MARGINS Theoretical and Experimental Institute: Inside the Subduction Factory

NSF Proposal

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1.0 INTRODUCTION

Subduction zones are locations of energy and mass transfer between the Earth∂s lithosphere and interior, and therefore subduction zone processes influence the geodynamical and geochemical evolution of the mantle and crust. Current understanding suggests that many of the key elements to subduction zone processes take place at or near the top of the subducted slab at depths between 50 and 150 km. Here, mechanical coupling and heat-transfer between the subducting slab and the overlying mantle drive convection in the mantle and effect mass transfer from the slab to the wedge. Together, these processes result in partial melting that is ultimately expressed in arc and back arc volcanism and that is widely thought to control the long-term growth and chemical evolution of the continental crust. These processes also change the composition of both the portions of the slab that ultimately descends to depths greater than 150 km and the overlying wedge, thereby influencing the composition and structure of the mantle.

The importance of subduction zones was recognized early in the formulation of modern plate tectonic theory, but owing to their complexity – particularly in the intermediate depths (~50-150 km) where devolatilization, melting, and intermediate depth earthquakes occur – subduction zones are arguably the least-well understood portions of the shallow global tectonic framework. In contrast to what we know at mid ocean ridges, for example, we still do not know where melting occurs beneath arcs, whether it is driven by water fluxes or upwelling, how hot the mantle and slab are, and what their mineralogy is. After thirty years of study, some of the most basic questions are still with us.

In recent years, however, our understanding of subduction zones has increased as a result of improved geophysical, geochemical, experimental and geodynamical methods. Seismic velocity and attenuation models based on tomography and waveform modeling permit inferences of temperature structure and partial melting within mantle wedges [e.g. Hasegawa et al., 1994; Zhao et al., 1994; Xu and Wiens, 1997; Zhao et al., 1997]. Geochemical tracers can now identify the separate contributions of subducted oceanic crust, sediments, and mantle wedge to arc volcanism (e.g., Tatsumi et al., 1986; Morris et al., 1990; Stolper and Newman, 1994; Hawkesworth et al., 1991; Plank and Langmuir, 1993; Elliott et al., 1997). Experimental petrology is now providing new data on melting and element partitioning in H2O-rich systems (e.g. Hirose and Kawamoto, 1995; Gaetani and Grove, 1998), traditionally very difficult processes to approach in the laboratory. And geodynamical models are beginning to incorporate dynamic slabs, melting, and chemical transport (Davies and Stevenson, 1992; Kincaid and Sacks, 1997; Iwamori, 1998). Momentum toward subduction zones is evidenced by several recent meetings, including the SubCon meeting (Avalon, CA, 1994), the Subduction Factory Workshop

(La Jolla, CA; 1998), and special sessions at Fall, 1998 AGU (e.g., Melting and Melt Extraction; Earthquakes, Crustal Deformation, and Neotectonics of the Cascadia and Nankai Subduction Zones;The Subduction Factory).

Despite this recent activity and the landmark advances, however, most studies (and AGU sessions!) are still done in isolation of other disciplines. Tomographic data could be combined with petrologic data to better constrain the locus of melting in subduction zones. Geochemical tracer studies of volcanic rocks need the experimental partitioning and phase relations to identify mineral reactions occurring in the slab and their P-T range. These mineral reactions, in turn, affect the seismic velocity structure of the slab, and perhaps even the location of earthquakes, and so are testable with independent observations. Quantum advancement in our understanding of the dynamic working of the subduction factory will only come from such multi-disciplinary studies. Such a multi-disciplinary approach to active systems is the underlying methodology of the MARGINS Program, and has been a success of the RIDGE program. For example, successful RIDGE Theoretical Institutes bringing together seismologists, petrologists, geochemists, geodynamicists and rheologists have led to vigorous exchanges between the disciplines, and the recent MELT experiment.

Formulating the essential problems, places and approaches to studying subduction processes was the main goal of the Subduction Factory Workshop, held at Scripps in June 1998, and the resulting Subduction Factory Science Plan, published on the MARGINS web site (http.://www.soest.hawaii.edu/margins/SF_Sci_Plan.html.). The Plan focuses on three main themes: (1) Subduction Parameters as Forcing Functions on Factory Output, (2) The Volatile Cycle through the Subduction Factory, and (3) Towards Mass Balance of Input and Output. In addition to the main science themes, the Subduction Factory initiative of the MARGINS program centers around two multi-disciplinary field experiments; one in the Central American arc of Nicaragua and Costa Rica and the other in Izu-Bonin-Marianas arc of the Western Pacific Ocean. Combination of geologic, geochemical, geophysical, and oceanographic studies of well-chosen regions will lead to better understanding of the processes affecting mass transfer into and out of subduction zones on a regional (and ultimately global) scale. In addition to the focus areas, allied studies at selected margins (the SubFac Science Plan specifically mentions the Aleutians and Cascadia) and paleo systems (such as exhumed subduction zones and arc basement) are necessary to make global comparisons to models that will emerge from the focus areas and to provide valuable further insight into these processes. In some cases these may occur after initial studies in the focus areas. In parallel with such field experiments, theoretical and experimental studies of subduction zone processes are an intrinsic part of the Subduction Factory initiative.

In order to begin to formulate projects to accomplish its thematic goals, the Subduction Factory Workshop and Science Plan recognized the immediate value of convening a Theoretical and Experimental Institute to address the Inside of the Subduction Factory. Many fundamental questions within the three main thematic areas focus on the intermediate depth in the subduction zone. How do forcing functions such as convergence rate, dip, slab temperature and slab output fluxes drive flow and melting of

the mantle wedge? The devolatilization of the subducting slab is an essential component of the Earth's water and CO2 cycle. Where does the slab dehydrate, how do the fluids migrate out, and how do the fluids affect slab stresses? Mass balance across the subduction zone is critically dependent on the rate at which magmatic arcs grow, which in turn is dependent on the melting rate in the mantle. What factors control the volume and rate of melting in the mantle? These are the primary questions that need to be solved for processes occurring Inside the Subduction Factory. More specific questions include (but are not limited to):

(1) How, why and where are new subduction zones started?
(2) How much melt is formed and what is the role of water and/or upwelling in its formation?
(3) What is the rate and mechanism of continental growth at convergent margins?
(4) What is the impact of subduction on mantle evolution?
(5) How does subduction lead to uni-directional changes in the composition of the continental crust?
(6) What are the dynamics of mantle flow in the mantle wedge?
(7) What is the role of water in melting in the sub-arc environment and what are the predominant modes and rates of melt aggregation and transport?
(8) What are the effects of H2O and melt on the rheology of the slab/wedge system?
(9) What is the effect of subducted volatiles on mantle seismic velocity and viscosity, slab embrittlement, and intermediate depth earthquakes?
(10) What is the stability of key hydrous and calcareous phases in the subducting slab and mantle wedge?

A key mechanism of focusing, and energizing these allied experimental and theoretical studies and of coordinating them with the field based experiments is to convene a Theoretical and Experimental Institute. We propose to support and focus emerging multi-disciplinary study of subduction zones by organizing a short course and associated workshop centered on the processes occurring Inside the Subduction Factory. This pair of meetings will be collectively refereed to as a Theoretical and Experimental Institute (TEI) in the remainder of this proposal and is intended to bring together modelers, experimentalists, and field based geochemists, geologists, and geophysicists. The purposes of the TEI are to:

* further understanding of mass and energy transfer in subduction zones and mantle wedges in the intermediate depth range (~50-~150 km)
* enhance communication between modelers, experimentalists, and field practitioners
* catalyze the multidisciplinary studies necessary to make substantive leaps in understanding subduction zone processes.

The proposed TEI will take place in the summer of 2000 on the campus of the University of Oregon.

2.0 GOALS

The specific goals of the proposed TEI include:

-Education of the community of researchers, including graduate students, as to the methodologies, interpretations, limitations, and prospects of geochemical, geophysical, experimental and field studies of subduction zone/wedge processes. This is necessary to train new practitioners coming into the field (graduate students and those migrating from specialties in other tectonic environments), and to enable practitioners of particular disciplines to have the perspective required to join forces with those in other disciplines - a prerequisite for formation of multi-disciplinary research efforts.

-Identification of key field or experimental observations that must be collected or theory that must be developed (or key integration of data and theory) required to address significant unsolved problems related to subduction zone/wedge processes.

-Facilitation of discussion between experimentalists, modelers, and field practitioners involved in data collection at the SubFac localities (Central America, Izu-Bonin-Marianas). Again, this is a necessary prerequisite for formation of multidisciplinary research initiatives. Equally important is that this is required to allow practitioners to interpret the significance of results from other field and to identify crucial unknowns that must be investigated.

-Incubation of a multi-disciplinary community that will continue to communicate as the Subduction Factory initiative proceeds.

3.0 ORGANIZING COMMITTEE

The committee responsible for organizing the technical sessions of the meeting consists of Geoff Abers (seismologist, University of Kansas), John Eiler (geochemist, Caltech), Karen Fischer (seismologist, Brown University), Marc Hirschmann (petrologist, University of Minnesota), Chris Kincaid (geodynamicist, University of Rhode Island), and Terry Plank (geochemist, University of Kansas). The host institution will be the University of Oregon. Dana Johnston has agreed to serve as chair of the host institution organizing committee that will help coordinate logistical arrangements on site (see attached letter). Personnel from the MARGINS office will also provide logistical support for the meeting, including help with participant registration, abstract submission, as well as additional on-site support.

4.0 STRUCTURE OF MEETING

The meeting will take place in Eugene, Oregon on the campus of the University of Oregon and will consist of a four day short course, followed by a one day workshop. In addition, there will be an optional 2-day field excursion to the Oregon High Cascades to see spectacular examples of modern arc volcanism, including Crater Lake and the Three Sisters region. This field excursion will be organized by the host institution Dana

Johnston (UO), Kathy Cashman (UO). Charlie Bacon (USGS Menlo Park) will be asked to lead the Crater Lake portion of the field trip.

5.0 SHORT COURSE

The Short course will be divided into three sections - Theoretical and Experimental Investigations of the Slab (1.5 days), Theoretical and Experimental Investigations of the mantle wedge (1.5 days) and Observations from the Subduction Factory focused field experiment areas (1 Day).

The first two sections will be broken up into 1 1/2 hour disciplinary units, each consisting of a 45 minute keynote address by an expert having a broad view of the topic, followed by moderated discussion and informal presentations. These sections will end with a 1 1/2 hour synthesis discussion, lead by a moderator. Keynote speakers will be asked to apportion their time approximately as follows: ~ 50-60% review and description of methodologies, 30-40% new results in the field and 10% outline of what needs to be done. In order to insure that knowledgeable individuals come prepared to contribute to the informal discussions, participants will be asked to arrive prepared with overhead transparencies sufficient to accompany ~5-10 minutes of remarks. It will be made clear that people are welcome to/expected to come forward and contribute comments during the discussion and the moderator of each session will be aware of the names and expertise of the potential informal contributors in the audience.

The field-based section will be divided into two 1/2 day sessions, one focused on Central America, the other on the Izu-Bonin-Marianas system. Each will be anchored by two 45 minute presentations, one emphasizing geochemical observations, the other emphasizing geophysical observations. Moderated discussion and informal presentations and a synthesis will also be included.

Presentations in the individual sections will follow the following structure. Names in parentheses are possible keynote speakers and/or potential key contributors to discussions.

Understanding the slab

Seismology (Geoff Abers, George Helffrich)
Thermal Evolution (Simon Peacock)
Rheology (Steve Kirby, Shun Karato)
Petrology - phase equilibria and fluid partitioning (John Holloway, Max Schmidt, James Brenan)
Geochemistry - evidence from volcanic rocks for mass transfer from the slab. (Chris Hawkesworth, Julian Pearce, Julie Morris)
Synthesis

Understanding the wedge

Seismology: (Doug Weins, Dapang Zhao)
Geodynamics (Mike Gurnis, Dave Sparks, Chris Kincaid)
Rheology (Greg Hirth, Dave Kohlstedt)
Petrology - melting and melt migration (Tim Grove, Glenn Gaetani, Peter Kelemen, H. Iwamori)
Geochemistry - Evidence from trace elements and isotopes (particularly Uranium series isotopes) for melting processes. (Marc Spiegelman, Jim Gill, Tim Elliott, Ed Stolper)

Focused field experiments

Central America (Mike Carr, Sue Schwarz, Julie Morris, Mark Reagan)
Izu-Bonin-Marianas (Bob Stern, Tim Elliott, Karen Fischer, Jim Gill)

All participants will be invited to bring posters highlighting their most recent or relevant work. This may include coverage of allied studies at the Aleutians and Cascadia and of exhumed subduction zones and arc basement. Abstracts for posters will be solicited prior to the meeting and distributed on arrival. Poster sessions will be divided thematically into 3-4 evening sessions.

6.0 WORKSHOP

The 1 day workshop will be less-structured than the short course and will limited to 30 attendees. The workshop will consist of a morning discussion regarding the Subduction Factory Science Plan, with a particular emphasis on the relationship between the overall goals of the Subduction Factory focused field experiments and the needed laboratory and theoretical progress that must accompany those experiments. This session will be moderated by the conveners. In the afternoon, workshop participants will break into working groups. One group will write a brief report outlining key outcomes of the meeting including identifying important initiatives required to solve subduction-zone related problems. This report will be posted on the Internet and will be either appended to or abstracted in a revised Subduction Factory Science Plan. Other working groups will identify and discuss crucial unsolved problems and will plan critical future data collection/experiments/theoretical activities. It is hoped that this process will lead to specific multidisciplinary proposals to address the priorities that emerge from the workshop. Migration of individual from one working group to another over the course of the afternoon will be facilitated.

7.0 PARTICIPANTS

Short Course participation will be limited to 100 individuals. In order to insure that the distribution and quality of expertise present at the meeting is sufficient to generate lively knowledgeable and incisive discussion, we expect to invite 25-35 participants in addition to the Keynote speakers, moderators and conveners named in this proposal. One emphasis of the meeting is to invite practitioners who have focused primarily on other tectonic regimes (e.g., ridges), in order to bring fresh thinking and expertise into the subduction factory community. We have developed a preliminary list of approximately 50 such individuals, and further refinement of the list will occur over the next year. We are withholding the list of names from this document so as not to compromise the impartiality most of the potential knowledgeable reviewers of this proposal. The TEI will be advertised in EOS and via the Internet and approximately 35 slots will be reserved for participation of interested individuals who respond to the advertisement. Selection (if necessary) of non-invited individuals will be done by the conveners in consultation with the MARGINS steering committee and will be based on submitted abstracts and relevance of research interests. Twenty slots will be reserved for students. Workshop participation will be limited to 30 people, with selection based on a letter of interest outlining past, current, and likely future research activities. Apart from keynote speakers and conveners, application for participation in the workshop will take the form of a letter of interest, which will be evaluated by the co-conveners on the basis of relevance to the workshop topic, quality of past research, and proposed research interests to be discussed during the workshop.

8.0 INTERNATIONAL PARTICIPANTS

The conveners recognize the importance of international participation in the TEI from Europe, Canada, Australia, and particularly locations proximal to the Subduction Factory focus experiments, Central America and Japan. Efforts will be made to coordinate organization with this meeting such that international participants may be able to obtain funding from their national funding organizations. Also, possible co-sponsorship with foreign (particularly Japanese).agencies is being investigated, and there may be addition of possible international co-conveners. However, there are a small number of individuals whose participation we believe to be of significant importance. In addition, in the interests of international cooperation we are requesting travel funds to allow practitioners in Central America (one of the Subduction Factory Focus areas to participate. Although specific commitments have not been made at this time, key international contributions are hoped for from George Helffrich (UK.), Dan McKenzie (UK), Tim Elliott (Holland), Rainier Kind (Germany), Chris Hawkesworth (UK), Dapeng Zhao (Japan), Akira Hasegawa (Japan), Y. Tatsumi (Japan), H. Iwamori (Japan), J. Brenan (Canada), S. Eggins (Australia), Woodhead (Australia). Likely participants from Central America include Marino Protti (Costa Rica) Eduardo Malavasi (Costa Rica), and Marta Navarro (Nicaragua). Travel funds to enable this international participation are requested.

9.0 VENUES

The University of Oregon has been selected as the site of both the short course and workshop both due to the level of support offered by colleagues at the university of Oregon (see attached letter from A.D. Johnston), and the close proximity to an active magmatic arc appropriate for a field excursion related to the TEI meetings. Our choice also has a certain historical appropriateness as the University of Oregon was host to The 1968 Andesite Conference, the first major conference to consider magmatism associated with island arcs in a plate tectonic context and a seminal event in the history convergent margin studies (McBirney, 1969).

10.0 PUBLICATION

Keynote speakers will be asked to prepare review articles to be published in a meeting volume, most likely as an AGU Monograph, as this format has proved successful for previous similar (RIDGE) Theoretical Institutes. In the spirit of the keynote presentations, the articles will address the state of understanding of the particular subject they have addressed in their keynote lecture, with particular emphasis on the methodologies relevant to their topic reviewing the state of understanding of subduction zone processes based on the particular discipline being addressed, and highlighting key unanswered questions.

11.0 TIMELINE

June, 1999 Invite Keynote speakers
June, 1999 First publicity on Internet
January, 2000 First paid advertising in EOS
March, 2000 Invite participants
May, 2000 Deadline for application of non-invited participants and for participant abstracts
June, 2000 Participant Registration
August, 2000 Meeting
October, 2000 Papers due
Spring, 2001 Final versions of papers to publisher -
Fall, 2001 Monograph Publication

12.0 OUTCOMES

In addition to more general outcomes outlined above, specific outcomes of the TEI will include:

-A volume of review papers, written by keynote speakers, that will review and summarize the current state of understanding of the main sub-disciplines represented at the meeting and that will serve as a benchmark for current understanding of the problem, as a pedagogical reference for the growing multidisciplinary community, and as a jumping-off point for future studies and publications.

- The informally published lecture notes of the keynote speakers, which will continue to serve as ad hoc texts for the community of researchers participants.

- The Workshop Summary document, to be published on the MARGINS web page and publicized via the MARGINS listserver and other listservers.

-An updated Subduction Factory Science Plan. In particular, this will include an updated statement of the research required in the short and long term to understand mass and energy transfer in subduction zones and the overlying mantle wedge.

- Multidisciplinary proposals formulated during and after the meeting that attack the problems in understanding of subduction zone/mantle wedge processes

13.0 EDUCATIONAL AND HUMAN RESOURCES STATEMENT

We envisage that the TEI will play a major role in the scientific development of the next generation of geoscientists working to understand convergent margin processes. A substantial portion of the budget has been set aside to ensure significant graduate student attendance in the TEI. For many of these students, participation in a Short Course in which internationally-recognized experts explain in detail the methodologies and interpretations of a wide range of disciplinary fields bearing on margins may be a capstone experience in their development and in their understanding of modern research in this field. For more senior scientists, the opportunity to delve into the methodologies and results from allied fields will also be of significant importance, particularly for those practitioners who may have developed their own expertise in other tectonic regimes (e.g., ridges) but who are increasingly working on convergent margin problems. In addition, the publication of a review volume as an AGU Monograph provides will disseminate the educational impact of the meeting well beyond the population of participants.