

**MARGINS Theoretical and Experimental
Institute: Rheology and Deformation of the
Lithosphere at Continental Margins**

NSF Proposal

MARGINS Theoretical and Experimental Institute: Rheology and Deformation of the Lithosphere at Continental Margins

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1.0 INTRODUCTION

Continental margins are the earth's principle locus for valuable resources, severe geologic and climatic hazards, and the greatest population density. Despite the societal and economic importance of margins, many of the mechanical, fluid, chemical and biological processes that shape and destroy continental margins are poorly understood. Progress is hindered by the sheer scope of the problems, the complex interplay and feedback mechanisms between disparate processes, and by the spatial-temporal scale of the processes. To overcome these obstacles, the MARGINS Program (a research initiative supported by the US National Science Foundation) has re-assessed the outstanding scientific problems in continental margins research and is promoting research strategies that redirect traditional approaches to margin studies.

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

One approach that has been adopted by MARGINS to promote progress toward this goal is the organization of Theoretical and Experimental Institutes. Theoretical Institutes were originally conceived by the Ridge Program and have proven successful in fostering stronger links between observationalists, experimentalists, and theoreticians, and in giving researchers and their students the required background to address complex, interdisciplinary problems. These type of Institutes will bring together specialists from a broad range of backgrounds to present and discuss margin research and work on problems of interdisciplinary interest. Such an exchange of ideas on fundamental and

current research problems across several disciplines aimed at examining a single system is not available elsewhere for continental margin studies.

This proposal requests funds to hold the first MARGINS Theoretical and Experimental Institute in the winter of 2000 to investigate "Rheology and Deformation of the Lithosphere at Continental Margins", which will address aspects of objectives defined by the National Academy Workshop held at Irvine, California. It will examine how the deformation evolves throughout margin evolution, which will lead to a better understanding of the varying margin architectures observed and a framework within which laboratory, field, and modeling experiments can be posed. The bringing together of researchers and students from a number of different fields to initiate a cross-disciplinary inquiry into the rheology and deformation of the lithosphere will provide valuable insights into the system as a whole.

2.0 SCIENTIFIC RATIONAL FOR THE 2000 MARGINS THEORETICAL AND EXPERIMENTAL INSTITUTE

Traditionally, investigations of the rheology and deformation of the lithosphere have taken place at one scale in the laboratory and at entirely different scale in the field. Laboratory experiments are generally restricted to centimeter-size samples and day/year-length times, while geological processes occur over tens to hundreds of kilometers and millions of years. Application of laboratory results to geological systems necessitates extensive extrapolation in both time and spatial scales, as well as a detailed understanding of the dominant physical mechanisms. Development of an understanding of large-scale processes requires an integrated approach. Communication between experimentalists and theoreticians is essential in order to design experiments to address the implications raised by macroscopic field observations. One of the principal objectives of the 2000 MARGINS Theoretical and Experimental Institute will be to stimulate cross-disciplinary inquiry into the rheology and deformation of the lithosphere, which will provide a better understanding of the varying margin architectures observed and a framework within which laboratory, field, and modeling experiments can be posed.

Rheology is the branch of Physics dealing with the deformation and flow of materials. Macroscopic observations of margins using remote sensing (e.g., seismics, gravity, magnetics) examine the style and wavelength of the deformation from which predictions are made concerning the "mode of deformation" (rheology) and how it varies throughout the deformational history. Laboratory experiments place constraints on the physical conditions required for materials to deform and illustrate how the deformational style varies as a function of temperature, strain rate, and material. Modeling efforts that incorporate and build on the results from laboratory experiments and make predictions of margin architecture that can be tested provide a potential vehicle to bridge the scaling problems of comparing physical experiments with natural systems.

The 2000 MARGINS Theoretical and Experimental Institute will consist of a four-day Short Course followed by a two-day Workshop. The proposed TEI will take place in the winter of 2000 at the Snowbird Conference Center, Utah.

- * Day 1 of the Short Course will provide an overview of the setting and nature of deformation at extensional and compressional continental margins.
- * Day 2 will concentrate on: a) observations supporting, and models explaining, strain partitioning within the crust and lithosphere and b) numerical and analog modeling experiments that address the scaling problem of comparing physical experiments with natural systems.
- * Day 3 will focus on laboratory observations related to frictional sliding and crack healing along fault surfaces.
- * Day 4 will center on experimental studies of the rheology of crustal rocks.
- * The Workshop on Days 5 & 6 will flesh out the Rupturing Continental Lithosphere science plan (fieldwork, modeling and experiments) and choose field areas for focused investigation. This MARGINS initiative derived from the two Deformation science foci identified in the MARGINS Initial Science Plan, 1996: (1) The Low-Stress Paradox and (2) Strain Partitioning During Deformation.

The main goals of the MARGINS Theoretical and Experimental Institute (TEI) on Rheology and Deformation are to:

- * educate researchers and students in rheology and deformation processes and to concentrate on aspects of theory that observations can test.
- * enhance communication and interaction between modelers, experimentalists, and observationalists
- * bridge the scaling problems associated with comparing physical experiments with natural systems
- * foster interdisciplinary studies required to make substantial advances in understanding how the earth deforms.

3.0 STRUCTURE AND SCIENTIFIC CONTENT OF THE 2000 MARGINS THEORETICAL AND EXPERIMENTAL INSTITUTE

In designing the MARGINS Theoretical and Experimental Institute, we examined the comments and evaluations concerning the structure, scientific content, and logistical arrangements for the RIDGE Theoretical Institutes. In so doing, we have built on the experience and knowledge gained from the numerous, successful RIDGE Institutes. Below are some of the benefits that were adopted from successful Ridge Theoretical Institutes.

3.1 Format of 2000 Margins Theoretical and Experimental Institute

1) Short Course Lectures

- * convenors will work with the lecturers to ensure that the talks are not too specialized and that they illustrate the interactive nature of the research in light of Rheology and Deformation of the lithosphere.
- * the convenors, together with the MARGINS Steering Committee have selected topics and a format so that the Short Course will present a cohesive examination of deformation and rheology rather than a series of unrelated presentations.
- * lecture notes will be available prior to the short course to allow participants to come prepared and maximize interaction.
- * lecture time limits will be strictly enforced to allow ample time for questions and discussions.

2) Overall Short Course Structure

- * conference location with lecture rooms, accommodations, and other facilities are on site to foster interaction amongst participants
- * question and discussion periods will be such as to ensure participant involvement and for the presentation of alternative perspectives
- * some free time and access to recreational activities to allow small group interactions will be a requirement of the selected site

3) Scheduling of MARGINS Theoretical and Experimental Institute

- * MTEI will be held in January, which is the semester break for many college faculty and students.
- * MTEI will be arranged to include a Saturday night to allow participants to minimize travel costs.

4) Workshop

- * an agenda will be distributed prior to the workshop to ensure that participants will bring pertinent information to fuel the discussions.
- * Workshop will immediately follow the Short Course to minimize the time commitment.
- * Short Course Lecturers will attend the entire workshop to provide thematic continuity.

3.2 Lecturers of 2000 Margins Theoretical and Experimental Institute

One of the principal objectives of the theoretical institute will be to stimulate cross-disciplinary inquiry into the rheology and deformation of lithosphere, which will provide a better understanding of the varying margin architectures observed and a framework with which laboratory, field, and modeling experiments can be posed. The MARGINS Steering committee is excited at the prospect of bringing together a number of research groups that traditionally do not interact, even though there is a common thread that philosophically links their research goals. At this point in time, we have sent an email to all the invited lectures to determine their interest in such a meeting and more importantly, to determine if they will participate as an invited lecturer in the proposed MARGINS TEI. The email response has been overwhelmingly positive from all the invited speakers.

Day 1

N. Driscoll (Overview: Margin deformation style evolution as functions of space & time) ndriscoll@whoi.edu

D. Sawyer (Case study: Seismic imaging of Iberia margin) dale@geophysics.rice.edu

E. Silver (Case study: Convergent margin - Costa Rica) esilver@earthsci.ucsc.edu

G. Davis (Continental example: Basin & Range) gdavis@usc.edu C. Burchfiel (Case study: mountain systems) bcburch@mit.edu

L. Ruff (Limits of the seismogenic zone) ruff@umich.edu

R. Hyndman (Thermal and rheological modeling of the subduction interface) hyndman@pgc.nrcan.gc.ca

Day 2

R. Buck (Macroscopic models of continental deformation) buck@ldeo.columbia.edu

J. Jackson (Strain partitioning induced by crustal faulting and interaction) jackson@esc.cam.ac.uk

B. Taylor (Case study: Woodlark basin system) taylor@soest.hawaii.edu

C. Keen (FEM models for lithospheric extensional deformation: Application to the North Atlantic margins) ckeen@agc.bio.ns.ca

K. McClay (Basin analogue models of transtensional and transpressional systems) k.mcclay@gl.rhbnc.ac.uk

S. Cohen (Finite element modeling of subduction zones) scohen@gsfc.nasa.gov

C. Beaumont (FEM modeling of compressional systems: Application to the Southern Alps, New Zealand) chris.beaumont@dal.ca

Day 3

M. Zoback (Observations on weak and strong faults and the state of stress in the lithosphere) zoback@pangea.stanford.edu

F. Chester (Observations of fault gouge and deformation fabrics around continental faults) chesterf@geopsun.tamu.edu

J. Rice (The low-strength fault paradox) rice@esag.harvard.edu

T. Tullis (Role of aqueous fluids and melts on the frictional strength reduction of sliding surfaces) terry_tullis@brown.edu

C. Marone (Relationship between laboratory observations of faulting and seismic observations) cjm@westerly.mit.edu

D. Olgaard (Relationship between the mechanics of overthrusting and metamorphism) lolgaa@epr.exxon.com

Day 4

J. Tullis (Rheology of the crust) jt@gech033.geo.brown.edu

T. Engelder (Fluid pressure observations in the crust) engelder@geosc.psu.edu

B. Hacker (Diagenesis and fault seismicity, observations on the Brittle-Ductile Transition) hacker@magic.geol.ucsb.edu

D. Kohlstedt & colleagues (Role of water and melts on crustal viscosity and strength) dlkohl@maroon.tc.umn.edu

B. Evans (Role of fluid pressure in modifying crustal rheology during deformation) brevians@mit.edu

3.3 Workshop on Rupturing Continental Lithosphere

With the input from the Short Course, the 2 day Workshop is designed to flesh out the Rupturing Continental Lithosphere science plan (fieldwork, modeling and experiments) and to choose field areas for focused investigation (as has been done previously at workshops for two of the other MARGINS Initiatives: the Seismogenic Zone Experiment and the Subducton Factory). The Rupturing Continental Lithosphere initiative derived from two of the five science foci identified in the MARGINS Initial Science Plan, 1996: (1) The Low-Stress Paradox and (2) Strain Partitioning During Deformation (see http://www.soest.hawaii.edu/margins/Science_Plan.html), and is briefly summarized here.

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

1. Determine the local and regional states of stress, the distribution and rate of strain, the pressures and temperatures, and the physical and chemical properties of rocks and

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

2. Determine the spatial and temporal distribution of strain by (i) mapping the geometry and offset of faults, (ii) inverting and modeling the stratigraphic and structural record to resolve the history of strain variation and its control on topography/erosion/deposition, (iii) using seismic, gravity/geoid and geothermal methods to obtain an integrated sum of the deformation and a measure of the ductile thinning of the lower crust, and (iv) evaluating the heterogeneity of the continental lithosphere prior to rifting.
3. Determine the pattern of mantle flow, the extent of melt generation, and the style of melt migration and emplacement during continental rifting and the early stages of seafloor spreading by imaging with seismic and electromagnetic methods an active rift-spreading transition, by measuring the heat flow distribution, and by analyzing the chemistry of magmas emplaced in these regions.

4.0 MEETING LOGISTICS

4.1 Convenors

Four individuals, representing a wide range of interests, have agreed to be convenors for the 2000 MARGINS Theoretical and Experimental Institute and have contributed largely to this proposal; their vitae are attached. Garry Karner from Lamont-Doherty Earth Observatory has considerable experience in lithospheric deformation and kinematic and isostatic modeling. Brian Taylor at SOEST, University of Hawaii, is an expert on marine tectonics and extensional systems, in particular, the mechanics of late stage continental extension and the onset of seafloor spreading. Dave Kohlstedt from the University of Minnesota, has worked on the rheology of the mantle, specifically on the influence of melts and water on mantle viscosity. Neal Driscoll from the Woods Hole Oceanographic Institution, a seismic stratigrapher, has worked on using the stratigraphic record to understand strain partitioning and how it evolves throughout the development of margins. The convenors have selected a Conference facility and a list of invited lecturers for the MTEI that are designed to facilitate both formal and informal interactions among the participants.

4.2 Participation

One of the broad goals of MARGINS is to involve numerous researchers and students from a variety of fields in interdisciplinary research aimed at the complex interplay of processes that govern the formation and evolution of continental margins. Consequently,

participation in the Short Course will be open to all researchers and students. Nevertheless, in an effort to maximize participation and effectiveness of communications, MARGINS supported attendance will be limited to 95 participants. For these participants, the MTEI will provide full travel and lodging costs for keynote speakers, convenors, students, and approximately 30 participants. Approximately 50% travel and lodging costs will be paid for an additional 20 participants. Registration fees will be reimbursed for keynote speakers, convenors, and students. High priority will be given to supporting students.

Workshop participation will be limited to 30 people will make the commitment to stay for the entire Workshop. Application for the MTEI will be a letter of interest, which will be evaluated by the Convenors and the MARGINS Steering Committee on the basis of relevance to the MTEI, quality of past research, and proposed interest to be discussed at the Institute.

4.3 Location and Timing of the MARGINS Theoretical and Experimental Institute

The MARGINS Theoretical and Experimental Institute will be held during January 2000; the tentative dates are January 23-28, 2000. The timing of the meeting during the semester break was selected to encourage participation by college faculty and more importantly students. The schedule of the MTEI is tentative, however, many of the invited lecturers have informed us that this time frame appears acceptable.

4.4 Publication

1) Short Course Lecture Notes and Workshop Agenda

Outlines of the lectures with key references and figures will be supplied by each lecturer to the MARGINS Office for inclusion in a set of notes that will be sent to all participants well in advance of the MARGINS Theoretical and Experimental Institute. Given that acquiring these notes from the invited lecturers always proves difficult, we will begin the process well in advance of the Institute. The four convenors will be the watch dogs to ensure timely submission of the lecture notes and references. At this time, the convenors will also place an advertisement in EOS announcing the meeting and calling for letters of interest from participants. In addition, a preliminary agenda will be sent to Workshop participants so that they may prepare for the discussions and bring the appropriate materials.

2) MARGINS Theoretical and Experimental Volume

Similar to the Ridge Initiatives, we plan to publish the papers derived from the MTEI lectures and associated participant research as a high-quality publication for broad

distribution. The vehicle for publishing previous Theoretical Institutes has been an AGU Monograph and we envision a similar strategy. Short Course lecturers will be expected to write a short review article on the basis of their presentations. These articles and other articles submitted by other participants will represent the first of many MARGINS Theoretical and Experimental Institute Volumes. Production and editing of the volume will require a considerable investment by both the invited lectures and the MARGINS Office.

5.0 EDUCATION AND HUMAN RESOURCES STATEMENT

MARGINS from its inception has actively involved both graduate students and young scientists in planning and implementing the MARGINS program. Numerous graduate students and young scientists have participated in MARGINS Workshops, with the first being the National Academy of Sciences Workshop held over 10 years ago in Irvine, California. Through the MARGINS Theoretical and Experimental Institutes, MARGINS is making a major contribution to education and development of human resources. The major goals of the Institutes are:

- * foster interdisciplinary studies required to make substantial advances in understanding how the earth deforms.
- * enhance communication and interaction between modelers, experimentalists, and observationalists
- * to educate researchers and students in rheology and deformation and to concentrate on aspects of theory that observations can test.

Finally, the educational impact of these Institutes will reach far beyond the participants that attended the meeting because the publications and short course notes will provide resources for seminars and courses on margin related topics at colleges and universities across the country.