GeoPRISMS
Draft Science Plan
2. Origin and Structure of GeoPRISMS

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The GeoPRISMS Draft Science Plan represents a community response to several fundamental scientific challenges. While the program is fundamentally new, it builds on the successes of the NSF MARGINS program and addresses the MARGINS Decadal Review. We provide a brief overview of the MARGINS Program to put GeoPRISMS in context, and summarize the proposed structure of the new program

2.1. Scope and Accomplishments of MARGINS

For the last decade or more, the MARGINS Program has provided a community focal point for science that aims to understand the origin and evolution of the continents through the investigation of their active margins. This was encapsulated in the MARGINS Program mission statement, "*to understand the complex interplay of processes that govern continental margin evolution globally,*" and encompasses what are perhaps some of the largest challenges in solid Earth science. The connection between global processes and continental evolution lies at ocean-continent margins, the sites of most processes that modify continents. The MARGINS program was divided into four major initiatives, which were designed to form inclusive and interdisciplinary vehicles for attacking these problems. The Initiatives and their respective Focus Sites were defined as:

- *RCL* – Rupturing Continental Lithosphere
  (Gulf of California/Salton Trough)
- *S2S* – Sediment Source to Sink
  (Waipaoa NZ; Fly River/Gulf of Papua)
- *SEIZE* – the Seismogenic Zone Experiment
  (Nankai; Central America)
- *SubFac* – the Subduction Factory
  (Izu-Bonin-Mariana; Central America)

These Initiatives addressed the mechanics, structure, and evolution of continental deformation at convergent and divergent margins, the mass and energy flux to resulting continents through subduction, and the sedimentary mass transfer from them. Several guiding principles characterized the program, many of which will continue in a modified form in GeoPRISMS:

- *Broadly interdisciplinary communities*. Each initiative addressed a complex system affecting many types of observable phenomena. Understanding these systems requires a wide variety of expertise, and integration across a broad range of disciplines.
- *Crossing the shoreline*. Any complete science program addressing continental margin evolution has to be amphibious, encompassing marine, coastal, and terrestrial elements. Thus, MARGINS crossed NSF division boundaries, and by necessity, integrated both Earth and Ocean Sciences.
- *Active systems*. Dynamic systems are best studied where the time and length scales, fluxes, and rates of processes are measurable today, so most field experiments occurred in active plate boundary systems.
- *Experiment, computation, and theory*. Laboratory, numerical, and analytical efforts provided critical independent approaches to help understand the diversity of observational evidence. These approaches also have special roles in the integration, synthesis, and visualization of observational results.
- *Focus sites*. To afford such ambitious multidisciplinary activities, major field exercises were concentrated in community-specified Focus Sites, one or two per Initiative. Most of the selected sites were outside of the U.S., so many international program partners were leveraged in the process.

Achieving the science goals within this framework in this manner required an integrated program, able to build communities with access to a broad range of tools, resources, and scientific approaches. This necessitated focusing research funding on targeted sites, and creating activities that provided oversight and fostered integration within and between sites. Normal "core" funding mechanisms at NSF could not achieve these goals. Some of the first major successes of the program were the thematic

workshops that built the broad interdisciplinary communities that remain active today, and stimulated successful proposals. This interaction between disparate scientific communities and clear, focused programmatic goals driven by compelling science was a hallmark of the MARGINS program and will remain so for its successor GeoPRISMS outlined here.

MARGINS science has been funded through individual and collaborative proposals to the NSF panel. An independent MARGINS Steering Committee (MSC) provides guidance, support and evaluation for the program (but not science proposals), and forms the principal link to the broader scientific community. To support the varied activities, a MARGINS Office facilitates communications, meetings, and other planning or assessment activities. It also serves as a focal point for several MARGINS-related education programs, centered on undergraduate and graduate student development. The MSC and MARGINS Office thus serve as primary vehicles for encouraging and enabling communication and integration among the disparate scientific communities involved.

The four MARGINS Initiatives have resulted in a great variety of scientific successes, which, in turn, have engendered a host of new opportunities across the subduction-rift-sediments community. The major highlights from each of the Initiatives and the program as a whole were summarized in preparation for the 2009 Decadal Review, including community-contributed Research Nuggets. These documents can be downloaded from the MARGINS Web Site: *www.nsf-margins.org/Review2009*.

2.2. MARGINS Decadal Review and Planning for GeoPRISMS

In late 2008, as the MARGINS Program approached its tenth year, an external committee was organized to provide a review of the program in its entirety, including science goals and accomplishments, program management, and broader impacts. The Decadal Review Committee (DRC, Prof. Anthony Watts, chair) was asked to evaluate progress to date and plans and promise for the future, and to provide comments and recommendations to NSF, and advice on the potential structure of a successor program. The DRC met February 2-3, 2009 to carry out this review; see *www.nsf-margins.org/Review2009* for the full report, documentation and response.

The DRC offered a highly favorable review of the program, recognizing the success of several core approaches of the MARGINS Program, including the broad approach to community building, the importance of crossing the shoreline, the use of focus sites to concentrate resources, the added value in cultivating international partnerships, and the importance of integrating computational and experimental research with field observation. The DRC also recognized that such activities could not have succeeded without a science program separate from core funding. The committee offered a strong recommendation to NSF that a MARGINS-like special program should be continued, building upon the strengths of MARGINS (See Box 2.1). These recommendations form the starting point for this Draft Science Plan.

In response, the NSF accepted the DRC report in principle, and requested the MARGINS Steering Committee to engage the broader geosciences community to help plan the future directions of MARGINS research. An open community workshop was organized Feb 15-17, 2010 in San Antonio for this purpose, with over 200 participants attending. This MARGINS Successor Planning Workshop (MSPW) was designed specifically to

- Identify compelling science issues that the community would like to see addressed in a possible successor program;
- Decide whether to implement thematic vs "focus site (hereafter referred to as primary site)" approaches, and to consider the pros and cons of both;
- Establish stronger linkages between Earth and ocean sciences for even stronger partnership between EAR and OCE;
- Further justify the need for a special program with sequestered funding in the context of the proposed science;

Box 2.1. Primary recommendations of the MARGINS Decadal Review Committee

- Both the SEIZE and SubFac Initiatives should continue, guided by community workshops to define their science plans for the next phase of study;
- A new initiative should be developed that would incorporate a broader view of rifted margin evolution, including passive margins and analysis of sedimentary architecture as recorders of the progress of rifting;
- The S2S Initiative should not be continued as a stand-alone initiative, but rather the appropriate aspects of sedimentology and stratigraphy should be incorporated explicitly within the other initiatives;
- Passive and ancient exhumed margins should be considered, as well as active margins.
- The focus site concept should be continued, but expanded to allow flexibility;
- Large-scale modeling, lab and experimental studies of margin analogs in the rock record should continue to be important elements;
- The program should continue to work productively with other large-scale NSF facilities: such as EarthScope, OOI, IODP, and R/V Marcus Langseth;
- Enhanced links with societal issues such as climate, sea-level and environmental change, geo-hazards, and energy and resources should be highlighted in the new program.

- Develop a draft Science Plan for consideration by NSF for authorization of a successor program.

The document presented here represents the community consensus on priorities emerging from that Workshop, introduced here as GeoPRISMS (Geodynamic Processes at RIfting and Subducting MarginS). It was written in the two months following the MSPW by ~20 participants chosen by, and including members of the MSC, incorporating community feedback on an early draft solicited during a Public Comment Period. The widely circulated document provides an outline of future science directions, justifications for a renewal program, and a summary of how such a program would be implemented. NSF authorization for a new program, if given, will set the stage for subsequent planning workshops to take place, to prepare the final GeoPRISMS Science Plan, although some program elements could commence immediately (See Section 6.3).

2.3. Building GeoPRISMS beyond the MARGINS Brand

As recommended by the DRC, GeoPRISMS will maintain the focus of its predecessor on subducting and rifting margins, and research efforts will be organized around several fundamental scientific questions that have the highest potential for achieving transformative breakthroughs on a decadal time scale. It emphasizes interdisciplinary inquiry, and crosses the shoreline. However, GeoPRISMS is not a continuation of MARGINS. Instead it builds on the MARGINS "brand", taking advantage of the progress and community building done previously to focus on several new problems and processes. New researchers from a broadened range of disciplines will be attracted into research collaborations to investigate processes that take place at the Earth's surface, as well as within the crust and mantle, to better understand how these intertwined systems drive each other in space and time. New tools and new facilities will be exploited as much as possible to drive transformative breakthroughs, and discoveries of the last few years will feature prominently in science goals. To fully realize these potentials, GeoPRISMS will:

- Address complex coupled systems through an integrated approach, combining field research in structure and tectonics, marine geology, geomorphology, geochemistry, geophysics, sedimentology, stratigraphy, and satellite-

based methods, but also with a sound basis in experimental, analytical and numerical modeling investigations;
- Involve large amphibious field programs as well as smaller focused field and lab-based studies;
- Be guided by Overarching Themes, which address the coupled geodynamic, surficial, and climatic processes that build and modify continental margins over a wide range of timescales (from s to My); and
- Develop comprehensive systems-based models to understand margin evolution and dynamics, the construction of stratigraphic architecture, and the implications for the accumulation of economic resources, associated geologic hazards, climate change and environmental management.

Following recommendations by the DRC and the MSPW community input, GeoPRISMS will consist of two broad Initiatives. The new initiatives are Subduction Cycles and Deformation (SCD) and Rift Initiation and Evolution (RIE). The SCD initiative will encompass the former SEIZE and SubFac Initiatives, building on a growing recognition resulting from a decade of MARGINS research that the two systems are tightly linked and respond to many of the same forcing functions, albeit manifested in very different ways. The RIE Initiative will encompass the former RCL and aspects of the Source to Sink Initiatives. RIE will expand its purview to include the study of passive margins as archives of the entire history of rift zone construction and evolution, with direct relevance to understanding both mineral and petroleum resources. These initiatives will be integrated through five Overarching Science Themes, which serve as an intellectual focus to the tectonically-defined Initiatives (Box 2.2).

Following DRC and MSPW recommendations, GeoPRISMS reaches beyond MARGINS in several novel directions:

- Explicit inclusion of surface processes (e.g., climate modulated weathering, erosion, sediment dispersion, and deposition) and their feedbacks in the evolution of continental margins;
- Consideration of inactive and potentially exhumed margins, where a process has gone to completion or where observations of deeper systems can be made in the field;
- Implementation of science objectives by way of a "hybrid" approach, merging focus-site studies with a more flexible thematic approach, to enable detailed study of a process or system where best expressed, as well as global comparisons to establish the significance of focused observations, or their fit into a temporal framework;
- Close relationships with many new major facilities now in operation to maximize their scientific return, including increased attention on US-based facilities such as EarthScope and the Cascadia Initiative;
- Expanded relevance of GeoPRISMS research to issues with direct societal impact, including accumulation of economic resources, understanding geologic hazards, and managing coastal development; and
- Broadened educational and outreach programs to engage the new generation of scientists into exciting continental margins science.

Box 2.2. GeoPRISMS Overarching Themes (Described in Section 3)

- Origin and Evolution of Continental Crust
- Fluids, Melts and Their Interactions
- Tectonic-Sediment-Climate Interactions
- Geochemical Cycles
- Plate Boundary Deformation and Geodynamics

2.4. Initiative Structure

Subduction Cycles and Deformation (SCD) will address coupled processes active at subducting margins and explore linkages among them, spanning the updip limits of the accretionary wedge and incoming plate, to the deep mantle and plate boundary interface, and associated cycling of fluids and volatiles, their role in rheology, melting, and magmatism, and ultimately, arc processes that

lead to the growth of continental crust. This new initiative formalizes the strong linkages between SEIZE and SubFac recognized during MARGINS, and will facilitate the interdisciplinary exchange of knowledge within the subduction zone community, enabling transformative discoveries of this highly coupled system. As elaborated in Section 4, the key questions guiding this initiative are:

- What governs the size, location and frequency of great subduction zone earthquakes and how is this related to the spatial and temporal variation of slip behaviors observed along subduction faults?
- How does deformation across the subduction plate boundary evolve in space and time, through the seismic cycle and beyond?
- How do volatile release and transfer affect the rheology and dynamics of the plate interface, from the incoming plate and trench through to the arc and backarc?
- How are volatiles, fluids, and melts stored, transferred, and released through the subduction system?
- What are the geochemical products of subduction zones, from mantle geochemical reservoirs to the architecture of arc lithosphere, and how do these influence the formation of new continental crust?
- What are the physical and chemical conditions that control subduction zone initiation and the development of mature arc systems?
- What are the critical feedbacks between surface processes and subduction zone mechanics and dynamics?

Rift Initiation and Evolution (RIE) will focus on the fundamental processes active within rifts and rifted margins, from the initial localization of continental rupture, the structural, magmatic, and sedimentary processes that control the growth of rift zones, through the late stages of rifting and the transition to oceanic spreading, and the resulting stratigraphic and tectonic architecture of passive margins. This initiative will emphasize the interactions between climate, erosion, and sediment transport and deposition, and plate boundary deformation, including mantle dynamics, to gain a comprehensive understanding of lithospheric evolution along rifted margins. As detailed in Section 5, the key questions guiding this initiative are:

- Where and why do continental rifts initiate?
- How do fundamental rifting processes (such as tectonics, magmatism, and erosion, transport, and sedimentation), and the feedbacks between them, evolve in time and space?
- What controls the architecture of rifted continental margins during and after breakup?
- What are the mechanisms and consequences of fluid and volatile exchange between the Earth, oceans, and atmosphere at rifted continental margins?

2.5. Integrated GeoPRISMS Science and its Societal Impact

Both GeoPRISMS Initiatives embrace the interconnectedness among surface, tectonic, and magmatic processes, addressing the complex interactions and feedbacks induced by climate, erosion, sediment transport, and deposition in controlling continental margins dynamics, crustal growth, fault mechanics, volatile flux, and magmatic activity. This approach will enhance collaborations between marine and terrestrial geologists and geophysicists, and will help to build stronger partnerships across NSF divisions. The new initiatives will engage interdisciplinary teams carrying out observational, experimental, and modeling studies to address their fundamental questions. These investigations have practical applications for sustainability in the face of climate change and sea level variation, increased pressures on energy and water resource management and availability, and hazard mitigation. Not only are the proposed studies of both basic and applied value, but they also provide unique opportunities to build an appropriately educated workforce, the next generation of GeoPRISMS scientists, and new knowledge on subjects of great importance to the broader public.

2.6. Justification for a Stand-Alone Program: Why Not Core?

Strong arguments can be made to maintain GeoPRISMS as a focused program, distinct from the standard NSF core programs. Like MARGINS, GeoPRISMS remains tightly focused on understanding the complex coupled systems that control continental margins dynamics, structure, stratigraphy, and evolution, from top to bottom, as viewed from onshore and off, and from inside and out. The extraordinary cross-disciplinary nature of MARGINS and GeoPRISMS science could lead to transformative breakthroughs, but must attract geoscientists who can work in teams that span the traditional NSF divisions. Consistent with this model, fulfilling the GeoPRISMS vision will require:

- A combination of on-land and marine investigations to fully capture processes and products that cross the shoreline, for example, mantle and lithosphere dynamics that control plate boundary deformation, and the subaerial to submarine pathways that control sediment dispersal and accumulation.
- Strong interdisciplinary research teams, for example, promoting collaborations among geomorphologists, sedimentologists, geochemists, geophysicists, and geodynamicists to understand the complex development of stratigraphic architecture along rifted margins., and the dynamic interplay between tectonics uplift, erosion, sedimentation, and megathrust fault mechanics.
- Guidance from a cogent Science Plan, that can focus major projects to address clear scientific objectives vetted by the community.
- Interdisciplinary NSF panels able to evaluate the breadth and scope of GeoPRISMS scientific proposals, and in particular, synthesis activities that may span a broad range of data sets and research techniques, including experimental and/or theoretical studies.
- A well-informed scientific community, conversant in the wide range of geological phenomena that govern continental margin processes. Such a community is an outgrowth of coordinated efforts to enhance communication, education, and knowledge exchange, for example, through workshops, newsletters, websites, and the oversight and steering committee, which the GeoPRISMS Office will manage.
- Coordinated efforts to disseminate the significance and relevance of GeoPRISMS science, for example, its impacts on understanding geohazards and economic resources to the broader community, including students, the public, and policy makers. A focused and managed program will facilitate such efforts beyond the abilities of individual PIs.

GeoPRISMS will also continue the demonstrated benefits of the focused MARGINS program, which include engaging and leveraging major international partnerships, providing a framework for science that uses major infrastructure facilities, and developing broad education and outreach efforts from numerous individual research projects. Furthermore, the facilities for data archiving, rapid public release policies, and development of educational access tools are best managed within a focused program. These education and outreach tools have been shown to contribute significantly to the success of MARGINS, and are expected to continue to do so within GeoPRISMS.