0. Executive Summary

Background and overview

GeoPRISMS was established in 2010 to guide a decade of community-driven and interdisciplinary research on the origin and evolution of continental margins and the active processes shaping them. The primary goal of the GeoPRISMS Program is to develop a fundamental understanding of these shoreline-crossing systems and their importance in global Earth processes, resource distribution, and geohazards. GeoPRISMS is both a community effort and a funding opportunity. The latter uses sequestered funds out of the OCE and EAR divisions of NSF. GeoPRISMS research uses a wide range of broadly integrative approaches that include large marine and terrestrial field campaigns along with experimental and modeling studies. It provides a strong scientific basis for the utilization of major NSF and related infrastructural investments and continues to build and educate a collaborative and interdisciplinary research community.

GeoPRISMS grew out of MARGINS following its positive decadal review. The initial community effort focused on the development of a draft science plan following the MARGINS Successor Planning Workshop of 2010. The initiatives and plans for primary sites were further developed in seven workshops that led to the completion of the GeoPRISMS Science and Implementation Plans in 2013.

The guiding goals for GeoPRISMS are: i) to use an integrated approach that combines field research with experimental and modeling investigations; ii) to employ a combination of large projects that investigate the continental margins from an amphibious and shoreline crossing perspective with smaller field projects and lab-based studies; iii) to address the coupled geodynamic, surficial and climatic processes that build and modify continental margins; iv) to develop comprehensive models of margin evolution and dynamics with implications for geohazards, climate change, and management of energy resources and the environment.

GeoPRISMS consists of two broad initiatives: Subduction Cycles and Deformation (SCD) and Rift Initiation and Evolution (RIE). The SCD initiative integrated the MARGINS SEIZE and SubFac initiatives following the growing recognition during MARGINS that the two systems are tightly linked and respond to many of the same forcing functions. Sedimentary processes are also embraced within this initiative. The RIE initiative encompasses the former RCL and aspects of the S2S initiatives. RIE objectives are expanded to include the study of passive margins as archives of the entire history of rift zone construction and evolution, with direct relevance to understanding mineral and petroleum resources. To focus resources and encourage new collaborative and international projects five primary sites were chosen: Alaska-Aleutians, Cascadia and New Zealand for SCD; and the Eastern North American Margin and the East African Rift System for RIE.

These tectonically defined initiatives were linked through five overarching science themes: 1) origin and evolution of the continental crust; 2) fluids, melts and their interactions; 3) tectonic-sediment-climate interactions; 4) geochemical cycles; and 5) plate boundary deformation and geodynamics. GeoPRISMS extends the MARGINS approach into several novel directions including: the inclusion of surface processes and their feedbacks on continental margin evolution; the consideration of inactive and exhumed margins; close relationships with major facilities such as EarthScope and the Cascadia Initiative; and expanded relevance to issues with societal impact.

The extraordinary cross-disciplinary and amphibious nature of the MARGINS and GeoPRISMS science objectives makes it essential to formulate a special program. It must attract geoscientists who can work in teams that cross traditional research disciplines. Continental margin processes and GeoPRISMS science objectives span the shoreline, which requires bridging the traditional and substantial divisional boundary between EAR and OCE. Fulfilling the GeoPRISMS vision requires a combination and integration of terrestrial and marine investigations, strong interdisciplinary research teams, guidance for a clear and logical science plan that is vetted by the community, a special interdisciplinary NSF panel able to evaluate the breadth and scope of GeoPRISMS science proposals, and a well-informed scientific community that is conversant in the wide range of geological phenomena that govern continental margin processes.

A Program Office facilitates efforts towards these goals, providing the ability to reach beyond the abilities and interests of individual PIs. The Program maintains well-established channels for data archiving and access, dissemination of science results, and engagement of a wide range of partnerships and access to major infrastructure facilities. The Office also defines a clear focal point for broad education and outreach efforts. All of these efforts are most efficiently managed and coordinated within a focused program, overseen by an active Office and steering committee.

Program Management

The GeoPRISMS funding opportunity is managed jointly by NSF program managers from EAR and OCE-MGG. The community efforts are overseen by the GeoPRISMS Steering and Oversight Committee (GSOC) and supported by a national Office, the director of which serves as the GSOC chair. Individuals in the Office and GSOC are not involved in the funding process, except perhaps to serve as ad hoc reviewers of proposals. The Office and GSOC are only informed of award information that becomes publically available. The GeoPRISMS Education Advisory Committee provides guidance on education and outreach activities. GeoPRISMS scientists are also involved in the management of the Amphibious Array through its affiliated steering committee.

The GSOC consists of a group of 12 to 14 scientists with diverse backgrounds and interests. Strict rules regarding rotation and affiliation cause the committee to be self-rejuvenating and diverse. GSOC responsibilities include facilitating discussions between NSF and the broader community, reviewing progress of the Program towards its stated science goals, guiding the development of new products relevant to the community, and fostering the growth of the interdisciplinary and international community.

The Office activities include: organization of workshops and meetings; maintenance of a website, listserv and presence on social media; publication of a bi-annual newsletter; facilitating meetings of and communication within the GeoPRISMS committees; hosting of the Distinguished Lecturer Program; and AGU activities that include mini-workshops, the Best Student Presentation competition, and the Townhall and Student Forum. Data management is provided, in coordination with the Office and GSOC, by the Interdisciplinary Earth Data Alliance facility at Lamont.

Funding and Major Accomplishments

In the first five years of GeoPRISMS funding (FY11-15) a total of 37 projects with 91 PIs have received awards. Funding levels to the Program have been reduced significantly to about $3.5M/yr, down from $6M/yr at the end of MARGINS, in part due to the Federal sequestration orders of 2013. To manage resources NSF, in consultation with the GSOC, implemented a phased funding plan, where each of the five primary sites would be open for submission of large field projects for a two-year period in a staggered fashion, starting with Cascadia (FY11-12) and ending with New Zealand (FY15-16) with a plan yet to be developed for the years thereafter.

Research activities funded through GeoPRISMS started only four years ago. Furthermore, the phased funding approach limits the application of large field projects to a few primary sites at a given time, with major data collection efforts still underway or only recently completed at Cascadia and Eastern North America, in the initial stages for Alaska-Aleutians, and not yet started in East Africa or New Zealand. NSF stipulated that primary sites (excepting Cascadia) could only compete for large projects after the planning workshop for this site had been held and the implementation plan was formulated. The direct impact of GeoPRISMS funding can therefore be measured only in a limited fashion by the number of data products or counts of research articles. The number of publications that come out of GeoPRISMS-funded projects is accelerating and tracks that at the same stage of MARGINS. MARGINS-funded projects relevant to GeoPRISMS continue to produce additional research publications. About 50-60 publications appear each year from research directly funded by GeoPRISMS and MARGINS.

To document progress thus far on GeoPRISMS-funded projects (and MARGINS-funded projects since last review) we have request the PIs of these projects to contribute short scientific reports. We had a very high response rate with almost 80% of projects reporting. These research 'nuggets', along with the primary literature, form the basis of the narrative of the major accomplishments of GeoPRISMS-funded activities thus far and that of recent MARGINS-sponsored work since last review.

SCD: goals and major accomplishments

The overarching goal of the SCD initiative is to study: 1) the strain buildup and release along the plate interface; 2) the transport and release of volatiles; 3) linkages among surficial processes, fault behavior and magmatism; and 4) the long-term growth and evolution of arc systems and the continental crust.

New heat flow measurements on the ocean floor offshore Cascadia have provided better insights into the thermal structure of the fore-arc with important implications for our understanding of the properties of the shallow seismogenic zone and have an additional application to climate change via studies of gas hydrates. Seafloor geodetic observations using novel data collection techniques provide constraints on strain buildup along the Cascadia plate boundary. Studies of existing seismic reflection data and new geodynamical modeling provide novel insights into the ability of outer-rise faulting to transport fluids into the Earth's mantle and their local stress conditions.

Studies of episodic tremor and slip in Cascadia demonstrate a higher seismic efficiency of slow earthquakes than previously thought. Combined seismological and mineral physics work in Alaska shows the importance of high pore-fluid pressures along the plate boundary. Reoccupation of GPS sites along the Shumagin gap is underway to provide a better assessment of the seismic risk and tsunami hazards. Deformation experiments on samples retrieved from deep drilling provide better constraints on the rheology governing seismic slip and, when combined with seismological observations, show that the very low frequency events at the base of the seismogenic zones occur under low stress and high pore pressure conditions.

Geodynamical modeling provides important constraints on the dynamics and thermal structure of the world's subduction zones, with a further quantification of the local conditions under which intermediate-depth seismicity and metamorphic dehydration reactions occur. Deformation experiments on serpentinite provide mineral physics constraints on the local conditions under which intermediate-depth earthquakes can occur.

Geophysical imaging combined with geochemical sampling at the active Unimak-Cleveland corridor in the Aleutians will provide better insights into the transport of fluids and magma from mantle through shallow crust to volcano. Geophysical imaging equipment, combining seismology and magnetotellurics, has been installed at Okmok volcano to study the magmatic plumbing and storage system beneath an active caldera. Work on the Katmai volcanic cluster demonstrates the importance of hydrothermal waters and connections between deep seismicity and surface venting.

The evolution of arc crust is being investigated in the Aleutians using both plutonic rocks (which are more easily accessible here than in other active arcs) and volcanic rocks of the central and western Aleutians that represent 40 Myr of arc history. Recent work demonstrating strongly oxidizing conditions for slab-derived fluids in the Aleutians is now expanded to determine along-strike variations and to investigate the role of H_2O in magmatic differentiation processes that form continental crust. Tomographic imaging of the Cascadian mantle wedge strongly suggests a complicated 3D flow pattern with three regions of hot upwelling beneath the back arc that are spatially correlated with the three main volcano clusters along the arc. A large interdisciplinary project to image the architecture of the Mount Saint Helens magmatic system has just finished most of its data collection effort. The project combines active & passive seismic imaging, a magnetotelluric investigation, and geochemical sampling and will provide important constraints on the pathways of magmas below the most active volcano in the Cascades.

New geochemical sampling of the Oregon High Cascades suggests a significant increase in magma formation processes associated with arc migration and rifting between 7.5 Ma-4.0 Ma.

New thematic work includes: studies of arc initiation which will accelerate as New Zealand comes into focus; studies of exhumed terranes to study slab processes at depth; investigation of exhumed arc rocks to investigate the evolution of arc crustal composition over time; and the quantification of the carbon cycle on continental margins.

RIE: goals and major accomplishments

The RIE initiative focuses on continental rifts and passive margins that encompass the majority of the world's population and hydrocarbon resources and that are vulnerable to long-term climate change and sea-level rise. This initiative seeks to develop predictive models of continental rifts by focusing on: 1) timing and causes of rifting; 2) temporal and spatial evolution; 3) controls on rifted architecture during and after breakup; and 4) the mechanisms and consequences of fluid exchange between the solid earth, hydrosphere and atmosphere.

The two primary sites represent complementary end-member stages of the rifting process with the active East Africa Rift System and the fully developed Eastern North American Margin. Thematic questions guide further research on rift obliquity, rifting as a function of strain, role of volatiles, and sediment production and routing.

The recently completed ENAM community seismic experiment provides an integrated, collaborative and amphibious approach for studying the structure of the Eastern North American margin. The open access data collection effort involved active and passive seismology on land and offshore with significant opportunities for training of graduate students and postdocs. The interdisciplinary MAGIC project studies the inland structure of the margin and links between dynamic uplift, orogenesis, volcanism and rifting. Studies of surprisingly young magmatism in Virginia suggest an origin related to continental delamination rather than to a mantle plume. There is strong synergy at this primary site between GeoPRISMS and EarthScope projects, particularly through flexible array studies and magnetotelluric deployments.

The East African Rift System allows for the investigation of all of the main RIE science questions given the large variety of rift processes and changes in maturity along the main rift. An analysis of a rare sequence of earthquakes in northern Malawi exposed previously unknown faults and led to the establishment of Malawi's first national seismic network. New GPS measurements will help determine the extent of active spreading in the Turkana depression and new analysis of existing data will lead to a community velocity model for Africa. A geodynamical study using laboratory and numerical models is underway to quantify the processes that supply magmatism in the three main branches. Significant related research efforts are underway by GeoPRISMS community members with funding from EAR Core and Continental Dynamics. These projects include new constraints on the driving forces for present-day rifting, the role of pre-existing structures on magmatism in the central Ethiopian rift, effects of magma and fluids on rift initiation, and the possible role of mantle

plumes in guiding the rift initiation and evolution.

A separate thematic study provides important constraints on how past relative sea level variations are recorded in river deltas, which in turn allows for a better determination of the stratigraphic extraction of records of climate change.

Community Building

As part of its mission to enhance interdisciplinary science, GeoPRISMS has made a concerted effort to broaden the scientific base of its research community, enabling deeper integration across the initiatives and themes. To date GeoPRISMS planning workshops have drawn 1050 participants (680 unique individuals). About 65% of these had not attended any MARGINS meetings. The Distinguished Lectureship Program has brought GeoPRISMS speakers to a combined attendance of more than 7000 people. The AGU mini-workshops have been attended by more than 700 individuals.

The funded projects also indicate the strong interdisciplinary and collaborative nature of late MARGINS and early GeoPRISMS research. A significant portion (27%) of GeoPRISMS-funded projects is interdisciplinary (defined as having PIs with significantly different observational approaches, or where observational work is combined with theoretical and/or experimental work). Almost 50% of these projects are collaborative (defined by having PIs from multiple institutions).

The GeoPRISMS community has strongly supported the goal to enfranchise early career investigators (students, postdocs, assistant researchers, and pre-tenure faculty). We have actively engaged the early career community as the source of fresh ideas and the practitioners of next generation science, both in the planning process and in research projects. Graduate students have made up ~20% of the attendees of GeoPRISMS workshops. The AGU activities center on graduate students with the GeoPRISMS Best Student Presentation prize competition and Townhall and Student Forum. GeoPRISMS projects provide significant training opportunities through field participation on land and cruises at sea. We think that this strong and focused approach over the long term leads to a more balanced group of investigators, where GeoPRISMS science is done by junior and senior investigators alike and new talent is entrained through exciting research opportunities at early stages in their careers.

This focused approach to actively engage early-career scientists was started in MARGINS and we believe this is in large part responsible for the improved demographics of PIs who are funded. A GeoPRISMS PI is 50% more likely to be early career, twice as likely to be female, and tends to be involved in projects that are more collaborative and interdisciplinary, compared to the average MARGINS PI.

Other Impacts

The GeoPRISMS program has been effective in building an interdisciplinary and growing community. While the focus on three US primary sites has reduced the direct engagement of international collaborators in the short term, new projects and Office activities engage researchers

across the globe. The refocusing of geographic areas has strongly increased the collaboration between GeoPRISMS and EarthScope. GeoPRISMS projects continue to build on the broad infrastructure for the terrestrial and marine earth sciences supported by NSF. A number of projects directly address geohazards, ranging from large earthquakes and tsunamis to volcanic eruptions and landslides. Several projects contribute significant new data for understanding the distribution of energy resources, and the causes and consequences of climate change. While the education and outreach activities of the Office are focused on undergraduate and graduate students, engagement with local communities and improvement of their infrastructure has been facilitated by GeoPRISMS PIs as part of the broader impacts of their projects.

Outlook and Concluding Remarks

The mid-life review of GeoPRISMS also allows for an internal evaluation of the Program and its impact. Several topics require careful consideration as we enter the second half of the decade. There are concerns whether the science goals can be accomplished after the significant cut (40%) to the sequestered OCE&EAR budget for GeoPRISMS. Both the phased funding model and the community experiment approach should be evaluated at this midpoint of the Program. The Sea Change report recommending significant reductions to OCE infrastructure may cut both ways in GeoPRISMS by reducing ability to use OCE-sponsored infrastructure, but also by creating more opportunities for PI-driven science. The GeoPRISMS community is strongly involved in discussions on the future of NSF-supported facilities and the conceptual planning of the Subduction Zone Observatory.

We are happy to report that the GeoPRISMS community is alive and well. Many PIs engage in GeoPRISMS-funded projects; many more scientists and students engage in closely related research participate in GeoPRISMS community activities; and the general public is exposed to new findings about the evolution and structure of continental margins. While GeoPRISMS-funded science projects in many cases are just getting underway or are just nearing completion, initial reports from funded projects demonstrate the high quality of exciting new interdisciplinary, collaborative and shoreline crossing work, which predicts a high impact of GeoPRISMS science activities even if the current reduced funding levels would continue.