GeoPRISMS
Draft Science Plan
6. Implementation of Science Objectives

6. Program Implementation

This Draft Science Plan describes the overall goals and architecture of GeoPRISMS, with the intent that a final Plan and full implementation will await further community workshops where specifics are fleshed out and prioritized, including any site selection. Here, we describe the proposed implementation structure for GeoPRISMS best suited to meet the scientific goals, then detail the overall timeline for generating a complete Science Plan vetted by the community. However, several recent and ongoing observational programs, including those launched under MARGINS or ARRA funds, already have strong community support and are compatible with GeoPRISMS objectives. These realities dictate that maximum scientific return will occur if some of these activities can commence immediately under proposals funded by the FY11 budget, and are part of the motivation for rapidly submitting this Draft Science Plan shortly after the MSPW. We justify these opportunities below.

6.1. Proposed Implementation Structure for GeoPRISMS

Achievement of the scientific objectives of the GeoPRISMS Program will require a new approach, modified slightly from the successful focus site approach of MARGINS. The selection of up to two focus sites for each initiative under the MARGINS program allowed for the concentration of resources and expertise, and enabled rich interdisciplinary selection of many non-US locales. These sites encouraged strong international collaborations as well as productive ODP and IODP drilling efforts in Nankai and Central America. Clearly, a great deal of research has, and continues to be, accomplished at these focus sites beyond that originally envisioned. The benefits of such concentrations of resources and effort at the MARGINS focus sites will carry into GeoPRISMS, defining strong reference data sets upon which subsequent research can be built. By default, the new "Primary" sites for the GeoPRISMS program will differ from the previous ones, unless strong justifications are made to the contrary.

Several of the science questions outlined above, however, also clearly reveal that there are many scientific questions integral to GeoPRISMS objectives that cannot be completely addressed at one or two research locales, but require more global comparisons. For example, rifting proceeds from early continental extension through lithospheric rupture to the generation of an ocean basin, and understanding the full evolution may be clearer by comparing a suite of archetypical sites. Similarly, the seismic cycle on plate-boundary thrusts can last hundreds of years, therefore much may be gained by contrasting multiple sites at different stages of the seismic cycle. In a rather different way, understanding the global volatile and mass fluxes at subduction zones seems likely to require global comparisons and different sites to constrain the fluxes to the deep Earth, or to constrain the conditions controlling arc growth rates. Finally, our understanding of the metamorphic reactions occurring along the downgoing-overriding plate boundary in subduction zones, and volatile-rock interactions associated with serpentinization requires close coupling and investigations of active processes and corresponding ancient, exposed rock sequences wherever they occur. These arguments lend support to including a thematic component in the new program, emphasizing community-selected, well-formulated, and tractable themes.

To achieve the scientific objectives of GeoPRISMS, we propose a "hybrid" approach, in which major field efforts predominantly take place at 1-2 Primary Sites per initiative, generally different from previous MARGINS focus sites. However, the program will fund critical efforts at other sites that provide essential observations not otherwise attainable at the Primary Sites, but which are central to Science Plan objectives, for example:

- *Sites that represent endmembers of critical parameters;*
- *Sites that supply critical components of global comparisons*

- *Sites that uniquely exhibit certain phenomena obscured at Primary Sites;*
- *Sites that typify different stages of margin evolution.*

Some of the MARGINS focus sites can serve as reference sites for such studies, benefiting from abundant baseline data or time series; comparative or complementary studies can evaluate their global or evolutionary significance. Research released from the constraints of focus sites also allows a broader community to participate, rather than favoring those most vested in a specific locale. This will serve to grow and strengthen the GeoPRISMS community. Major initiative workshops, described in Section 6.2, will be held to organize Primary Site and Theme selection and to coordinate research plans. The chosen models implemented for carrying out the science objectives for the GeoPRISMS program can also vary between the initiatives. These decisions will be made at the community workshops to ensure the best science in the most appropriate locations. This approach builds on the MARGINS Focus Site approach but extends it, as recommended by the 2009 DRC Report.

Given the availability of new near-US facilities (EarthScope, OOI, etc.), enthusiasm for the study of US coastal systems and geohazards, and basic logistical considerations, it seems likely that at least part of the successor program's focus will lie near North America. However, scientific needs, strong international partnerships, and critical infrastructure at present outside of North America (e.g., the next few years of riser drilling) will motivate some non-US sites. The appropriate balance between these opportunities will be made at directed community workshops.

As with MARGINS, outstanding research proposals that address the broad themes and initiative goals of GeoPRISMS, but fall outside the specific Primary Site and thematic topics identified by the community, could also be considered for funding. Examples include broad laboratory, modeling and theoretical studies as a basis for synthesizing and generalizing Primary Site field efforts. Such studies have been critical to the success at MARGINS in integrating observations from distant disciplines. Also, the theoretical results provide a strong basis for generalizing results from individual sites to understand the underlying processes, including the over-arching themes that span the SCD and RIE initiatives. New facilities and resources, such as CIG and CSDMS, provide new opportunities for increased rigor and community participation in these efforts.

6.2. Approach and timetable for finalizing the GeoPRISMS Science Plan

The SCD and RIE initiative plans, key scientific questions, and implementation methods outlined above represent preliminary consensus, based primarily on the outcome of the MARGINS Successor Planning Workshop. While these discussions offer a strong basis for proposing the GeoPRISMS successor program, there are clearly many details still to be resolved. In particular, the community must agree upon the specific themes that will be tackled, as well as how and where the research will be carried out. Primary Sites, where deemed necessary, will have to be selected based on the best science and the strength of the available or acquirable data sets. These decisions will impact future interactions with international partners and industry colleagues, as well as with other NSF programs and facilities such as EarthScope. The ultimate decisions and selections will certainly factor into the feasibility and fundability of the GeoPRISMS program.

To make these final decisions, initiative-based planning workshops will be organized as soon as possible, and announced after the hoped-for NSF approval of GeoPRISMS. The call for workshop applications will tap the wider community, independent of previous participation in the MSPW or MARGINS, to ensure the broadest input, with the anticipation of two workshops, one for each Initiative. Workshop objectives will include:

- Refine the initiative themes and key unanswered questions outlined here
- Resolve which themes require Primary Sites to answer

- Prioritize the scientific objectives, themes, and questions
- Identify, justify, and select 1-2 Primary Sites per initiative
- Finalize plans for ramping down work at existing MARGINS Focus Sites
- Identify international partners and national collaborative agencies
- Outline research approaches and timetables for each theme and focus site
- Identify and charge the final Science Plan writing team

Smaller workshops may be organized around overarching themes to help clarify the specific questions and scientific approaches required for each initiative, and to guide the initiative-based workshops.

Pending NSF approval and funding availability, these planning workshops will be organized for Fall 2010, providing the necessary input for the final Science Plan to be drafted by the end of 2010. This timetable could lead to a full solicitation in 2011, in time for FY12 funds, should NSF allow.

6.3. Immediate (FY11) Opportunities for GeoPRISMS

A number of ongoing and new data collection efforts provide critical and immediate opportunities for GeoPRISMS. As a result, there is great community momentum and need for a focused program in the short term, taking advantage of these facilities and the excitement they have engendered. Hence, there are several opportunities and reasons to begin support of some activities immediately, on the basis of this Draft Science Plan and the recommendations of the DRC. As detailed below, these include:

(1) activities in existing MARGINS Focus Sites that ramp down efforts but bridge to GeoPRISMS priorities, including syntheses and continuation of long-lead-activities;
(2) multidisciplinary and amphibious activities taking advantage of the joint ARRA-funded MARGINS-EarthScope Cascadia Facility Enhancement (2010-2014);
(3) studies that complement the USArray Transportable Array deployment as it reaches US passive margins (2010-2013);
(4) collaborations with the USGS and NOAA in Law of the Sea activities (2010-2015);
(5) and relevant rapid response surveys, should they occur.

Other time-sensitive activities in subsequent years (after 2011) might include complements to Alaska-Aleutian deployment of the USArray and activities that complement priorities of an IODP successor; these can be specified in future Science Plan revisions. The priorities elucidated here should form sufficient motivation to institute funding as soon as approved by NSF without substantial hiatus.

6.3.1 Time-sensitive Opportunities at Existing MARGINS Focus Sites and Integration Activities

While it is expected that work at existing MARGINS Focus Sites (Figure 6.1) will wind down, as envisioned in that program's decadal science plan and recommended by the DRC, certain activities form a natural bridge to GeoPRISMS and should be supported. As recommended by the DRC, there are uncollected data sets at several of the MARGINS focus sites that are still needed to answer the fundamental initiative questions (e.g., Gulf of California/Salton Trough), whereas others have gained stature as international focus sites for IODP drilling (e.g., Nankai, Izu-Bonin and Central America). At some sites, new infrastructure provided by other programs (e.g. EarthScope at

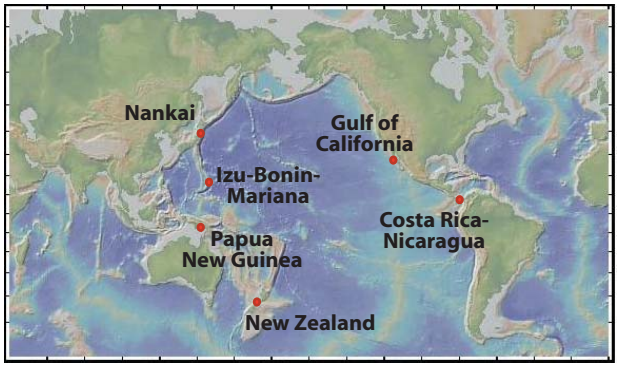

Figure 6.1. 2000-2010 MARGINS Focus Sites.

Salton Trough; IODP at Nankai) will produce new major data sets regardless, and GeoPRISMS could play a critical role in providing a complementary multidisciplinary perspective and broad intellectual framework for studies of these data. Also, some priorities of GeoPRISMS (e.g. understanding strain and deformation; understanding eruptive outputs of volcanoes) are best addressed via long-term records, many of which have been started at SubFac, SEIZE and RCL focus sites. Such long-term records seem worth continuing in many cases, and in most cases, it would be inappropriate to abandon ongoing research begun under MARGINS, not all of which have reached completion. Within the next year, it is expected that initiative communities will establish final priorities for supporting continuing research projects vs. initiating surveys in new locations.

In addition, work that does not involve a large investment in field campaigns could begin immediately. It is envisioned that GeoPRISMS will incorporate a host of computational, experimental and analytical studies, as did MARGINS, and such laboratory-based projects could begin before specific research sites are selected. In particular, it seems likely that global comparisons or broad theoretical studies could go far toward quantifying a framework of specific hypotheses that could be tested at old and new focus sites. Examples of such global and theoretical comparisons abound in both the SCD and RIE descriptions above.

6.3.2. Cascadia Initiative

NSF's Earth Sciences (EAR) and Ocean Sciences (OCE) divisions each received $5M in facility-related investment from the 2009 American Recovery and Reinvestment Act (ARRA) spending to support EarthScope and MARGINS science objectives in the Cascadia region. The resulting amphibious geophysical facility (Figure 6.2) enhances EarthScope/PBO GPS stations, deploys 27 USArray-style Transportable Array (TA) stations, and builds a pool of 60 shallow and intermediate depth Ocean Bottom Seismographs (OBS's) that will be deployed offshore of the Cascadia margin starting in May/June 2011. After an initial 3-5 year Cascadia deployment, the OBS and TA stations will become part of the OBS and PASSCAL Instrument Pools to be deployed elsewhere. Additionally, nodes of the Ocean Observatories Initiative (OOI) will be installed off Cascadia in the coming years, making this margin one of the best-instrumented subduction zones on the planet.

To guide this facility, in July 2009 the chairs of the EarthScope and MARGINS Steering Committees convened a 24-person Planning

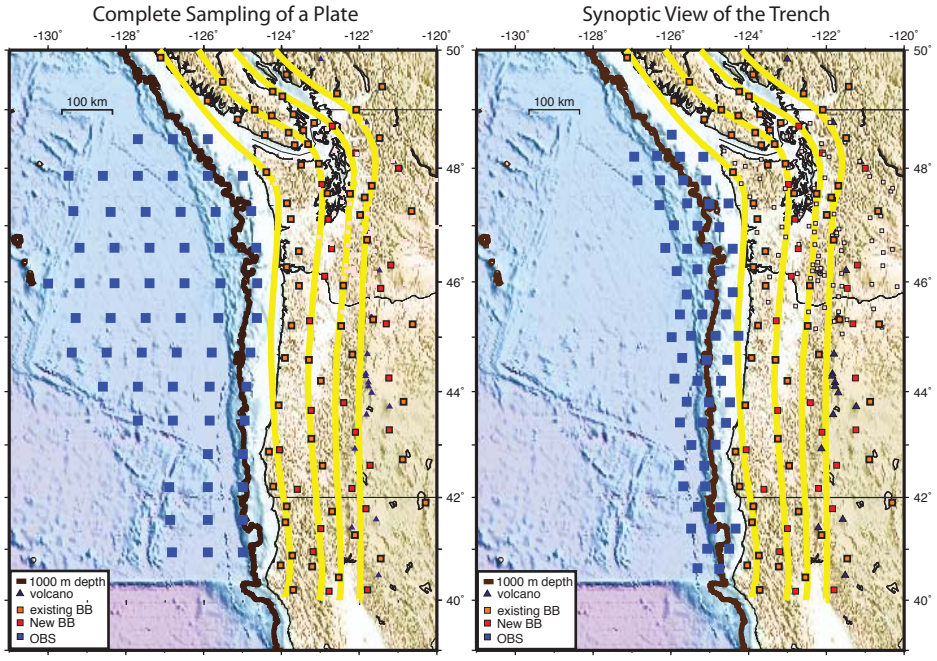

Figure 6.2. Possible deployment options for Cascadia Amphibious Array (2009 Whitepaper).

Group (see whitepaper: *www.nsf-margins.org/Cascadia/09meeting*). Subsequently, a smaller Amphibious Array Steering Committee (AASC) was formed to provide advice and facilitate coordination between the facilities and the community, and to convene a community-wide workshop in October 2010 to elucidate scientific objectives and implementation plans.

Most of the science objectives initially identified have significant overlap with those of MARGINS and GeoPRISMS. These include: (1) understanding the connections between thermal structure, fault zone composition, metamorphic dehydration, pore pressure, fault strength and fault slip behavior; (2) determining water transport in a young subduction zones; (3) identifying melt production and the plumbing system of volcanoes; (4) understanding seismic anisotropy and mantle flow patterns and the segmentation at subduction zones. Even without the large infrastructure investment, Cascadia is a high-priority subduction zone site, for several reasons. As recognized in the MARGINS Science Plan, Cascadia represents an extreme thermal endmember of subduction. The subducting Juan de Fuca plate is the youngest to subduct anywhere and still generate a volcanic arc. It is also one of the first margins at which Episodic Tremor and Slip (ETS) have been observed, and still has arguably the strongest and most extensive ETS record. Thus, this is likely a high-priority site for GeoPRISMS.

GeoPRISMS can complement EarthScope support of science in Cascadia in several ways. It provides a global framework for subduction zone studies. It also provides access to a deeply interdisciplinary community, who can bring tools that complement the geophysical facility investment and can put discoveries in broader context. Finally, it provides a natural means for crossing the shoreline, conducting marine and amphibious studies that complement terrestrial observations of EarthScope.

Because this facility is being deployed in 2010-2011, and is expected to move after 3-5 years, urgency exists in funding any projects making use of it.

6.3.3. USArray Studies of Other US Margins

The EarthScope facility represents a major investment in the Geosciences in generating data streams of high relevance to GeoPRISMS. The multiple components of the EarthScope program provide open-access, commonly real-time data from seismic, geodetic, electro-magnetic, and borehole data to measure the multiple time and length scales of plate boundary deformation (PBO), to recover rock samples from the seismogenic zone (SAFOD), and to seismically image continental lithospheric and deep Earth structure (TA). As the TA marches across North America from west to east, it serves as a natural focus on a variety of scientific problems. In particular, its swaths of ~400 broadband seismographs reach the Texas Gulf Coast and northern East Coast passive margin areas beginning in 2010 and 2013, respectively (*http://www.usarray.org/maps*). Thus the window for concurrent complementary studies across these margins is fairly short, and planning activities should begin immediately.

The Gulf Coast and Atlantic Coast targets are areas of interest to RIE, given the potential to understand the full history of the opening of the Gulf of Mexico and Atlantic Ocean, through the study of the crustal structure of both passive margins. Such inquiry is a natural complement to what was learned from the Gulf of California MARGINS focus site, as recognized by the Decadal Review Committee. For example, comparison of the non-volcanic eastern and magmatic western Gulf of Mexico margins, East Coast margins, Gulf of California, and other margins worldwide allows for an unprecedented study of the role of inherited tectonic features on their magmatic and structural evolution, and also allows for a direct comparison of the role of sediment flux on margin evolution. The Gulf of Mexico also allows leveraging of a large industry dataset, enhancing industry ties as emphasized by the DRC, and will impact ongoing petroleum exploration efforts in the Gulf. Thus, studies of these margins fit in well with GeoPRISMS priorities outlined previously, and the infrastructure investment provided by EarthScope has potential to foster significant new discovery.

The partnership here between the EarthScope science program and GeoPRISMS seems natural and probably necessary to achieve both program's goals. The full import of the EarthScope experiment can only be achieved through combined offshore-onshore efforts, both with seismic and MT experiments, and in 3-D. Both programs have major elements that integrate lithosphere-scale Earth structure with deformation on its surface, and with near-surface geologic processes. Research opportunities are enhanced by vintage industry seismic and borehole data sets along the US East Coast, as well as onshore well and seismic data. GeoPRISMS and EarthScope can leverage industry in a common partnership, as in the Gulf Coast.

TA's west-to-east imaging swaths conclude in 2015 when instrumentation is scheduled to move to Alaska. The potential for innovative and compelling SCD Initiative science in onshore-offshore experiments in Alaska are tremendous, and will be clearly an important topic at a Subduction Initiative workshop expected in late 2010.

There is some sense of urgency to TA and GeoPRISMS linkages on the East Coast passive margins, given the ca. 3 year lead time for the OBS equipment pool.

6.3.4. Law of the Sea - the US ECS Project

The U.S. multi-agency Extended Continental Shelf (ECS) Project was created to establish the full extent of the nation's "continental shelf" consistent with international law. The United Nations Convention on Law of the Sea (UNCLOS) provides the criteria for defining this region beyond 200 nmi from the territorial baselines, based upon knowledge of bathymetry, sediment thickness and geologic context. The US Department of State, US Geological Survey, and NOAA are the primary partners in this effort.

The ECS Project has identified a dozen regions with potential for ECS along the margins of the US and its Pacific Islands (Figure 6.3; *http://continentalshelf.gov/*). New 2D seismic reflection data are required for the Arctic, the Bering Sea, the Gulf of Alaska, the Atlantic margin, and possibly also the Northern Marianas region and the Line Islands collected by the USGS. Targeted OBS refraction data are also needed in each of these potential ECS regions. New

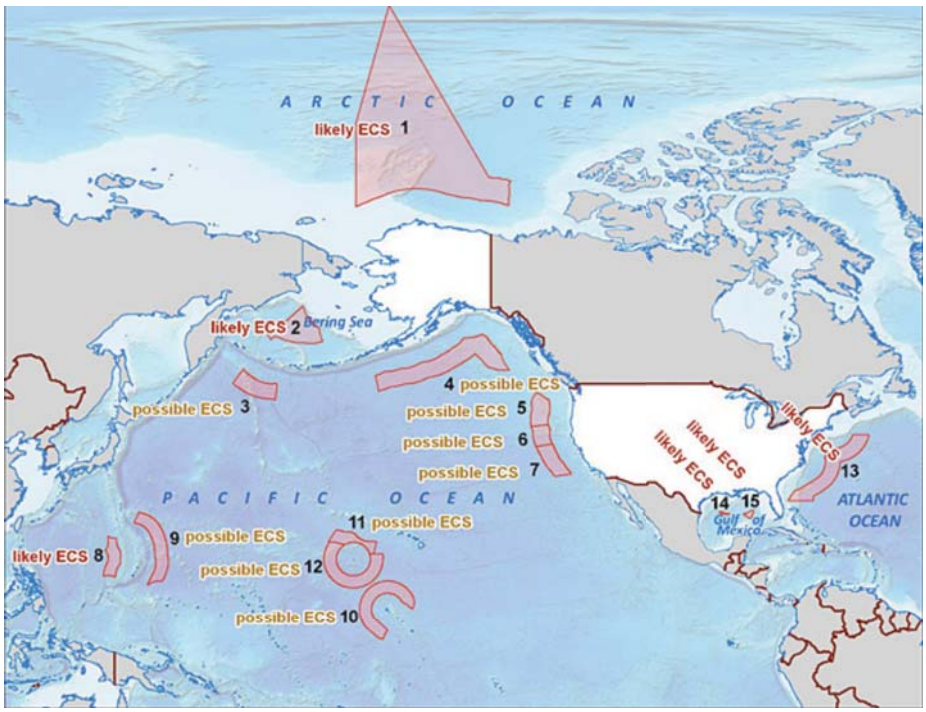

Figure 6.3. Areas where the U.S. is considering collecting and analyzing data as part of the ECS program (continentalshelf.gov).

multibeam bathymetry data have also been collected or are planned to meet specific ECS objectives in each of these regions, by NOAA and Univ. New Hampshire (*http://ccom.unh.edu/*).

The time line for the ECS project is to complete all necessary data acquisition within ~5 more years (e.g. by ~2015). The planning of ECS-specific data acquisition is inherently governmental, but the funded ECS program provides an opportunity to plan coordinated studies that will enhance the value of both ECS and academic programs. The regions of ECS interest have significant overlap with previous and proposed GeoPRISMS study areas and USArray focus areas in both rifts and subduction zones. In general, the ECS studies will focus on deep-water regions to 350 nmi from the coast. Data collected by the US for the ECS project will generally be non-proprietary and will be publicly available. Analysis for ECS purposes may be highly specific, and further use of these data for academic studies is encouraged. Thus, the ECS studies offer opportunities for broad synergy between the ECS project work and GeoPRISMS, including potential access to tremendous new data sets in critical areas.

6.3.5 Rapid Response Research Opportunities

Potentially transformative scientific opportunities exist through a dedicated Rapid Response Plan. Many of the motivating questions posed in this Science Plan bear directly on the occurrence of unpredictable phenomena, such as large megathrust earthquakes and volcanic eruptions. The 2004 and 2005 Sumatra earthquakes, as well as the Feb 27, 2010 Chile earthquake offered rare and unique opportunities to acquire data immediately following a great earthquake, including aftershock distributions, postseismic surface displacements, and offshore bathymetric and/or seismic surveys to identify the rupture zone. Rapid responses to volcanic eruptions provide critical insights as well. NSF has readily promoted such rapid response surveys where feasible, often building on existing projects and leveraging research teams with appropriate international collaborations to facilitate logistical issues, now covered by the RAPID program. Data sets arising from such efforts will play an increasing role in clarifying the fundamental geologic processes of interest to GeoPRISMS research.

MARGINS researchers have been prominent participants in two major rapid response activities, during the 2003 Anatahan volcanic eruption [*Wiens et al*., 2005; *Wade et al*., 2005], and the recent boninite eruption in northern Tonga [*Todd et al*., 2009]. The successes of these two endeavors demonstrate the importance of mobilizing research activities in response to rare or extraordinary events, and the MARGINS-GeoPRISMS community affords an unparalleled nimbleness in this regard. GeoPRISMS is also ideally poised to offer new insights into a separate, but fundamentally important process: fluid-involved fault slip and seismically 'silent' dike intrusions, such as the Afar 2005 mega-dike intrusion. These events accommodate a significant but poorly quantified proportion of plate boundary strain, and involve complex relations between magma, volatiles and rocks (dikes) and metamorphic reactions, volatiles, and rocks (ETS). GeoPRISMS rapid response efforts will also support studies of seismically quiet, magma-involved rifting and subduction episodes to ensure measurements of volatile and magma flux, strain accommodation throughout the plate, and rheology of the crust and mantle.

Independent of the timeline for initial funding for the successor program, we recommend that a protocol exist for submission and approval of event-driven rapid response surveys of direct relevance to GeoPRISMS, which would enable rapid acquisition and release of data and observations to further advance GeoPRISMS scientific objectives. As such events are, by their nature, unpredictable, they offer immediate opportunities for GeoPRISMS-related investigations outside of the normal call for proposals, and should be considered in the near term.