of the many domestic and international studies elucidating active processes of the Red Sea rift. A range of new geological and geophysical results from some of these studies will be presented in the "Geodynamics of Lithospheric Extension" session at the 2006, Fall AGU Meeting (see p. 22).

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Annual MARGINS Prize for Outstanding Student Presentation

The MARGINS Program offers a $1000 prize for the Outstanding Student Oral Presentation or Poster on MARGINS-related science at the 2006 AGU Fall Meeting. The prize is open to any student from any country who is presenting a MARGINS-related talk or poster for which they are the first author and presenter. MARGINS is an NSF-funded program that seeks to facilitate outstanding interdisciplinary research, with foci on rupture of continental lithosphere, the (subduction) seismogenic zone, source-to-sink sedimentation, and material and chemical fluxes in the subduction factory. This prize highlights the important role of student research in accomplishing MARGINS science goals, and encourages cross-disciplinary input to the MARGINS Program. To be considered, students must apply no later than November 24, 2006 at: www.nsf-margins.org/AGU2006/. The entry must include a brief statement of how the research relates to some aspect of MARGINS science. This statement is important, as it will be used for pre-screening of entries of relevance, and may be considered in the final choice of winner. The winner and any honorable mentions will be notified after the conference and will be recognized in the MARGINS website and newsletter. Please direct email enquiries to the MARGINS Office: margins@nsf-margins.org.

Student prize entrants are encouraged to attend the MARGINS Student and Community Reception, Tuesday, 12 December, 6-9 pm , Salon 9, San Francisco Marriott. This informal event will give you an additional opportunity to discuss your research with MARGINS Prize judges, members of the MARGINS Steering Committee and others who study continental margins.

Thermochronometric constraints on tectonic and geomorphic evolution of the northern and central Saudi Arabian Red Sea Rift Margin

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The Tertiary Red Sea-Gulf of Suez rift system is one of the best-exposed examples of a continental rift (Figure 1) and a prime example of active continental break-up [e.g., *Cochran, 1983*; *Bosworth et al., 2005*]. Though much progress has been made in understanding the plate tectonic framework and modern strain field of the Red Sea [see *Reilinger et al., 2006*, this newsletter], limited knowledge of how extensional strain is spatially and temporally distributed along the continental margins has made it difficult to adequately evaluate and test models for the dynamic evolution of this rift system. Traditionally, the timing of growth and exhumation of rift flanks is determined by identifying erosional products within the basin fill. In the Red Sea, however, most of the pre-, syn-, and post- rift sedimentary rocks are either deeply buried within the rift, have been uplifted and eroded away, or are poorly dated due to the scarcity of datable synrift Tertiary volcanic rocks, hampering attempts to adequately reconstruct the rifting history along the entire margin of the Red Sea. Although the Egyptian and Yemeni margin of the Red Sea has been studied in some detail [e.g., *Omar et al., 1987*, *1989*; *Menzies et al., 1997*], little is known about the timing of Tertiary rifting of the Saudi Arabian margin. In this unprecedented collaborative project with the Saudi Geological Survey, we have been undertaking a comprehensive low-temperature thermochronometric investigation integrated with structural and geomorphic studies to determine the timing, origin, and geometry of extensional faulting and rift flank exhumation along the central and northern Red Sea margin in Saudi Arabia (Figure 1). The primary aim of this thermochronometric study is to systematically resolve the timing and spatial resolution of extensional faulting and post-rift erosion along the Saudi Red Sea margin and to distinguish between different models proposed for the geodynamic evolution of the Red Sea rift system.

Tectonic and Geological Evolution of the Central and Northern Red Sea

The Saudi Arabian Red Sea coastal margin has experienced a complex geological, tectonic, and geomorphic history. The margin is lithologically underlain by an assemblage of Neoproterozoic granitic gneisses, metasedimentary and volcanic rocks, ophiolites, and voluminous syn- to post-kinematic granitic intrusions and felsic to mafic Pan-African dikes. Basement fabrics are dominated by NW-trending foliations in the basement and WNW- to NW-trending basement shear zones of the late Pan-African Najd fault system. The Neoproterozoic assemblage is regionally unconformably overlain by a flat-lying Paleozoic sedimentary sequence. The overall picture of the Red Sea prior to rifting is that of a low relief, low elevation continental to marine realm. Subsequent uplift and exhumation related to the opening of the Red Sea has caused erosion of much of the pre-rift stratigraphy.

Volcanism began throughout the Red Sea at ~32-30 Ma and appears to largely predate earliest rift sedimentation. Rapid extension did not start until early Miocene times and is constrained by the oldest definite synrift strata in the northern Red Sea and Gulf of Suez at ~22 Ma [see summary in *Bosworth et al., 2005*]. This timing for the onset of Red Sea rifting is supported by apatite fission track and (U-Th)/He data from the Gulf of Suez region recording rapid rift flank exhumation at 21-23 Ma [*Omar et al., 1989*; *Stockli and Bosworth, unpubl.*]. Along the southern Saudi Arabian margin, however, *Bohannon and others* [1989] reported an onset of rapid extension that is distinctly older (23-28 Ma), possibly suggesting a diachronous onset of rifting along strike. *Menzies and others* [1997], on the other hand, obtained apatite fission track ages from the Yemen portion of the Red Sea margin that indicate rapid cooling occurred <25 Ma, post-dating the main period of basaltic volcanism (32-29 Ma). Basaltic volcanism on the Saudi Arabian margin has continued from the Late Oligocene throughout the entire development of the Red Sea and is characterized by large flood basalt provinces known as Harrats. The eruptive centers of the older flows follow a N30°W trend parallel to the Red Sea, while younger fields are oriented more northerly (N20°W - N10°E) [*Coleman et al., 1983*; see *Nyblade et al., this newsletter*]. Tertiary dikes, flows, and intrusions on the Saudi coastal plain bracket the age of rifting. Along the central Red Sea coast near Jeddah, the earliest synrift volcanic rocks range from >27 Ma to ~20 Ma [*Pallister, 1987].* The emplacement of NW-trending dikes at 24-18 Ma has been interpreted to represent a change in style of magmatism indicative of a dramatic increase in the extension rate [e.g., *Pallister, 1987*].

Geomorphic Evolution of the Saudi Arabian Margin

The Saudi Arabian Red Sea margin can be subdivided into two distinctly different geomorphic domains: (1) From about 21°N to the southern tip of Yemen, the

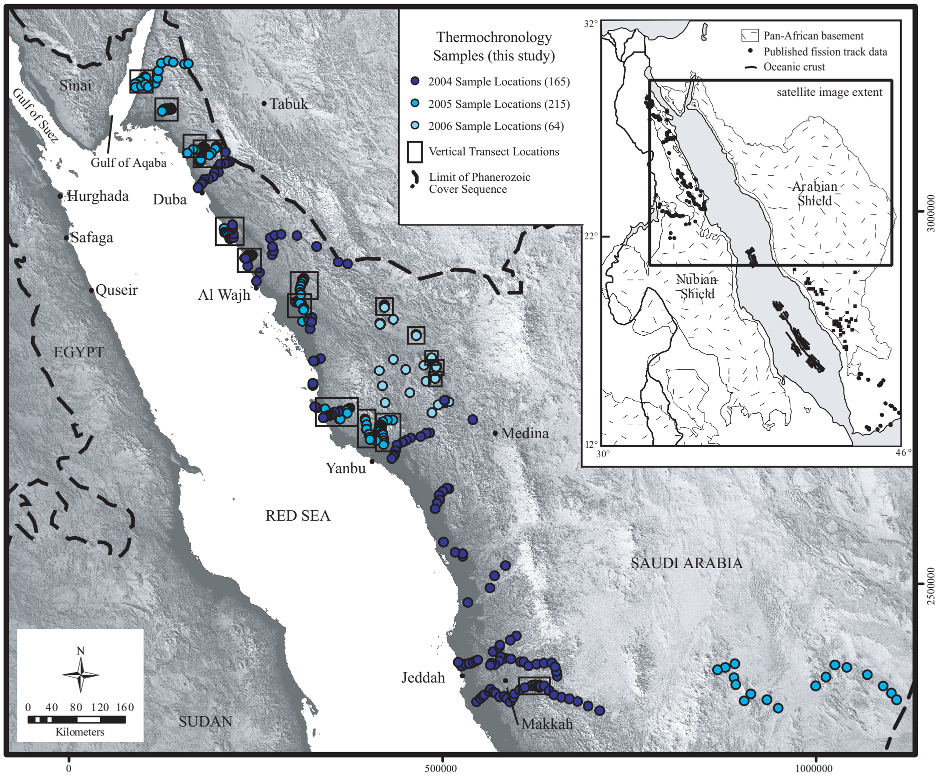

Figure 1. Shaded digital relief map of the central and northern Red Sea showing locations of low-temperature thermochronometric samples and vertical sampling transects collected from the Saudi Arabian Red Sea margin for this collaborative study. Inset map outlines Neoproterozoic basement exposures of the Arabian and Nubian Shields and published thermochronometric sample locations.

Saudi Red Sea margin is dominated by an impressive continuous ~2-3 km high erosional escarpment. The escarpment is the result of erosional rift flank retreat and appears to be independent of any structures in the underlying Precambrian. In central western Saudi Arabia, this upper surface is a mature erosion surface that extends east from the lip of the escarpment and bevels late Cretaceous-middle Eocene sedimentary rocks. East of Makkah (Mecca) this surface is partially overlain by Oligo-Miocene Harrat flood basalts and is likely late Cretaceous in age. (2) North of Makkah the Red Sea escarpment is discontinuous and less elevated and is interrupted by paleovalleys that descend from elevations of 1000-1500 m to the coastal plain. These paleovalleys post-date rifting and are infilled by ~5-10 Ma flood basalt that spilled from their eruptive centers east of the escarpment. We are currently carrying out detailed $^{40}Ar/^{39}Ar$ and magnetite (U-Th)/He dating of geologically significant basalts sequences.

The central Saudi Arabian Red Sea margin comprises erosional surfaces in addition to the prominent pre-Tertiary erosional surface dominating southern Saudi Arabia and Yemen. A very distinctive surface is well developed between the modern coastal plain and the main rift flank escarpment. It stretches for >500 km and dips gently seaward ranging from 300-100 m in elevation. A small escarpment (50-75 m high) separates this surface from the modern coastal plain, which is often rimmed by uplifted middle Miocene carbonate reefs. This surface likely represents a major wave-cut platform associated with the middle Miocene tectonic reorganization in the Red Sea coeval with the development of the Gulf of Aqaba transform. New apatite (U-Th)/He data from the area between Yanbu and Umm Lujj support a middle to late Miocene age for this erosional surface. North of Al Wajh, additional coastal uplift related to tectonism along the Aqaba transform system is expressed by spectacular coastal cliffs that appear to increase in height from south to north. New apatite (U-Th)/He data from the area between Dhuba (Duba) and the Gulf of Aqaba exhibit significant post-Miocene cooling and exhumation increasing in magnitude from south to north.

Low-Temperature Thermochronometry

Over the past three years, our collaborative efforts have focused on a comprehensive thermochronometric study of exhumed crystalline basement along the central and northern Saudi Arabia Red Sea rift margin, stretching from the costal escarpment south of Makkah/Jeddah to the northern Gulf of Aqaba (Figure 1). Apatite and zircon (U-Th)/He and apatite fission track analysis directly date the timing of onset of extension and also quantify the pre- and post-rift erosional denudation of the rift flanks. A critical aspect of constraining the evolution of rifting and rift flank exhumation is acquiring chronological constraints on faulting, rift segmentation, and rift localization. The answers to these questions have far-reaching implications for the understanding of rifting dynamics and the interplay between extensional faulting and subsidence during syn-rift sedimentation. In addition, integration of detailed thermochronometric data with detailed structural and kinematic analysis is necessary to interpret the temporal constraints in their proper tectonic framework [e.g., *Stockli et al., 2005*].

We have collected more than 400 thermochronometric samples to resolve the timing of extensional faulting and to differentiate between different episodes of cooling and exhumation affecting the Saudi Arabian Red Sea margin. Our sampling strategy can be summarized by two major approaches:

(1) Following the strategy described by *Stockli et al*. [2005], a series of detailed vertical transects were collected across the exhumed crustal blocks and topographic escarpments along the Saudi Red Sea margin to constrain the timing and spatial distribution of extensional

faulting and evolution of rift segmentation and localization, as well as rift flank exhumation (Figure 1). The detailed vertical transects, spanning up to 3000 m in elevation between Jeddah and the Gulf of Aqaba, allow for detailed reconstruction of the Mesozoic to late Cenozoic thermal history. In addition, vertical transects were collected in the footwall of the inland Hamd-Jizl halfgraben north of Medina to elucidate the temporal relationship between distributed inland extension and normal faulting within the main Red Sea basin.

(2) Horizontal traverses were collected across the entire rift margin from the modern coastal plain to the edge of the exposed Neoproterozoic Arabian Shield (Figure 1). These thermochronometric traverses range from ~100 km in length in northern Saudi Arabia (Gulf of Aqaba and Dhuba) and ~200 km (Al Wadj and Yanbu) to ~600 km (Jeddah/Makkah). These long-baseline traverses were designed to investigate the width of exhumation related to rifting and crustal attenuation and to constrain how far extensional faulting encroaches into the rift margins beyond the border fault systems, such as in the Hamd-Jizl basins north of Medina (Figure 1). Knowledge of the temporal and spatial distribution of crustal attenuation and the timing of flexural amplification and exhumation of the entire width of the rift flank is critical for evaluating the role of processes such as active versus passive asthenospheric upwelling, secondary convection, and flexural unloading of the crust, as well as the distribution of sub-crustal lithospheric extension relative to crustal thinning.

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Seismic Structure of the Arabian Shield Lithosphere and Red Sea Margin

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Introduction

In this MARGINS project we are using broadband seismic data from the Saudi Arabia National Digital Seismic Network (SANDSN) to investigate crust and upper mantle structure beneath the eastern margin of the Red Sea and the Arabian Shield. The SANDSN has been operated since 1998 by the King Abdulaziz City for Science and Technology (KACST), and consists of 38 stations mostly distributed across the Arabian Shield (Figure 1) [*Al-Amri and Al-Amri, 1999*]. Twenty-seven of the stations are equipped with broadband (Streckeisen STS-2) sensors. Five years of data (1999-2003) from the network have been made available for this project, and the data are being used to 1) map first-order structure surrounding the ruptured Red Sea lithosphere, 2) evaluate the heterogeneity of the continental lithosphere prior to rifting, and 3) constrain ambient stress fields and lithospheric rheology using local seismicity.

Here we report preliminary findings from a surface wave tomography study to map differences in upper mantle structure between the eastern margin of the Red Sea, the Arabian Shield, and the Arabian Platform (Figure 1). The basement of the study region consists of an amalgamation of Proterozoic terrains, and across the Arabian Shield these terrains have been subjected to Cenozoic uplift and volcanism. The locations of the volcanic regions are shown in Figure 1a. The oldest volcanic rocks on the Shield are contemporaneous with flood basalt volcanism in Yemen and Ethiopia and the initiation of rifting in the Red Sea c. 30 Ma [*Mohr, 1988*; *Camp et al., 1991*; *Coleman and McGuire, 1988*]. Younger volcanic rocks (c. 12 Ma to present; *Camp and Roobol, 1992*) are found in the central and northern part of the Shield (Figure 1a). The average elevation across the Shield is 1 km, but in some areas near the Red Sea elevations are as high as 3 km. The uplift of the Shield probably occurred between 20 and 13 Ma, post-dating the onset of rifting in the Red Sea by at least 10 Ma [*McGuire and Bohannon, 1989*; *Bohannon et al., 1989*].

Although a great deal of work has been done to understand the origin of Cenozoic uplift and volcanism in the Arabian Shield, the development of these features in relation to rifting in the Red Sea remains enigmatic and must be ascertained before the tectonic evolution of the Red Sea rift can be fully understood. The surface uplift and volcanism are generally assumed to be due to hot, buoyant material in the upper mantle that may have eroded the base of the lithosphere [*Camp and Roobol, 1992*]. However, the lateral and vertical extent of the thermal anomaly in the upper mantle under the Shield is uncertain, as is its relationship to rifting in the Red Sea.

Previous seismic work in the region has revealed low seismic velocities in the upper mantle beneath the Shield [e.g., *Sandvol et al., 1998*; *Mellors et al., 1999*; *Rodgers et al., 1999*; *Debayle et al., 2001*; *Julia et al., 2003*; *Benoit et al., 2003*], consistent with the presence of a mantle thermal anomaly. Global tomographic models suggest that the region of low seismic velocities could extend from shallow upper mantle depths across the transition zone into the lower mantle [e.g., *Ritsema et al., 1999*; *Debayle et al., 2001*; *Zhao, 2001*; *Grand, 2002*]. *Daradich et al.* [2003] have used these models to suggested that the uplift of the Shield is caused by thermally buoyant mantle rising from the core-mantle boundary all the way to the surface. Other studies, however, have found little evidence for thinning of the transition zone under the Shield, [e.g., *Kumar et al., 2002*; *Benoit et al, 2003*], suggesting that the low velocities, and hence thermal anomaly, do not extend as deep as the transition zone.

Hansen et al. [2006] recently published results from shear wave splitting analyses using data from the SANDSN stations. Their results show a N-S fast polarization direction across the Shield (Figure 1c), similar to the results from *Wolfe et al.* [1999] for the Saudi Arabian PASSCAL experiment stations [*Vernon et al., 1996*]. The N-S pattern of fast polarization directions is not easy to explain by flow in the mantle in the direction of plate motion or to fossil anisotropy in the Proterozoic lithosphere, and consequently *Hansen et al.* [2006] have attributed it to a combination of plate and density driven flow in the asthenosphere. The density driven flow is associated with warm material from the Afar hotspot moving to the northwest channeled by the thinner lithosphere under the Red Sea, implying the existence of a thermal anomaly within the upper part of the mantle beneath the Shield.

Surface Wave Tomography

To investigate further the depth and lateral extent of the low velocity region in the upper mantle beneath the eastern margin of the Red Sea and the Arabian Shield, we have conducted surface wave tomography using measurements of Rayleigh wave phase velocities. In addition to data from the SANDSN network, we have included data from two seismic experiments in Ethiopia (the Ethiopian Broadband Seismic Experiment, *Nyblade and Langston, 2002*; EAGLE, *Maguire et al., 2003*), the Saudi Arabia PASSCAL Experiment [*Vernon et al., 1996*], and several permanent seismic stations in the region (Figure 1a).

Interstation phase velocities were obtained using the method described by *Lawrence et al.* [2006], which is based

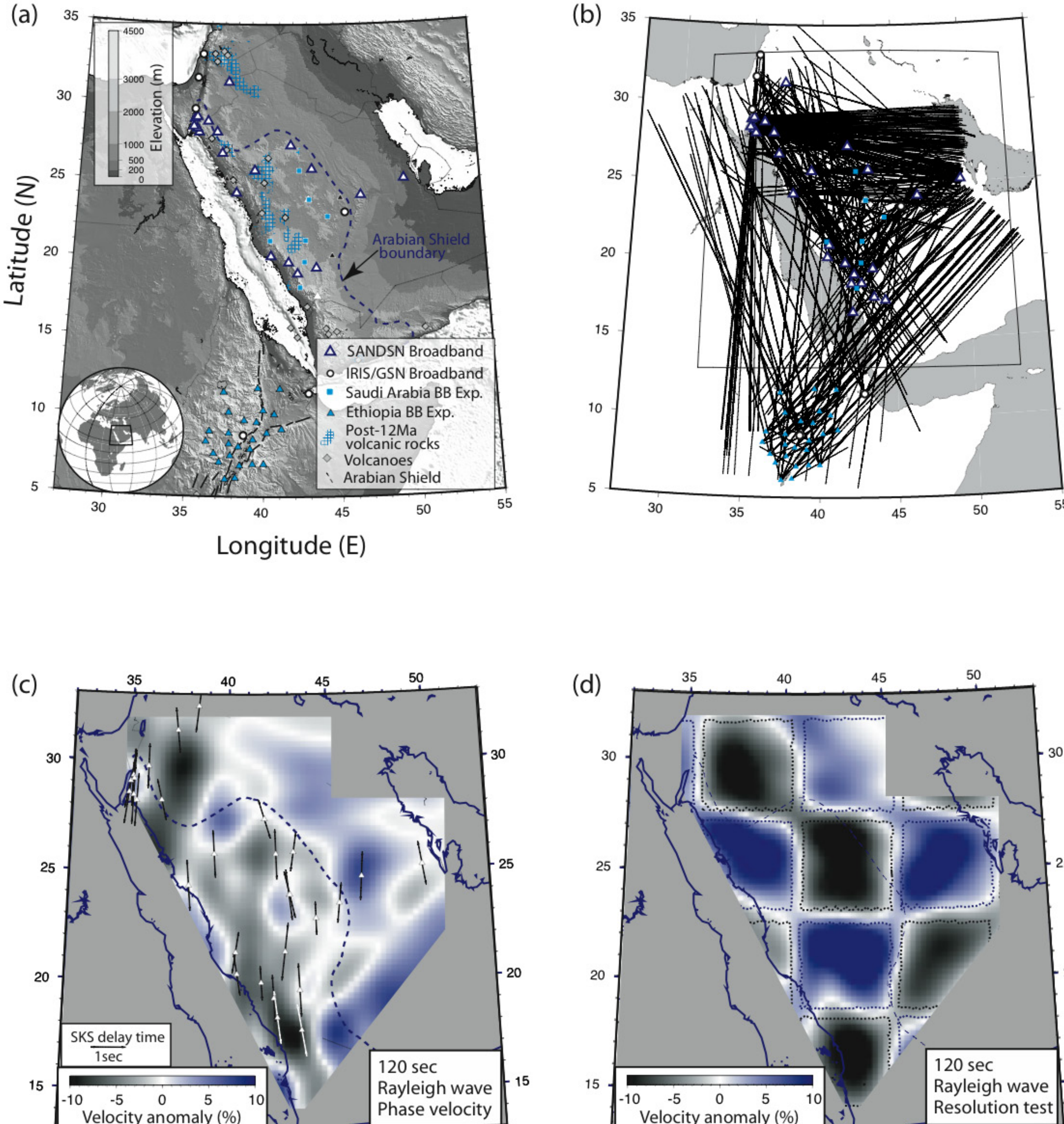

Figure 1. (a) Map of Arabian Peninsula and surrounding regions showing topography (grey scale), seismic station locations, Cenozoic volcanic fields, and the outline of the Arabian Shield. (b) Ray path coverage for 120 sec. period Rayleigh waves. (c) Phase velocity variations for 120 sec. period Rayleigh waves with shear-wave splitting results from Hansen et al. [2006] superimposed. (d) Checkerboard resolution test for Rayleigh wave phase velocity variations at 120 sec. period. The dotted lines show the +/- 9% contour interval for the input checkerboard anomalies. The blue and grey shaded regions show the recovered structure.

on an array analysis technique modified from *Menke and Levin* [2002], to solve for the variation in ray path from a great circle. When applied to the available data, we obtained 900 or more interstation phase velocity curves, each constructed from interstation phase velocities measured at up to 30 period bands from 16 to 180 s. The best ray coverage is obtained between periods of 60 and 120 s. Using the phase velocities measurements, we have preformed inversions using a least squares algorithm to construct phase velocity maps, and we have tested the resolution of the maps using standard checkerboard methods.

A preliminary result, using about 80% of the available data, is shown in Figures 1b, c and d. The ray coverage is best across the Shield and the northern and central parts of the Platform. The number of rays, as well as the density of crossing ray paths, degrades in the Red Sea and in the southern part of the Platform.

Because most of the teleseismic earthquakes come from the east or the west, there are relatively few ray paths oriented north-south. Inclusion of interstation measurements between the KACST and Ethiopian stations in the inversion was necessary to improve the density of crossing ray paths.

The phase velocity maps between periods of 65 and 120 s show similar velocity variations across the study region and have similar resolution. Because we are primarily interested in lithospheric mantle structure under the Shield, we show in Figure 1c the map for 120 s, which is broadly indicative of structure deeper than about 100-120 km. The map shows a simple pattern of lower-than-average phase velocities beneath the Shield, as well as to the north of the Shield near the Gulf of Aqaba. Faster-than-average velocities are found beneath the Platform surrounding the Shield.

Preliminary resolution tests indicate that anomalies on the order of a few hundred kilometers in wavelength can be resolved. Figure 1d shows the results from a 400x400 km checkerboard test; clearly anomalies of this size, which are somewhat smaller than the dimensions of the Shield, can be resolved.

Discussion

Our preliminary results suggest that the mantle lithosphere everywhere beneath the Shield to the east of the Red Sea rift has been modified thermally, and that there is a fairly abrupt change in lithospheric structure across the Shield-Platform boundary. The reduction in Rayleigh wave phase velocities at 120 s period under the Shield compared to the Platform is between 5 and 8%. Similar results have been reported recently by us [*Park et al., 2005*] from an S body wave tomography of the region using the SANDSN data, and preliminary results from S receiver function analysis of the SANDSN data also indicate the presence of thermally modified upper mantle beneath the eastern margin of the Red Sea and the Shield [*Hansen, personal communication*]. Previous tomographic images of the Arabian Peninsula using regional data sets indicate the presence of thermally perturbed mantle lithosphere under the Shield [*Benoit et al., 2003*; *Debayle et al, 2001*], but they do not show an abrupt change in lithospheric structure across the Shield-Platform boundary, as suggested by our preliminary results (Figure 1).

How do these results advance our general understanding of rift processes in continental settings? And more specifically, how do they help to achieve the science goals of the MARGINS Rupturing Continental Lithosphere initiative? Certainly, the rheology of the continental lithosphere on the eastern margin of the Red Sea has been thermally weakened, and thus the post-rift thermal evolution of the lithosphere has likely been affected. But beyond that, answers to these questions depend in large part on whether the thermal anomaly imaged in the upper mantle to the east of the Red Sea extends under the Red Sea. If the thermal anomaly under the shield developed about 10 Ma after the initiation of rifting, then it is not clear how this could have influenced strain partitioning at the time of rifting. However, if the anomalous mantle structure under the Shield extends beneath the Red Sea, then the tectonic development of the Red Sea and Shield would appear to be linked.

More detailed imaging of the upper mantle under the Red Sea and the Arabian Shield is clearly needed. Completion of the surface and body wave tomography studies underway at Penn State, King Saud University, and Lawrence Livermore National Lab using the SANDSN data should provide images with improved resolution of upper mantle structure across the region, letting us determine if the low velocity structure in the upper mantle under the Shield extends beneath the Red Sea.

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See "Seismic" cont. on pg. 25

Geodetic constraints on Rupturing of Continental Lithosphere along the Red Sea

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Our project uses the Global Positioning System (GPS) to monitor and quantify patterns and rates of tectonic and magmatic deformation associated with active rifting of the continental lithosphere in the northern Red Sea and the transition to sea floor spreading in the central Red Sea. Figure 1 shows the current network and preliminary velocities for GPS sites with sufficient observations, together with GPS-velocities from our broader collaborative project (*Reilinger et al., 2006*). As briefly described here, these new data allow us to: 1) identify, and quantify present-day motion of the Sinai micro-plate that is distinct from both Nubia and Arabia; 2) determine more precisely the motion of the Arabian plate relative to Nubia and Eurasia (Euler vectors); 3) establish baseline observations to quantify the spatial distribution of deformation associated with rupturing of the continental lithosphere as a function of the stage of rifting (i.e., along strike of the rift); and 4) quantify the relationships between deformational processes around the periphery of the Arabian plate to provide new constraints on the dynamics of Arabia plate motion and associated rifting along the Red Sea. In addition, independent but coordinated observations in Eritrea are beginning to quantify bifurcation of rifting in the southern Red Sea near the Afar Rift/Rift/Rift Triple Junction, promising to provide powerful new constraints on the dynamics of Red Sea rifting and the influence of rheology on the kinematic response of the lithosphere.

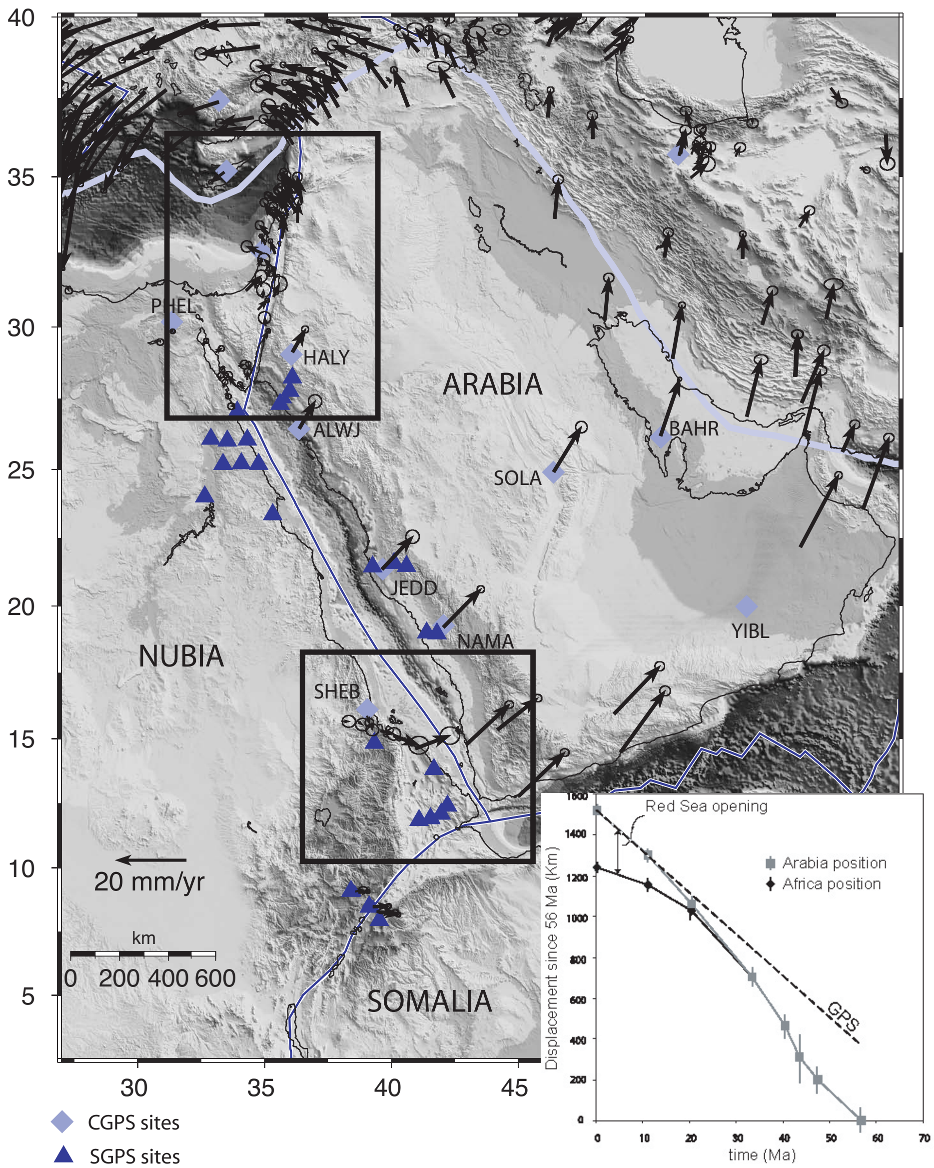

Figure 1. Red Sea and surroundings showing idealized plate boundaries (Arabia-Nubia-Somalia, dark blue; Arabia and Nubia-Eurasia, light blue) and GPS-derived velocities relative to Eurasia with 1-sigma error ellipses. The boxes show the locations of Figures 2 (north) and 3. The inset, modified from McQuarrie et al. (2003), shows the motion of Arabia and Nubia relative to Eurasia since 56 Ma along with the GPS-derived motion for Arabia extrapolated to this time interval.

Sinai Micro-plate [*Mahmoud et al., 2005*]

GPS survey sites in the Sinai Peninsula show northerly motion relative to Africa (Nubia) at 1.4 ± 0.8 mm/yr north and 0.4 ± 0.8 mm/yr west (Figure 1). Continuous IGS GPS sites in Israel, west of the Dead Sea fault [*Wdowinski et al., 2004*] show a similar northerly sense of motion relative to Nubia (2.4 ± 0.6 mm/yr north and 0.04 ± 0.7 mm/yr east), suggesting that the entire Sinai Block south of Lebanon is characterized by northward translation relative to the Nubian plate. We develop an elastic block model constrained by the GPS results that is consistent with regional tectonics and allows us to estimate slip rates for Sinai bounding faults (Figure 2). The substantial, and perhaps unanticipated left-lateral strike-slip motion within the Gulf of Suez is supported by geologic analyses that indicate a late Pleistocene change in the regional stress field from rift-normal to N-S extension [*Bosworth and Strecker, 1997*]. These observations indicate that the Sinai Peninsula and Levant region comprise a separate sub-plate sandwiched between the Arabian and Nubian plates. The relatively recent change in Gulf of Suez extension provides an important new constraint on the dynamics of rifting in the N Red Sea.

Arabia Plate Motion

The separation of Arabia from Nubia and associated extension in the Red Sea initiated in the Miocene roughly simultaneously with the onset of continental collision between Arabia and Eurasia along the Bitlis-Zagros suture zone (inset, Figure 1). Collision continues today as evidenced by the intense seismic activity along the borders of the Arabian plate. We initiated GPS observations in the Kingdom of Saudi Arabia by establishing 5 continuously recording stations (Figure 1). These stations, IGS stations in Bahrain and Damascus, and survey sites in SE Turkey, Oman, and Yemen, constrain Arabia motion and provide boundary conditions on the distribution of extension along the Red Sea plate boundary. The GPS velocities are consistent with coherent motion of the Arabian plate with internal deformation below the current resolution of our measurements (~ 1-2 mm/yr). The GPS-determined Euler vectors for Arabia-Nubia, and Arabia-Somalia relative motions are indistinguishable from geologic Euler vectors determined from marine magnetic anomalies in the Red Sea and Gulf of Aden [*Chu and Gordon, 1998, 1999*], implying that, to the resolution of our observations, spreading in the central Red Sea is primarily confined to the central rift (±10-20%). This contrasts with the N Red Sea and Gulf of Suez where extension appears more spatially distributed. Furthermore, Arabia-Eurasia relative motion from GPS is equal within uncertainties to relative motion determined from plate reconstructions suggesting that Arabia plate motion has remained constant (±10%) during at least the past ~10 Ma (Figure 1, inset). The new constraints on Arabia motion provide corresponding strong constraints on slip rates for the faults bounding the plate, including the Red Sea rift, Dead Sea fault, Makran subduction, faults along the Zagros Mountains, and the East Anatolian Fault (EAF) that separates the Arabian and Anatolian plates. Surprisingly, we find that while the EAF is characterized by predominantly left-lateral strike slip, it also shows a small component of extension. Likewise we find extension in the direction of relative plate motion north of the Arabian plate in the Lesser Caucasus. These observations appear to be incompatible with classic "indentor/extrusion" models for present-day deformation within this continental collision zone.

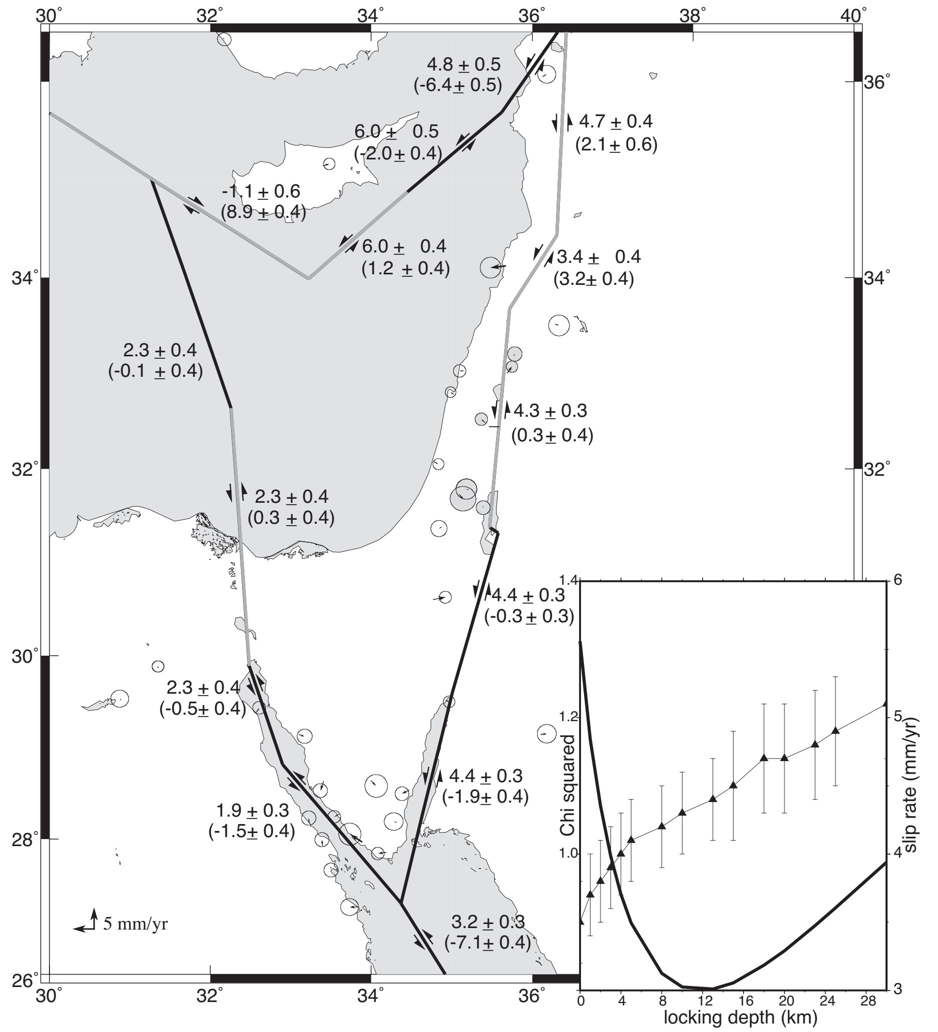

Figure 2. Elastic block model for the Sinai micro-plate showing residual GPS velocities and 95% confidence ellipses, and fault slip rates (fault-normal slip rates in brackets, positive for left lateral and compression). The inset shows the trade-off between locking depth and slip rate for the model, indicating the best fit for a slip rate of 4.3 mm/yr and a 13 km locking depth for the central DSF (see Mahmoud et al., 2005 for details).

Baseline Measurements of the Spatial Character of Extension Along the Red Sea

Figure 1 shows survey sites established along profiles perpendicular to the Red Sea spreading axis in Egypt (collected and analyzed by the National Research Institute of Astronomy and Geophysics -

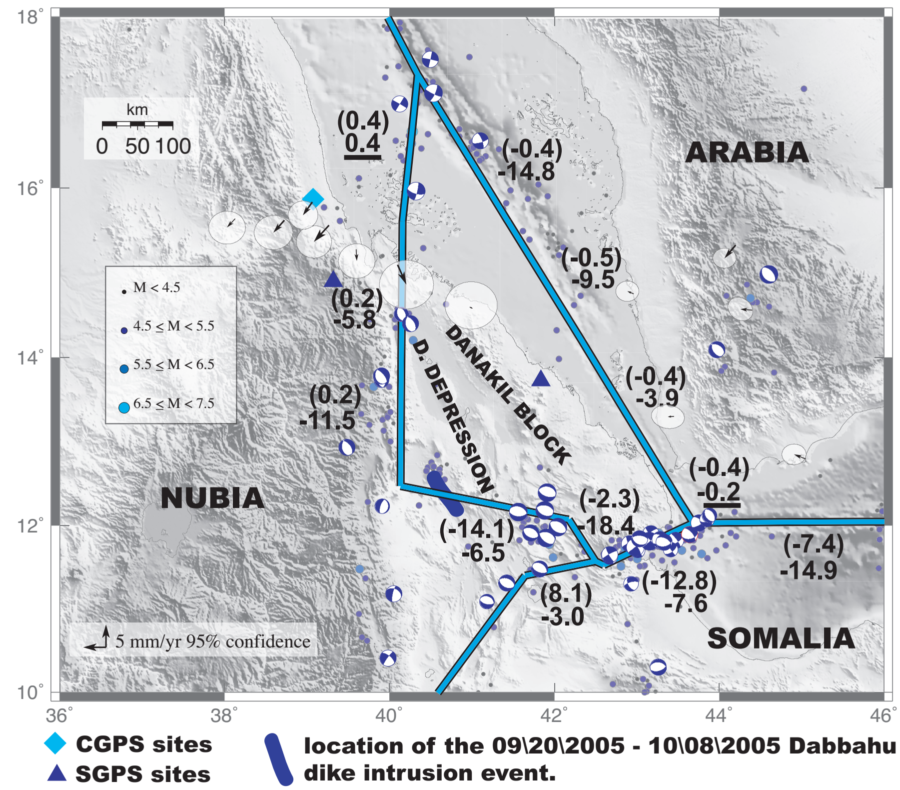

Figure 3. Elastic block model for the S Red Sea and Afar region. The model is highly idealized and still poorly constrained by GPS. The model involves coherent rotation of the Danakil micro-plate with extension increasing from N-S on the western plate boundary and decreasing from N-S along the Red Sea.

NRIAG), Saudi Arabia, and Eritrea. Except in the vicinity of the Sinai Peninsula/northernmost Red Sea and in the southern Red Sea adjacent to Eritrea, the survey sites have an insufficient observation history to determine reliable velocities. In addition, we anticipate small strains along the coast for the central Red Sea based on the approximate coincidence of GPS-plate motion and seafloor spreading estimates of spreading rates (< ~2mm/yr). More definitive conclusions about the distribution of extension will require repeat surveys over sufficient time for the anticipated small signals to emerge from the GPS uncertainties.

Plate Dynamics and Rupturing of the Continental Lithosphere

An overarching objective of our geodetic research is to establish an observational basis to constrain better the dynamics of plate motions and continental deformation. This is a difficult problem involving trade-offs between driving forces and rheology that has occupied Earth scientists since the advent of Plate Tectonics. However, we believe that the fundamentally new kinematic observations provided by space-based geodesy, new quantitative geological techniques that allow precise dating of tectonic events, and advances in seismology that are quantifying lithospheric and mantle structure and anisotropy, provide powerful new constraints on dynamic and rheological Earth models.

We alluded above to the implications of Arabia-Anatolia relative motion for the extrusion model [*Reilinger et al., 2006*]. For the Red Sea, a fundamental question concerns the relative importance of ridge "push" by the Red Sea and Gulf of Aden ridges and the Afar hot spot, and slab "pull" along the Makran subduction zone (and Zagros?) for driving the separation of NU and AR and the collision of AR with Eurasia. In the case of ridge push, we would expect intra-plate, ridge-normal compression within Arabia, while slab pull would induce trench-normal extension. While at present we prefer models where subduction dominates the dynamics, we continue to develop the geodetic observations necessary to quantify present-day strain of Arabia to evaluate better the importance of different plate driving forces.

Bifurcation of Rifting in the Southern Red Sea

Although our MARGINS project is confined to the simpler part of the rift in the northern and central Red Sea, our Eritrean partners have taken the initiative to extend our geodetic network to the southern Red Sea (Figure 1). This part of the Nubia-Arabia plate boundary includes the Danakil Block and adjacent Depression that appear to result from bifurcation of the rift north of the Afar plume (Figure 3). This extension of our network is highly valuable in that it provides a basis to investigate further the influence of lithospheric rheology on rifting processes.

Spreading in the southern Red Sea is thought to deviate towards the west, south of about 17°N, forming the Danakil Depression that is separated from the Red Sea proper by the intervening NW-SE striking Danakil Block [e.g., *Chu and Gordon, 1998*] (Figure 3). The Red Sea rift and Danakil Depression do not appear to be connected by a transform fault as is typical for offset ridges in more mature ocean basins. We propose a kinematic model for the S Red Sea that includes a "Danakil micro-plate", as hypothesized by *Chu and Gordon* [1998], and shown in Figure 3. The model involves linearly increasing spreading rates from N to S within the Depression and linearly decreasing rates along the Red Sea rift such that their sum is equal to the full Arabia-Nubia spreading rate. While the model is very preliminary and poorly constrained by the available GPS data, it has a number of interesting features, including: 1) the proposed Danakil micro-plate boundaries correspond well with seismic activity; 2) the "junction" where the Red Sea rift "bifurcates" at ~ 17°N involves negligible deformation of the SW Red Sea, consistent with the absence of any well defined tectonic features on the sea floor; 3) the model results in coherent rotation of the Danakil block, consistent with its geological structure and aseismic character, and 4) the model involves coherent rotation of the Arabian plate, consistent with the absence of tectonic deformation or significant seismic activity in Yemen. Interestingly, the width of the Danakil depression at the latitude of the Afar triple junction (~12°N) is roughly 300 km. Arabia-Nubia relative plate motion at this latitude is about 17 mm/yr. If AR-NU relative motion has been roughly constant since the initiation of Red Sea rifting, as indicated by geological studies (Figure 1 inset), the depression would develop in ~18 Myr, roughly the time that Arabia is thought to have separated from Nubia (*McQuarrie et al., 2003*). This implies that the Danakil micro-plate has been an integral part of rifting/triple junction processes throughout the history of separation of the Arabian and Nubian plates.

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A MARGINS Interdisciplinary Mini-Workshop

Seismogenesis and Subduction Fluxes in the Middle America Subduction Zone: The role of IODP and ORION

AGU Fall Meeting, 2006, Mon., 11 Dec., 8 pm onward, Salon A3, San Francisco Marriott

Conveners: K. Brown (University of California, San Diego), N. Bangs (U. Texas at Austin), S. Schwartz (U. California, Santa Cruz)

This public mini-workshop will focus on interconnections between the dynamics of both seismic and aseismic slip processes and along-strike variations in subduction fluxes (fluids, sediments, and chemical species) through the Middle America arc and fore-arc. How do the physical and hydrologic structure and composition of the incoming plate and fore-arc control both fluxes and seismogenic processes along the Middle America Trench? Can these controls be quantified sufficiently to make predictions from Central America to other non-accretionary subduction zones? Topics addressing these questions will include: physical, geophysical and hydrological properties of the system; material/chemical fluxes; integration of onland and offshore studies; relation of laboratory and numerical studies to field observations; and development of new technologies and methodologies.

This mini-workshop immediately follows the MARGINS Izu-Bonin-Marianas mini-workshop in the same location. Food and drink will be provided at both events.

MARGINS at the 2006 AGU Fall Meeting

In this section we highlight several MARGINS events taking place at the 2006 AGU Fall meeting, 11-15 December, Moscone Center West, San Francisco. This will be the first AGU meeting with the new Boston University MARGINS Office at the helm, and they are looking forward to an interesting week for MARGINS at AGU.

As the Washington University MARGINS Office closes its doors at the end of its three year rotation, on pages 22-25 we include our last attempt to pick out AGU sessions of special interest to MARGINS Newsletter readers. We hope you find it useful, and Meredith Berwick and Paul Wyer are sorry to be missing this year's meeting.

As usual, the MARGINS Student Prize will run throughout the week, with a special emphasis on prize participants at the MARGINS Student and Community Reception (Tues., 12 Dec., 6-9 pm, Salon 9, San Francisco Marriott). This reception is a chance for members of the community to mingle in a relaxed environment, and will feature Program updates from the new MARGINS Chair, Geoff Abers, and NSF Marine Geology and Geophysics Program Director, Bilal Haq.

Interdisciplinary mini-workshops for Izu-Bonin-Marianas (see p. 5) and Central America (see p. 19) during AGU week represent the first responses to the MARGINS Office solicitation. The call is repeated on p. 26. We hope the AGU mini-workshops will attract a wide audience and guarantee the success of future events of this type.

The MARGINS Database continues at Lamont Doherty Earth Observatory. You can visit them and demo some of their data and tools at booth #329 in the AGU Exhibition Hall.

Finally, we are pleased to promote the IODP Town Hall Meeting, Thurs., 14 Dec., 7:30 pm, Salons 4-6, San Francisco Marriott. Topics in the IODP program will include: Charting IODP Investigations; Planning Workshops; and an Update on IODP Platforms. IODP is actively interested in input and proposals from beyond the traditional ocean drilling community; we hope this will encourage a wide range of scientists reading this newsletter to attend.

Calendar:

- **MARGINS Interdisciplinary Mini-Workshop on the Izu-Bonin-Marianas Subduction Factory Focus Site (Mon., 11 Dec., 6-8 pm, Salon A3, San Francisco Marriott)**
- **Seismogenesis and Subduction Fluxes in the Middle America Subduction Zone: The role of IODP and ORION (Mon., 11 Dec., 8 pm onward, Salon A3, San Francisco Marriott)**
- **MARGINS Student and Community Reception (Tues., 12 Dec., 6-9 pm, Salon 9, San Francisco Marriott)**

The Washington University MARGINS Office, October 2006

MARGINS Student and Community Reception
AGU Fall Meeting 2006

With comments on the MARGIN Program's status from NSF Program Director, Bilal Haq and MARGINS Chair, Geoff Abers.

Tuesday, 12 December, 6-9 pm, Salon 9, San Francisco Marriott

The MARGINS Reception at Fall AGU is an open event, welcoming participants in MARGINS-funded studies and all others with an interest in the program. This year, the reception will highlight the participants in the MARGINS Student Prize by offering space to display and discuss posters presenting their research. Students are encouraged to use this event as an opportunity to further share their results and interact with a wide spectrum of MARGINS scientists.

There will be ample time to mingle, with food and drink courtesy of Boston University and the new Boston MARGINS Office. Among those present will be Geoff Abers (MARGINS Chair), members of the MARGINS Steering Committee, and Program Directors for MARGINS from the National Science Foundation (NSF).

Geoff Abers and NSF Program Director, Bilal Haq, will use this event as an opportunity to welcome those present, introduce the new MARGINS Office, and update the community on MARGINS funding and other issues, including a discussion of the recent change to the Red Sea status and other ancillary sites.

Sessions Related to MARGINS Science at the Fall 2006 AGU Meeting

6The extensive list of sessions in AGU's Fall Meeting program can be daunting, so each year the MARGINS Office assembles a list of sessions that we think may be of special interest to the MARGINS community. The concise summaries included with our subjective choices are edited excerpts from the original AGU session abstracts (www.agu.org/meetings/fm06).

AGU Code Key: ***Section: Day of Week*** *(1-5)****: Session Time*** *(1X: 8:00; 2X: 10:20; 3X: 13:40; 4X: 16:00). E.g.,* ***OS12A*** *= Ocean Sciences, Monday, Session 2A (10:20).* ***MCS*** *= Moscone Center South;* ***MCW*** *= Moscone Center West. Please refer to the AGU meeting program to verify session times and locations.*

Sessions directly addressing MARGINS themes

OS: Studies of Sediment Transfer From Land Through the Ocean and into the Stratigraphic Record

Because of the global diversity in tectonic setting, climate, and fluid-energy dissipation, the fate of fluvial discharge in continental margins is complex and our ability to quantify and predict the fluxes of dissolved and particulate substances over space and time requires a concerted interdisciplinary effort. This session is intended to provide a venue for the broad community investigating the production, transport, storage and accumulation of terrestrial and marine materials along the source-to-sink pathways in the world's continental margins. *OS12A, OS13D, OS14A (MCS 206), OS23A, OS23B (MCW Level 2)*

OS: New Algorithms and Models for Fluvial and Coastal Sediment-Transport and Surface Dynamics

Continuing advances in our understanding of fluid dynamics, particle behavior, bed characteristics and the evolution of morphology are resulting in new algorithms and models for sediment transport. This session will focus on emerging concepts in sediment dynamics that are appearing in process-oriented models. Presentations describing observations of novel processes, presenting new analyses of sediment-transport processes, or describing algorithms for incorporating increasingly realistic dynamics into practical models are welcomed. *OS24A (MCW 3009)*

T: The Geodynamics of Lithospheric Extension

This session focuses on the geodynamics of lithospheric extension at all scales. Contributions are invited that elucidate the evolution of extensional tectonics, from a tectonic, sedimentary, magmatic and metamorphic point of view, and over the whole range of geodynamic conditions, from post-orogenic extension of overthickened crustal belts, to continental break-up and oceanic spreading. *T23F, T24A (MCW 3004), T31B, T31D (MCW Level 1)*

T: New Observations From the Mantle Wedge: Consequences for Water, Petrology, Melt, and Flow

This session seeks to highlight new constraints on structure, flow, dehydration and melting processes within the subduction zone mantle wedge. Papers from seismology, geodynamical modeling, mineral physics, geochemistry, and petrology are encouraged. *T21G, T22C, T33E (MCS 302)*

T: New Perspectives on the Seismogenic Zone: From the Surface to Depth and Modern to Ancient

Most of the world's largest earthquakes and tsunamis initiate in subduction zones, yet our understanding of fault zone processes is limited. Recent studies of modern and ancient subduction zones as part of the Seismogenic Zone Experiment (SEIZE) and related studies provide new perspectives on these processes. This session welcomes results of onland field work on ancient prisms, onland and offshore geophysical investigations, modeling and laboratory studies, and seafloor/subseafloor observations that provide insight on seismogenic zone processes. *T12C, T13G (MCS 302), T21A (MCW Level 1)*

T: Extensional Processes Leading to the Formation of Basins and Rifted Margins, From Volcanic to Magma-Limited

New observations and models allow us to investigate the processes responsible for continental extension and lithospheric rupture in unprecedented detail. Key questions that need to be addressed on all rifted margins concern the style of the early phases of extension, delineating the factors that are most important in controlling strain localization and partitioning throughout rifting (e.g., pre-existing weaknesses, detachment and/or rolling hinge faults, syn-rift magmatism, etc.), and understanding how variations in rheology with depth influence the style of rifting and final breakup. *T51C, T52C (MCW 3004), T53A (MCW Level 2)*

T: Development of the Gulf of California and Other Young Divergent Plate Boundaries Along Tectonically Active Continent Margins

Lithosphere ruptures in continent interiors and along active continental margins. The Gulf of California is an oblique-divergent plate boundary formed along a volcanic arc and between older magmatic arcs. Recent onshore and offshore, and surface to mantle studies, from MARGINS and other projects have made major advances in understanding the history of the plate boundary and processes of rifting. Contributions are invited from the Gulf of California and other young rifts along active continental margins. *T41D (MCW Level 2)*

V: Lessons From the Izu-Bonin-Mariana and Central American Subduction Factories

Presentations are invited that discuss all aspects of the Izu-Bonin-Mariana and Central American subduction zones, including subduction input, forearc processes and the origin and evolution of magma and crust. Topics might include: character and origin of the crust; relationship between subduction input and output in the forearc and volcanic arc; how differences in the mantle wedge or subduction parameters affect magma composition; reasons for spatial and temporal variations in magma composition, including volatiles; and flux estimates. *V41B (MCW, Level 2), V51F, V52B (MCW 3010)*

Other sessions relevant to MARGINS science

B: Advances in Process Understanding and Implications of Exchanges Across the Sediment-Water Interface

The depth of surface-water penetration, retention time within shallow subsurface environments, and the solute flux within these subsurface environments relative to water and solute flux at the surface are all important when addressing the solute retention/transformations in these environments. This session seeks to bring together a combination of coupled field and modeling approaches that addresses both the physical processes altering solute transport across sediment-water interfaces and the resulting biogeochemical implications. *B22C (MCW 3004), B23A (MCW Level 2)*

ED: Successful Partnerships in Geoscience Education: Past and Present

Starting in the 1970s the Earth Science community embarked on innovative programs to increase diversity in the geosciences. New programs that grew from these early programs took on best practices and innovative educational components that are now incorporated in programs for all children and teachers. This session will look back at some of these programs in a historical framework and will look forward by examining the success of current programs that aim to increase the participation of diverse students in the earth and environmental sciences. *ED33C (MCS 310), ED51A (MCW Level 2)*

ED: Hands-on, Inquiry-Based Classroom and Laboratory Assignments: Bringing Research in Earth-Surface Processes and Hydrology to K-12 and Undergraduate Students

Presenters in this session will introduce a lab exercise, demonstration, or hands-on activity that they have designed or adapted for use in their K-12 or undergraduate geoscience classroom or lab. In addition to their oral or poster presentation, the presenters will display their activity, lab exercise, or demonstration in the "Hands-on Gallery" during the poster session, so that participants in the parallel teacher workshop can test the materials. *ED51D (MCS 274), ED53A (MCW Level 2)*

ED: Facilitating Undergraduate Research in the Geosciences: Classroom Innovations that Encourage and Support Student Investigations

A wide range of projects supported by the National Science Foundation's Course, Curriculum, and Laboratory Improvement (CCLI), Geoscience Education, and COSEE programs, NASA programs, and other funding sources have sought to bring the tools and methods of geoscience research into undergraduate classrooms. This session seeks to highlight those classroom approaches that have been effective in aiding undergraduate students in the transition from learner to investigator. *ED33B (MCW Level 2)*

H: Soft Computing Tools for Hydrological Modeling

Soft computing is an emerging computational approach which integrates several artificial intelligence methodologies to deal with uncertainty and imprecision associated with modeling and understanding hydrologic systems. This session will invite presentations that will focus on applications of soft computing techniques to deal with a variety of problems within the field of surface and subsurface hydrology at different spatial and temporal scales. *H23D (MCW Level 2)*

H: Coastal Geomorphology and Morphodynamics

Coastal environments, including sandy shores, rocky coasts, marshes, estuaries and deltas, evolve in response to winds, waves, currents, tides, and changes in relative sea-level. This session will focus on large-scale coastal evolution (scales >> m and >> days), exploring feedbacks between changes in morphology and forcing agents, including the influence of the geological framework on coastal dynamics. *H31I, H32C (MCW 3002), H33B (MCW Level 2)*

H: Hillslope, Glacial, and Drainage Basin Posters

This is a general poster session on processes that affect the form and function of the surface of the Earth. These processes, in which physics, chemistry, and biology have roles, occur over a wide range of temporal and spatial scales, and include fluvial, Aeolian, and coastal sediment transport and the resulting erosion and sedimentation; hillslope mass movements; glacial and periglacial activity; weathering and pedogenesis; surface manifestations of volcanism and tectonism; and human activities that modify the surface of the Earth. *H53B (MCW Level 1)*

IN: Standardizing Fine-Grained Access to Geoscience Data

Web services provide the opportunity for on-demand open access to observational and other geoscientific data in support of scientific investigations. However, the style of data required varies significantly across the geosciences. This topical session is intended to provide a forum for investigators working on data models and structures, schemas and service interfaces in support of fine-grained data access within the geosciences. *IN51B (MCW Level 2), IN53C (MCW 3020)*

IN: Standards-Based Interoperability Among Tools and Data Services in the Earth Sciences

Groups are actively developing interoperable data access, analysis and display systems based on evolving international standards, such as the Open Geospatial Consortium (OGC) protocol set. Presentations and demonstrations for this session are encouraged for GALEON, GSN and similar interoperability efforts. There will be a special electronic poster area set up for live, online demonstrations of these interoperability technologies. *IN42A (MCS 309), IN43C (MCW Level 2)*

NG: Autogenic Dynamics in Landscape Evolution and the Geologic Record

Nonlinearity and noisiness in sediment transport systems produce fractal surfaces and dynamic unpredictability. This internally-generated ("autogenic") variability acts as a filter to obscure the signal of environmental ("allogenic") change. Stratigraphy is the accumulated record of these partially-preserved surfaces and hence is a signal that has been further filtered. The goal of this session is to bring together research that explores the characteristic length and time scales of autogenic processes and their influence on the evolution of landscapes and the stratigraphic record. *NG43D (MCW Level 2), NG53A (MCW 3022)*

NS: Applications of Near-Surface Geophysics in Coastal Environments

Near-surface geophysical methods are used increasingly in support of coastal geological and engineering studies, resource management, and hazard mitigation research. Seismic, electrical, resistivity, and electromagnetic (EM and GPR) methods provide high-resolution information for investigation of coastal geomorphology and stratigraphy, geoarchaeological context, hazard assessment, geotechnical characterization, and groundwater exchange in coastal aquifers. This session welcomes contributions in these areas. *NS24A (MCS 220), NS31B (MCW Level 2)*

OS: Nearshore Processes

For over 30 years, our understanding of nearshore processes has developed and grown in large part from the pioneering work of Dr. Edward B. Thornton and others. This session invites abstracts that focus on the dynamics of waves, currents, turbulence, and sediment transport from the beach face to the shelf break along both sandy and muddy coastlines. Abstracts covering all aspects of nearshore processes research are welcome. *OS21D, OS22B, OS23D (MCW 3009)*

OS: Cabled Ocean Observatories: Novel Science Experiments, Technologies and Data Management Systems

Cabled ocean observatories can transform the ocean sciences with the introduction of power, high bandwidth communication, elaborate sensor networks, and abundant real-time data return spanning decades. Existing and emerging observatories include LEO 15, VENUS, MARS, NEPTUNE, ARENA and ESONET. The session will consider the novel community science experiments, new and modified technologies, and complex data management systems handling the abundant (Gb/sec) real-time data stream, including video and HDTV. The profound impact of the scientific, technological, educational and outreach opportunities will be examined. *OS31C (MCW Level 2), OS34F (MCS 220)*

OS: Communicating Broadly: Perspectives and Tools for Ocean, Earth and Atmospheric Scientists

Across the geosciences, opportunities abound for researchers to communicate with people who have distinct and sometimes divergent interests – journalists, resource managers, environmentalists, policy makers, philanthropists, educators, and industry leaders, to name just a few. In this session, scientists and others within the academic community are invited to reflect on their experiences with such communication. Presentations that describe resources for building scientists' communication skills – for example, organizations, programs, workshops, courses and publications – are also highly encouraged. *U41F, U42C, U43D, U44C (MCW 3006)*

S: Geophysical Structure and Dynamics of the Western United States

Broad ranges of geological and geophysical datasets are currently being collected and geodynamical models are in development to provide new constraints on the structure and dynamics of the western United States. The rich and complex tectonic processes and history of this region are still under significant debate, thus necessitating a host of new multidisciplinary examinations. New observations and models from seismology, geodynamics, mineral physics, and petrology as they relate to this region are encouraged, particularly those which marry complementary datasets and methodologies. *S43A (MCW Level 2), S51D, S52A (MCW 3009), S54A (MCS 305)*

S: The July 17, 2006 Java Earthquake and Tsunami: What Are We Learning?

The precise rupture processes and controlling mechanism of such slow source tsunami events as the July 17, 2006 Java Earthquake and Tsunami are poorly understood, in part because they likely occur in a weak subduction interface that is often considered to be unable to nucleate earthquake rupture. This session invites contributions that seek to improve identification and our understanding of this and other such events, and the processes that control their tsunami generation. *S14A (MCW 3009), S21A (MCW Level 1)*

T: Episodic Tremor and Slip: Correlatoins to Geologic and Geophysical Segmentation in Cascadia

Many different types of observations from the Cascadia Subduction Zone suggest along-arc segmentation. The purpose of this session is to bring together investigators from different disciplines to review and update observations of arc (sensu lato) segmentation in order to explore links among disparate data sets and provide insights into the underlying processes that control the observed segmentation. *T53G (MCS 300)*

T: GeoFrame: A Geologic Framework for EarthScope's USArray

The GeoFrame initiative is a new geologic venture that focuses on the construction, stabilization, and modification of the North American continent through time. The purpose of this session is to present recent research in the areas identified during a recent EarthScope workshop (a mega swath including Cascadia, the Northern Rockies, the Black Hills/Great Plains, the Superior Province in the US, the Mid-Continent region, and the central Appalachians and a long swath along the Walker Lane trend) and to provide a forum for the community to present research results, in addition to making suggestions and modifications to the target areas. *T42A (MCS 301), T43C (MCW Level 2)*

T: Seismogenesis and Tsunami Hazards of "Aseismic" Island Arcs

The tectonic environment of the Nicobar and Andaman Islands section of the Sumatra-Andaman Earthquake rupture zone is not typical of subduction zones that experience giant earthquakes, and yet it experienced slip equivalent to an earthquake of magnitude 9 or greater. Our inability to explain why this segment experienced such large-scale rupture prompts us to reconsider whether the Chilean-Mariana paradigm for seismic vs. aseismic subduction is adequate for underpinning assessments of tsunami hazard in island arcs and ocean basins bordered by them. This session aims at assessing the current state of knowledge of seismogenesis and tsunami hazards in island arcs, especially those in tectonic environments that are thought to not favor the occurrence of giant earthquakes. *T21F (MCS 301), T23A (MCW Level 1)*

T: Phenomenology, Mechanisms, and Hazard Implications of Episodic Aseismic Slip, Tremor, and Earthquakes

Repeating episodes of aseismic fault slip, seismic tremor, and perhaps associated earthquake rate changes are best documented in subduction zones around the world, but have also been observed in a growing number of other geologic settings. This session seeks presentations that critically examine the observational constraints on these phenomena, compare their differences from region to region, test explanatory physical models, and discuss their implications for assessing volcanic and earthquake hazards. *T54A (MCS 300)*

T: New Observations of Dike Injection Episodes in Extensional Terrains

In September 2005, a seismic swarm around the Dabbahu (Boina) rift segment in Afar, Ethiopia, was associated with the intrusion of a 60 km long dike, up to 8 m wide, along the entire rift segment. This is the largest rifting episode to have occurred subaerially since the Krafla (Iceland 1975-1984) and Asal-Ghoubbet (Djibouti, 1978) episodes, and offers a unique opportunity to learn about crustal growth at divergent plate boundaries. This session invites contributions that describe results from the broad spectrum of geophysical and geological techniques that have been applied to subaerial and submarine rifting episodes. *T33E (MCW 3002), T41B (MCW Level 2)*

T: Postcollisional Extension

Within the last quarter century, our understandings of post-collisional continental extension have improved substantially. However, there are still many important questions such as the nature and geometry of initial normal faults formed during post-collisional extension, and the nature and depth of the ductile-brittle transition. It is also still debated whether the post-collisional continental extension is initiated by simple shear or pure shear. The main purpose of this session is to bring together researchers working on the problems of post-collisional continental extension and associated structures such as metamorphic core complexes in different parts of the world. *T33B (MCW Level 1), T41E (MCS 301)*

U: Communicating Broadly: Perspectives and Tools for Ocean, Earth and Atmospheric Scientists

Across the geosciences, opportunities abound for researchers to communicate with people who have distinct and sometimes divergent interests – journalists, resource managers, environmentalists, policy makers, philanthropists, educators, and industry leaders, to name just a few. In this session, scientists and others within the academic community are invited to reflect on their experiences with such communication. Presentations that describe resources for building scientists' communication skills – for example, organizations, programs, workshops, courses and publications – are also highly encouraged. *U41F, U42C, U43D, U44C (MCW 3006)*

U: Consequences of Subduction and the Evolution of the Mantle

The chemical and physical properties of subducted oceanic lithosphere are not well-known, but control many aspects of Earth's convective/tectonic state as well as it's thermal history. This session welcomes studies from geochemistry, geodynamics, seismology and mineral physics, and in particular studies that combine approaches from different disciplines, in an effort to integrate the nature of subduction with deep mantle processes. *U11A, U12A, U13B, U14B (MCS 308), U12A (MCW Level 2)*

U: The Indian Ocean Tsunami 2004: Two Years On.

Based on the enormous amount of new work on the Andaman-Sumatra earthquakes and tsunamis, the objective of the session is to bring together scientists from all disciplines to present their research in the region and to foster and encourage multidisciplinary collaboration. Applications of the research in the Indian Ocean to other areas are also encouraged. *U44A, U51B, U52A (MCS 308), U53A (MCW Level 1), U53C (MCS 308)*

U: Large Distributed Arrays of Geophysical and Environmental Sensors

Using modern technological systems, it is now possible to monitor the Earth and its space environment with increasing accuracy and frequency, and to receive the data with near-real-time promptness, using very large arrays of data acquisition and data transportation links. The purpose of this special session is to bring together working representatives involved with very large distributed arrays of sensors in order to foster communication about the practicalities of operating such systems, to discuss theoretical issues that might pertain to their management and future development, and to promote cooperation and coordination. *U41B (MCW Level 2)*

V: To What Depth Can Continental Crust be Subducted: Observations From Ultra-high-Pressure Metamorphic Rocks, Experiments, and Numerical Modeling

Ultra-high pressure metamorphic rocks (UHPM) are the best natural laboratory to study to what depth continental crust may be subducted. The main task of this session is to formulate clear statements: (1) what do we really know from the UHPM rocks about deep subduction of the crustal material; (2) how is modern experimental and numerical modeling consistent with the "facts" collected from natural rocks? *V31A (MCW Level 1), V43F, V44B (MCW 3011)*

V: Observations and Interpretations of Low-Frequency Earthquakes in Volcanic and Nonvolcanic Environments

Recent observations and research have highlighted that ordinary stick-slip failure may produce LF earthquakes in certain volcanic settings due to exceptionally high strain rates within the magma, low rupture velocities, and/or complexities in the path between source and seismometer. The goals of this session are to investigate the range of mechanisms that may produce LF events and the range of settings in which various types of LF events occur. *V41A (MCW Level 1), V52A (MCW 3012)*

Other sessions of interest

T: Interpreting the Tectonics of the Pacific Rim Using Plate Kinematics and Slab Window Volcanism. *T51C (MCW Level 2), T53E (MCS 301)*

V: Crystal-scale records of magmatic processes. *V51B (MCW Level 2), V53E (MCW 303)*

V: Origin, Storage, and Transport of Water in Earth's Mantle. *V41D (MCW Level 2), V53F, V54A (MCS 304)*

V: The Dynamic Reaction: Interactions of Metamorphic Reactions and Deformation in Nature, Experiments, and Models. *V31C (MCW Level 1), V33F (MCW 3012)*

"Highlights" cont. from pg. 7

AGU Fall Meeting mini-workshops on pp. 5 and 19).

13. Other matters:
    - The new MARGINS Office at Boston University would officially take over operations on October 1, 2006. The MSC and NSF Program Officers thanked Paul Wyer and Meredith Berwick for their role in the success of the MARGINS Office at Washington University in Saint Louis and their continuing support as the new office takes over.
    - Interim Chair, Doug Wiens was thanked for providing direction and continuity at Washington University since Julie Morris began her rotation as NSF-OCE Division Director in April, 2006.
    - John Milliman was thanked for his dedicated commitment as he rotated off the Steering Committee.

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"Seismic" cont. from pg. 15

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Call for interdisciplinary MARGINS mini-workshops

The MARGINS Office and Steering Committee aim to support efforts that expedite synthesis of results from MARGINS science in the various focus areas and initiatives. To this end, the MARGINS Office offers to help MARGINS funded investigators organize and fund mini-workshops held at national meetings for the purpose of bringing together a group of multi-disciplinary investigators to synthesize results to date. Such mini-workshops can be associated with GSA, AGU, or other national meetings at which your research area is well represented. They can be 3-4 hour workshops one evening after sessions, or half-day to day-long sessions before or after the meeting. They can bring together multiple investigators from a single focus site or from both focus sites within an initiative, or can address a theme that transcends initiatives, according to what makes the most scientific sense and where there is the greatest need.

There are some ground rules for such mini-workshops, as discussed below. The rules are intended to maximize the benefit of such workshops to a larger scientific community and emphasize opportunities for interdisciplinary integration, as opposed to providing a venue for a single or few proponent groups to meet. Once the MARGINS Steering Committee approve a mini-workshop proposal, arrangements will be made as follows:

1. The MARGINS Office will provide the cost of a meeting room, presentation equipment and non-alcoholic refreshments, and will work with the meeting conveners and local hotels to make logistical arrangements. Regretfully, the MARGINS Office CANNOT afford to provide travel or lodging costs for participants. Alcoholic refreshments may be served as a goodwill gesture from another appropriate organization (a convener's home institution, for example), but CANNOT be subsidized using MARGINS Office funds.
2. Workshop conveners are responsible for developing the science program, communicating with workshop participants on scientific matters and working with the MARGINS Office to arrange logistics.
3. Any MARGINS Office supported mini-workshop will be open to all interested parties and will be advertised via the MARGINS mailing list, MARGINS website, and meeting program.
4. Workshop conveners will provide a brief write-up of the major results of the workshop for dissemination via the MARGINS website and newsletter, so that important outcomes may be shared with the larger community.

If you are interested in hosting a mini-workshop, coordinate with your colleagues, and then send the MARGINS Office a 1-2 page outline of your meeting plan as soon as possible. Requests should generally come not later than 3 months ahead of the meeting. The MARGINS Steering Committee will review the submitted proposal before the MARGINS Office will agree to support a synthesis mini-workshop. Your write-up should include:

- Scientific rationale for the meeting and reasons for its timeliness.
- Evidence that a wide group of interdisciplinary researchers would be able to attend.
- A draft scientific program for the mini-workshop.
- The national meeting with which the mini-workshop would be associated.
- The format (evening, half-day or full day, pre- or post-meeting) desired and acceptable dates.
- Size of meeting envisioned.
- Anticipated cost items (meeting space, refreshments, A/V equipment, etc.). Note that a detailed budget for these costs is not initially required.

Thank you for considering such an undertaking, and we look forward to hearing from you.

With best regards,

The MARGINS Office and Steering Committee

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MARGINS

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Farewell from the Washington University MARGINS Office. We've enjoyed our run and will miss working with you.

Best wishes to the new MARGINS Office at Boston University. If your three years yield as many challenges, solutions and rewards as ours, we know you'll have a great time!

This newsletter was produced and distributed on behalf of MARGINS by the out-going MARGINS Office at Washington University in St. Louis:
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