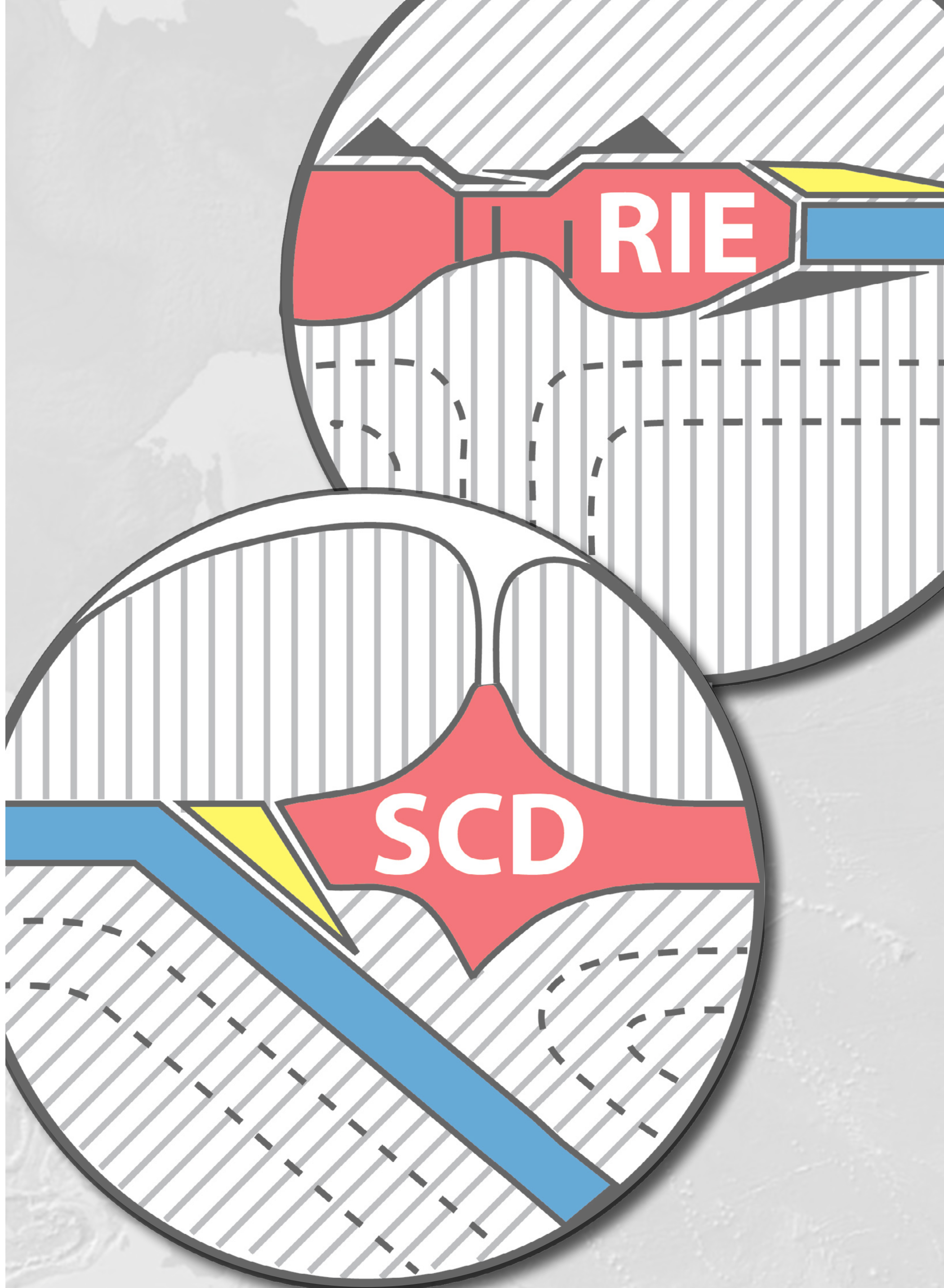
GeoPRISMS



Review 2015

i. Foreword

The materials contained in this review report document the current progress within the decadal GeoPRISMS science initiative. We describe the history of the program and its connections to MARGINS before it and document the progress towards the science objectives and goals for community building along with updates on national and international partnerships.

The documents before you were prepared with significant community input through the contribution of science 'nuggets' which provide a short description and illustration of ongoing and completed research efforts. An ad-hoc review writing committee was responsible for the writing of most chapters. It based the documentation of scientific progress on the nuggets, newsletter articles, and the primary literature. The ad-hoc committee met in person for two days in July in Eugene, OR. It worked on-site and remotely using the collaborative editing tools provided through Google docs.

The committee consisted of the following former or current steering committee members, in alphabetical order: John Jaeger (University of Florida), Maureen Long (Yale University), Julia Morgan (Rice University), Sarah Penniston-Dorland (University of Maryland), Peter van Keken (University of Michigan; GeoPRISMS Office) and Paul Wallace (University of Oregon). The citation database that is maintained by Andrew Goodwillie (Lamont-Doherty Earth University) was expanded with contributions from Liz Hajek (Pennsylvania State University), Tyrone Rooney (Michigan State University) and Gene Yogodzinski (University of South Carolina). Andrew Goodwillie also provided materials for maps and the description in 4.3 of the MARGINS and GeoPRISMS data management systems maintained by LDEO. We received contributions to individual chapters from Geoff Abers (Cornell, last MARGINS chair) and Tyrone Rooney. A draft of Chapter 1 was shared and discussed with cognizant program managers. The award information contained in this document was obtained from NSF (from the program managers and from the publically available award information). The appendices that provide background information and metrics were compiled by the GeoPRISMS Office. Anaïs Férot formatted the document.

We quoted liberally from the GeoPRISMS Science and Implementation Plans and science nuggets in this document. We mostly avoided strict quotations to improve the flow of the narrative; we find this appropriate since both this document and the science and implementation plans are documents written by committees with many authors. This review document is a continuation of the community-driven documentation of GeoPRISMS.

August 4, 2015

Peter van Keken, GeoPRISMS Office, University of Michigan

ii. Table of Contents

Appendices

iii. List of Acronyms

List of acronyms and (hyper)technical terms; with useful links

AA	Alaska-Aleutians (GeoPRISMS primary site)
or:	Amphibious Array
AASC	Amphibious Array Steering Committee
AGU	American Geophysical Union
ARRA	American Recovery and Reinvestment Act of 2009
BGR	Bundesanstalt für Geowissenschaften und Rohstoff (Hannover, Germany) (Federal Institut for Geosciences and Natural Resources)
CAS	Cascadia (GeoPRISMS primary site)
CAM	Central America (MARGINS focus site)
CCLI	Course, Curriculum and Laboratory Improvement (NSF)
CI	Cascadia Initiative
CIET	Cascadia Initiative Expedition Team
CMT	Central Moment Tensor
COPDESS	Coalition for Publishing Data in the Earth and Space Sciences
CSDMS	Community Surface Dynamics Modeling System
DLP	GeoPRISMS Distinguished Lecturer Program
DMC	The IRIS Data Management Center
DRC	Decadal Review Committee (specifically for MARGINS)
DSP	GeoPRISMS Draft Science Plan
DSDP	Deep Sea Drilling Project
DUE	Department of Undergraduate Education (NSF)
E&O	Education and Outreach
EAR	Division of Earth Sciences, part of the NSF GEO directorate
EARS	East African Rift System (GeoPRISMS primary site)
ENAM	Eastern North America (GeoPRISMS primary site)
ENAM CSE	ENAM Community Seismic Experiment
FY	US Fiscal Year (October 1 - September 30).
GAGE	Geodesy Advancing Geosciences and Earthscope Facility
GEO	NSF Directorate for Geosciences
GEOMAR	Helmholtz centre for Ocean Research (Kiel, Germany)
GeoPRISMS	Geodynamic Processes at Rifting and Subducting MarginS
GoC	Gulf of California (RCL focus site)
GSOC	GeoPRISMS Steering and Oversight Committee
IBM	Izu-Bonin-Marianas (GeoPRISMS focus site)
IEDA	Interdisciplinary Earth Data Alliance
IRIS	Incorporated Research Institutions for Seismology

iMUSH	Imaging Magma under St. Helens
IFM-Unimak	Island of Four Mountains - Unimak (GeoPRISMS project)
IODP	International Ocean Discovery Program (formerly Drilling Program)
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
K-12	Kindergarten through 12th grade (pre-university education)
LDEO	Lamont-Doherty Earth Observatory
MAGIC	Mid-Atlantic Geophysical Integrative Collaboration
MARGINS	Predecessor of GeoPRISMS (but not actually an acronym)
MGG	Marine Geology and Geophysics, program in the OCE division of NSF
MSPW	MARGINS Successor Planning Workshop (2010)
MSC	MARGINS Steering Committee
MT	Magnetotelluric (method)
NGDC	National Geophysical Data Center (NOAA)
NSF	National Science Foundation
NZ	New Zealand (GeoPRISMS primary site)
OBS	Ocean Bottom Seismometer
OBSIP	Ocean Bottom Seismometer Instrument Pool
OCE	Division of Ocean Sciences, part of the NSF GEO directorate
OOI	Ocean Observatories Initiative
PASSCAL	Portable Array Seismic Studies of the Continental Lithosphere (IRIS)
PBO	Plate Boundary Observatory (part of EarthScope)
PI	Principal Investigator (on a NSF proposal)
PNG	Papua New Guinea (S2S focus site)
RCL	Rupturing Continental Lithosphere (MARGINS initiative)
RIE	Rift Initiation and Evolution (GeoPRISMS Initiative)
ROV	Remotely Operated Vehicle
RSL	Relative Sea Level
S2S	Source-to-Sink (MARGINS Initiative)
SAGE	Seismological Facilities for the Advancement of Geosciences and Earthscope
SCD	Subduction Cycles and Deformation (GeoPRISMS Initiative)
SEIZE	Seismogenic Zone (MARGINS Initiative)
SESAME	EarthScope Flexible Array study: the Southeastern Suture of the Appalachian Margin Experiment
SIO	Scripps Institution of Oceanography
SubFac	Subduction Factory (MARGINS Initiative)
SUGAR	EarthScope Flexible Array study: SUwanee suture and GA Rift basin experiment
Texans	Here: Reftek-125 rapidly deployable one-channel seismometers.
UNOLS	University-National Oceanographic Laboratory System
USGS	United States Geological Survey
UNAVCO	University NAVSTAR Consortium
VLF	Very low frequency (earthquake)

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.

1. GeoPRISMS as a decadal program

1.1 Introduction - GeoPRISMS Objectives, Goals and Approach

GeoPRISMS (Geodynamic Processes at RIfting and Subducting MarginS) is the successor to the NSF MARGINS Program. GeoPRISMS was established in 2010 to guide a decade of community-driven and interdisciplinary research on the origin and evolution of, and active processes occurring at, continental margins. 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 research uses a wide range of broadly integrative approaches that include large marine and terrestrial field campaigns, along with experimental and modeling studies. GeoPRISMS also provides a strong scientific basis for the utilization of major NSF and related infrastructural investments and for leveraging US and international collaborations. Finally, the program continues to build and educate a broad research community intended to elevate continental margin studies to a new level.

Figure 1.1. The GeoPRISMS logo incorporates the main surficial expressions of the domains that we study: rifted margins and sedimentary basins, volcanic arcs, continental dynamics and accretionary prisms

1.2 GeoPRISMS History

The predecessor MARGINS Program initiated the community-based approach to shoreline-crossing science focused on understanding the origin and evolution of the continents through the investigation of their active margins. The MARGINS Program was divided into four major initiatives, each of which supported one or two Focus Sites. The Initiatives and their respective Focus Sites were:

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)

The four MARGINS Initiatives resulted in some profound scientific successes. The major highlights from each of the Initiatives and the program as a whole were summarized in preparation for the MARGINS Decadal Review in 2009. An external committee was appointed by NSF 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) chaired by Prof. Anthony Watts from Oxford University was asked to evaluate progress to date and to weigh the plans and promise for the future. It was also asked to provide comments and recommendations to NSF, as well as advice on the potential structure of a successor program. The DRC met in February 2009 to carry out this review. The full set of documents related to the review (including recommendation and responses by steering committee and NSF) are available from the MARGINS website.

The DRC review of the program was highly favorable. It recognized the success of several core approaches of the MARGINS Program, including the broad approach to community building, the importance of amphibious science to address MARGINS scientific questions, 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 observations. The DRC also recognized that such activities could not have succeeded without a science program with funds sequestered from core funding. The committee offered a strong recommendation that NSF support a successor program that would build upon the strengths of MARGINS. As summarized from the DRC report, the primary recommendations of the MARGINS Decadal Review Committee included:

1. NSF should set up a new themed program to follow on from the existing MARGINS program;
2. The new program should not be restricted to active margins, but should also address passive margins to understand how these margins are formed;
3. The new program should maintain the focus site concept, but be flexible to allow the old sites to be wound down and new ones brought in as the science dictates;
4. Two initiatives should be defined, with one encompassing the MARGINS SEIZE and SubFac Initiatives, and the second encompassing rifts and sediments;
5. 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;
6. Large-scale computer modeling, laboratory experimental studies, and studies of margin analogues in the rock record should continue as important elements of the new program;
7. The program should continue to work productively with other large-scale NSF facilities, such as EarthScope, OOI, IODP, and the R/V Marcus Langseth;
8. The new program should highlight links with societal issues such as climate, sea-level and environmental change, geo-hazards, energy and resources;
9. A new Steering and Oversight Committee should be set up to manage the new program and should include representatives of industry and state/national surveys;

10. The Distinguished Lectureship Program should be expanded to include highly visible and recorded lectures at public, academic, and international institutions;
11. The current 5-year review timescale of MARGINS should be retained in the new program.

The MSC response laid out the broad vision of a new decadal program that has now led to GeoPRISMS. The NSF accepted the DRC report in principle and charged the MARGINS Steering Committee to engage the broader geosciences community to plan the future directions of MARGINS research. An open community workshop was organized Feb 15-17, 2010 in San Antonio for this purpose and had an attendance of more than 200. 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" approaches and to consider the pros and cons of either;
- 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;
- Develop a draft Science Plan for consideration by NSF for authorization of a successor program.

The major product of the planning workshop is the Draft Science Plan (DSP), which incorporated substantial community input and feedback. The DSP was submitted to NSF in April 2010. It provides an outline of future science directions, justifications for a renewal program, and a summary of how such a program would be implemented.

Figure 1.2. The MARGINS Successor Workshop participants in front of the Alamo in San Antonio, TX.

Following the recommendations of the DRC, GeoPRISMS was structured to maintain the focus of its predecessor on subducting and rifting margins. The initiatives were designed to approach the margins as coupled systems with rethought and updated scientific questions. Research efforts were organized around several fundamental scientific questions that would have the highest potential of achieving transformative breakthroughs on a decadal time scale. The new program followed the MARGINS emphasis on interdisciplinary inquiry and shoreline-crossing science. The plans for GeoPRISMS built upon the progress and community building of MARGINS, but expanded the scope to focus on several new problems and processes. New researchers from a wider range of disciplines were to 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 would be exploited as much as possible to drive transformative breakthroughs. New discoveries of the last few years would feature prominently in science goals. The guiding goals for GeoPRISMS include:

- 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 that span the initiatives and address the coupled geodynamic, surficial, and climatic processes that build and modify continental margins over a wide range of timescales (from seconds to millions of years);
- 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.

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 Source to Sink 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 both mineral and petroleum resources. These tectonically defined initiatives were linked through five overarching science themes, demonstrating the commonality of the continental margin processes:

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

Following the DRC and MSPW recommendations, GeoPRISMS reached 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;
- Broadened educational and outreach programs to engage the new generation of scientists into exciting continental margins science.

1.3 Initiative Structure and Primary Sites

Subduction Cycles and Deformation (SCD) addresses coupled processes active at subducting margins and explores linkages among them. The regions of interest span from the updip limits of the accretionary wedge and incoming plate to the deep mantle and plate boundary interface. It focuses on the cycling of fluids and volatiles, their role in rheology, melting, and magmatism, and ultimately the arc processes that lead to the growth of continental crust. This initiative formalizes the strong linkages between SEIZE and SubFac recognized during MARGINS. It facilitates the interdisciplinary exchange of knowledge within the subduction zone community, enabling transformative discoveries of this highly coupled system.

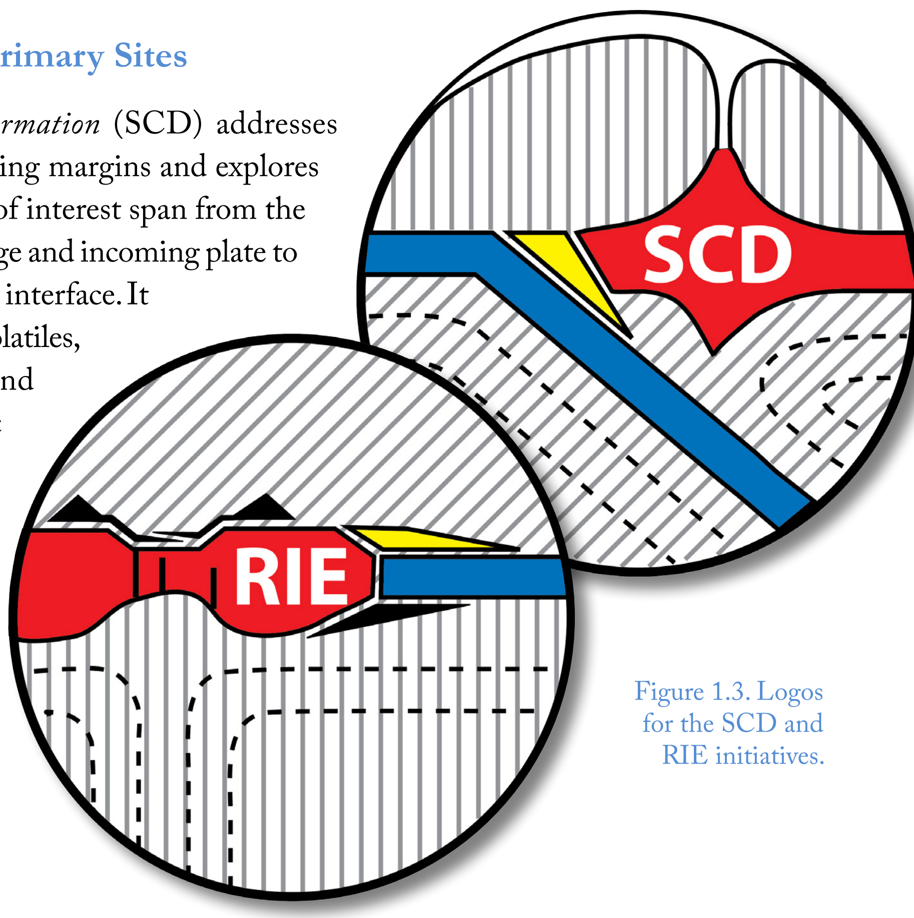


Figure 1.3. Logos for the SCD and RIE initiatives.

Rift Initiation and Evolution (RIE) focuses 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 emphasizes the interactions between climate, erosion, and sediment transport and deposition, and includes the dynamics of plate boundary deformation to gain a comprehensive understanding of lithospheric evolution along rifted margins

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 serves to enhance collaborations between marine and terrestrial geologists and geophysicists and helps to build stronger partnerships across NSF divisions. The new initiatives engage interdisciplinary teams carrying out observational, experimental, and modeling studies to address their fundamental questions. The proposed studies have both basic and applied value and provide unique opportunities to build an educated workforce, the next generation of GeoPRISMS scientists, and new knowledge on subjects of great importance to the broader public.

Refinement of the Initiatives was carried out through two community workshops, held in late 2010 (RIE) and early 2011 (SCD). Each was attended by more than 120 participants. At these workshops the community prioritized the scientific goals of the initiative, selected Primary Sites at which major research efforts would be concentrated, identified immediate and long-term research needs, opportunities, and strategies for these sites, and outlined thematic studies to complement and integrate GeoPRISMS primary site and MARGINS focus site investigations.

Three primary sites were selected for SCD. These are in order of priority: Alaska (including the southern mainland and extension into the Aleutian Islands), Cascadia, and New Zealand. We will refer to the first primary site as Alaska-Aleutians or AA in the remainder of this document. These three sites offer tremendous potential to address major questions about subduction earthquake and fault slip processes in societally critical settings. They allow investigators to carry out comparative studies of deep-seated interactions that drive volatile release and magmatic processes to build the continents. The three sites provided immediate and long-term opportunities to leverage recent and upcoming investments in infrastructure, through EarthScope and the Cascadia Initiative at the US sites, and through collaborations with international researchers, particularly in New Zealand but also by continuing work at MARGINS focus and ancillary sites.

Five process-based themes were identified within SCD that require broader research approaches than can be achieved at the primary sites. Such thematic studies are fundamental to constrain and contextualize observations made at the primary sites and will enable complementary global geochronological, petrological, structural, and geochemical studies, in addition to laboratory experiments and computational modeling efforts.

The five themes are:

- Theme 1: Identifying controls on fault slip behavior and deformation history
- Theme 2: Understanding mantle wedge dynamics
- Theme 3: Fore-arc to back-arc volatile fluxes
- Theme 4: Physical and chemical conditions and processes at depth
- Theme 5: Subduction initiation

Two primary sites were selected for RIE investigations: the active East African Rift System (EARS), which exhibits the entire history of continental rupture, and the fully developed Eastern North American Margin (ENAM), which preserves an extensive post-rift evolution. Both systems also exhibit variations in the degree of magmatic activity along strike and span a north-south climatic gradient with resulting diversity in sediment flux and tectonic-climate interactions. Research at the ENAM site can leverage considerable US infrastructure investments, including EarthScope and the Extended Continental Shelf surveys being carried out by the USGS. The selection of these two sites introduces a new approach for carrying out amphibious studies, where a mostly offshore system is paired with a mostly onshore system, to enable broadly integrated comparisons of the earliest and latest stages of rifting. This exciting approach should lead to strong interactions between marine and terrestrial researchers interested in rift initiation and evolution.

Five thematic studies were identified within RIE to address the influence of parameters poorly represented at the two primary sites. These investigations, intended to be complementary but subsidiary to primary site studies, enable diverse comparative field, experimental, and numerical investigations and build upon results of past MARGINS studies. The five themes are:

- Theme 1: Rift obliquity
- Theme 2: Rift processes as functions of strain rate
- Theme 3: Volatiles in rift zone processes
- Theme 4: Sediment production, routing and transport during and after rifting
- Theme 5: Discrete events at rifted margins

The GeoPRISMS Implementation Plan was fleshed out progressively, following community planning workshops for each Primary Site. These workshops took place between 2011 and 2013. The workshops were timed to reflect both the community prioritization and timeliness within the initiatives and to take advantage of joint organization with partner organizations such as EarthScope. The outcomes of these planning and implementation meetings included community identification of key research questions and potential targets within each primary site, research strategies and partnering opportunities in each location, and specific broader impacts. All GeoPRISMS documents were released for public comment and comments received were incorporated into the documents. Additional opportunities continue to be provided for community refinement of the implementation plans through GeoPRISMS Mini-Workshops held during annual AGU Meetings and through smaller discussions in association with other national meetings (such as those of EarthScope). These inexpensive gatherings offer opportunities to disseminate preliminary results (e.g., Cascadia), and to define specific research approaches (e.g., Aleutians platform), develop new collaborative projects, strengthen integrative research (e.g., CSDMS Geodynamics Focused Research Group), and reach out to the broader scientific community, including early career investigators. The resulting Implementation Plans, finalized in December 2013, also lay out potential experimental and modeling approaches to further the goals of the initiative, and outline tentative synthesis and integration plans for each initiative.

As a consequence we can report that the GeoPRISMS Science and Implementation Plans were developed through significant community input obtained during the planning workshops, along with several mini-workshops or breakout sessions hosted during other national meetings (e.g., AGU, IRIS, EarthScope, etc.). The three North American Primary Site workshops were co-sponsored by EarthScope, providing a valuable bridge between two focused NSF programs, where their science priorities overlap. In this way, GeoPRISMS is able to leverage the onshore infrastructure provided by EarthScope, as recommended by the DRC.

2010	MARGINS Successor Planning Workshop - San Antonio, TX
	RIE Implementation Workshop - Santa Fe, NM
2011	SCD Implementation Workshop - Bastrop, TX
	Alaska-Aleutians Planning Workshop - Portland, OR (joint w/ EarthScope)
	Eastern North American Margin Planning Workshop - Bethlehem, PA (joint w/EarthScope)
2012	Cascadia Planning Workshop - Portland OR (joint w/ EarthScope)
	East Africa Rift System Planning Workshop - Morristown NJ
2013	New Zealand Planning Workshop - Wellington, New Zealand

Table 1.1. Dates and locations of the eight main workshops that helped define the GeoPRISMS Science and Implementation plans

1.4 Summary of funding and accomplishments since last review

The MARGINS Program was officially concluded on September 30, 2010, at which time the community definition of the successor GeoPRISMS Program was well underway. As a consequence, we have counted projects funded in FY11 and later to be part of GeoPRISMS even though an annotated NSF-MARGINS solicitation was used through FY12 (see for example the NSF announcement in the Spring 2011 newsletter). The first formal GeoPRISMS Program solicitation was for projects in FY13 (NSF 12-537). This call for proposals has since been replaced by NSF14-556 and the current NSF15-564.

Due to the necessary ramp-up time, the timeframe for GeoPRISMS-funded research funded starting in FY11 is relatively short. A significant number of projects addressing high priority science have begun, but we cannot expect the research products to be as well developed as they were for MARGINS-funded project at the time of the Decadal Review. We summarize significant scientific advances and details of ongoing field projects in the next two chapters. Given the transition from MARGINS to GeoPRISMS, and their overlap in scope, we also include the scientific advances of MARGINS projects reported from 2009 onwards in some of our analysis and description. We make a clear distinction between GeoPRISMS- and MARGINS-funded research throughout.

The fiscal crisis of the late 2000s and the current sequestration of NSF have had significant impact on the amount of science funding that is made available to GeoPRISMS. For reference, funding levels in MARGINS before the 2009 review were around \$5M-\$6M per year. The America Recovery and Reinvestment of 2009 (ARRA) provided a pulse of funding to MARGINS. Perhaps the biggest impact of ARRA on the Program was the \$10M (split equally between EAR and OCE) invested in developing the Cascadia Initiative Amphibious Array, which directly supports GeoPRISMS research and will continue to do so for years to come. Additional ARRA funding was provided to specific MARGINS projects in FY09, as indicated in the list of funded projects in Appendix A1. Funding for FY10 was initially expected to stay stable at approximately \$6M/yr, but this was revised downward to \$5M/yr in 2012. We saw significant budget reductions following the federal sequestration orders starting in FY13. The current budget for projects within GeoPRISMS is about \$3.5M/yr, representing a reduction of nearly 40% from that at the beginning of the decade.

We note that the \$3.5M/yr stated above should be seen as a nominal minimum for actual funding to projects. The GeoPRISMS projects directly benefit from ship time that is awarded separately from GeoPRISMS grants. Similarly, projects benefit from significant investments in IRIS, UNAVCO, PASSCAL, etc. We also wish to highlight the important logistical support that is sponsored by NSF following community requests for Aleutian research (Jicha et al., 2014). This support, formalized in Spring 2014, has provided a ship with helicopter support for two field seasons (the first of which is underway as we write this document). We also note that a number of projects in the North American primary sites have been funded jointly by EarthScope and GeoPRISMS. EarthScope also independently supports projects of relevance to GeoPRISMS objectives.

Even at the initial estimated budget level of \$6M/yr, it was evident to NSF and the community that it would be difficult to accommodate large field experiments (such as active or passive seismology on land, seismic reflection and refraction studies at sea, or data collection requiring helicopter support) at all five primary sites at the same time. As a result NSF and the GeoPRISMS Steering and Oversight Committee (GSOC) established a phased funding approach for large experiments for the five primary sites. The 'large' here is loosely defined as having a budget of \$1M or more. Cascadia was opened for proposals in FY12, Cascadia and Eastern North America competed in FY13, etc. The phased funding model was formalized in Spring 2013 (NSF 12-537) and it followed logically and fairly from the ramping up stages for Cascadia and Alaska-Aleutians in the two funding cycles before this. The table below shows the current implementation of the phased funding. The choice to use windows of opportunity of two (rather than three) years per primary site was dictated by the decadal time scale and by the community's choice to have five primary sites. The full impact of the phased funding model will need to be evaluated. There is currently no firm plan for the remaining years in this decadal program. We expect that NSF and the community, with facilitation of the GSOC, will initiate the discussion on these matters in the near future.

Fiscal Year	FY12	FY13	FY14	FY15	FY16	FY17
Proposal deadline	July 11	Jul 12	Jul 13	Aug 14	Jul 15	
	CAS	CAS				
		ENAM	ENAM			
			AA	AA		
				EARS	EARS	
					NZ	NZ

Table 1.2. Phased funding plan for the five primary sites

During FY11-FY15 37 projects (with 91 PIs) were awarded. We provide a more detailed analysis of the awarded grants and the comparison between GeoPRISMS- and MARGINS-funded projects in Chapter 4.

With the initial phase of GeoPRISMS projects starting only about four years ago we cannot expect that the program's effectiveness can be fully measured by the number of publications or data products. Publications are beginning to appear for the Cascadia and Eastern North America primary site, but research that depends on large field projects at the other primary sites has been limited by the phased funding model. This applies in certain ways still also to Cascadia and Eastern North America, where significant data collection and analysis are still underway (such as in the iMUSH project and the ENAM community science experiment). Most Alaska-Aleutians projects have only been initiated recently. The window of submitting proposals for large projects in East Africa and New Zealand has only just opened. To represent the scope of GeoPRISMS science to date we asked the community to contribute 'science nuggets,' which provide short descriptions of funded projects that may have been completed or are still ongoing. We directly contacted all PIs of projects that were funded during GeoPRISMS (FY11-15) and during the last two years of MARGINS (FY09-10). We received 62 nuggets (35 from GeoPRISMS-funded work; 21 from late-MARGINS-funded work, along with 6 from closely related NSF-funded projects). Out of the 63 projects funded in FY09-15, nuggets were received from at least one PI for 49 projects (78%). This high response rate indicates to us the strong buy-in that PIs have in the GeoPRISMS program and its community effort. The nuggets are provided in Appendix B.

Although we noted that GeoPRISMS research productivity is as yet difficult to measure directly by numbers of scientific articles, it is instructive to list the numbers and to compare the first few years of GeoPRISMS-funded research activity with that of MARGINS. In Figure 1.4 we show the number of papers that were directly funded by MARGINS and by GeoPRISMS. We only include papers that were cited by the authors in the public final or annual reports published on nsf.gov (which are certainly not complete), were provided by the PIs in the nuggets, or had GeoPRISMS funding explicitly acknowledged in the paper (e.g., by providing the NSF award number). The GeoPRISMS-funded publications are listed in Appendix A3. The MARGINS-funded publications since last review (2009) are listed in Appendix A4. We also counted papers that we deem to be GeoPRISMS-related. These are papers written by PIs who have been funded by MARGINS or GeoPRISMS on topics that are closely related to the science objectives but do not explicitly mention MARGINS or GeoPRISMS funding. We found 349 citations starting in 2011; this is likely a rather large underestimate, but still clearly indicates that the GeoPRISMS science community is very active and productive.

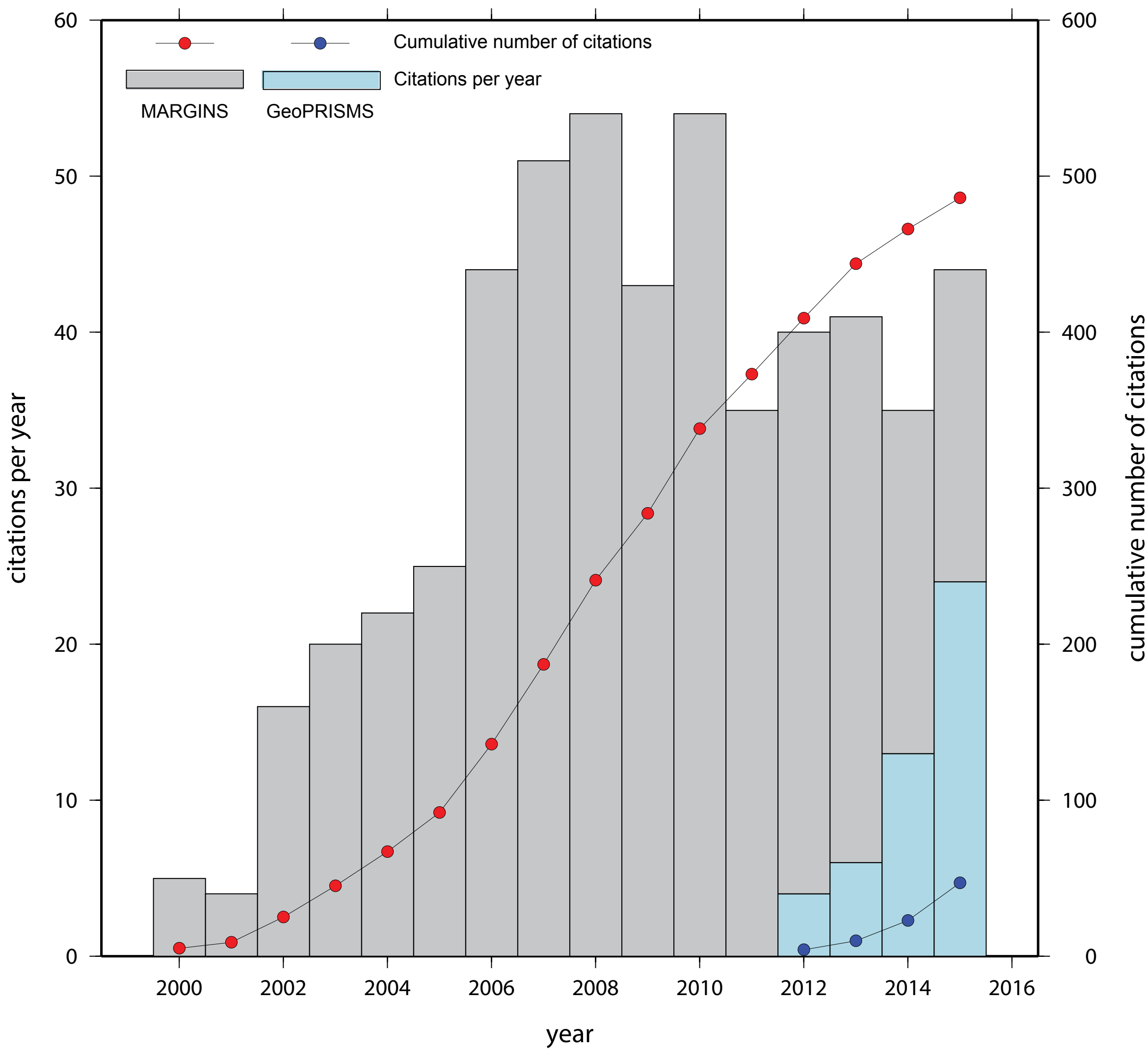


Figure 1.4. Graph of MARGINS/GeoPRISMS funded research papers since 2000. For 2015 we extrapolated the numbers to date to the end of the year. For 2011-2015 we have an average of 70 citations per year for work that is related to GeoPRISMS science objectives, but not explicitly funded by it.

1.5 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. One demonstration of this is the cumulative workshop attendance during the formative years of the program. To date GeoPRISMS planning workshops have drawn 1050 participants (680 unique individuals). About 65% of these had not attended a MARGINS meeting. The Distinguished Lecturer 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. We will provide further details and a comparison with MARGINS in Chapter 4.

Figure 1.5. Fifteen countries were represented at the Planning Workshop for the East African Rift System Primary Site held in Morristown, New Jersey in October 2012. Image made with Google Maps.

The list of funded projects (Appendix A1) also indicates the strong interdisciplinary and collaborative nature of late MARGINS and early GeoPRISMS research. A significant portion (27%) of GeoPRISMS-funded projects are 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 entrain early career investigators (students, postdocs, assistant researchers, and pre-tenure faculty) into the program in a meaningful way. 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 submitting research proposals. We have implemented this by including student and postdoc symposia at planning meetings, engaging early-career investigators as scribes and discussion leaders during break-out sessions, providing preferred travel support to graduate students and postdocs, and including early-career scientists as keynote and invited speakers at workshops. Graduate students have made up 15-20% of the attendees of GeoPRISMS workshops (further discussed in Chapter 4). We think that this approach over the long-term leads to a more balanced group of investigators, where GeoPRISMS science is done by junior and senior investigators alike. A further indication of the buy-in of new investigators into the GeoPRISMS community is that 23% of the PIs in GeoPRISMS-funded projects are early-career (Appendix A1).

Figure 1.6. Participants of the Planning Workshop for the East African Rift System. Photo credit: Anaïs Férot, GeoPRISMS.

The community basis of scientific decision making within the program has allowed GeoPRISMS to lead the way in defining and carrying out community experiments and community expeditions. The Cascadia Initiative, an onshore-offshore geophysical and geodetic project funded by NSF and designed to address MARGINS/GeoPRISMS and EarthScope scientific goals, represents an early implementation of this approach. Grassroots efforts to acquire seismic reflection and refraction data

Figure 1.7. GeoPRISMS funding supports the multi-disciplinary iMUSH (imaging Magma Under St Helens) project which is the first of its kind in the US to image a volcano from top to bottom (photo credit: Anaïs Férot).

across the Eastern North American Margin (ENAM) led to the successful ENAM community seismic experiment in 2014-2015. Both experiments are characterized by substantial community input into the planning process, broad participation in data gathering, and open data access. This allows any and all to work with the resulting data and to seek grants to support those activities. A related approach to enable broader community access to GeoPRISMS research opportunities is through community resources such as the shared logistical support for remote field studies in the Aleutians that NSF is sponsoring this year and next. In all such cases this kind of approach enable larger groups of people to benefit quickly from the data or research platforms. The shared use by a broader community will maximize their scientific impact. This approach also facilitates the involvement and training of junior scientists and students. Future opportunities of this kind will be pursued where feasible.

1.6 Justification for a stand-alone program

Strong arguments have been made previously to maintain GeoPRISMS as a focused program and with funding that is sequestered from NSF core programs. We reiterate these here to establish their role in the recent program accomplishments. In particular, the extraordinary cross-disciplinary nature of MARGINS and GeoPRISMS science must attract geoscientists who can work in teams that span the traditional NSF divisions. Continental margin processes and GeoPRISMS science objectives span the shoreline, which requires bridging the traditional and substantial divisional boundary between EAR and OCE. GeoPRISMS is one of the few programs that crosses internal GEO boundaries by leveraging strong interdisciplinary research teams and pooled NSF funding.

Fulfilling the GeoPRISMS vision requires:

- The combination and integration of on-land and marine investigations and resources to fully capture processes and products that cross the shoreline.
- Strong interdisciplinary research teams that are able to bring diverse perspectives and expertise to bear on understanding the complex interplay of continental margins processes.
- Guidance from a cogent Science Plan, detailing major projects and approaches to address clear scientific objectives vetted by the community.
- An interdisciplinary NSF panel able to evaluate the breadth and scope of GeoPRISMS science 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, through workshops, newsletters, and websites.
- Coordinated efforts to disseminate the significance and relevance of GeoPRISMS science and its impact on understanding geohazards and economic resources to the broader community, including students, the public, and policy makers. A focused and managed program overseen by the program office facilitates such efforts beyond the abilities of individual PIs.

GeoPRISMS engages and leverages a wide range of partnerships and provides access to major infrastructure facilities to the broader community. The program maintains well-established channels for data archiving and access, data and information dissemination, and general communication, which serve numerous individual research projects. The program and Office also define a clear focal point for broad education and outreach efforts. All of these efforts are most efficiently managed and coordinated within a focused program, by an active Office and steering committee.

While we consider it essential to use sequestered funds to allow for interdisciplinary, shoreline crossing research and NSF division bridging research, there is an explicit understanding that this funding should go towards funding of competitive proposals that address community-wide objectives at selected primary sites, along with a smaller number of thematic studies and postdoctoral fellowships. Prospective PIs have always been encouraged (through the newsletter, listserv announcements, and the GeoPRISMS Townhall) to throw a wide funding net and consider core funding or special programs within the GEO Directorate for GeoPRISMS-related science projects. The funding footprint for GeoPRISMS-related science is large and can easily be seen by browsing the CVs of PIs or the NSF awards pages. OCE Program Manager Donna Blackman provided a concrete example for the NSF presentation at the 2014 AGU Townhall. In FY11-FY14 15 projects were funded out of MGG core that directly addressed science objectives at GeoPRISMS primary sites. A further 15 MGG funded projects addressed MARGINS and GeoPRISMS science objectives outside of these primary sites. A similar comparison by EAR Program Manager Jennifer Wade provided a total of 61 EAR-funded projects in FY11-15 that address GeoPRISMS science objectives, including 16 at CAS, 9 at AA, 8 at NZ, 7 at EARS and 4 at ENAM. Some of the OCE and EAR core grants are extensions of work funded during MARGINS or provide support to infrastructure that GeoPRISMS researchers benefit from.

In the remainder of this document we provide a detailed description of GeoPRISMS activities and their impact. In Chapter 2 we describe research projects and activities that are underway in the SCD initiative. In Chapter 3 we do the same for the RIE initiatives. A more detailed breakdown of funding provided through GeoPRISMS and the GeoPRISMS Office activities is described in Chapter 4. The Education and Outreach activities are described in Chapter 5, followed by a discussion of impacts on other NSF sponsored and international science projects. We conclude with a brief summary and outlook. The appendices provide significant background information and metrics supporting the narrative of the document.

2. Subduction Cycles and Deformation (SCD) Initiative

This chapter describes the major accomplishments thus far of the Subduction Cycles and Deformation (SCD) initiative. The accomplishments are organized by main regions of the subduction system and by thematic approaches. Within these sections we highlight work done at the primary sites. Due to the phased funding approach, major research initiatives at the New Zealand primary site have not yet been considered for funding, so there is limited progress to report for that primary site.

2.1 Original Goals

The mission of the SCD initiative is to focus holistically on subduction margin evolution and material transfer over short to long time scales. In particular, the initiative encourages studies of 1) the properties, mechanisms, and manifestations of strain buildup and release along the subduction plate boundary, 2) the transport and release of volatiles through the megathrust zone, the fore-arc, and sub-arc and through the mantle, 3) linkages among surficial processes, fault-slip behavior, and magmatism, and 4) the many ways in which their interconnections affect the long-term growth and evolution of volcanic arcs, back-arcs, and continents. A main goal of SCD is to improve fundamental scientific understanding of some of the most destructive natural hazards on the planet.

The key questions addressed through GeoPRISMS SCD research include the following:

- 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 to the arc and back-arc?
- How are volatiles, fluids, and melts stored, transferred, and released through the subduction system?
- What are the geochemical products of subduction zones and how do these influence the formation of new continental crust?
- What are the physical and chemical conditions that control the initiation and development of subduction zones?
- What are the feedbacks between surface processes and subduction zone mechanics and dynamics?

The GeoPRISMS approach to these scientific questions has been highly collaborative and interdisciplinary. It builds on and expands the approach used for the SEIZE and SubFac initiatives of MARGINS. The SCD strategy drives the science in new directions in response to discoveries over the MARGINS time period and focuses on new locations: Alaska-Aleutians, Cascadia, and New Zealand. These questions span from the submarine realm of the incoming plate to the subaerial realm of the volcanic arc. Addressing them requires an amphibious portfolio of science; something that the sequestered funding of GeoPRISMS is ideally suited to support. In addition to primary site-focused research, five thematic research topics were identified as important for the SCD science plan: 1) Identifying controls on fault slip behavior and deformation history, 2) Understanding mantle wedge dynamics, 3) Fore-arc to back-arc volatile fluxes, 4) Conditions and reactions in subduction zones at depth and 5) Subduction initiation.

2.2 Major Accomplishments

We group the major accomplishments of the GeoPRISMS SCD initiative in the next five subsections. The first four are arranged by region of the subduction zone: incoming plate and shallow fore-arc, seismogenic zone (or megathrust), slab processes, and mantle wedge and arc crust. A fifth section deals with progress in thematic goals. At the end of each subsection we will list the relevant publications from research funded directly by GeoPRISMS. We also list relevant papers that have been published from MARGINS-funded research since last review (2009).

2.2.1 The incoming plate and shallow fore-arc

The nature of the incoming plate sets the stage for the dynamics and structure of subduction zones. The compositional differences between the initial rock type and volatile content of the oceanic crust and mantle are of fundamental importance to the processes that happen once a plate subducts and undergoes progressive metamorphism and volatile loss. These processes in turn have important consequences for our understanding of the nature of the seismogenic zone, the character of deep earthquakes, and arc volcanism and the formation of arc crust. The fore-arc also is a natural laboratory for geophysical observations that can determine the nature of the shallow updip limit to the seismogenic zone.

2.2.1.1 Cascadia

The temperature of the décollement is a critical parameter in identifying the potential slip area for the next large megathrust earthquake (estimated to be up to magnitude 9) in the Pacific Northwest. The objective of the GeoPRISMS project of PIs Johnson, Solomon and Harris is to determine the heat flow and fluid flux regime on the Washington State portion of the Cascadia subduction zone through a field program using the R/V Atlantis and ROV Jason II. The diverse data sets collected are being integrated and used in the development of numerical models of both fluid circulation and isotherm distribution within the sedimentary wedge (Johnson et al., 2013; Homola et al., 2015). An interesting broader impact of this study is that the data can be used to study the effects of climate change via studies of gas hydrates (Hautala et al., 2014).

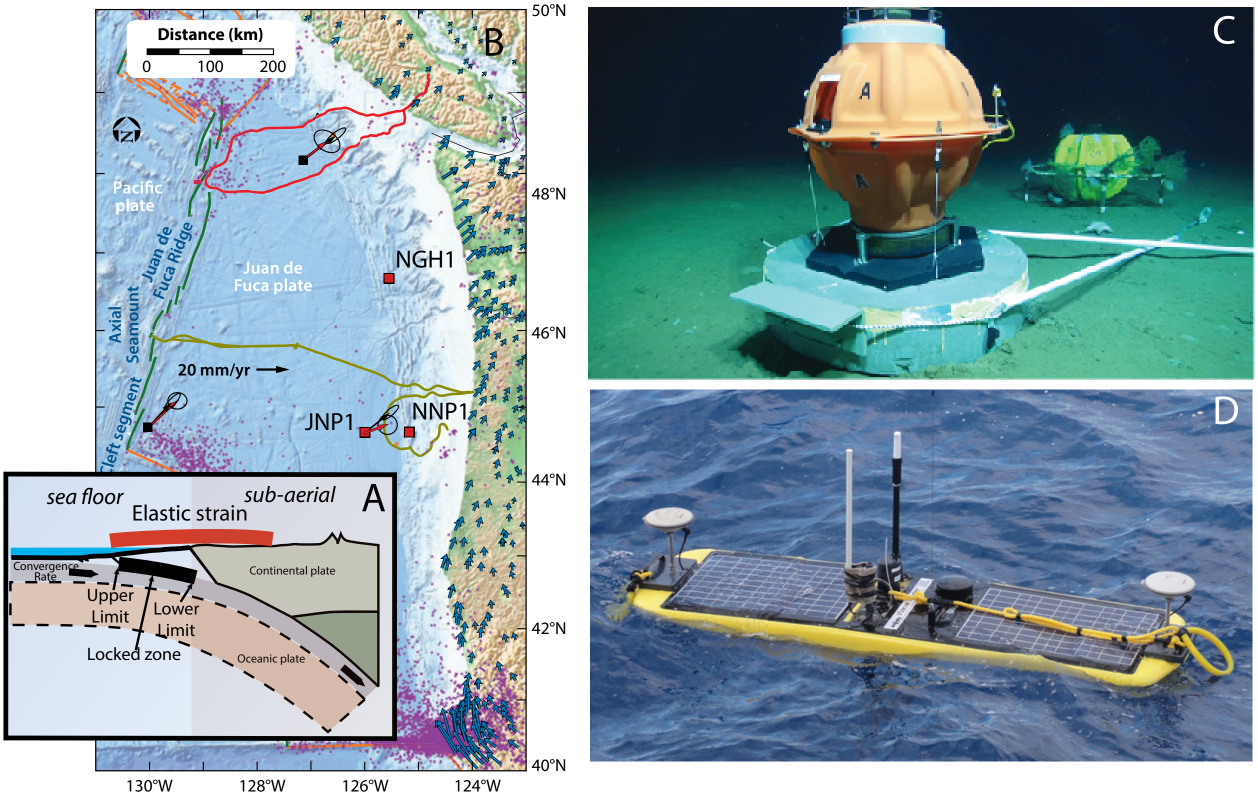


Figure 2.1. (A) Subduction cross-section showing incoming plate in contact along interface with upper plate which accumulates elastic strain as uplift and contraction. Much of the deformation occurs offshore, highlighting the significance of seafloor measurements in a space geodetic frame to bridge the subaerial and marine regions. (B) In 2014 two submarine geodetic sites, NNP1 and NGH1, were established - the first sites on the seaward slope of Cascadia subduction zone, and site JNP1 was reestablished and its position remeasured. Two earlier GPS-Acoustic sites (black squares) are also shown. Red and black arrows show the GPS-Acoustic and geomagnetically-derived plate motions relative to North America, respectively. (C) Foreground shows new seafloor benchmark with commercial transponder placed approximately 2 m from old (circa 2000) transponder at site offshore Oregon. (D) Wave Glider configured for GPS-Acoustic operations underway at sea.

Measuring strain partitioning across the megathrust requires geodetic observations of ongoing deformation, which have traditionally been made onshore for logistical purposes. However, strain buildup and release at the trench and deformation front is a key component of co-seismic tsunamigenesis. The GeoPRISMS project of PI Chadwell directly addresses this observational gap by making seafloor geodetic measurements of plate motion on the submerged oceanic portion of the Cascadia subduction zone to constrain the distribution of slip on the megathrust (Figure 2.1). Three sites have been deployed across the megathrust. An important contribution of this project to subduction zone observations is the implementation of a GPS-Acoustic Wave Glider, which can act as a replacement for high-cost ships in Cascadia and other subduction zones (e.g., offshore Alaska). The Wave Glider costs a few dollars a day to operate compared to several tens-of-thousands of dollars per day for a ship that has dynamic positioning, which is needed to hold station within 30 meters. The remeasurement of the JNP1 site (3000 m deep offshore Newport on the incoming Juan de Fuca plate) using the glider technology has allowed for a record that now spans from 2000 to 2014, making it the longest seafloor position time series anywhere. Preliminary results show that the convergence velocity is comparable to the geologically predicted rate. This supports the hypothesis that creep is occurring at the Cascadia subduction zone in central Oregon.

2.2.1.2 Hydration of the oceanic plate by outer rise normal faulting

Recent observations indicate that the mantle of the incoming oceanic plate in some subduction zones may be highly serpentinized, hypothesized to result from seawater circulation along inherited and reactivated normal faults generated at the spreading ridge (Ranero et al., 2003). Although documentation of this phenomenon remains scarce, it provides an important potential mechanism for transport of H_2O to subarc depths and possibly beyond (e.g., van Keken et al., 2011). The extent of serpentinization and its effects on the mechanics of the subduction system are poorly constrained.

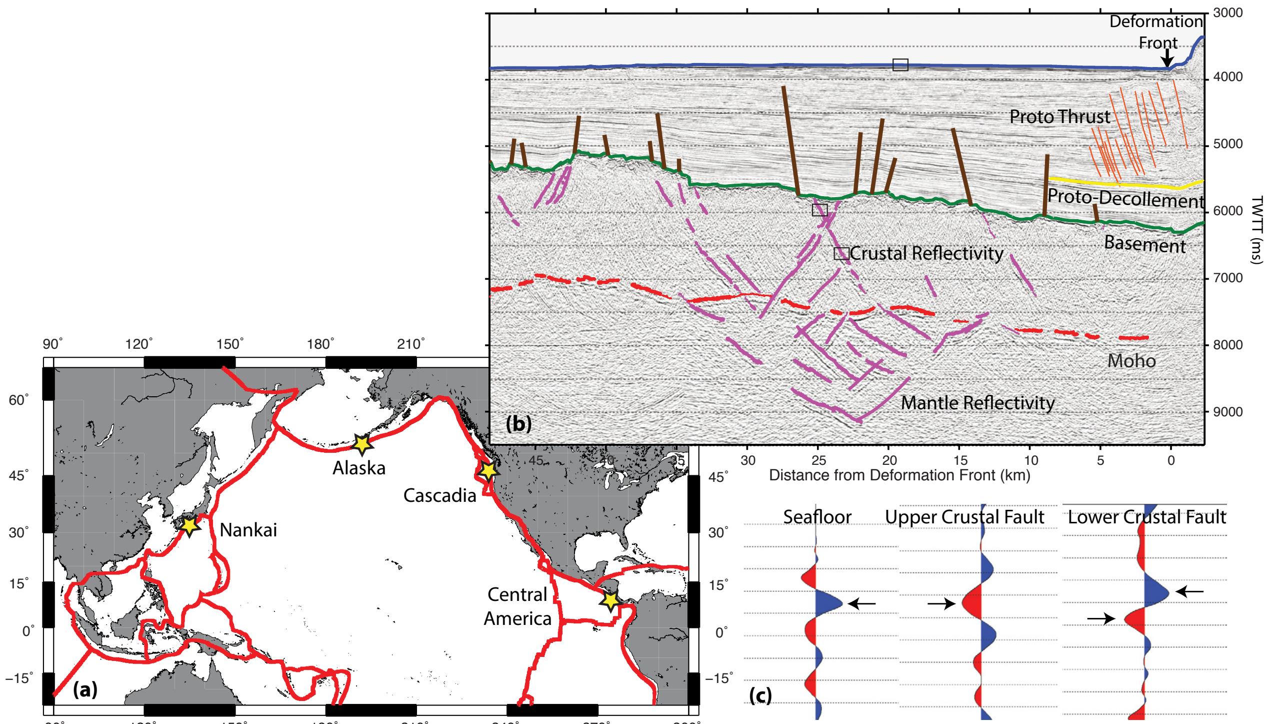


Figure 2.2. (a) Locations of the four subduction zones: Cascadia, Nankai, Central America, and Alaska (marked by yellow stars) examined in a project by Bangs and Han. (b) Prestack-time migrated MCS image of the incoming Juan de Fuca plate seaward of Cascadia subduction zone with interpretation. Seafloor, top of the oceanic crust, and Moho are shown as blue, green, and red lines; Normal faults, protothrust faults, and proto-décollement in the sediment section are shown as brown, orange, and yellow lines. Crustal and mantle reflections that are interpreted as fault plane reflections are shown in magenta lines (from Han et al., submitted.) (c) Waveform of the reflections of seafloor, upper crustal fault, and lower crustal fault in the black rectangles of (b).

The internal structure and hydraulic conductivity of the outer-rise faults and their variation over time and space have not been fully examined and quantified. In a recently funded GeoPRISMS project, PI Bangs and postdoc Han are using previously collected multichannel seismic (MCS) data to investigate the structure and fluid content in faults within representative segments of the subducting plate at four MARGINS and GeoPRISMS study sites (Figure 2.2). They will conduct amplitude preserved prestack-depth migration, 2D waveform modeling of fault plane reflections, and fluid flow modeling on 2D MCS data, and use the results to quantitatively assess the hydration state of the incoming plate at these sites.

Modelling by GeoPRISMS PI Billen and post-doc Naliboff has focused on discerning the relationship between outer-rise deformation, plate driving forces and lithospheric rheology at both short (<10,000 years) and long (>10 Myr) time scales using three-dimensional numerical modeling of the generation of outer rise faults. Analysis of time-averaged outer-rise faulting patterns indicates that downgoing plate age and velocity, downgoing-overriding plate coupling, and slab pull all significantly affect faulting patterns, while variations in brittle rheology have a significantly smaller impact (Figure 2.3; Naliboff et al., 2013).

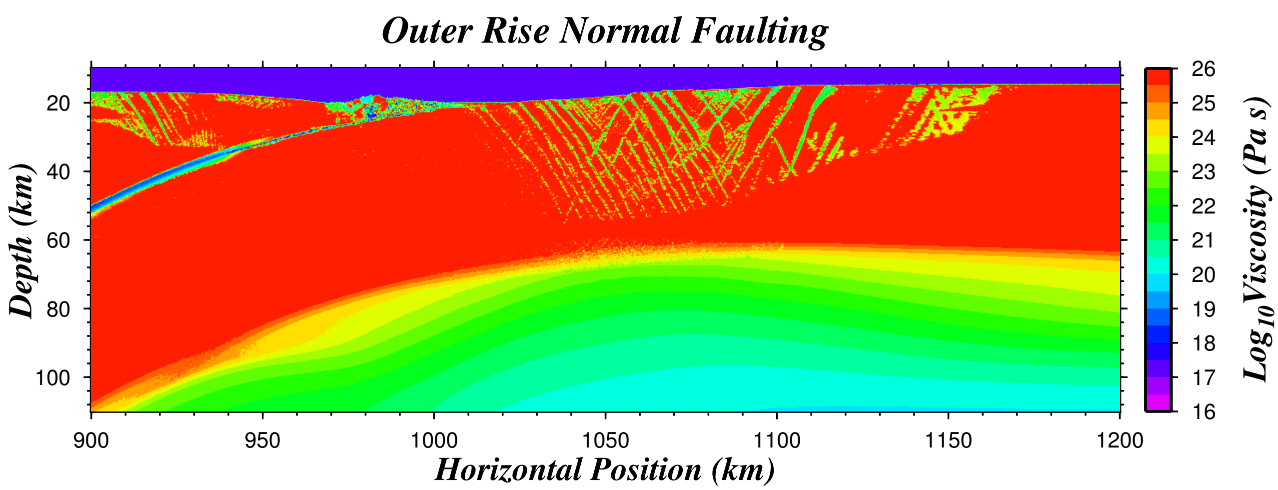


Figure 2.3. Modeling results showing viscosity structure of the overriding- (upper left) and downgoing-plate after ~ 400,000 years of deformation. Normal faults (brittle shear zones) develop seaward of the trench in the outer rise region in response to extensional bending stresses and slab pull forces.

2.2.2.3 Results from MARGINS and closely related research projects

Significant work related to the hydration state of the incoming plate has come through MT studies of Nicaragua (funded by MARGINS) and by seismic studies off Cascadia (funded by OCE-MGG).

OCE-MGG funded work by PI Carbotte employed a combined multi-channel seismic and wide-angle ocean bottom seismometer survey. The relative size of the Juan de Fuca plate allowed full seismic imaging of a plate from ridge to trench (Han, 2015). This study found that the crust becomes rapidly mature (within 1 Myr after formation) and has a structure where hydration is limited to the upper crust. No outer-rise hydration of the mantle is detected, but paleo-segment boundaries may cause enhanced hydration and locally affect subduction zone processes.

The MARGINS-funded SERPENT project used seafloor electromagnetic instruments to produce a profile of electrical resistivity along an 800 km transect spanning the outer rise and accretionary prism offshore of Nicaragua (Figure 2.4). This work provided an important corroboration of the earlier seismic work that showed extensive outer-rise faulting and mantle hydration (Ranero et al., 2003; Ivandic et al., 2008), as well as direct evidence for fluid release into the accretionary prism.

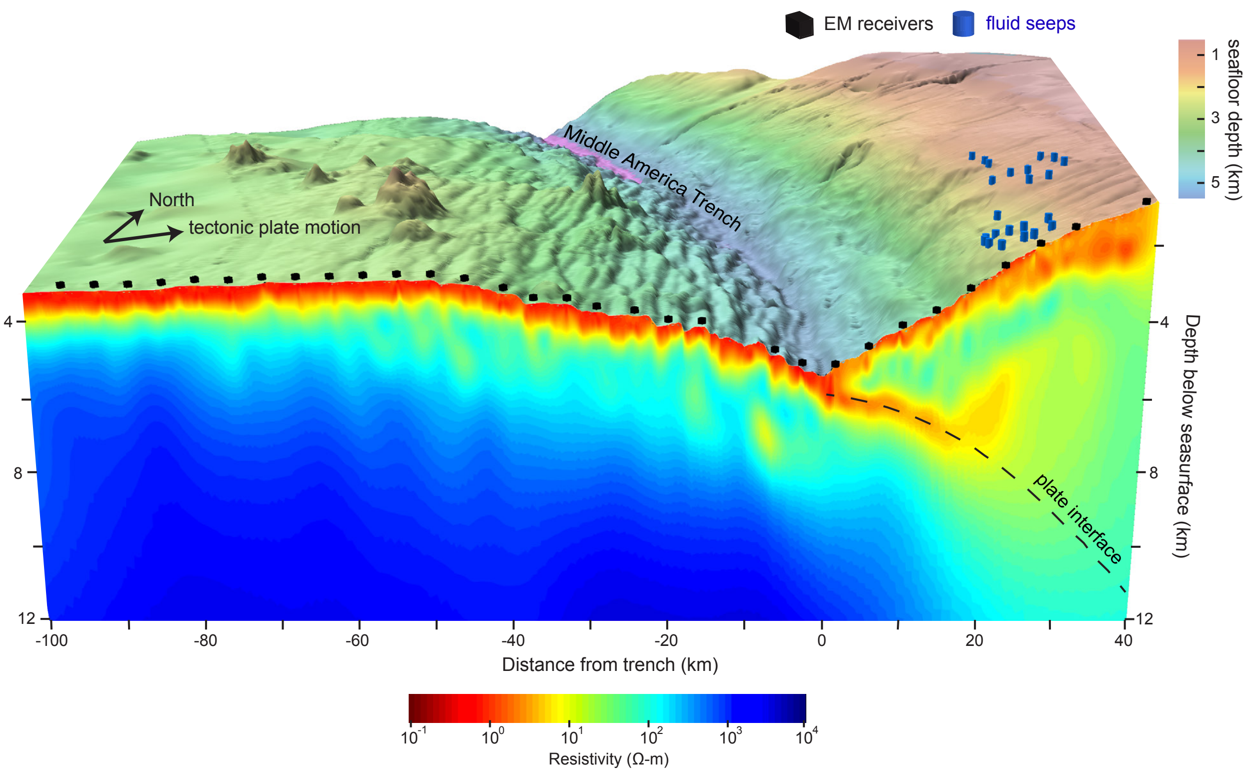


Figure 2.4. The electrical structure of the incoming Cocos plate from nonlinear inversion of deep-towed CSEM data. The vertical cross-section shows the sub-seafloor electrical resistivity structure and the stitched upper panel shows seafloor bathymetry. The black cubes show the location of EM receivers. The region of the seafloor marked by steeply dipping relief correlates with sub-vertical conductive channels, which is interpreted as evidence for the migration of seawater along bending faults. The channel of low resistivity beneath the fore-arc – congruent with the geometry of the plate interface – is caused by subducted sediments.

2.2.1.4 Related GeoPRISMS-funded publications (from appendix A3)

Rethinking turbidite paleoseismology along the Cascadia subduction zone – Atwater et al., 2014.
Faulting within the Pacific plate at the Mariana Trench: implications for plate interface coupling and subduction of hydrous minerals – Emry et al., 2014.
Incoming plate faulting in the Northern and Western Pacific and implications for subduction water budgets - Emry and Wiens – 2015.
Contemporary ocean warming dissociates Cascadia margin gas hydrates – Hautala et al., 2014.
In situ measurements of thermal diffusivity in sediments of the methane-rich zone of Cascadia Margin, NE Pacific ocean – Homola et al., 2015.
Heat flow and fluid flux in Cascadia's seismogenic zone – Johnson et al., 2013.

A geophysical and hydrogeochemical survey of the Cascadia subduction zone – Johnson et al., 2014.
Dynamics of outer-rise faulting in oceanic-continental subduction systems – Naliboff et al., 2014.
IODP workshop on using ocean drilling to unlock the secrets of slow slip events - Wallace et al., 2012.

2.2.1.5 Related MARGINS-funded papers (2009 and later; appendix A4)

Massive methane release triggered by seafloor erosion offshore southwestern Japan – Bangs et al., 2010.
Cenozoic tectonics of the Nicaraguan depression, Nicaragua, and Median Trough, Salvador, based on seismic-reflection profiling and remote-sensing data – Funk et al., 2009.
A model for the long-profile shape of submarine canyons – Gerber et al., 2009.
Rapid forearc basin uplift and megasplay fault development from 3D seismic images of Nankai Margin off Kii peninsula, Japan – Gulick et al., 2010.
Submarine landslide potential near the megasplay fault at the Nankai subduction zone – Ikari et al., 2011.
Marine electromagnetic studies of seafloor resources and tectonics – Key, 2012.
Electromagnetic detection of plate hydration due to bending faults at the Middle America Trench - Key et al., 2012.
Spatial and temporal evolution of the megasplay fault in the Nankai Trough – Kimura et al., 2011.
Fore-arc motion and Cocos Ridge collision in Central America – Lafemina et al., 2009.
The impact of splay faults on fluid flow, solute transport, and pore pressure distribution in subduction zones: a case study offshore the Nicoya Peninsula, Costa Rica – Lauer and Saffer, 2015.
Possible strain partitioning structure between the Kumano fore-arc basin and the slope of the Nankai Trough accretionary prism – Martin et al., 2010.
Integration of arrival-time datasets for consistent quality control: a case study of amphibious experiments along the middle America Trench – Moore-Driskell et al., 2013.
Analysis of normal fault populations in the Kumano forearc basin, Nankai Trough, Japan. 1. Multiple orientations and generations of faults from 3-D coherency mapping – Moore et al., 2013.
Melt-rich channel observed at the lithosphere-asthenosphere boundary – Naif et al., 2013.
Water-rich bending faults at the Middle America Trench – Naif et al., 2015.
A serpentinite-hosted ecosystem in the Southern Mariana Forearc – Ohara et al., 2012.
Analysis of normal fault populations in the Kumano forearc basin, Nankai Trough, Japan: 2. Principal axes of stress and strain from inversion of fault orientations - Sacks et al., 2013.
Evaluation of in-situ smectite dehydration as a pore water freshening mechanism in the Nankai Trough, offshore southwest Japan – Saffer et al., 2009.
Hydrostratigraphy as a control on subduction zone mechanics through its effects on drainage: an example from the Nankai Margin, SW Japan – Saffer et al., 2010.
Pore pressure development beneath the décollement at the Nankai subduction zone: implications for plate boundary fault strength and sediment dewatering – Skarbek and Saffer, 2009.
Origin and evolution of a splay fault in the Nankai accretionary wedge – Strasser et al., 2009.
Velocity-porosity relationships in smectite-rich sediments: Shikoku Basin, Japan – Tudge and Tobin, 2013.

2.2.2 The Seismogenic Zone

Recent large damaging earthquakes, such as the 2004 Sumatra, 2010 Chile, and 2011 Tohoku-oki events, demonstrate the societal importance of understanding the subduction megathrust and provide unprecedented new datasets to understand fault behavior. Discoveries in the last ten years have revealed that subduction zone faults show a wide range of previously unknown fault slip behaviors and rates, from coseismic slip to silent earthquakes, slow slip events (SSE), episodic tremor and slip (ETS), low frequency earthquakes (LFE), and very low frequency earthquakes (VLF), in addition to "normal" fast-slip earthquakes.

Although our community has made some progress in characterizing these phenomena, we do not know if these new observations represent fundamentally new types of seismic moment release or fall along a continuum ranging from normal earthquakes to creep (e.g., Ide et al., 2007). We also do not fully understand the underlying physical processes that give rise to these slip phenomena, in terms of intrinsic fault rock properties, fault architecture, and conditions (such as the pore pressure, stress state, and temperature) on the fault interface, or how these other slip processes may influence great earthquake occurrence.

A major focus of the SCD initiative is obtaining key observational and experimental constraints on faulting processes across the entire range of slip conditions and sampling these at various stages over the earthquake cycle. This effort requires a combination of: (1) new seismic, geodetic, and other geophysical field observations made at the three primary sites; (2) long-term observations of in situ mechanical, geochemical, thermal, and hydrologic conditions relevant to these slip processes; (3) theoretical and laboratory-based experimental approaches that link observations and the underlying physical mechanisms; and (4) integration of observations across multiple study sites to sample the full range of slip behaviors and/or stages in the seismic cycle.

2.2.2.1 Cascadia

Ghosh et al. (2015) performed a systematic search for VLFs in the Cascadia subduction zone under Washington during an episodic tremor and slip event as part of a postdoc project funded to PI Brodsky. They detected and located VLFs, estimated their source parameters by a moment tensor inversion method, analyzed their spatiotemporal distribution relative to tremor, and explored implications for possible source characteristics of slow earthquakes. They found VLFs in Cascadia under northern Washington during a 2011 episodic tremor and slip event (Figure 2.5). VLFs are rich in low-frequency energy (20–50 s) and depleted in higher frequencies (higher than 1 Hz) compared to local earthquakes. They found that VLFs are located near the plate interface in the zone where tremor and slow slip are observed and that they migrate along strike with tremor activity. Their moment tensor solutions show double-couple sources with shallow thrust mechanisms, consistent with shear slip at the plate interface. The seismic moment released by a single VLF is comparable to the total cumulative moment released by tremor activity during an entire episodic tremor and slip event. The VLFs contribute more seismic moment to this episodic tremor and slip event than cumulative tremor activity and indicate a higher seismic efficiency of slow earthquakes in Cascadia than previously thought. Spatiotemporal correlation of VLF and tremor activity suggests that they are the results of the same physical processes governing slow earthquakes.

2.2.2.2 Alaska-Aleutians

Variations in the in-situ conditions and physical properties of the megathrust plate interface are primary controls on great earthquake rupture, the mode of fault slip, and the manner in which slip might reach the trench to produce tsunamis. The ongoing Aleutian megathrust project by PIs Keranen, Shillington, Saffer, Abers, Becel and Nedimovic is integrating laboratory data from modern oceanic sediment and exhumed metapelites with existing, multi-resolutional geophysical data to improve the understanding of in situ conditions and processes along the plate boundary megathrust from the trench to ~30-40 km depth. Their study focuses on the Alaska-Aleutian primary site, where several existing geophysical datasets and DSDP/IODP cores can be used (Figure 2.6). They seek to develop an improved quantitative understanding of the conditions and materials along the megathrust and their relationship to seismicity, and provide a template for similar studies at other margins.

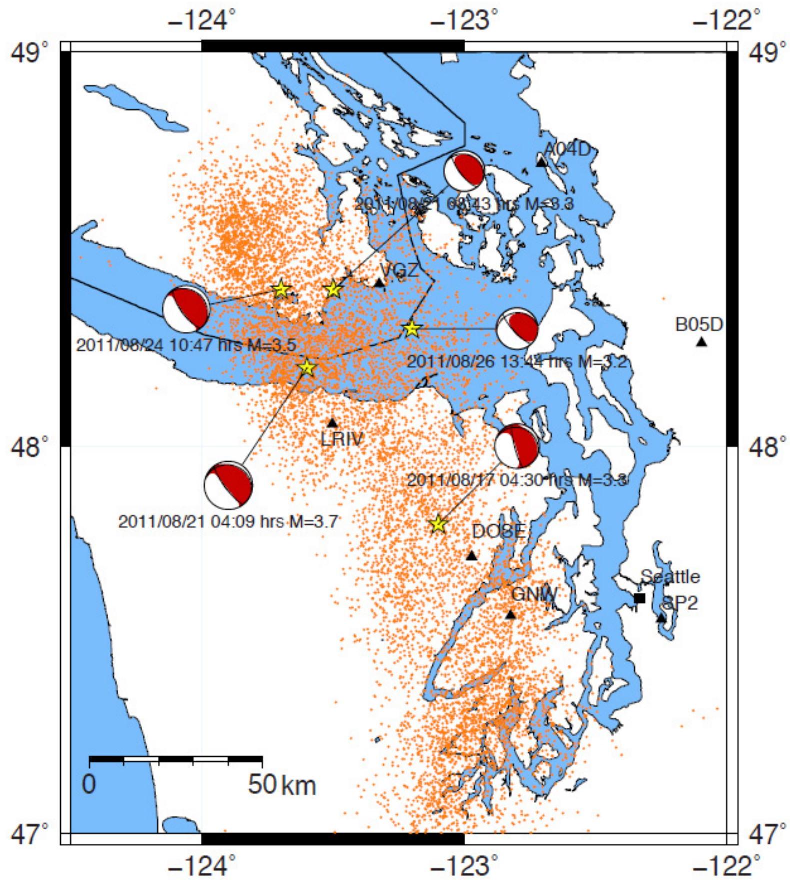
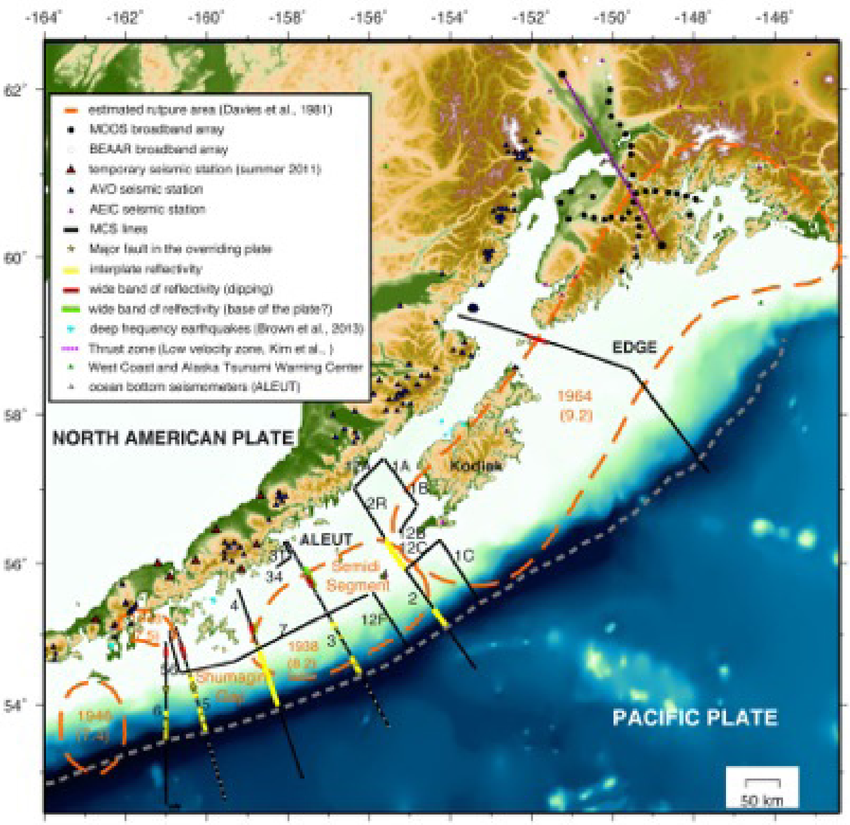


Figure 2.5. Tremor (orange dots), VLFs (yellow stars), and their focal mechanisms during August 2011. The date of occurrences and moment magnitudes (Mw) of VLFs are noted. Black triangles are the seismic stations used to obtain source parameters of the VLFs (from Ghosh et al., 2015).

The Keranen et al. project directly addresses the role of fluid production on the dynamics of the subduction interface. The downdip end of the locked zone and transition to tremor appears to be marked by a broadening of deformation based on seismic reflection data. Receiver functions indicate that the megathrust is associated with a few km wide zone with 20-30% slower Vs than its surroundings and anomalously high Vp/Vs ratios both within and downdip of the main rupture zone of the 1964 earthquake (Figure 2.7; Kim et al., 2014). Low velocity zones, high Vp/Vs and high reflectivity observed in seismic data in Alaska and in other subduction zones have been interpreted to represent very high pore-fluid pressures along different parts of the plate boundary, but could also arise from changes in sediment porosity and lithology with depth or from anisotropy in elastic properties.

A primary SCD objective is to understand what controls variations in seismic activity along a margin where tectonic plates converge. The Alaska Peninsula segment of the Aleutian megathrust

Figure 2.6. Map showing existing drilling and seismic data along the Alaska subduction zone.



includes the transition from a wide, locked region on the plate interface to a dominantly creeping section. The co-location of an island chain across this segment provides an ideal setting for measuring deformation in the recently funded GeoPRISMS project of PI Freymueller. These data will be used to determine the distribution of recent slip (or lack thereof) along the plate boundary fault. This is the first time that a detailed view of how the seismogenic zone varies from a locked to a creeping section will be obtained. The findings will inform assessment of earthquake and tsunami hazards, both in relation to the Alaska Peninsula and along the US west coast due to trans-Pacific tsunamis.

In a more general sense, the availability of inexpensive, but highly precise continuous geodetic instruments on land, and improvements in similar measurements offshore, now make it possible to fully constrain the patterns of deformation that accompany the full seismic cycle within a decadal time frame by working in several subduction zones simultaneously. This is accomplished through a combination of ongoing GeoPRISMS studies (PI Chadwell in Cascadia; PI Freymueller in Alaska and related research efforts that leverage EarthScope Plate Boundary Observatory activities).

2.2.2.3 Experimental studies

The frictional behavior of natural subduction megathrust fault rocks is studied experimentally by PIs Saffer, Marone and postdoc den Hartog to evaluate the stability of megathrust rocks at in situ pressures and temperatures. A novel aspect of this project is the use of a unique suite of natural megathrust fault zone samples obtained by drilling and from well-characterized, exhumed subduction paleo-décollements. Initial results show that the behavior of these materials is similar to that of quartz-phyllosilicate mixtures and can be subdivided into three regimes: 1) low-temperature gouges with stable, velocity-strengthening behavior, 2) intermediate-temperature gouges with potentially unstable,

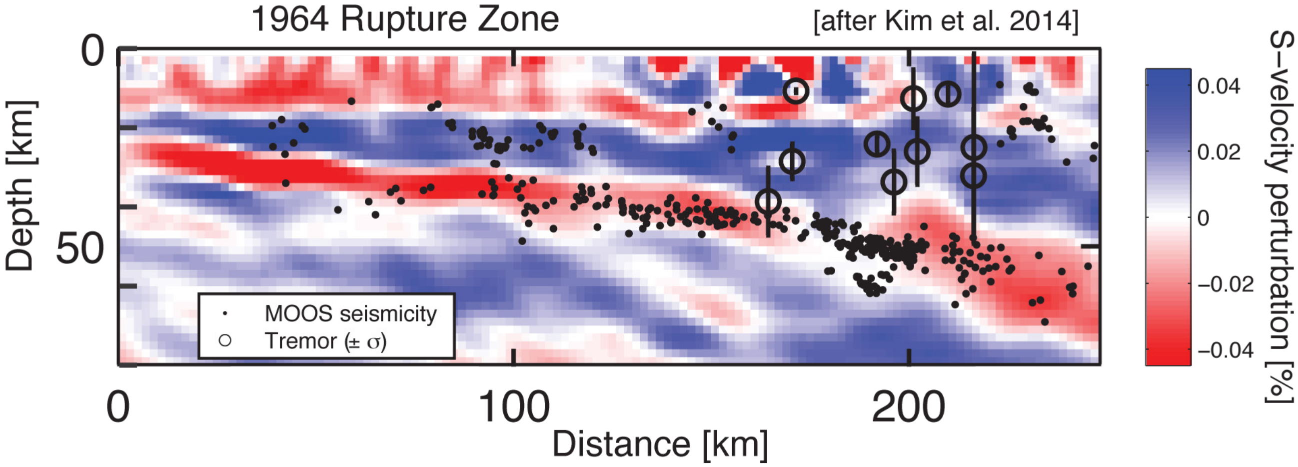


Figure 2.7. Receiver function image across Alaska subduction zone, showing low velocities along the megathrust.

velocity-weakening behavior, and 3) high-temperature gouges with velocity-strengthening behavior (den Hartog et al., 2012, 2013). The three-regime behavior is well-explained by a microphysical model in which frictional behavior is governed by a competition between rate-independent frictional slip on aligned phyllosilicates and thermally activated deformation of intervening quartz clasts by pressure solution.

In a separate GeoPRISMS-funded project PI Saffer and postdoc Kitajima study the stress conditions of both sediments coming into the trench and that of the seismogenic zone at depth. The conditions of the seismogenic zone at depth are determined by combining laboratory-derived relationships between seismic velocity, stress and pore pressure with observed velocities from geophysical surveys. Importantly they provide the first quantitative evidence that the very low frequency events down-dip from the seismogenic zone occur under conditions of low stress and high pore pressure (Kitajima and Saffer, 2012). In a separate study they determined the consolidation state of sediments retrieved from boreholes in Nankai. The determination of this initial state of the sediments is crucial in our understanding of how further consolidation and dewatering aids in the nucleation of seismicity along the megathrust (Figure 2.8; Kitajima and Saffer, 2014).

2.2.2.4 Related work from late-MARGINS funded projects

A grant to PIs Dixon and Schwartz established a GPS and seismic network on Nicoya Peninsula, Costa Rica through an international partnership. The network was fully operating when the 2012 Mw 7.6 earthquake struck. This timely observational effort allows for a much improved understanding of the earthquake cycle (see nugget by Dixon and Schwartz).

2.2.2.5 Related GeoPRISMS-funded publications (appendix A3)

Very low frequency earthquakes in Cascadia migrate with tremor – Ghosh et al., 2015.
Crustal anisotropy from tectonic tremor under Washington State in the Cascadia [sic] - Huesca-Perez and Ghosh, 2015.

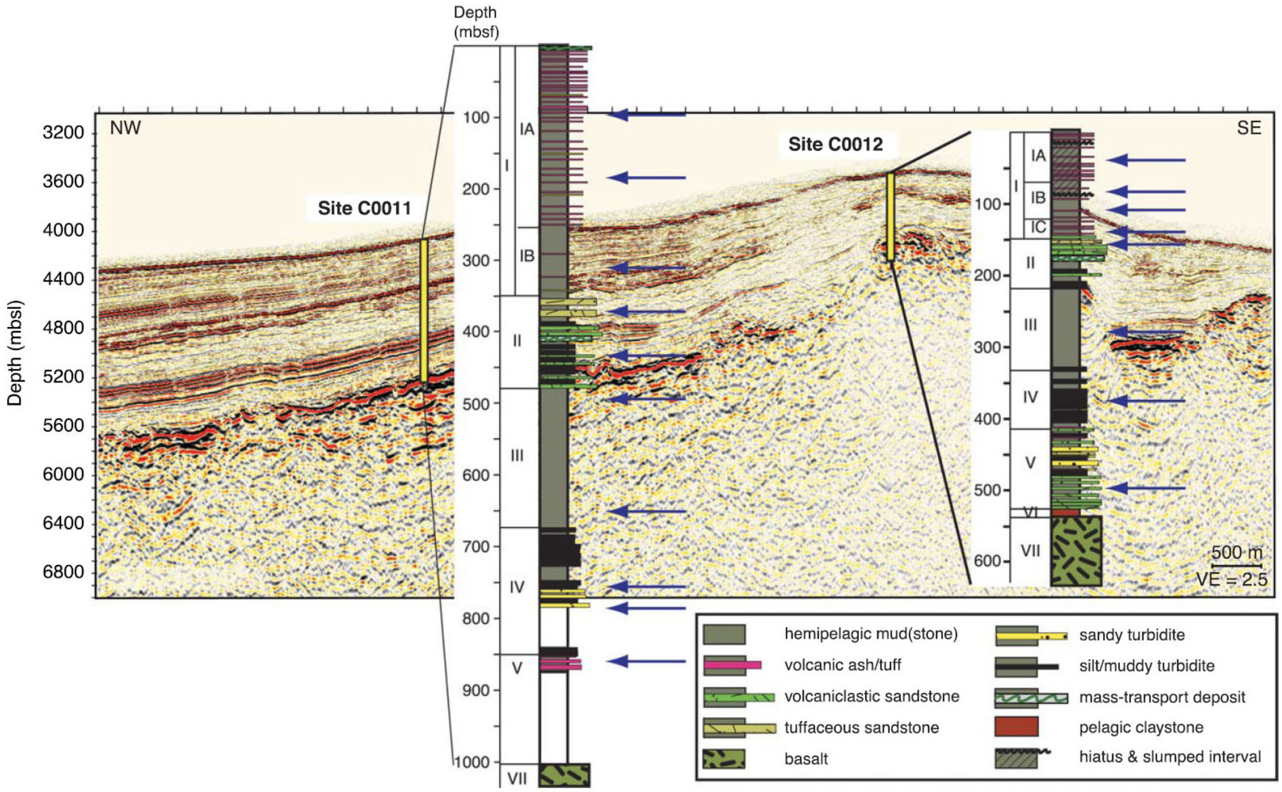


Figure 2.8. Determination of the consolidation state of sediments entering the Nankai trench is essential to determine the nature of further compaction and its role in earthquake nucleation (from Kitajima and Saffer, 2014).

Elevated pore pressure and anomalously low stress in regions of low frequency earthquakes along the Nankai Trough subduction megathrust - Kitajima and Saffer, 2012.

Consolidation state of incoming sediments to the Nankai Trough subduction zone: implications for sediment deformation and properties – Kitajima et al., 2014.

The permeability of active subduction plate boundary faults – Saffer, 2015.

Effects of smectite to illite transformation on the frictional strength and sliding stability of intact marine mudstones – Saffer et al., 2012.

Potential for geologic records of coseismic uplift and megathrust rupture along the Nicoya Peninsula – Spotila et al., 2015.

2.2.2.6 Related MARGINS-funded papers (2009 and later; appendix A4)

Hydrologic control of forearc strength and seismicity in the Costa Rican subduction zone - Audet and Schwartz, 2013

Broad, weak regions of the Nankai Megathrust and implications for shallow coseismic slip - Bangs et al. 2009

Spatial variations in earthquake source characteristics within the 2011 Mw = 9.0 Tohoku, Japan rupture zone - Bilek et al., 2012

The 25 October 2010 Sumatra tsunami earthquake: Slip in a slow patch - Bilek et al., 2011

The role of subduction erosion on seismicity – Bilek, 2010.

A geological fingerprint of low-viscosity fault fluids mobilized during an earthquake - Brodsky et al., 2009

Deep low-frequency earthquakes in tremor localize to the plate interface in multiple subduction zones – Brown et al., 2011.

Detailed data available for recent Costa Rica Earthquake – Dixon et al., 2013.

Along-strike variability of rupture duration in subduction zone earthquakes - El Hariri et al., 2013.
Organized melt, seismic anisotropy, and plate boundary lubrication – Holtzman and Kendall, 2010.
Slip weakening as a mechanism for slow earthquakes – Ikari et al., 2013.
Non-volcanic tremor associated with the March 2010 Gisborne slow slip event at the Hikurangi subduction margin, New Zealand – Kim et al., 2011.
Imaging a steeply dipping subducting slab in southern Central America – MacKenzie et al., 2010.
No slab-derived CO_2 in Mariana trough back-arc basalts: implications for carbon subduction and for temporary storage of CO_2 beneath slow spreading ridges – Macpherson et al., 2010.
A tremor and slip event on the Cocos-Caribbean subduction zone as measured by a global positioning system (GPS) and seismic network on the Nicoya Peninsula – Outerbridge et al., 2010.
A low-velocity zone with weak reflectivity along the Nankai subduction zone – Park et al., 2010.
Nicoya earthquake rupture anticipated by geodetic measurement of the locked plate interface - Protti et al., 2014.
Collateral damage: evolution with displacement of fracture distribution and secondary fault strands in fault damage zones – Savage et al., 2011.
The role of frictional strength on plate coupling at the subduction interface - Tan et al., 2012.
Elevated fluid pressure and extreme mechanical weakness of a plate boundary thrust, Nankai Trough subduction zone - Tobin and Saffer, 2009,
Intraoceanic thrusts in the Nankai Trough off the Kii Peninsula: Implications for intraplate earthquakes - Tsuji et al., 2009.
Persistent tremor within the northern Costa Rica seismogenic zone – Walter et al., 2011.
The synchronous occurrence of shallow tremor and very low frequency earthquakes offshore of the Nicoya Peninsula, Costa Rica – Walter et al., 2013.
Interseismic megathrust coupling beneath the Nicoya Peninsula, Costa Rica, from the join inversion of InSAR and GPS data – Xue et al., 2015.
The 5 september 2012 Nicoya, Costa Rica Mw 7.6 earthquake rupture process from joint inversion of high-rate GPS, strong-motion, and teleseismic P wave data and its relationship to adjacent plate boundary interface properties – Yue et al., 2013.

2.2.3 Slab Processes

As the slab descends it undergoes dramatic changes in ambient pressure and temperature conditions. This leads to a series of progressive metamorphic reactions that release volatiles, resulting in strongly changing physical properties at depth. When the slab comes into contact with the hot mantle wedge, the dehydration of the slab accelerates (e.g., van Keken et al., 2011) and fluids are released that trigger arc melting. The nature of the processes in the slab can be deduced directly from geophysical imaging, indirectly from geochemical output in arc volcanoes, and from the field by studying exhumed terranes.

The GeoPRISMS project of PIs van Keken, Hacker and Abers continues a geodynamical-seismological-petrological collaboration to investigate whether the presence of fluids within Earth's mantle is a controlling factor determining where intermediate seismicity occurs and how fluids affect the seismological structure of the mantle wedge. There are tantalizing indications that petrological conditions play a direct role in intermediate-depth seismicity because this seismicity is located within the crust at 'cool' subduction zones, such as Alaska and Tohoku, but in the mantle at 'warm' subduction zones, such as Cascadia and Nankai (Abers et al., 2013). In Tohoku and Hokkaido, the seismicity in the crust ends when the major blueschist to eclogite transition is predicted to occur (van Keken et al., 2012) except in a narrow region at the transition from the Tohoku to Hokkaido arc (Morishige and van Keken, 2014; Morishige, in press). The correlation with very low P-wave velocities and predicted presence of free fluids from new dynamical models (Wilson et al., 2014) provide very strong evidence that, at least in the oceanic crust below NE Japan, the flow of fluids triggers intermediate-depth seismicity. The thermal-petrological models developed as part of this project are also used to predict seismic velocities that further confirm the role of fluids in the slab and in the mantle wedge. Intriguingly, an earlier prediction that the fluids that contribute to the water content of arc volcanoes in Cascadia can only be derived from the hydrated mantle portion (van Keken et al., 2011) has now been corroborated by combined geochemical and geodynamical work (Walowski et al., 2015).

Serpentinite is present in both subducting mantle and in the overlying mantle wedge. The rheology of serpentinite may play a key role in controlling seismicity and the dynamics of plate motion and movement of material within the plate interface (Hirth and Guillot, 2013). Intermediate-depth earthquakes in subduction zones have been attributed to dehydration embrittlement, in which prograde dehydration of minerals is thought to result in brittle fracturing. Deformation experiments funded by GeoPRISMS to PIs Hirth and Goldsby investigate the behavior of serpentine and suggest that serpentine deforms via semi-brittle flow, with grain-scale ductile deformation active at high pore fluid pressures (Chernak and Hirth, 2010; Proctor and Hirth, 2015). These results suggest that earthquakes in serpentinized mantle are not due to dehydration embrittlement. The experiments also demonstrate that extreme dynamic weakening occurs when rapid slip is imposed onto a fault zone rich in serpentinite (Proctor et al., 2014). The slip velocity at which dynamic weakening is observed increases in the presence of gouge. The onset of weakening for both bare surfaces and with a layer of gouge is well-explained by flash weakening at asperity contacts.

2.2.3.1 Related GeoPRISMS-funded publications (appendix A3)

Rheology and tectonic significance of serpentinite – Hirth and Guillot, 2013.
A new regime of slab-mantle coupling at the plate interface and its possible implications for the distribution of volcanoes – Morishige, 2015.
Along-arc variation in the 3D thermal structure around the junction between the Japan and Kurile arcs - Morishige and van Keken, 2014.
Role of pore fluid pressure on transient strength changes and fabric development during serpentine dehydration at mantle conditions: implications for subduction-zone seismicity – Proctor and Hirth, 2015.
Fluid flow in subduction zones: The role of solid rheology and compaction pressure - Wilson et al., 2014.

2.2.3.2 Related MARGINS-funded papers (2009 and later; appendix A4)

Thermo-petrological controls on the location of earthquakes within subducting plates – Abers et al., 2013.
The relationship of intermediate- and deep-focus seismicity to the hydration and dehydration of subducting slabs – Barcheck et al., 2012.
Three-dimensional thermal structure of subduction zones: effects of obliquity and curvature – Bengtson and van Keken, 2012.
P and S velocity tomography of the Mariana subduction system from a combined land-sea seismic deployment – Barklage et al., 2015.
Farallon slab detachment and deformation of the Magdalena Shelf, Southern Baja California – Brothers et al., 2012.
Deformation of antigorite serpentinite at high temperature and pressure – Chernak and Hirth, 2010.
Fluidity: A fully unstructured anisotropic adaptive mesh computational modeling framework for geodynamics

– Davies et al., 2011.
Along-strike translation of a fossil slab – Eichenbaum-Pikser et al., 2012.
Upper and mid-mantle anisotropy beneath the Tonga slab – Foley and Long, 2011.
Intermediate-depth earthquakes facilitated by eclogitization-related stresses – Nakajima et al., 2013.
Along-strike translation of a fossil slab - Pikser et al., 2012.
Long-term preservation of slab signatures in the mantle inferred from hydrogen isotopes - Shaw et al., 2012
Links between fluid circulation, temperature, and metamorphism in subducting slabs - Spinelli et al., 2009.
The dynamics of plate tectonics and mantle flow: from local to global scales – Stadler et al., 2010.
Systematic biases in subduction zone hypocenters - Syracuse and Abers, 2009.
The global range of subduction zone thermal models – Syracuse et al., 2010.
Structure and serpentinization of the subducting Cocos plate offshore Nicaragua and Costa Rica – van Avendonk et al., 2011.
Seismic evidence for fluids in fault zones on top of the subducting Cocos plate beneath Costa Rica – van Avendonk et al., 2010.
Subduction factory: 4. Depth-dependent flux of H_2O from subducting slabs worldwide - van Keken et al., 2011.
Thermal structure and intermediate-depth seismicity in the Tohoku-Hokkaido subduction zones - van Keken et al., 2012.
Intraslab stresses in the Cascadia subduction zone from inversion of earthquake focal mechanisms – Wada et al., 2010.
Effects of heterogeneous hydration in the incoming plate, slab rehydration, and mantle wedge hydration on slab-derived H_2O flux in subduction zones - Wada et al., 2012.
Fossil slabs attached to unsubducted fragments of the Farallon plate – Wang et al., 2012.

2.2.4 Mantle wedge and arc crust

The fluids released from the descending slab trigger melting in the mantle wedge. These melts migrate and differentiate and contribute to explosive arc volcanism and the formation of continental crust. Studies of the processes of melt generation and migration are essential for quantifying the volatile fluxes and cycling that is a primary objective of the GeoPRISMS science program. Exactly half of the SCD-funded projects (appendix A1) fall in this wedge and arc crust category; most have a strong focus on magmatic and continental crust forming processes.

2.2.4.1 Alaska-Aleutians: magma migration below volcanoes

Two recently funded projects will investigate the origin, storage and ascent of magma in different parts of the Aleutian arc with an emphasis on the role of volatiles. The first, by PIs Plank, Roman and Hauri, is an integrated geochemical and geophysical study of the Unimak-Cleveland corridor, a region of the Aleutians that encompasses six volcanoes that have erupted in the past 25 years with a wide range of magmatic water contents. The main goal is to better understand how shallow crustal processes link to and are controlled by the large-scale crustal tectonics and deep mantle melting that are ultimately responsible for arc volcanism. The results of this project will help to establish the links between two normally disconnected, big-picture problems: 1) the deep origin of magmas and volatiles, particularly the processes that control magma H_2O content, and 2) the formation and eruption of crustal magma reservoirs.

The second project, by PIs Key and Bennington, involves a seismic and magnetotelluric survey at Okmok to characterize the magmatic system beneath an active volcano in the Aleutians. The main goals are to test hypotheses regarding the role of slab fluids in arc melt generation, melt migration within the crust, and the crustal magmatic plumbing and storage system beneath an active caldera. These data will be used to study the mantle melt flux, the possible storage of melts at the base of the crust, the distribution of partial melt and magma bodies in the mid-upper crust, and the thermal and mechanical properties of the upper crust beneath the caldera.

A related project by PI/postdoc Lopez at the Katmai Volcanic Cluster in Alaska investigates the relationship of fluid movement in the subsurface of active volcanoes to elevated seismicity (see [article in the Spring 2014 newsletter](#)). Geochemical data on volcanic gases at three volcanoes in this region (Mount Mageik, Mount Martin, Trident) have been used to reveal information on the source, flux, migration and seismic signatures of fluids. He-isotope ratios at two of the volcanoes (Mount Mageik and Trident) indicate that the fluids derive in part from mantle-derived basaltic magma, whereas N and C isotopes indicate contributions from sediment and limestone, either recycled by subduction from a slab component or acquired through crustal contamination. Elevated CO_2 concentrations relative to SO_2 and HCl in the fumarolic samples from both Mount Mageik and Trident are consistent with scrubbing of magmatic gases by hydrothermal fluids. The evidence for scrubbing, combined with the strong meteoric signature of steam condensates indicates that both Mount Mageik and Trident have well-developed hydrothermal systems. Compositional gas changes can be correlated with two deep low frequency earthquakes occurring ~2 months prior.

Figure 2.9. Seismic station installation on Okmok volcano as part of the project by PIs Key and Bennington.

2.2.4.2 Alaska-Aleutians: from arcs to volcanic crust

Arc magmatism is the most important process that generates continental crust today and likely throughout Earth's history. However, average continental crust composition is andesitic and calc-alkaline, whereas average arc lava composition is basaltic and tholeiitic. One hypothesis that could help to explain this difference is that the plutonic parts of arcs, which are largely unexposed and unsampled, may be more similar to the continental crust. Therefore, understanding the genesis of plutonic rocks is a key to understanding continental crust formation and evolution via arc magmatism. The Aleutian arc is uniquely well-suited for such a study because of the extensive exposures of plutonic rocks, unmatched in any other intra-oceanic arc.

A recently funded project led by PIs Kelemen, Goldstein, and Cai will map and sample plutonic rocks exposed on the central Aleutians and their coeval volcanic host rocks to understand the extent and origin of the compositional differences between lavas and plutons through time and space. In a pilot study using samples of plutons from the Aleutians collected by the US Geological Survey from 1950 to 1980, they found that Eocene-Miocene plutonic rocks and Holocene volcanic rocks show distinctly different elemental and isotopic signatures, which indicate that they were derived from distinct parental magmas. This difference could reflect temporal variation of the mantle under the region or fundamentally different mechanisms that form plutons and lavas.

The timing of Aleutian Arc inception and subsequent compositional evolution through the initial stages of arc growth are poorly known. PIs Jicha and Kay are funded to better determine the age and early stages of this inception (see their Spring 2015 newsletter article). $^{40}Ar/^{39}Ar$ incremental heating experiments and geochemical analyses revealed that most of the subaerial samples of the older portions of the central and western Aleutians are <40 Ma and thus provide little information on subduction initiation. As a result, the project was refocused to constrain the along- and across-arc chemical evolution of the central and western Aleutians over the last 40 Myr of arc history. A key finding from the new data is that a subduction-recycled sediment melt component was not involved during the early development of the western Aleutian Arc, but has become more pronounced during the Quaternary. One $^{40}Ar/^{39}Ar$ age of a mafic xenolith from Kanaga Island (interpreted as a lower crustal cumulate related to arc magmatism, e.g., Kay et al., 2014) has yielded the oldest ages yet reported in the Aleutian arc (47.8±4.3 Ma). They interpret this age as a time of metamorphism and recrystallization of mafic arc cumulates by younger arc magmas intruding the existing arc crust. Chemical and $^{40}Ar/^{39}Ar$ analyses of lavas and gabbros indicate a change in the strike of magmatic centers on Attu, which combined with paleomagnetic data suggests a significant clockwise rotation of the western Aleutians along with uplift between 16 and 8 Ma.

Among the key characteristics shared by bulk continental crust and some subduction zone magmas is calc-alkaline affinity, a rapid draw-down in Fe concentration early in a magma's cooling and differentiation history. Resolving the key roles that H_2O, oxygen fugacity (fO_2), and magma bulk composition play in controlling calc-alkaline trends is important for understanding how continents initially formed and have grown through time. GeoPRISMS research by PIs Jackson, Cottrell and Kelley examines the role of fO_2 in calc-alkaline differentiation and the creation of continental crust in the Aleutian arc. This work builds on MARGINS-funded research (Cottrell et al., 2009; Kelley and Cottrell, 2009, 2012; Brounce et al., 2014) which had the important conclusion that slab fluids may be very oxidized. The main goals of the new project are to examine how fO_2 of magmas varies during differentiation and degassing at individual volcanoes and how it varies along strike of the Aleutian arc as a function of material derived from the subducted slab. The work will also include an experimental study quantifying the effects of H_2O and fO_2 on calc-alkaline differentiation trends during crystallization of magmas at crustal pressures. In Fall 2015, they will collect new samples of the most strongly calc-alkaline Aleutian magmas as part of the NSF-sponsored shared platform for Aleutians research.

2.2.4.3 Cascadia

Recent studies at Cascadia can be used to correlate the metamorphic state of the slab (Rondenay et al., 2008; van Keken et al., 2011; Cozzens and Spinelli, 2012) and the volatile concentrations of primitive basaltic magmas (Ruscitto et al., 2010, 2011, 2012; Walowski et al., 2015) providing important evidence for the pathways of fluids rising from slab to the arc. Two GeoPRISMS research programs in the Cascades are focused on the processes of mantle upwelling and magma generation beneath the arc and back-arc and the movement and storage of magma within the crust.

Full wave ambient noise tomography has revealed three separate, low shear-wave velocity anomalies along the back arc in the upper mantle ~200 km east of the Cascade arc (Gao and Shen, 2014). The back-arc low velocity anomalies are spatially correlated with the three main arc-volcano clusters in northern California, Oregon, and Washington (Figure 2.10). The geometry of the low-velocity regions suggests they are caused by subduction-driven upwelling and decompression melting beneath the back-arc. Gao and Shen (2014) interpret the along strike variation as an indication that large-scale, plate-motion-induced flow in the back-arc mantle wedge is modulated by small-scale convection, resulting in a highly 3D process that defines the segmentation of volcanism along the Cascade arc.

The goal of the ongoing iMUSH project is to image the architecture of the greater Mount St. Helens (MSH) magmatic system from the subducted plate to the surface, including the extent and characteristics of highly crystalline magma bodies, and to resolve major tectonic controls on volcanism along the Cascade arc. MSH was chosen as the target because it is currently the most active volcano of the Cascades arc in the northwestern US. This four year collaborative effort involves 12 PIs at 7 institutions in the US and Europe and is supported by both GeoPRISMS and EarthScope. The project involves a variety of geophysical techniques (active and passive seismic experiments, extensive magnetotelluric sounding) integrated with geochemical and petrological data to image and interpret the crust and upper mantle in the greater MSH area. The iMUSH geochemical work focuses on crystal mush inclusions/xenoliths sampled from dacitic volcanic rocks from MSH. Dating of zircons in these inclusions shows that they are part of the young MSH magmatic system and thus provide information on crystallization, differentiation and storage of magma feeding the volcano.

An important aspect of understanding the temporal evolution of crust produced in arcs is to determine how changes in large-scale crustal tectonics affect the composition of arc magmatism and productivity of melting in the underlying mantle. To investigate these questions, PIs Kent, Duncan and Grunder are conducting geochemical and geochronological studies of the Deschutes Formation (~7.4- 4.0 Ma) in the Central Oregon Cascades (see nugget by Pitcher et al.). Located just east of the active High Cascades, the Deschutes Formation preserves a remarkable stratigraphy that records the initial stages of the High Cascade arc following a major eastward shift in volcanism ~7.5 Ma. Over 120 (uncorrelated) airfall tuffs and 130 ignimbrite units are contained within the formation, suggesting that the arc may have been much more magmatically productive and explosive during this phase than at any other time within the last 17 Ma. An important new result is that glass compositions from the Deschutes Formation ignimbrites have much higher FeO* at a given CaO or SiO_2 concentration when compared to other Quaternary Cascade lavas. In this regard, they are more similar to volcanics

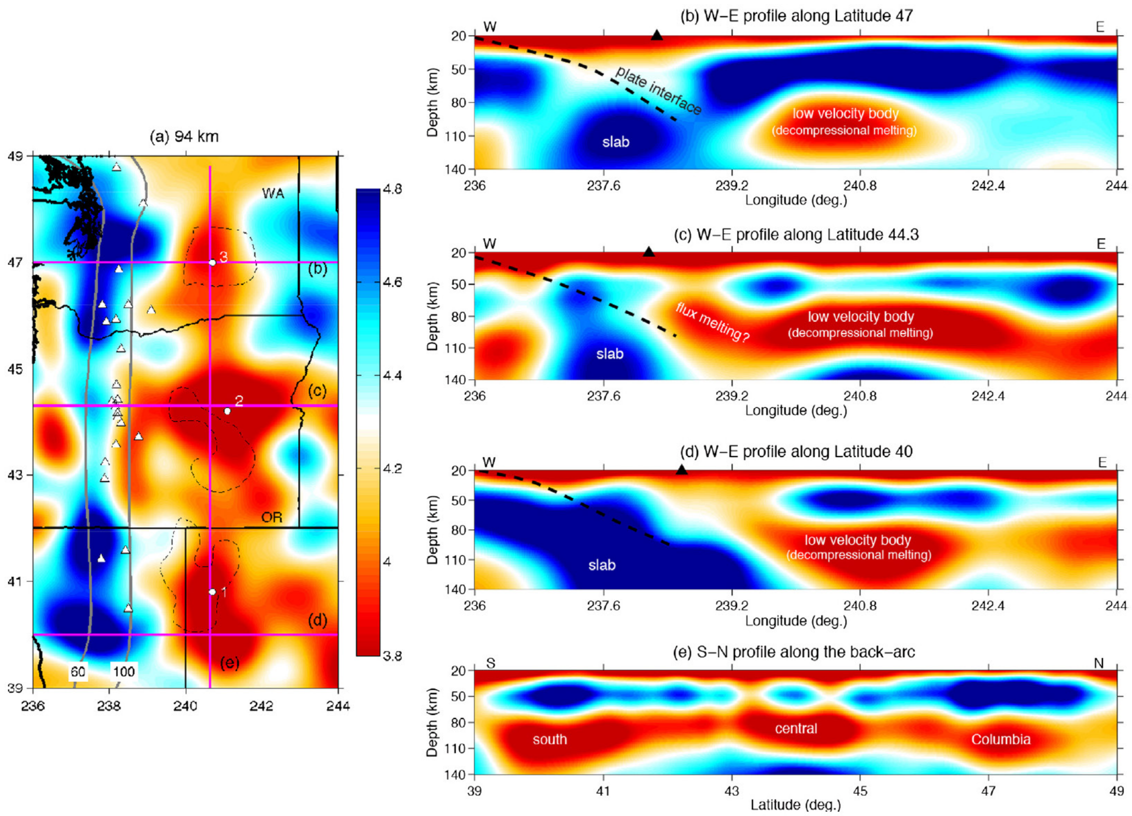


Figure 2.10. Segmented low-velocity anomalies along the Cascade back-arc. (a) Horizontal slice at depth of 94 km (Vs in km/s). The black dashed lines outline the amplitude of largest negative Sp phase from receiver functions. The magenta lines mark profile locations in (b)-(e), respectively. All the panels share the same color bar. (b-d) W-E profiles across the back-arc anomalies. The triangles mark the volcano centers. The Juan de Fuca plate interface at depths of 20-100 km is projected. (e) S-N profile along the back-arc low-velocity anomalies, which spatially correlate with the three volcano clusters as in (a). Gao and Shen (EPSL, 2014).

from the High Lava Plains. This could be an indication of hotter and drier melting conditions during rift-related mantle upwelling and partial melting of mafic crust.

2.2.4.4 Other studies

The Rosario segment of the Alisitos oceanic arc (Baja California, Mexico) is under investigation by PIs DeBari and Busby as a field analog for the Izu-Bonin Arc. Their study focuses on a tilted but undeformed and unmetamorphosed upper to middle crustal section mapped in detail by Busby et al. (2006). They are determining the detailed relationships between plutonic, hypabyssal, and volcanic rocks using field, geochemical, and geochronological data to investigate the relationship and proportion between volcanic and plutonic rocks in juvenile arc crust and whether arc crust composition changes with time. The primary goal is to construct an island arc crust "Virtual Field Model" as a reference model for Izu-Bonin-Mariana drilling outcomes from the IODP Expeditions in 2014.

MARGINS and GeoPRISMS-funded research by Hacker and others (Rioux et al., 2010; Hacker et al., 2011a, b; Behn et al., 2011; Hacker et al., 2012; Worthington et al., 2013) addresses important questions about the generation of continental crust. Their research demonstrates that buoyancy differences between mafic and felsic rocks during subduction can potentially result in overall addition of more felsic rocks to the lower crust. Processes that contribute to this differentiation include sediment subduction, subduction erosion, arc subduction, and continent subduction (see nugget by Hacker). An important suggestion is that bulk continental crust may be more silica rich than generally considered.

2.2.4.5 Related GeoPRISMS-funded publications (appendix A3)

Upper mantle structure of the Cascades from full-wave ambient noise tomography: evidence for 3D mantle upwelling in the back arc – Gao and Shen, 2014.

Validation of recent shear wave velocity models in the United States with full-wave simulation – Gao and Shen, 2015.

Continental lower crust – Hacker et al., 2015.

Sharing resources for Aleutian arc research – Jicha et al., 2014.

$^{40}Ar/^{39}Ar$ geochronology of subaerial Ascension island and a re-evaluation of the temporal progression of basaltic to rhyolitic volcanism – Jicha et al., 2013.

Reaction-driven cracking during retrograde metamorphism: olivine hydration and carbonation – Kelemen and Hirth, 2012.

Acoustic characterization of explosion complexity at Sakurajima, Karymsky, and Tungurahua volcanoes – Matoza et al., 2014.

2.2.4.6 MARGINS-funded papers (2009 and later; appendix A4)

Shear wave anisotropy beneath Nicaragua and Costa Rica: implications for flow in the mantle – Abt et al., 2009.

Constraints on upper mantle anisotropy surrounding the Cocos slab from SK(K)S splitting – Abt et al., 2010.

Chlorine isotope variations along the Central American volcanic front and back arc – Barnes et al., 2009.

Malaguana-Gadao Ridge: identification and implications of a magma chamber reflector in the southern Mariana Trough – Becker et al., 2010.

Implications of grain size variation on the seismic structure of the oceanic upper mantle – Behn et al., 2009.

Fluid circulation in a complex volcano-tectonic setting, inferred from self-potential and soil CO_2 flux surveys: The Santa Maria-Cerro Quernado-Zunil volcanoes and Xela caldera (Northwestern Guatemala) – Bennati et al., 2011.

Correlating geochemistry, tectonics, and volcanic volume along the Central American volcanic front – Bolge et al., 2009.

An inversion-based self-calibration for SIMS measurements: Application to H, F, and Cl in apatite, Boyce et al., 2012.

Lunar apatite with terrestrial volatile abundances – Boyce, 2010.

Variations in $Fe^{3+}/\Sigma Fe$ of Mariana Arc Basalts and Mantle Wedge fO_2 - Brounce et al., 2014.

Temporal evolution of mantle wedge oxygen fugacity during subduction initiation – Brounce et al., 2015.

RU_CAGeochem v.3, a database and sample repository for Central American volcanic rocks at Rutgers University – Carr et al., 2013.

High-precision determination of iron oxidation state in silicate glasses using XANES - Cottrell et al., 2009.

The oxidation state of Fe in MORB glasses and the oxygen fugacity of the upper mantle - Cottrell et al., 2011.

Redox heterogeneity in mid-ocean ridge basalts as a function of mantle source – Cottrell et al., 2013.

Ingassing, storage, and outgassing of terrestrial carbon through geologic time - Dasgupta, 2013

The deep carbon cycle and melting in Earth's interior - Dasgupta and Hirschmann, 2010.

Sulfur isotope fractionation during the May 2003 eruption of Anatahan volcano, Mariana islands: implications for sulfur sources and plume processes – de Moor et al., 2010.

Directions of seismic anisotropy in laboratory models of mantle plumes – Druken et al., 2013.
CO_2 solubility and speciation in rhyolitic sediment partial melts at 1.5–3.0 GPa – Implications for carbon flux in subduction zones - Duncan and Dasgupta, 2014.
Eruption of South Sarigan Seamount, Northern Mariana Islands: insights into hazards from submarine volcanic eruptions – Embley et al., 2011.
Constraints on upper plate deformation in the Nicaraguan subduction zone from earthquake relocation and directivity analysis – French et al., 2010.
Hydration of mantle olivine under variable water and oxygen fugacity conditions - Gaetani et al., 2014.
Galapagos-OIB signature in southern Central America: mantle refertilization by arc-hot spot interaction – Gazel et al., 2009.
Plume-subduction initiation in southern Central America: mantle upwelling and slab melting – Gazel et al., 2011.
Continental crust generated in oceanic arcs - Gazel et al., 2015.
Crustal and mantle shear velocity structure of Costa Rica and Nicaragua from ambient noise and teleseismic Rayleigh wave tomography – Harmon et al., 2013.
Crustal structure across the Costa Rican volcanic arc – Hayes et al., 2013.
Emergence of a low-viscosity channel in subduction zones through the coupling of mantle flow and thermodynamics - Hebert et al., 2009.
Izu-Bonin-Mariana Forearc crust as a modern ophiolite analogue – Ishizuka et al., 2014.
Centam & IBM Geochem database version 1.02 – Jordan et al., 2012.
Mantle melting as a function of water content beneath the Mariana arc – Kelley et al., 2010.
Water and the oxidation state of subduction zone magmas – Kelley and Cottrell, 2012.
The influence of magma differentiation on the oxidation state of Fe in a basaltic arc magma – Kelley and Cottrell, 2012.
Origin of cross-chain geochemical variation in Quaternary lavas from the northern Izu arc: using a quantitative mass balance approach to identify mantle sources and mantle wedge processes – Kimura et al., 2010.
Arc Basalt Simulator version 2, a simulation for slab dehydration and fluid-fluxed mantle melting for arc basalts: modeling scheme and application – Kimura et al., 2009.
The influence of magmatic differentiation on the oxidation state of Fe in a basaltic arc magma - Kelley and Cottrell, 2012.
Shearing melt out of the Earth: an experimentalist's perspective on the influence of deformation on melt extraction – Kohlstedt et al., 2009.
Nature of crustal terranes and the Moho in northern Costa Rica from receiver function analysis – Linkimer et al., 2010.
The impact of slab dip variations, gaps and rollback on mantle wedge flow: insights from fluids experiments – MacDougall et al., 2014.
Electromagnetic constraints on a melt region beneath the central Mariana back-arc spreading ridge – Matsuno et al., 2012.
Upper mantle electrical resistivity structure beneath the central Mariana subduction system – Matsuno et al., 2012.
Nitrogen sources and recycling at subduction zones: insights from the Izu-Bonin-Mariana arc – Mitchell et al., 2010.
The effect of tetrahedral Al^{3+} on the partitioning of water between clinopyroxene and silicate melt - O'Leary et al., 2010.
Along-arc variations in the pre-eruptive H_2O contents of Mariana arc magmas inferred from fractionation paths - Parman et al. 2011
Why do mafic arc magmas contain ~4wt% water on average? – Plank et al., 2013.
Seismic attenuation tomography of the Mariana subduction system: Implications for thermal structure, volatile distribution, and slow spreading dynamics – Pozgay et al., 2009.
Shear velocity structure of the Mariana mantle wedge from Rayleigh wave phase velocities – Pyle et al., 2014.

New Pliocene-Pleistocene $^{40}Ar/^{39}Ar$ ages fill in temporal gaps in the Nicaraguan volcanic record – Saginor et al., 2011.
Evaluation of geochemical variations along the Central American volcanic front – Saginor et al., 2013.
The seismic mid-lithosphere discontinuity – Selway et al., 2015.
Deep pooling of low degree melts and volatile fluxes at the 85E segment of Gakkel Ridge: evidence from olivine-hosted melt inclusions and glasses – Shaw et al., 2010.
Constraints on the composition of the Aleutian arc lower crust from Vp/Vs – Shillington et al., 2013.
Mid-ocean-ridge basalt of Indian type in the northwest Pacific Ocean basin – Straub et al., 2009.
Slab and mantle controls on the Sr-Nd-Pb-Hf isotope evolution of the 42 Ma Izu-Bonin volcanic arc – Straub et al., 2010.
Temporal Evolution of the Mariana Arc: Mantle Wedge and Subducted Slab Controls Revealed with a Tephra Perspective - Straub et al., 2015.
Viscous constitutive relations of solid-liquid composites in terms of grain boundary contiguity: 1. Grain boundary diffusion control model – Takai et al., 2009a.
Viscous constitutive relations of solid-liquid composites in terms of grain boundary contiguity: 2. Compositional model for small melt fractions – Takai et al., 2009b.
Viscous constitutive relations of solid-liquid composites in terms of grain boundary contiguity: 3. Causes and consequences of viscous anisotropy – Takai et al., 2009c.
Silicic magmas in the Izu-Bonin Oceanic Arc and implications for crustal evolution – Tamura et al., 2009.
Two primary basalt magma types from Northwest Rota-1 Volcano, Mariana Arc and its mantle diapir or mantle wedge plume – Tamura et al., 2011.
Sources of constructional cross-chain volcanism in the southern Havre Trough: New insights from HFSE and REE concentration and isotope systematics - Todd et al., 2010.
Hf isotopic evidence for small-scale heterogeneity in the mode of mantle wedge enrichment: Southern Havre Trough and South Fiji Basin back arcs - Todd et al., 2011.
Across-arc geochemical trends in the Izu-Bonin arc: Contributions from the subducting slab, revisited - Tollstrup et al., 2010.
Melting phase relation of nominally anhydrous, carbonated pelitic-eclogite at 2.5-3.0 GPa and deep cycling of sedimentary carbon - Tsuno et al., 2011.
The effect of carbonates on near-solidus melting of pelite at 3 GPa: Relative efficiency of H_2O and CO_2 subduction - Tsuno et al., 2012a.
Flux of carbonate melt from deeply subducted pelitic sediments: Geophysical and geochemical implications for the source of Central American volcanic arc - Tsuno et al., 2012b.
Recent contribution of sediments and fluids to the mantle's volatile budget – Turner et al., 2011.
Grain-size distribution in the mantle wedge of subduction zones - Wada et al., 2011a.
Sharp thermal transition in the forearc mantle wedge as a consequence of nonlinear mantle wedge flow – Wada et al., 2011b.
Monogenetic, behind-the-front volcanism in southeastern Guatemala and western El Salvador: $^{40}Ar/^{39}Ar$ ages and tectonic implications – Walker et al., 2011.
Light elements and Li isotopes across the northern portion of the Central American subduction zone – Walker et al., 2009.
The role of water in generating the calc-alkaline trend: new volatile data for Aleutian magmas and a new tholeiitic index – Zimmer et al., 2009.

2.3 Thematic studies

2.3.1 Subduction initiation

Subduction initiation is a major event in plate tectonics and the initial stages of subduction zone development are different from established, mature subduction zones. Initiation of new subduction zones may be associated with major rearrangement of the forces that drive and resist plate tectonics. Unique magmas may be produced that are limited in time to the earliest stages of subduction. As subduction zones mature through time, they may also evolve structurally and manufacture continental crust.

New Zealand was chosen as the primary study site for investigating processes of subduction initiation because it has two of only a few well-preserved examples of subduction initiation worldwide – the newly initiating Puysegur Trench to the south of New Zealand and an outstanding record of Eocene subduction initiation at the Tonga-Kermadec-Hikurangi Trench in the north. However, because of the phased funding approach, this topic has yet to be addressed in New Zealand in the GeoPRISMS program. Interaction with New Zealand scientists through a series of well-attended workshops has been key for developing science plans for proposals to be submitted to NSF for the 2015 and 2016 GeoPRISMS deadlines. Related work in the Aleutians is underway as described above.

2.3.2. Feedback between subduction dynamics and surface processes

A primary distinction of the GeoPRISMS program compared to MARGINS is the explicit inclusion of surface processes and their feedbacks in the evolution of continental margins. Earth surface processes impact lithospheric evolution and continental margin structure remarkably. Surface processes convey materials and alter them as they are transported. Important questions remain about the relative roles of biological processes, climate, and erosion rate in modulating material flux and weathering rate and processes. Other surface processes including erosion and glaciation/deglaciation on central volcanoes may also have significant influence on volcanic outputs owing to decompression or compression of underlying mantle and/or of magma chambers, and these in turn may influence arc volatile fluxes and therefore climate. On a longer time scale, the formation, transport, storage, and ultimately the delivery of sediments from the upper reaches of volcanic terranes to fore-arcs to trenches have a direct influence on the subducting volatile fluxes. The resulting distributions of different sediment types also influence the distributions, geometries, and mechanisms of deformation and fault slip across the boundary, which in turn influence rates of uplift and exhumation. Clarifying the interplay between surficial and deep-seated processes at subducting margins is fundamental to understanding the long-term evolution of plate boundaries and interpreting ancient analogs.

To address the role of surface processes on tectonic, subduction zone and volcanic arc processes, PI Koons and Hallet have instituted a numerical modeling approach to examine late Pleistocene climate-tectonic processes in southern Alaska. This location is ideal for addressing many of the questions related to surface processes and sediment production and delivery to subduction zones because of the large sediment flux signal created by Pleistocene glacial erosion coupled with extensive seismic reflection mapping and scientific drilling to constrain the mass flux through time and to provide physical samples for inclusion in integrative studies.

Accretion, uplift, and erosion of sedimentary rock on the continents bring previously buried organic carbon (OC) to the surface (Figure 2.11). If mass wasting is sufficiently rapid, as is the norm on convergent margins, the exposed fossil C is recycled into the sedimentary system, thereby avoiding oxidation in subaerial outcrops. The recycled fossil C is blended with younger material as sediments move across the surface. The primary objective of the GeoPRISMS project by PI Blair is to assess the presence of multicycle organic C (fossil plus younger terrestrial material) on subduction margins beyond the mid-continental slope. They analyzed samples from the three GeoPRISMS primary SCD focus sites to determine if terrestrial OC and kerogen (from eroding bedrock on land) are delivered to the respective trenches. In a cross-margin transect, North Island NZ, the %OC is relatively constant (0.4-0.6%), but the reactive (terrigenous and biogenic) OC decreases dramatically offshore, suggesting that the bulk of OC delivered to the Hikurangi Trough is primarily kerogen. In Alaska, at site U1417 of IODP Expedition 341, observations of discrete coal and plant fragments, coupled with initial shipboard measurements, imply good preservation of a traceable, terrestrial organic carbon signal at this input site to the Aleutian Trench (Jaeger et al., 2014). Variations in the volume or nature of kerogen delivered to this location may indicate an altered terrestrial erosion pattern, which is likely driven by a combination of tectonics/uplift and glacial incision of bedrock in the Southern Alaska Margin.

2.3.3 ExTerra: the study of exhumed terranes

The SCD science plan recognized that addressing the key research questions also requires research that cannot be accomplished solely at primary sites. In particular, processes taking place at depth within subduction zones, processes not presently taking place in modern subduction zones, or processes that can only be resolved through comparative study, cannot be directly sampled or observed within the primary sites or over the decadal time scale of GeoPRISMS. Yet these processes are fundamental to constraining and contextualizing observations made at the primary sites. Thus five thematic research areas were identified in the SCD science plan. One of these research areas (Conditions and Reactions in Subduction Zones at Depth) has captured the interest of a group of self-organized researchers, called ExTerra (for Exhumed Terranes), working under the umbrella of GeoPRISMS, investigating rocks exhumed from fossil subduction zones. This community has worked to define research questions specific to the study of exhumed rocks through workshops supported by GeoPRISMS (AGU mini-workshop, 2011; website and communication support) and NSF Petrology and Geochemistry (Goldschmidt workshop, 2013). The community has identified Field Institutes as a way to approach the study of exhumed rocks. The ExTerra Field Institute concept develops a new paradigm for collaborative geological research: collaborative fieldwork to collect materials held communally, broad interactions through workshops, and student exchanges among research laboratories. Each researcher contributes a different analytical expertise in a collaborative effort towards a transformative understanding of dynamic subduction-zone processes. This community is actively working to find venues and resources with which to explore this new paradigm of collaborative research.

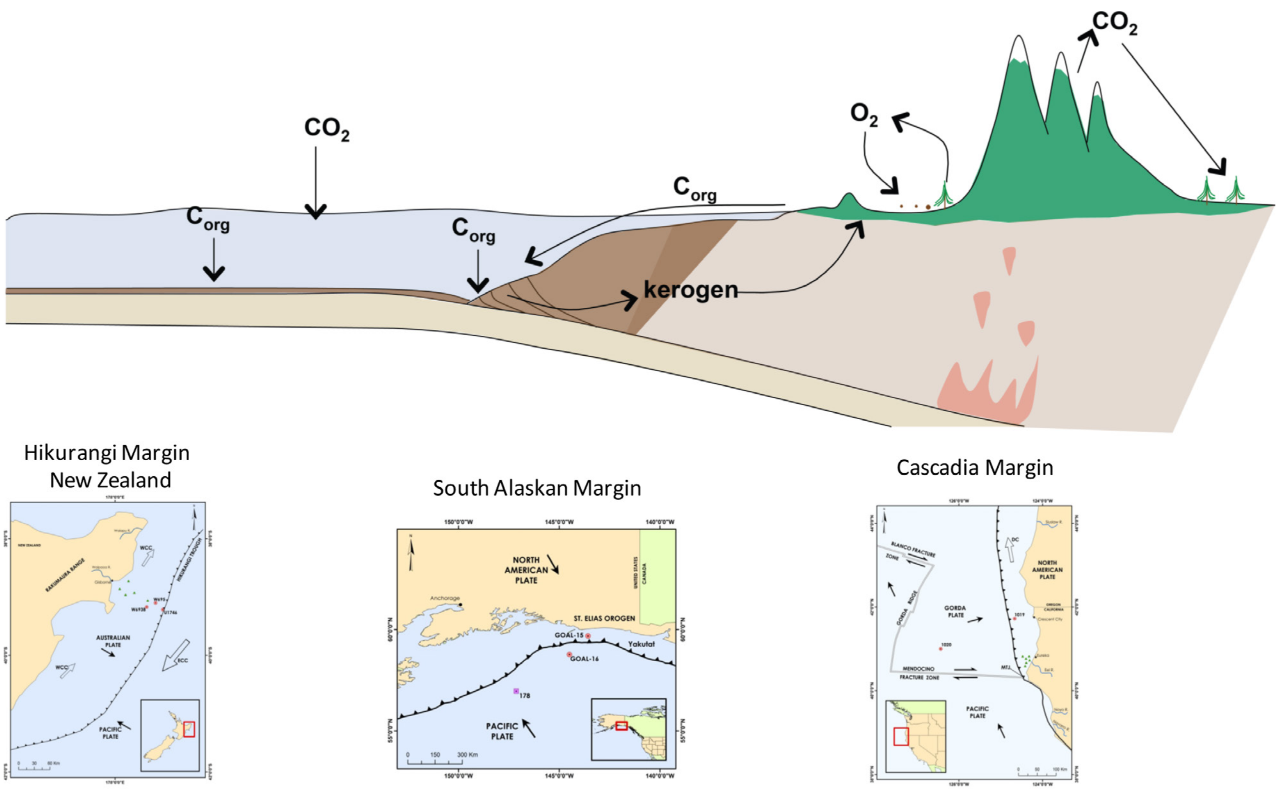


Figure 2.11. The subduction margin carbon cycle and the three SCD study areas.

2.3.4 MARGINS-funded work (2009 and beyond)

Riverine coupling of biogeochemical cycles between land, oceans, and atmosphere - Aufdenkampe et al., 2011.

Terrestrial sources and export of particulate organic carbon in the Waipaoa sedimentary system: Problems, progress and processes, Blair et al., 2010.

Silica gel in a fault slip surface: field evidence for palaeo-earthquakes? - Faber et al., 2014.

The timescales of subduction initiation and subsequent evolution of an oceanic island arc - Ishizuka et al., 2014

Migrating Shoshonitic magmatism tracks Izu-Bonin-Mariana intra-oceanic arc rift propagation - Ishizuka et al., 2010.

Signals of watershed change preserved in organic carbon buried on the continental margin seaward of the Waipaoa River, New Zealand - Leithold et al., 2013.

Record of mega-earthquakes in subduction thrusts: the black fault rocks of Pasagshak Point (Kodiak Island, Alaska) - Meneghini et al., 2010.

The processes of underthrusting and underplating in the geologic record: structural diversity between the Franciscan Complex (California) and the Kodiak Complex (Alaska) and the Internal Ligurian Units (Italy) – Meneghini et al., 2009.

Fore-arc basalts and subduction initiation in the Izu-Bonin-Mariana system - Reagan et al., 2010.

The geology of the southern Mariana fore-arc crust: Implications for the scale of Eocene volcanism in the western Pacific - Reagan et al. 2013.

The influence of crustal strength fields on the patterns and rates of fluvial incision – Roy et al., 2015.

Structural geology of Robben Island: implications for the tectonic environment of Saldanian deformation – Rowe et al., 2010.

Signature of coseismic decarbonation in dolomitic fault rocks of the Naukluft Thrust, Namibia – Rowe et al., 2012a.
Fault rock injections record paleo earthquakes – Rowe et al., 2012b.
Fluid-rich damage zone of an ancient out-of-sequence-thrust, Kodiak Islands, Alaska – Rowe et al., 2009.
Emplacement and dewatering of the world's largest exposed sand injectite complex – Sherry et al., 2012.
To understand subduction initiation, study forearc crust: To understand forearc crust, study ophiolites - Stern et al., 2012
A variably enriched mantle wedge and contrasting melt types during arc stages following subduction initiation in Fiji and Tonga, southwest Pacific - Todd et al., 2012
Heading down early on? Start of subduction on Earth - Turner et al., 2014.
Fluid-rock interaction recorded in black fault rocks in the Kodiak accretionary complex - Yamaguchi et al., 2014.
The 'subduction initiation rule': a key for linking ophiolites, intra-oceanic forearcs, and subduction initiation - Whattam et al., 2011

2.4 Summary of Progress to Date, and Future Directions

The SCD Science Plan is ambitious in scope, reflecting the vital scientific and societal interest in subduction zone processes. The wide community input at the SCD planning workshop identified the outstanding questions that should be studied in the upcoming decade, and it prioritized approaches that could address these questions. Subsequent guidance provided by GSOC to the NSF on further prioritization of projects has settled on a phased primary site approach, but within the Science Plan itself, the consensus has been to encourage competitive proposal submissions that address any of the seven primary SCD questions within this phased primary site approach (Section 2.1). At this midpoint review of SCD, it is apparent that this approach has proven successful, given the wide range of GeoPRISMS studies funded to address these seven research areas. Substantial progress has been made on these seven topical areas because of these GeoPRISMS features: workshops and AGU special sessions that brought investigators together repeatedly; strong leveraging of resources with other NSF and federal and state programs; the establishment of primary sites where existing resources/data were present; and the encouragement of a thematic approach to address questions or topics that could not be completely addressed at just the primary sites.

Because subduction zones are such complex systems, the phased approach for deployment of field experiments at the primary sites has been the optimal method to maximize limited resources. Existing resources in Cascadia (Cascadia Initiative/EarthScope; USGS Volcano Observatory) made this a logical choice for initial focus. SCD field programs here are wrapping up or are ongoing. Of the seven primary SCD questions, all but subduction initiation have been initially addressed in Cascadia. The logistical challenges of working in Alaska-Aleutians (AA) have resulted in many of the campaign-scale geophysical and sampling projects just coming on line. However, the wealth of existing samples collected over decades in the Aleutians has allowed for several geochemical and geochronological questions to be addressed and are guiding future sampling programs. Another key aspect of SCD work in AA that has fostered results on the key questions in the first five years is the leveraging of existing field data in marine geophysics and scientific ocean drilling. Because of the phased approach, the seven SCD questions have yet to be addressed in New Zealand in the GeoPRISMS program. Interaction with New Zealand scientists through a series of well-attended workshops has been key to moving science planning along at this primary site and a proposed International Ocean Discovery Program drilling expedition to the Hikurangi Subduction Margin in FY18 holds promise for addressing several SCD questions. The eventual phasing in of support for work in New Zealand and data collection at the two other primary sites will further the ability to conduct the synthesis studies that require a comparative, synoptic approach.

3. Rift Initiation and Evolution (RIE) Initiative

3.1 Original Goals

Continental rifts and passive margins define the majority of the Earth's coastlines, encompass much of the world's population and hydrocarbon resources, and are vulnerable to irreversible changes induced by long-term climate change and sea-level rise. The overarching objective of the Rift Initiation and Evolution (RIE) initiative is to identify the key processes that drive continental rifting and margin evolution and to determine the parameters and physical properties that control these processes. Rifts are locations where the continental lithosphere is modified by tectonic, magmatic and sedimentary processes; where magmas and fluids are generated and transferred; where climatic and surface processes govern mass transfer and tectonic activity; and where volcanic activity and alteration of mantle rocks result in poorly understood volatile exchange. Continental margins reflect an active interplay of mantle, crustal, and surface processes requiring the system-level, amphibious research approach of the GeoPRISMS program.

The RIE initiative seeks to develop predictive models for the spatial and temporal evolution of rifts and rifted continental margins with a focus on four key questions identified by the GeoPRISMS Science and Implementation Plan:

- Where and why do continental rifts initiate?
- How do fundamental rifting processes, 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?

Several of these questions can only be addressed in areas of active rifting, where rift initiation and the early and intermediate stages of rift evolution can be directly observed and measured. Such investigations are complemented by studies of passive margins, where rifting has gone to completion, and the cumulative history of tectonic, magmatic, isostatic, and surficial processes is preserved. RIE studies emphasize problems that span the temporal and spatial range of rifted margin evolution, including the influence of magmatism and volatile flux on rift evolution, documenting the feedback between surface processes, tectonics, and lithospheric and asthenospheric processes, predicting passive margin evolution from initial rifting processes and conditions, and understanding active processes and associated hazards throughout the entire evolution of rifts.

The community selected two primary sites that represent complementary end-member stages of the rifting process: the active East African Rift System (EARS) and the fully developed Eastern North American Margin (ENAM). The EARS exhibits the entire history of continental rupture, the initiation of border faulting in the south to incipient seafloor spreading in the Afar, whereas the ENAM captures an extensive post-rift evolution of the passive margin sedimentary prism, as well as the cooling and further evolution of the mantle lithosphere below. Both EARS and ENAM capture a diversity of magmatic and mantle influences on the rifting process. The ENAM system in particular encompasses archetypes of fully magmatic rifting adjacent to the southeastern US, as well as magma-limited continental break-up offshore Nova Scotia and Newfoundland. Both systems also span a north-south climatic gradient with resulting diversity in sediment flux and potential tectonic-climate interactions. There are further compelling logistical benefits to each site: ENAM leverages considerable US infrastructure, including EarthScope and the USGS Law of the Sea survey activities, while the intermingling of on-land and lacustrine rift settings in the EARS presents exciting opportunities to intimately connect across the onshore-offshore divide that motivates the scope of GeoPRISMS science.

Several thematic studies are also defined to enable studies of the full temporal evolution of continental rifts, as well as a wider range of rifting parameters. RIE thematic studies are intended to be subsidiary to research that can be carried out at the selected primary sites, but should also complement and complete such investigations. The five themes identified to guide such investigations include:

- Theme 1: Rift obliquity
- Theme 2: Rift processes as functions of strain rate
- Theme 3: Volatiles in rift zone processes
- Theme 4: Sediment production, routing and transport during and after rifting
- Theme 5: Discrete events at rifted margins

3.2 Major Accomplishments

3.2.1 The Eastern North American Margin (ENAM) Primary Site

As a mature passive continental margin, the east coast of North America represents a prime site to investigate rifting processes that have gone to completion, as well as post-rifting evolution. From a logistical point of view, GeoPRISMS-supported activities in ENAM have been enhanced by leveraging other data collection efforts, particularly through the USArray components of EarthScope providing extensive seismic and magnetotelluric data sets. The joint GeoPRISMS-EarthScope implementation workshop held at Lehigh University in October 2011 identified three major geographical focus areas within ENAM as priorities for focused research efforts in the northern, central, and southern portions of the margin. To date, there have been three GeoPRISMS-funded projects that have focused on the central and southern portion of the margin: a major community-led effort to collect a suite of onshore & offshore geophysical data within ENAM; a multidisciplinary project to study mantle dynamics, lithospheric structure, and topographic evolution of the southeastern US continental margin; and a geochemical and petrological investigation of Eocene basalts in Virginia and West Virginia. In addition to these GeoPRISMS-funded efforts, there have been a number of projects funded via other NSF programs and, in many cases, enabled by the collection of EarthScope data, that have yielded insights into the science questions posed in the GeoPRISMS science and implementation plans.

The ENAM Community Seismic Experiment (ENAM CSE; see nugget by van Avendonk et al.) is an ambitious effort to collect a suite of seismic data, designed for imaging structures over a range of spatial scales, with completely open data access that can be used by the community to address a wide spectrum of GeoPRISMS (and EarthScope) science questions. The ENAM CSE was executed by a diverse team of twelve PIs at eight different institutions, acting on behalf of the community. Plans for data collection were shaped by community input beginning at the 2011 ENAM implementation workshop and continuing through a series of straw polls, AGU workshops, and other opportunities for community feedback. It is important to note that funding for the ENAM CSE included support for data collection, but not for scientific investigations using the data; the intention is that individual PIs will write follow-up proposals to use the CSE data for GeoPRISMS-related investigations. An important aspect of the CSE is the effort to involve young scientists (students, postdocs, and early-career investigators) in the acquisition of a diverse onshore/offshore, active/passive dataset and to provide training in data collection, analysis, and interpretation through a series of workshops (see nugget by Shillington et al.). This project already has had significant impact on student and postdoc training (as will be discussed in Chapter 5).

The ENAM CSE data collection effort (Figure 3.1) included a number of components, designed to allow for multiscale imaging of crustal and lithospheric structure and stacked geomorphological features over a shoreline-crossing footprint. The passive source data acquisition included the deployment of 30 broadband ocean bottom seismometers (OBS) in spring 2014 and their recovery in 2015 aboard the R/V Endeavor (Figure 3.2), along with the deployment of three onshore broadband seismometers

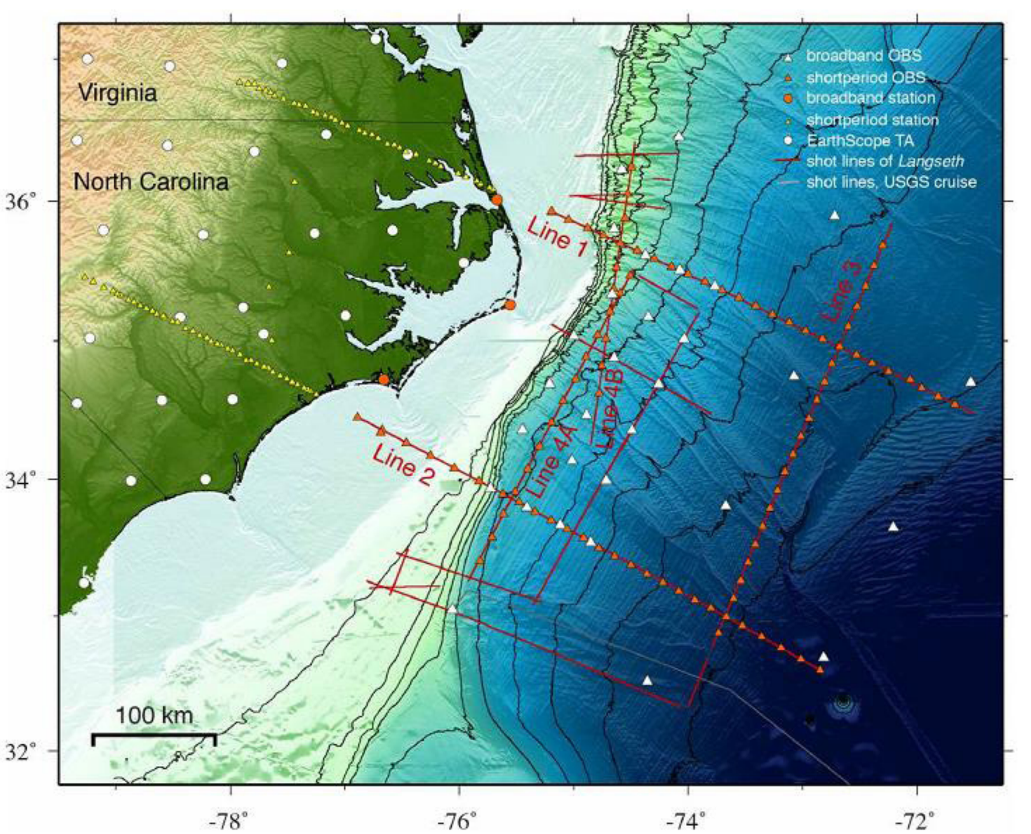


Figure 3.1. Map of ENAM CSE deployment. Broadband OBS instruments (white triangles) were deployed in April 2014 and recovered in April 2015 aboard the R/V Endeavor. Broadband onshore stations on the Outer Banks (orange circles) operated between May 2014 and May 2015. Orange triangles indicate short-period OBS stations deployed and recovered during September-October aboard the R/V Endeavor. Red lines indicate shot lines for the active source seismic program on the R/V Langseth in September-October 2014; those shots were also recorded on land (short period stations shown with yellow triangles). Active source refraction lines were shot on land during summer 2015.

Figure 3.2. OBS deployment by ENAM CSE crew working on the R/V Endeavor. Photo by Gary Linkevitch.

on the Outer Banks of North Carolina. Offshore active source data were collected in September-October 2014 with the R/V Langseth, which shot refraction profiles that were recorded on short-period OBS instruments deployed by the R/V Endeavor. The Langseth also acquired multi-channel seismic (MCS) data along both the primary transects and shorter ancillary lines, allowing for the detailed imaging of shallow (up to ~1 km) structure. The Fall 2014 offshore shots were also recorded with short-period instruments deployed onshore. Finally, an active source experiment was carried out on land in June 2015, with a series of 11 on-land shots recorded on ~1400 Texans. All data from the experiment have been (or soon will be) made publicly available via data portals such as the IRIS Data Management Center (DMC).

The Mid-Atlantic Geophysical Integrative Collaboration (MAGIC; see nugget by Long et al.) is a multidisciplinary project funded jointly by GeoPRISMS, EarthScope, and the Geomorphology and Land Use Dynamics programs of NSF. It is focused on understanding the structure and dynamics of the mid-Atlantic Appalachians and involves a collaboration among seismologists, geodynamicists, and geomorphologists. The scientific goals of MAGIC focus on the evolution of the margin through multiple episodes of orogenesis and rifting. Although ENAM has been a passive continental margin for nearly 200 Ma, the eruption of basalts during the Eocene (Mazza et al., 2014) and the likely rejuvenation of topography during the Neogene (Miller et al., 2013) provide evidence for its relatively recent modification, perhaps connected to processes in the deep mantle. MAGIC involves the deployment of 28 broadband seismometers in a dense linear transect from Charles City, VA to Paulding, OH, with data collection beginning in late 2013 and continuing until late 2016 (Figure 3.2). The geodynamical modeling effort focuses on quantitatively testing hypotheses for the pattern of mantle flow beneath eastern North America (e.g., Long et al., 2010) using 3-D, time-dependent, numerical models. Predictions from these models of seismic anisotropy and dynamic topography will be tested against observations from the seismology and geomorphology components of the project. The geomorphology component uses quantitative stream profile data and cosmogenic isotopes to understand past and present erosion rates, and to identify regional patterns in transient topographic change whose association with crustal and/or mantle features might illuminate the causes of topographic rejuvenation. The seismic deployment involves a substantial education and outreach component to primarily undergraduate colleges and universities in the MAGIC field area (see nugget by Long and Benoit).

A third GeoPRISMS-funded project in the central corridor of ENAM is a geochemical and petrological study of Eocene magmatic rocks in the Valley and Ridge province of Virginia and West Virginia, near the city of Harrisonburg (Figure 3.3, Mazza et al., Geology 2014; see nugget by Gazel et al.). The Eocene magmatic event provides a direct window into the composition and structure of ENAM upper mantle and furnishes a complementary view to that of geophysical data. To date this project has yielded $^{40}Ar/^{39}Ar$ ages, geochemical data, and radiogenic isotope measurements that constrain the likely processes that produced a pulse of magmatism ~150 Myr after rifting. Application of a geothermobarometer to the measured chemical composition of basalt samples yielded temperature and pressure estimates of ~1410°C and ~2.3 GPa, respectively, which are conditions close to the dry peridotite solidus (Mazza et al., 2014). The inferred temperatures are slightly higher than would be expected for ambient mantle melting at a ridge, but not as high as would be expected for a mantle plume. Isotopically, Eocene ENAM samples resemble the signatures of Atlantic hotspots, suggesting that the

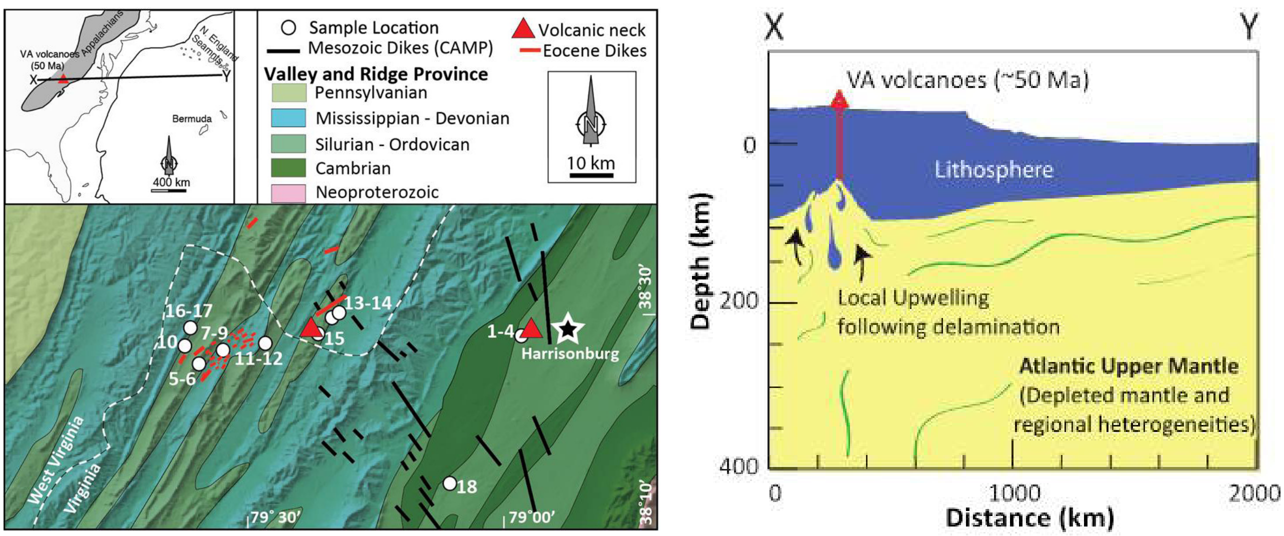


Figure 3.3. From Mazza et al. (2014). Left: Simplified geologic map showing sample locations of Eocene magmas, along with the (contrasting) orientations of Mesozoic Central Atlantic Magmatic Province (CAMP) dikes and Eocene dikes. Right: Schematic model of melting mechanism by lithospheric delamination and possible mantle sources of Virginia volcanoes. Line of cross-section X-Y is shown in map at left.

Atlantic upper mantle may have been homogenized via large-scale dissemination of mantle material following the opening of the Atlantic. Mazza et al. (2014) suggest that a lithospheric delamination event may have triggered asthenospheric upwelling and melting to form the ENAM Eocene magmas; ongoing analyses of geophysical data from USArray (including the MAGIC experiment, which includes 5 stations deployed within ~25 km of the Eocene magmatic rocks) will provide additional observations to constrain this hypothesis.

In addition to these three GeoPRISMS-funded projects, a number of ongoing research initiatives in the ENAM region are synergistic with GeoPRISMS projects. For example, tomographic models that include data from Transportable Array stations on the East Coast are revealing intriguing features in the upper mantle, including a pronounced low-velocity zone beneath the Eocene volcanics (Figure 3.4; Schmandt and Lin, 2014). A number of PI-driven Flexible Array deployments funded by the EarthScope program are exploring science questions encompassed by the ENAM science and implementation plans. This includes i) SESAME (PIs Fischer, Hawman, Wagner and Forsyth); ii) SUGAR (PI Shillington), which crosses the Suwanee Suture and the South Georgia Rift Basin; iii) the Quebec-Maine Transect (PIs Menke, Levin, Darbyshire, Forte and Hynes) in the northern ENAM corridor identified in the GeoPRISMS implementation plan, and iv) the planned collection of magnetotelluric data along the MAGIC line.

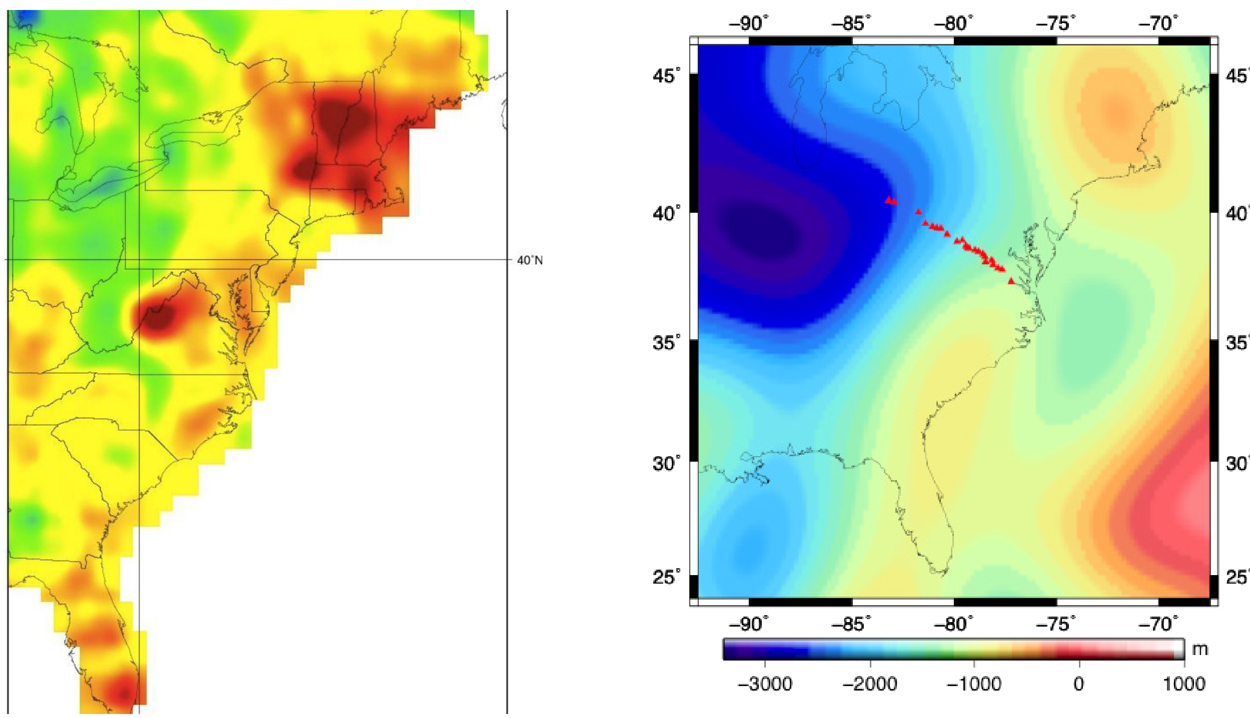


Figure 3.4. Left: Tomographic image of S wave velocities in the upper mantle at a depth of 125 km, from the model of Schmandt & Lin (GRL, 2014). Pronounced low velocity anomalies are visible beneath the Eocene volcanics in Virginia (Mazza et al., 2014) and beneath New England. Figure generated using the IRIS DMC Earth Model Collaboration viewer. Right: Predicted dynamic topography obtained by converting S40RTS velocities (Ritsema et al., 2011) to density and predicting resulting mantle flow. The red triangles indicate the stations in the MAGIC deployment (from nugget by King et al.).

3.2.2 The East Africa Rift System (EARS) Primary Site

GeoPRISMS research at the East African Rift System (EARS) Primary Site launched after the EARS Implementation Planning Workshop in October 2012. The phased funding model allowed for funding opportunities for large field projects only for FY14 and FY15. To date only a few projects have been funded, although related projects have built upon ongoing efforts supported through NSF and NASA (discussed in 3.2.2.1).

EARS exhibits a wide variety of rift processes and characteristics, making it an ideal target for GeoPRISMS goals. Aspects of all of the four key rift initiation and evolution (RIE) questions defined in the GeoPRISMS draft science plan can be addressed in part or entirely in this primary site, given the great variety of rift processes and characteristics expressed in this setting. Proposed GeoPRISMS research at this primary site is organized around the primary focus area of the Eastern Rift, which encompasses the rift from the Tanzanian divergence in the south to Lake Turkana and southern Ethiopia to the north. It also has several secondary focus areas in the Afar and Main Ethiopian Rift, and the Western Rift and SW branch, in which collaborative and international efforts could be leveraged (Figure 3.5). Synoptic investigations across the entire rift are also deemed important and will help to constrain and characterize the consequences of rift-wide variations in the origin, composition, and timing of volcanism, the rate and distribution of strain along and across the rift systems and large scale pre-rift structure and dynamics underpinning the rift system. Components of EARS science thus could include broad and open data assimilation efforts, strategic infilling of climatic, geochemical, and geophysical observations, and modeling and experimental work, which would provide a framework for the focused investigations along the rift.

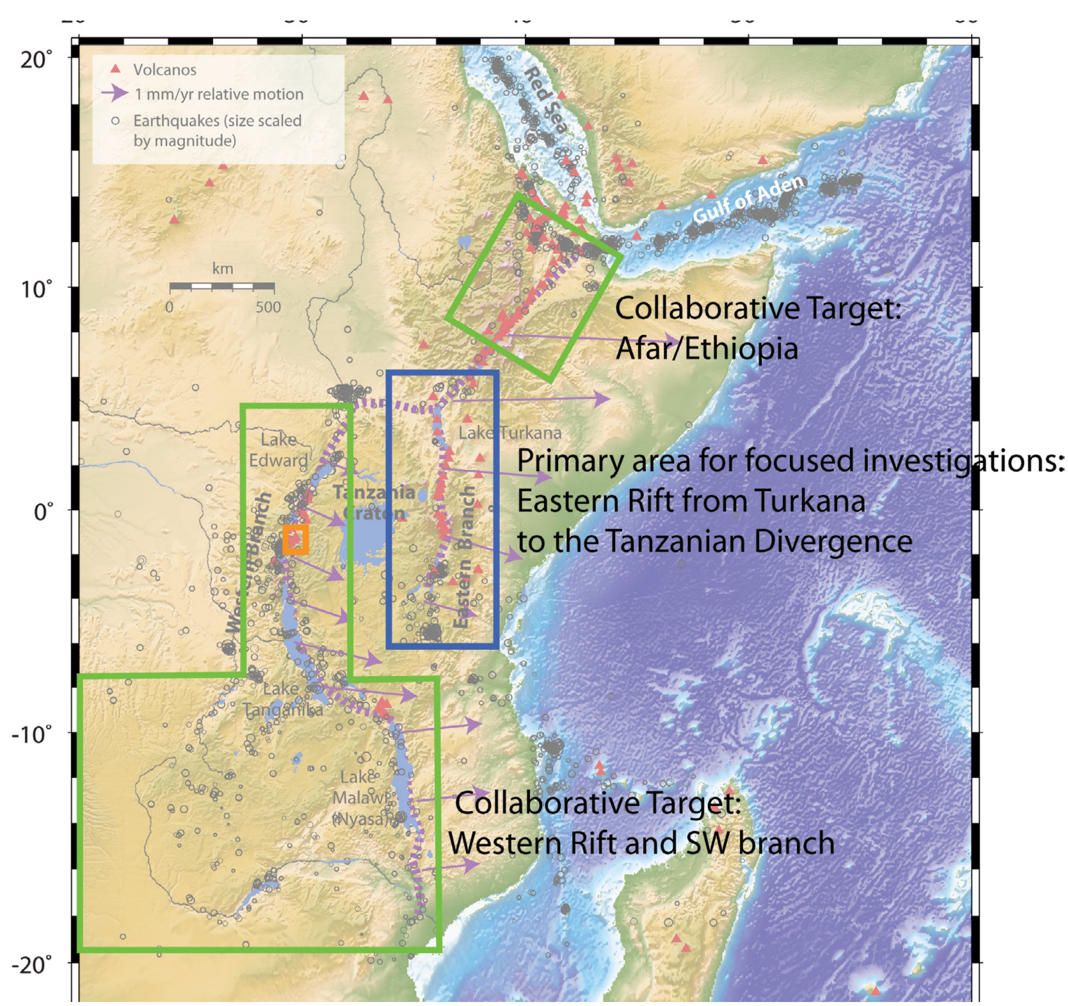


Figure 3.5. A map of the East African Rift System (EARS) highlighting the primary focus area and the collaborative targets of opportunity (from GeoPRISMS Implementation Plan).

The earliest project funded for the EARS Primary Site was to PIs Gaherty, Shillington, Pritchard, and Nooner. In this project a rare 2009 sequence of earthquakes in the northern Malawi rift valley and the associated geodetic response was analyzed (Figure 3.6; see nugget by Gaherty et al.). The Karonga events are far removed from the border fault and instead appear to have taken place on one or several previously unknown shallow hanging wall faults. There is no evidence for magmatic control on earthquake occurrence. The conclusions of this study have significant implications for earthquake hazards in this setting. The project engaged the Malawi Geological Survey Department in both data collection and research. It also led to Malawi government funding of the country's first national seismic network.

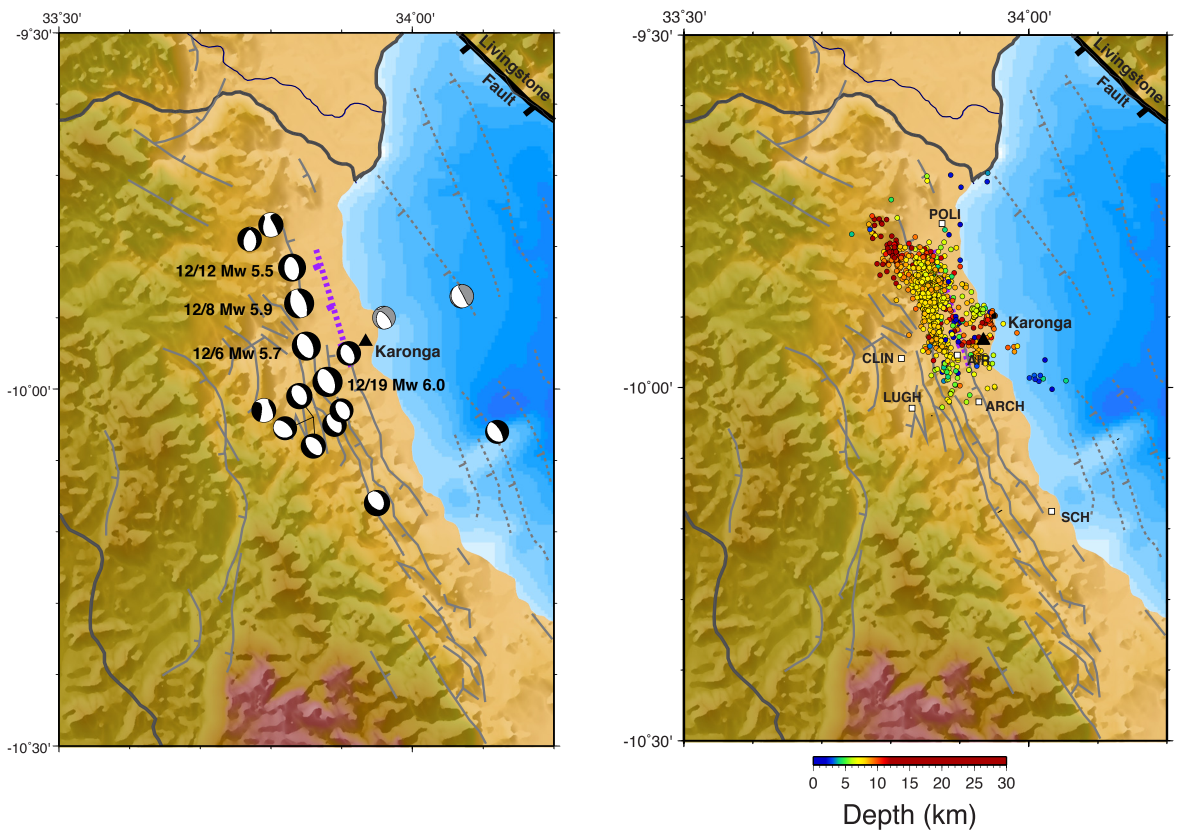


Figure 3.6. Left: Focal mechanisms of the largest 17 events of the 2009-2010 Karonga sequence. Surface projection of the buried St. Mary's fault, inferred from InSAR, is shown with purple line. Fault locations from PROBE and geologic data shown in grey lines. Right: Epicenters of ~1000 aftershocks relocated using HypoDD, with depth shown by color. The earthquake distribution north of Karaonga is consistent with events on the west-dipping St. Mary's fault. The earthquakes beneath and south of Karonga earthquake clusters suggest multiple west-dipping faults.

A one-year project begun in 2014 (see nugget by Bendick and King), encompasses two activities: deployment of new GPS stations across the presumed actively spreading region of the Turkana Depression and compilation and analysis of existing geodetic data over all of East Africa to develop a community velocity model. This latter effort will facilitate systematic comparisons of different structural rift segments, providing a synoptic framework for other active tectonics research in the area. This effort is still underway and results are not yet available.

A new project for FY15 to PI Mittelstaedt supporting postdoc Sybrandt (see nugget by Mittelstaedt) will use coupled laboratory and numerical experiments to quantitatively assess the contribution of both melt production and melt extraction processes on the distribution of volcanic activity along the three main branches of the actively spreading East African Rift System. Initial work has been focused on determining appropriate modeling fluids and laboratory set-ups; modeling work will start this fall.

3.2.2.1 Related work at the East African Rift System

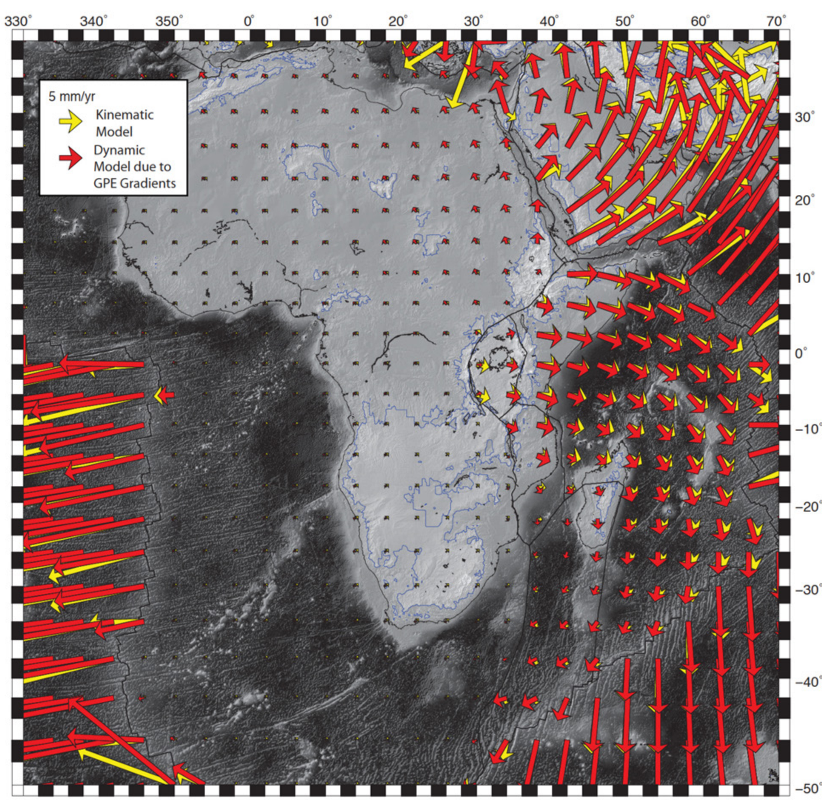
Recent advances in our understanding of the RIE East Africa primary site have also come from projects funded through NSF (including EAR Core and the Continental Dynamics program) and NASA. This work features many of the PIs who have been active in the RIE community and lays the groundwork for upcoming field deployments in the EARS.

Plate motions across East Africa derived from permanent GPS stations within the Africa Array and temporary GPS stations deployed over several decades have now been modeled as part of an EAR postdoctoral fellowship to PI Stamps to constrain the driving forces responsible for present-day rifting. The models show that density variations within the lithosphere are enough to explain current rifting velocities, but rift initiation would have required an additional source of forcing or lithospheric weakening (Stamps et al., 2014).

From a grant funded by the NASA Planetary Geology and Geophysics program in 2011, PI Rooney and others have studied the distribution of volcanism in the Central Main Ethiopian Rift and its relationship with lithospheric structures (Figure 3.9). Results from this project show that the transition from mechanical thinning towards magmatic intrusion may be more protracted than originally predicted and that pre-existing lithospheric structures may control the intrusion of magma into the lithosphere (Rooney et al., 2014).

From a collaborative award made through the NSF Tectonics program in 2011, PIs Ebinger, Kattenhorn, Roecker and Fischer examined the role of magma and

Figure 3.8. Measured vs. modeled GPS velocities across Africa, showing that velocities can be largely explained by gravitational potential energy (Stamps et al., 2014).



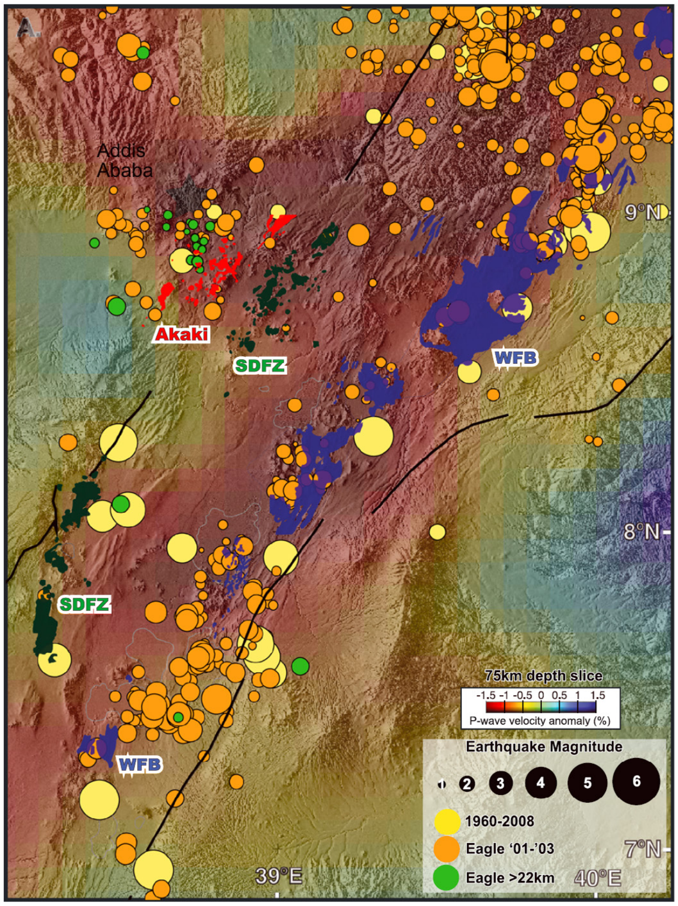


Figure 3.9. Region of the Central Main Ethiopian Rift (border faults shown as black lines) showing the distribution of Pliocene-Quaternary volcanism of the Akaki Magmatic Zone, Silti Debre Zeyit Fault Zone (SDFZ), and Wonji Fault Belt (WFB) overlain on topography. Also shown are earthquakes and their magnitudes recorded in the region. Color background represents P wave velocity anomalies at 75 km in the region of study. The Akaki Magmatic Zone and adjacent northern SDFZ lie above a very pronounced low velocity seismic anomaly that continues broadly along the rift axis to the south. See Rooney et al., (2014) for details and citations.

related fluids in early stage rifting within the focus site. Early results from this project show that the mechanism of upper crustal extension varies with rift maturity such that in early-stage rifts, upper crustal dikes are not a significant mechanism for accommodating extension, as they are confined to areas in and around transfer zones. In contrast more evolved rift basins exhibit more rift-parallel dikes and thus accommodate upper crustal extension by diking along the full length of the basin (Muirhead et al., 2015).

An award from the NSF Petrology & Geochemistry program in 2010 to PI Hilton and others has been used to examine noble gas characteristics along the East African Rift system. Results of this work indicate the potential of a common mantle plume source along the entire rift system (Halldorsson et al., 2014). A study of noble gases, H_2O and CO_2 in basalts from the Gulf of Aden, funded by NSF Marine Geology and Geophysics in 2013 to PIs Graham and Michael, has resulted in new constraints on the composition of the regional lithospheric mantle (Sgualdo et al., 2015).

Through an award made through the NSF Tectonics program in 2011, PIs Bendick, Keranen, and Flesch have been examining how extension may be accommodated beyond the confines of the defined rift valley in Ethiopia. Results to date (Kogan et al., 2012) have suggested that lithospheric extension may be accommodated over a significantly greater area than is occupied by the rift valley.

The earliest stages of continental extension in EARS are under investigation with funding from a grant from the NSF Continental Dynamics program in 2011 to PIs Buck, Gao, Harder, Canales, and Atekwana. In a recent publication by Leseane (2015) it is hypothesized that strain localization at continental rift initiation could be achieved through fluid-assisted lithospheric weakening without asthenospheric involvement.

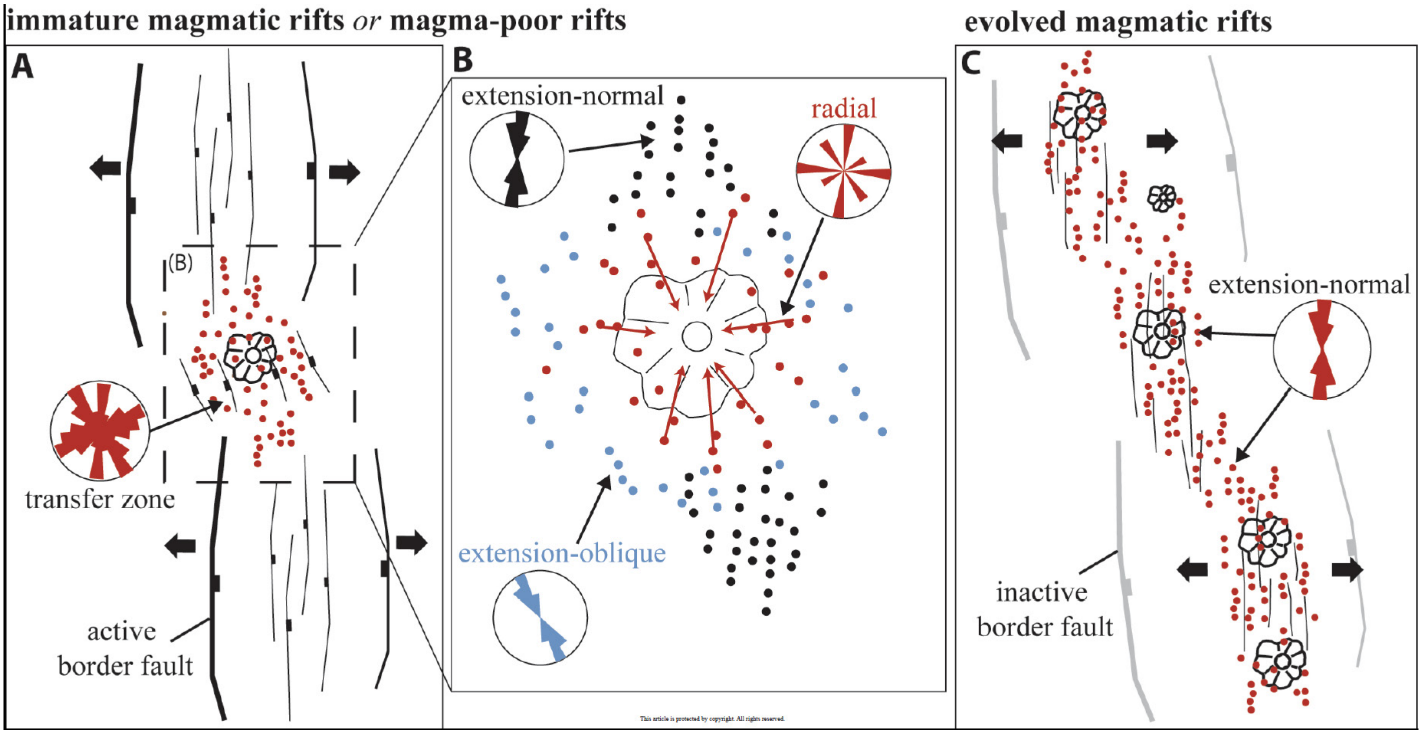


Fig. 3.10. Results of Muirhead et al., (2015) showing the relationship between strain accommodation and diking. A: In immature magmatic rifts and magma-poor rifts. B: The range of cone trends distributed within transfer zones in immature magmatic rifts and magma-poor rifts. C: Distribution of extension-normal cone lineament trends along evolved magmatic rifts.

3.2.3 Thematic Studies of Rifting and Passive Margins

To date, the GeoPRISMS program has funded one thematic study in RIE that is not aimed at a particular primary site. PI Straub focused on the stratigraphic evolution of passive margins (see nugget by Straub). This work aims to understand the evolution of deltas and in particular how the cycles of relative sea level (RSL), itself a function of climate and tectonics, are stored in deltaic stratigraphy. This project encompasses laboratory experimental work (Figure 3.11) that demonstrates that RSL cycles with magnitudes and periodicities less than the spatial and temporal scales of the internal (autogenic) dynamics of deltas cannot be extracted from the physical stratigraphic record of passive margins. The set of experiments carried out under this project defines quantitative limits on the range of paleo-RSL information that can be extracted from passive margin stratigraphy, which could aid the prediction of deltaic response to climate change. Results from this work (Kim et al., 2014; Armstrong et al., 2014) will play a role in placing quantitative limits on the fidelity of the stratigraphic record at passive margins.

A small number of other GeoPRISMS- and late MARGINS-funded projects from Appendix A1 should also have provided updates on thematic studies, but we have not been able to describe these due to lack of contributed nuggets or results in the primary literature.

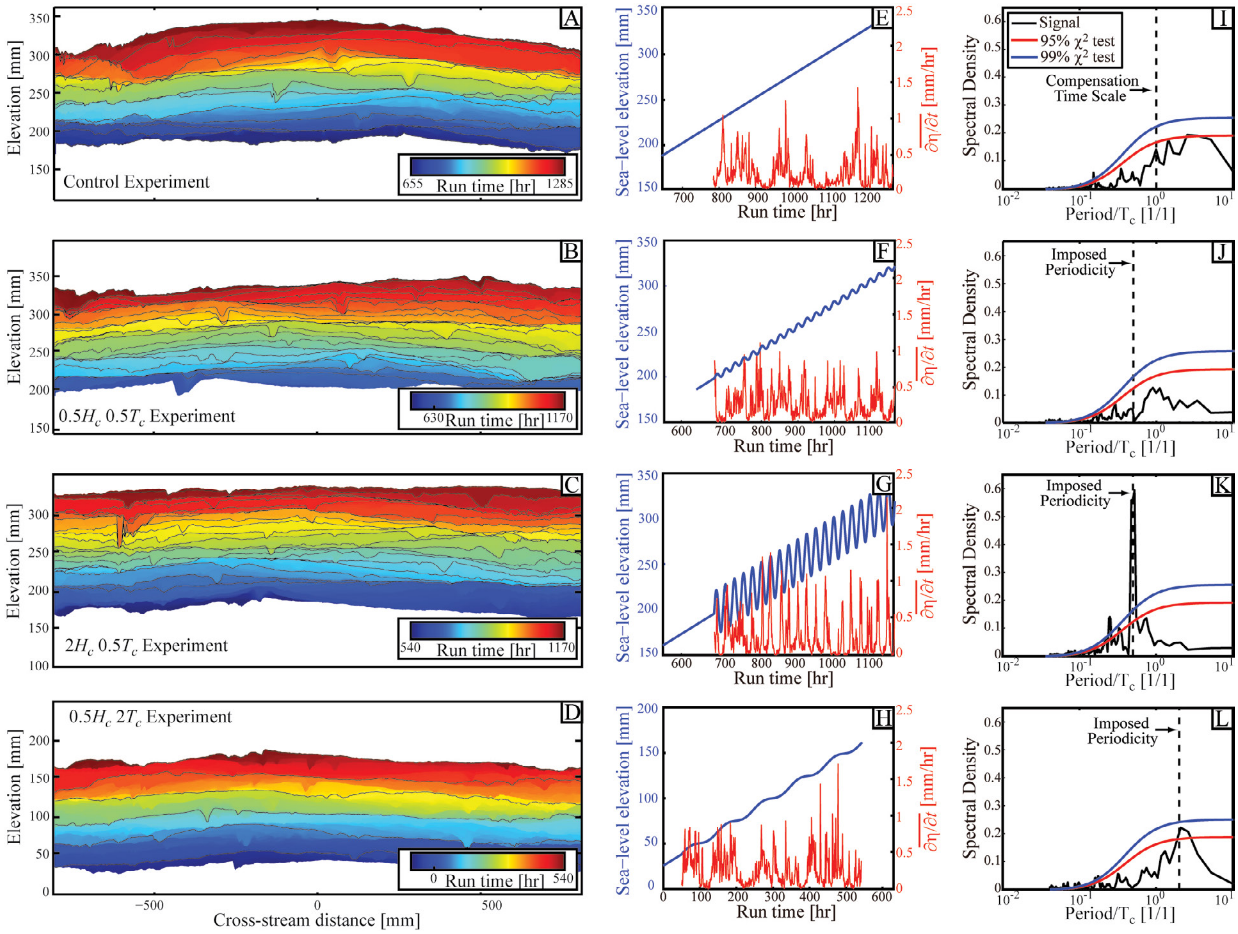


Figure 3.11 (courtesy of Kyle Straub). Time series analysis of mean deposition rate calculated from preserved stratigraphy for all experimental deltas with comparison to sea level time series. A-D) Synthetic stratigraphy. Solid black lines represent time horizons; in B-D the lines demarcate the start of each RSL cycle. E-H) Sea level and mean deposition rate time series along proximal transects; I-L) Power spectra of mean deposition time rate series (with c2 confidence limits).

3.3 Summary of Progress to Date and Future Directions

The highly successful ENAM CSE data collection effort has resulted in high-quality datasets, suitable for imaging structure across a range of scales and interrogating a range of processes in a single shoreline-crossing footprint, that are now publicly available. While the science that takes advantage of this unique dataset for the most part remains to be carried out, the data are now in place within the central part of ENAM to address the full suite of science goals articulated by the GeoPRISMS implementation plan, including those related to tectonic inheritance, the role of magmatism in rifting, along-strike segmentation of rifting processes, controls on offshore landslides, and post-rift evolution from the surface to the deep mantle. Geochemical and petrological study of the ENAM Eocene volcanics is yielding new clues about the post-rifting evolution of the passive margin and the links between deep mantle processes and the surface. Multidisciplinary projects such as MAGIC, which combines constraints from seismology, geodynamics, and geomorphology and which complements the geochemical and petrological investigations of the ENAM Eocene volcanics, are integrating constraints across disciplines to address GeoPRISMS science goals. In general, efforts to take advantage of synergies between ENAM GeoPRISMS initiatives and those of other programs and agencies, particularly EarthScope, have been successful. It is important to note, however, that science investigations using the ENAM CSE data are only just getting underway. Furthermore, ENAM projects funded by GeoPRISMS to date have focused exclusively on the central portion of the margin, with comparatively little attention paid so far to the southern ("Charleston corridor") and northern ("Nova Scotia corridor") focus areas.

In comparison to ENAM, GeoPRISMS efforts in the EARS primary site are somewhat less developed. Numerical and analog modeling aimed at understanding the regular spacing of volcanic centers within EARS is in its very early stage. New constraints on faulting in early-stage rifts have been obtained from the study of the unusual earthquake sequence in northern Malawi using seismic and InSAR data. In terms of new data collection, efforts in EARS are building on several projects that are funded by other NSF programs. Some new GPS data has been collected, and a new community GPS velocity model for East Africa has been produced, constraining the kinematics of extension. According to the phased funding schedule, proposals for large data collection efforts were scheduled to be accepted for the summer 2015 proposal competition and we expect significant future work on major data collection efforts in EARS.

We anticipate that key RIE efforts over the remaining years of the GeoPRISMS Program will entail detailed analysis and interpretation of the rich ENAM data sets and acquisition and analysis of focused data sets (including field studies) in EARS. Synthesis and integration within and across the two primary sites will be critical to achieving the goals of the RIE initiative, in particular, comparison between the early stages of rifting (EARS) and mature rifting (ENAM). Experimental and numerical investigations will probably play a significant role in this latter analysis.

3.3.1 RIE: Related GeoPRISMS-funded publications

Influence of growth faults on coastal fluvial systems: Examples from the late Miocene to Recent Mississippi River Delta - Armstrong et al., 2014
Galicia bank ocean-continent transition zone: new seismic reflection constraints – Dean et al., 2015.
Active features along a 'passive' margin: the intriguing interplay between Silurian-Devonian stratigraphy, Alleghanian deformation, and Eocene magmatism of Highland and Bath Counties, Virginia – Haynes et al., 2014.
Investigating the autogenic process response to allogenic forcing - Kim et al., 2014
Volcanoes on the passive margins: the youngest magmatic event in eastern North America – Mazza et al., 2014.
The Cryogenian intra-continental rifting of Rodinia: evidence from the Laurentian margin in eastern North America – McLellan and Gazel, 2014.
Influence of water and sediment supply on the stratigraphic record of alluvial fans and deltas: process controls on stratigraphic completeness – Straub and Esposito, 2013.

3.3.2 RIE: Related MARGINS-funded publications (2009 and beyond)

Modern sediment dispersal and accumulation on the outer Poverty continental margin – Alexander et al., 2010.
Geodetic constraints on present-day motion of the Arabian plate: implications for Red Sea and Gulf of Aden rifting – ArRajehi et al., 2010.
Oblique rifting ruptures continents: example from the Gulf of California shear zone – Bennett and Oskin, 2014.
Transtensional rifting in the proto-Gulf of California near Bahia Kino, Sonora, Mexico – Bennett et al., 2013.

How sediment promotes narrow rifting: application to the Gulf of California – Bialas and Buck, 2009.
How much magma is required to rift a continent? – Bialas et al., 2010.
New insights into deformation along the North America-Pacific plate boundary from Lake Tahoe, Salton Sea and southern Baja California – Brothers, 2009.
Tectonic evolution of the Salton Sea inferred from seismic reflection data – Brothers, 2009.
Estimation of the spectral parameter kappa in the region of the Gulf of California, Mexico – Castro and Avila-Barrientos, 2015.
Location of moderate-sized earthquakes recorded by the NARS-Baja array in the Gulf of California region between 2002 and 2006 – Castro et al., 2011.
The long lasting aftershock series of the 3 May 1887 Mw 7.5 Sonora earthquake in the Mexican Basin and Range Province – Castro et al., 2010.
Geometry and Quaternary slip behavior of the San Juan de los Planes and Saltito fault zones, Baha California Sur, Mexico – Coyan et al., 2013.
Late Oligocene to middle Miocene rifting and synextensional magmatism in the southwestern Sierra Madre Occidental, Mexico: the beginning of the Gulf of California rift – Ferrai et al., 2013.
Report on the August 2012 Brawley earthquake swarm in Imperial Valley, Southern California – Hauksson et al., 2013.
The 2010 Mw 7.2 El Mayor-Cucupah earthquake sequence, Baja California, Mexico and Southernmost California, USA: Active seismotectonics along the Mexican Pacific margin – Hauksson et al., 2011.
Late Pleistocene cyclicity of sedimentation and spreading-center structure in the Central Gulf of California – Kluesner et al., 2014.
Lithospheric strength and strain localization in continental extension from observations of the East African Rift - Kogan et al., 2012.
Frequency-dependent shear wave splitting and heterogeneous anisotropic structure beneath the Gulf of California region – Long, 2010.
Thick deltaic sedimentation and detachment faulting delay the onset of continental rupture in the northern Gulf of California: analysis of seismic reflection profiles – Martin-Barajas et al., 2013.
Kinematics of the southern Red Sea – Afar triple junction and implications for plate dynamics – McClusky et al., 2010.
Viscous dissipation, slab melting, and post-subduction volcanism in south-central Baja California, Mexico – Negrete-Aranda et al., 2013.
Seismic evidence of a ridge-parallel strike-slip fault off the transform system in the Gulf of California – Ortega and Quintanar, 2010.
A comparison between P-wave and S-wave propagation characteristics in the southern part of the Gulf of California, Mexico – Ortega and Quintanar, 2011.
Rayleigh wave dispersion measurements reveal low-velocity zones beneath the new crust in the Gulf of California – Persaud et al., 2015.
(U-Th)/He zircon and archaeological ages for a late prehistoric eruption in the Salton Trough (California, USA) – Schmitt et al., 2013.
Oceanic magmatism in sedimentary basins of the northern Gulf of California rift – Schmitt et al., 2013.
The mechanisms of earthquakes and faulting in the Southern Gulf of California – Sumy et al., 2013.
Middle Miocene to early Pliocene oblique extension in the southern Gulf of California – Sutherland et al., 2012.
Why did the Southern Gulf of California rupture so rapidly? Oblique divergence across hot, weak lithosphere along a tectonically active margin – Umhoefer, 2011.
Late Quaternary faulting history of the Carrizal and related faults, La Paz region, Baja California Sur, Mexico – Umhoefer et al., 2014.
An attenuation study of body waves in the South-Central Region of the Gulf of California, Mexico – Vidales-Basurto et al., 2014.
Convective upwelling in the mantle beneath the Gulf of California – Wang et al., 2009.
Seismic tomography in the crust and upper mantle of the Gulf of California region – Wang et al., 2012.

Geodynamics of the Gulf of California from surface wave tomography – Zhang and Paulssen, 2012.
3D shear velocity structure beneath the Gulf of California from Rayleigh wave dispersion – Zhang et al., 2009.

3.3.3 Other S2S/RCL MARGINS-funded publications (2009 and beyond)

Storm and fair-weather driven sediment transport within Poverty Bay, New Zealand, evaluated using coupled numerical models – Bever and Harris, 2010.
Hydrodynamics and sediment transport in the nearshore of Poverty Bay, New Zealand: observations of nearshore sediment segregation and oceanic storms – Bever et al., 2011.
A 1-D mechanistic model for the evolution of earthflow-prone hillslopes – Booth and Roering, 2011.
Topographic signatures and a general transport law for deep-seated landslides in a landscape evolution model – Booth et al., 2013.
Restoration of the contact surface in FORCE-type centered schemes II: non-conservative one- and two-layer two-dimensional shallow water equations – Canestrelli and Toro, 2012.
A mass-conservative centered finite volume model for solving two-dimensional two-layer shallow water equations for fluid mud propagation over varying topography and dry areas – Canestrelli et al., 2012.
One-dimensional numerical modeling of the long-term morphodynamic evolution of a tidally-dominated estuary: the lower Fly River (Papua New Guinea) – Canestrelli et al., 2014.
Quantifying temporal variations in landslide-driven sediment production by reconstructing paleolandscapes using tephrochronology and lidar: Waipaoa river, New Zealand – Cerovski-Darriau et al., 2014.
A numerical exploration of time and frequency-domain marine electromagnetic methods for hydrocarbon exploration in shallow water – Connell and Key, 2013.
Formation and preservation of sedimentary strata from coastal events: insights from measurements and modeling – Corbett et al., 2014.
Variable styles of sediment accumulation impacting strata formation on a clinoform: Gulf of Papua, Papua New Guinea – Crockett et al., 2009.
The influence of sea level and tectonics on late Pleistocene through Holocene sediment storage along the high-sediment supply Waipaoa continental shelf – Gerber et al., 2010.
Chute channel dynamics in large, sand-bed meandering rivers – Grenfell et al., 2012.
Sediment transport and event deposition on the Waipaoa river shelf, New Zealand – Hale et al., 2014.
Sediment accumulation patterns and fine-strata formation on the Waiapu River shelf, New Zealand – Kniskern et al., 2010.
Characterization of a flood-associated deposit on the Waipaoa river shelf using radioisotopes and terrigeneous organic matter abundance and composition – Kniskern et al., 2014.
Exploring the transfer of Earth materials from source to sink – Kuehl and Nittrouer, 2011.
Steady state reach-scale theory for radioactive tracer concentration in a simple channel/floodplain system – Lauer and Willenbring, 2010.
Shelf sedimentation on a tectonically active margin: a modern sediment budget for Poverty continental shelf, New Zealand – Miller and Kuehl, 2010.
Thick evaporites and early rifting in the Guaymas Basin, Gulf of California – Miller and Lizarralde, 2012.
A hydrodynamic and sediment transport model for the Waipaoa Shelf, New Zealand: sensitivity of fluxes to spatially-varying erodibility and model nesting – Moriarty et al., 2014.
Recent sedimentation patterns and facies distribution on the Poverty Shelf, New Zealand – Rose and Kuehl, 2010.
Siliciclastic influx and burial of the Cenozoic carbonate system in the Gulf of Papua – Tcherepanov et al., 2010.
Spatial and temporal variability in sediment deposition and seabed character on the Waipaoa River margin, New Zealand – Walsh et al., 2014.
Understanding fine-grained river-sediment dispersal on continental margins – Walsh and Nittrouer, 2009.
Coastal progradation and sediment partitioning in the Holocene Waipaoa sedimentary system, New Zealand – Wolinsky et al., 2010.

4. Program Management

The GeoPRISMS Program is a combination of a funding opportunity, which is managed jointly by the NSF EAR and OCE Divisions, and a broad community effort, which is coordinated by a national Office and overseen by the GeoPRISMS Steering and Oversight Committee (GSOC). The funding program is managed completely independently from the community effort, but the NSF program managers, GSOC, and Office Director are in regular communication to maximize the impact of the GeoPRISMS Program as a whole.

4.1 Funding and management structure

Funding opportunities and awards

Funding opportunities for GeoPRISMS research are provided through an annual call for proposals with a deadline or target date typically in July. The solicitation for 2015 is available as NSF 15-564. GeoPRISMS funding in the first five years has been awarded to 37 projects with 91 PIs, compared to 135 projects (271 PIs) in 11 years of MARGINS funding. Full details on the awards are provided in Appendix A1. The average number of projects funded per year has declined somewhat since MARGINS. Statistics for projects funded to date (FY11-FY15) and the demographics of their PIs are shown in Table 4.1 with a comparison to those in MARGINS awards (FY00-FY10).

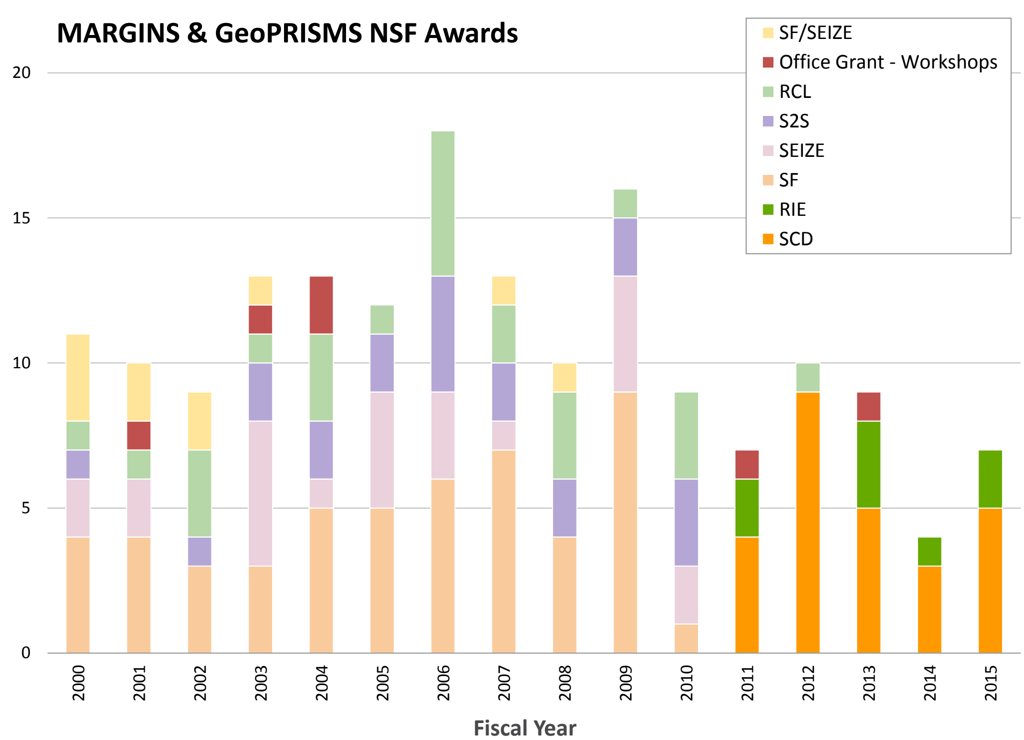


Figure 4.1. MARGINS and GeoPRISMS funding by initiative.

We notice significant and positive trends in the nature of the projects and the demographics of the PIs. Compared to the average MARGINS PI, 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 interdisciplinary and collaborative. The full list of funded projects with an indication of the demographics and nature of funding used as basis for the table below is provided in appendix A1.

	GeoPRISMS	MARGINS
Number of projects	37	135
Number of PIs	91	271
Early career PIs *	23	46
Female PIs *	33	45
Early career PIs (%)	23%	17%
Female PIs (%)	33%	16%
Interdisciplinary projects** (%)	27%	13%
Collaborative projects*** (%)	49%	37%
Number of PIs per project	2.7	2.0

Table 4.1. Comparison of the demographics of the PIs and nature of funded projects between GeoPRISMS (FY11-FY15) and MARGINS (FY00-FY10).
* We counted a postdoc who was supported by a grant (but not listed as formal PI) as an additional early career and (where appropriate) female PI.
** We define interdisciplinary as a combination of multiple observational approaches that are significantly different or as a combination of observational work with experimental and/or theoretical work.
*** We define collaborative projects as those involving PIs at multiple institutions.

Proposals are reviewed following standard NSF practices, based on ad-hoc reviews by independent experts, a recommendation by an annual GeoPRISMS panel at NSF, and award decisions made by NSF program managers. Announcements of awards are typically made at the end of the first quarter. The process from submission to review and final decision is carried out completely independently from the GeoPRISMS Office and GSOC. The Office and GSOC are only informed of the recommendations for successful proposals, the amount of the awards, and the success rate, which is all public information. During the early years of the MARGINS Program the MARGINS Steering Committee Chair was asked to provide a short presentation to the review panel at NSF, but this practice was discontinued and has never been implemented in GeoPRISMS. As a consequence neither the Office nor the steering committee has any knowledge about the identities of panel members or how funding decisions are made. This safeguards against real and perceived conflicts of interests.

GeoPRISMS Steering and Oversight Committee (GSOC)

The GSOC is a continuation of the MARGINS Steering Committee (MSC). It is composed of 12-14 members who generally serve a three-year term. Candidates for GSOC membership can be proposed by the community, but are most commonly suggested by the sitting members of the committee. Former MSC or GSOC members cannot serve again except in the case that they will become the new Office Director. Only one member can be on the committee from a given institution. This set of practices has made sure that the representation of the community rejuvenates and remains broad and diverse. We also strive to include a few early career scientists (with two serving on the current committee) and seek to maintain gender balance as much as possible. We followed in part the recommendation of the Decadal Review Committee to include members from industry, from the USGS, and from abroad. Lori Summa from Exxon served in the early years of GeoPRISMS and currently Tony Watts from Oxford University serves on the committee. The USGS participation was not realized in the early stages but this may be pursued in future years.

The current membership of the GSOC and their appointments is in Table 4.2. A full list of the members of the 60 MSC and 27 GSOC members is in appendix A5.

Peter van Keken (Chair)	University of Michigan	2013-2016
Estella Atekwana	Oklahoma State University	2014-2017
Brandon Dugan	Rice University	2014-2017
Jeff Freymueller	University of Alaska Fairbanks	2014-2016
Liz Hajek	Penn State	2014-2017
Kerry Key	Scripps Institute of Oceanography	2015-2018
Maureen Long	Yale University	2013-2016
Sarah Penniston-Dorland	University of Maryland	2014-2017
Tyrone Rooney	Michigan State University	2014-2017
Harold Tobin	University of Wisconsin Madison	2013-2016
Harm van Avendonk	University of Texas Austin	2014-2017
Paul Wallace	University of Oregon	2014-2017
Tony Watts	University of Oxford	2014-2017
Gene Yogodzinski	University of South Carolina	2013-2016

Table 4.2. Current membership of the GeoPRISMS Steering and Oversight Committee

The GSOC functions as a channel of communication between NSF and the community. It provides feedback and advice to NSF on programmatic issues. It also helps to implement community activities that serve the Program as a whole. The GSOC currently meets at the National Science Foundation once a year. The frequency of meetings has gone down in 2013 to one from two per year to reduce cost. This decrease in number of meetings was also justified by the completion of the initial planning process for the new Program. GSOC meetings are generally held in March, which is when the funding decisions of the previous round tend to be complete and before the new solicitation is released. The meeting venue at NSF facilitates discussion with program managers from related programs in EAR and OCE (such as Tectonics, IODP, Petrology & Geochemistry, and EarthScope) and with the EAR and OCE directors.

Current tasks of the GSOC include: i) reviewing the community's progress towards the Program's science goals; ii) guiding the development of databases, educational products and other infrastructure; iii) aiding in AGU activities including the selection of the mini-workshops; iv) fostering the growth of the interdisciplinary community; and v) exploring international collaboration and communication. Individual members are also expected to promote the GeoPRISMS science goals within their communities. GSOC members have also been instrumental in organizing the science planning meetings, preparing the GeoPRISMS Science and Implementation Plans (in the early years of GeoPRISMS), and preparing this mid-program review document. The agenda for the 2015 meeting is attached as appendix A7 to provide an illustration of topics of discussion during a GSOC meeting. GSOC meeting highlights are distributed in the Spring Newsletter.

GeoPRISMS Chair and Office Director

The Director of the GeoPRISMS Office serves as the Chair of the GSOC. Directors are appointed by NSF for a three year period. Julia Morgan (Rice University) served as Director from 2010-2013. Peter van Keken (University of Michigan) is currently the Director (2013-2016). Before the start of their tenure the Director submits a full Office proposal that is reviewed by NSF following standard practices. The role of the Office and its budget is described in more detail below.

GeoPRISMS Education Advisory Committee (GEAC)

The GEAC is a continuation of the MARGINS Education Advisory Committee. It meets irregularly and typically by phone conference. The committee provides guidance on education and outreach activities in GeoPRISMS and also selects the AGU Student Prize winners. There are no term limits on membership and the members are invited by the Office Director with advice from the GSOC. The current membership is in Table 4.3.

Cathy Manduca	Carleton College
Rosemary Hickey-Vargas	Florida International University
Jeff Marshall	Cal State Pomona
Sarah Penniston-Dorland	University of Maryland
Ex officio:	
Andrew Goodwillie	Lamont-Doherty Earth Observatory
Peter van Keken	University of Michigan
Julia Morgan	Rice University

Table 4.3. Current membership of the GeoPRISMS Education Advisory Committee

Amphibious Array Steering Committee (AASC)

The AASC was formed at the request of NSF to provide guidance on the use of the Amphibious Array that was built using instrumentation provided through 2009 Stimulus or ARRA (American

Recovery and Reinvestment Act) funding. This array includes new ocean bottom seismometers, new seismic instruments in reoccupied sites from the EarthScope Transportable Array, and improvements in on-land GPS capabilities. The initial deployment of this array was for onshore and offshore studies in Cascadia (the Cascadia Initiative; Toomey et al., 2014) and is intended to support research within the EarthScope and MARGINS/GeoPRISMS science objectives.

The current chair is Susan Schwartz (UC Santa Cruz). Membership is typically for three years and service primarily consists of participating in conference calls. The committee was charged initially with making sure the Amphibious Array deployment followed the science plans developed for Cascadia. The current membership, which includes representatives of EarthScope, GeoPRISMS, and the Ocean Bottom Seismograph Instrument Pool (OBSIP) is listed in Table 4.4.

Susan Schwartz (Chair)	UC Santa Cruz
Jeff Freymueller	University of Alaska Fairbanks
Heidi Houston	University of Washington
Gabi Laske	UC San Diego
Steve McNutt	University of South Florida
Brandon Schmandt	University of New Mexico
Haiying Gao	University of Massachusetts
Rob Evans	Woods Hole Oceanographic Institution
Ex Officio:	
Ramon Arrowsmith	EarthScope
Don Forsyth	OBSIP
Peter van Keken	GeoPRISMS

Table 4.4. Current membership of the Amphibious Array Steering Committee

4.2 GeoPRISMS Office Activities

The GeoPRISMS Office provides significant community support through the organization of workshops and meetings, dissemination of scientific results via newsletter and website, facilitation of database efforts, development of new research directions, and organization of education and outreach activities. The Office Director is also the Chair of the GSOC and is appointed by NSF. Julia Morgan (Rice University) was the first Office Director. During her tenure she oversaw the development of the GeoPRISMS Science and Implementation Plans, with significant community input through planning workshops. The current Office at the University of Michigan is overseen by Peter van Keken. Support is provided by full-time staff members Anaïs Férot (science coordinator) and Jeanne Bisanz (administrative coordinator). The Rice Office also included a part-time staff member to help build new education and outreach efforts, but funding for this was discontinued when the Office moved to Michigan.

Office Budget

The Office budget consists of staff salaries, academic salaries for Office Director (which can be used for teaching buyout), benefits, travel support for GSOC meetings, funds for website development and maintenance, production and dissemination of newsletter, support for planning and research meetings (which have also been funded through supplements to the Office), travel support for Office personnel to attend related meetings and AGU, funds to support AGU activities (such as the GeoPRISMS Townhall, mini-workshops and Best Student Presentation awards), and funds for the Distinguished Lecturer Program (including honoraria for the speakers). The Office budget is supplied out of the sequestered GeoPRISMS budget. A breakdown of the main budget items for the Rice Office (initial and final) and the Michigan Office is shown in Figure 4.2.

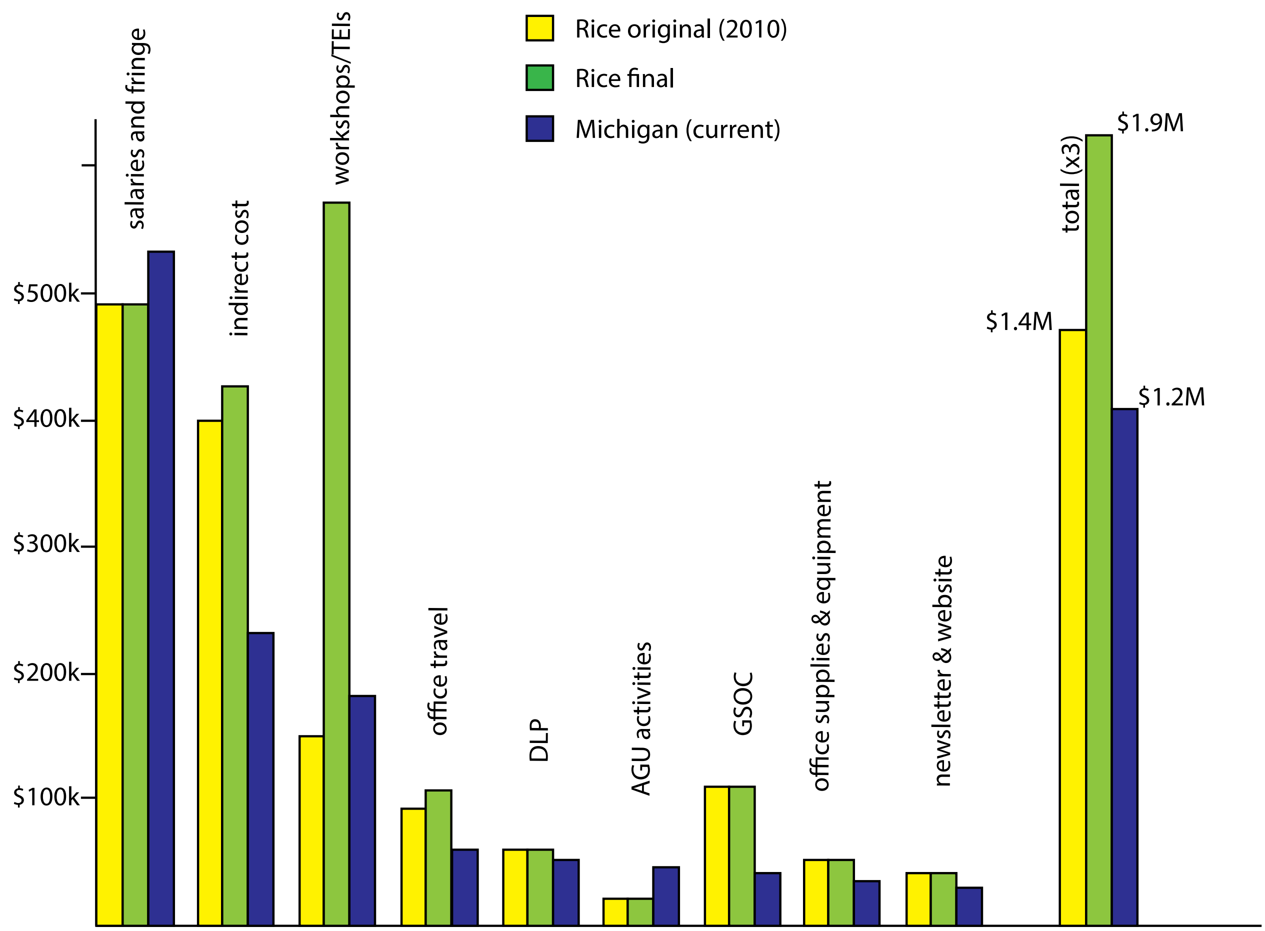


Figure 4.2. Comparison of initial Office budget at Rice (yellow), final Rice budget (green) and current Michigan budget (blue). The Michigan request was reduced from $1.43M to $1.2M (19% reduction) because of the federal sequestration starting in FY13 (the first year of the Michigan award).

The difference between the initial and final Rice budgets is principally due to the organization of seven large planning workshops. The original budget request out of Michigan was $1.43M but was cut by nearly 20% in the FY13 sequestration. The cuts were accommodated by the elimination of the 0.5 FTE education and outreach coordinator and significant reductions in the funds for the two Theoretical and Experimental Institutes that had been planned for each initiative. The significant reduction in indirect cost going from Rice to Michigan is due to the successful negotiation of an administrative overhead rate at 30% compared to the research overhead rate of 55% at the University of Michigan.

The GSOC was asked by NSF in March 2015 to evaluate the role of the Office and to judge whether the cost (currently at $400k per year or 11% of a nominal GeoPRISMS budget of $3.5M/yr) was justified. The GSOC provided a written response to NSF (appendix A8) in which it concluded that "it would be hard to find internal cost savings that can significantly reduce the current Office budget" and that "the Office is essential for the program." The committee commented further that "[t]he strong and effective community building (as displayed for example by the nearly 1,000 unique individuals that have attended GeoPRISMS meetings) [is] essential to keep GeoPRISMS a vibrant and growing program" and "[t]he Office activities provide several mechanisms to reach new members of the geosciences community through the DLP, student symposia at meetings, and the AGU Townhall and Student Forum." Finally, the GSOC pointed out in its written comments that "[w]hile the relative cost appears high when measured to just GeoPRISMS-funded science, it is clear that GeoPRISMS reaches a much larger audience than just those funded by GeoPRISMS and that many research activities funded by NSF outside of GeoPRISMS benefit from Office activities. The true relative cost of the Office is therefore seen as significantly less than 11%." The committee unanimously recommended that the Office remains an integral part of the GeoPRISMS effort.

GeoPRISMS website and listserv

The GeoPRISMS website is vital to the Program as it provides the main platform for the collection, archiving, and dissemination of information about science planning, meeting outcomes, and opportunities for jobs and funding. It also provides support to various initiatives, including application for participation (examples: ExTerra workshop, Cascadia Initiative Apply-to-Sail Program) and dissemination of reports. The GeoPRISMS website is also used for the public dissemination of GeoPRISMS-related material contributed by community members.

The Rice Office developed the first GeoPRISMS website using the free content management system Joomla and the site was heavily used for all of the above activities. Following the transition of the Office, the GeoPRISMS website underwent a major redesign leading to greater functionality and improved aesthetics (Figures 4.3). Anaïs Férot, science coordinator and administrator of the website, completed the transition with help from Peter Knoop who is an IT expert at University of Michigan. The new, faster, website has been developed using a free open source content management system (WordPress). All content from the old website is now up to date and transferred to the improved version. The modern and more responsive design makes it easier to navigate on any device.

The GeoPRISMS Listserv is managed by the Office and has more than 1950 subscribers. We have kept daily statistics since the move of the website to a new service provider in April 2014. Since that time we have gained 130 users suggesting a net growth of about 100 users per year. Listserv

Figure 4.3. Home page of the fully updated and modernized geoprisms.org website. The website is now easier to navigate on a variety of devices including handhelds.

announcements are usually sent out twice a week and consist of job postings, student opportunities, updates on GeoPRISMS-related science, call for participation in GeoPRISMS events, partner updates, etc. Anyone can submit a request to send out an announcement to the GeoPRISMS Listserv. All listservs are archived on the GeoPRISMS website.

GeoPRISMS social media

The GeoPRISMS Office maintains a Facebook page (more than 450 followers) and a Twitter account. We use these social media for the announcement of GeoPRISMS activities and dissemination of science efforts. We note that several GeoPRISMS-funded projects (including iMUSH, IFM-Unimak 2015, ENAM CSE, and MAGIC) maintain their own Facebook pages, blogs, or Twitter accounts, further providing broad dissemination of GeoPRISMS research and E&O activities.

GeoPRISMS newsletter

The GeoPRISMS newsletter is published twice annually and provides an update to the community about GeoPRISMS activities and scientific advances. To reduce costs the newsletter is now distributed each year once in print and electronic form, and once in electronic form only. The print version is sent out to 950 domestic and 400 international addresses. Following the transition of the Office to the University of Michigan Anaïs Férot made a significant set of changes in the layout, typesetting and cover page, leading to a much more appealing and easy to read newsletter.

The newsletter in general contains updates from the Office chair and NSF program managers, a few articles focusing on scientific advances, a report from the field (generally contributed by a team of students or a postdoc), announcements of meetings and research opportunities, and education and outreach activities, including those at the AGU Fall meeting.

GSOC meeting support

The Office supports the GSOC meeting (currently once yearly at NSF) in coordination with NSF staff by providing support for travel logistics and reimbursements and housing. The GSOC members' travel and onsite costs are fully supported but there is no honorarium.

The Office prepares detailed minutes of the meeting for approval by the GSOC. Extracts (with minor redaction for sensitive information) are published as GSOC meeting highlights in the following issue of the Newsletter.

Planning workshops and TEIs

The Office organizes workshops and Theoretical and Experimental Institutes to allow community science planning and effective dissemination of results. The Rice Office was responsible for seven planning workshops that led to the development of the GeoPRISMS Science Implementation Plans. The Michigan Office had planned to organize two Theoretical and Experimental Institutes (TEIs). These TEIs are intended to document progress towards the science goals, to develop new initiatives, to augment the largely observational nature of the program with theoretical and experimental work, to enhance multidisciplinary collaboration, and to enfranchise new talent such as early career scientists, graduate students and scientists who are not yet fully associated with GeoPRISMS.

Two TEIs were planned for 2014 (SCD initiative) and 2015 (RIE initiative) but due to budget uncertainty and limitations it was decided by NSF and the Office Director, with approval of the GSOC, to use the budgeted funds for a single TEI focused on the SCD initiative and to have the next Office organize an RIE-focused TEI. The SCD TEI will be held at the Portofino Hotel (just south of the main airport of Los Angeles, CA) during the week of October 12, 2015.

Office activities that support these workshops and TEIs include providing teleconferencing facilities for the conveners, providing travel logistical support and reimbursements, organizing the venue including meeting rooms, accommodation and food, helping to organize the student symposia, and support and oversight for report writing, and dissemination of the results through the website and newsletter.

Figure 4.4. Top: Evolution of the cover of the newsletter since the start of the GeoPRISMS Office at Rice. Previous page: The Spring newsletter open at the Report from the Field written by students participating in the iMUSH project.

The workshops organized thus far have been well attended with participation counts ranging from 90 to over 200. Figure 4.5 provides a comparison of the attendance at each workshop organized by MARGINS (since 2000) and GeoPRISMS. Note that we list the MARGINS Successor Planning Workshop (MSPW; convened by Julia Morgan) as the first GeoPRISMS workshop even though it was supported by and with funds through the Lamont MARGINS Office directed by Geoff Abers. The first initiative workshop (RIE in 2010) was jointly organized by the outgoing MARGINS Office and incoming GeoPRISMS Office.

Participant lists for all meetings are available through the GeoPRISMS (geoprisms.org) and MARGINS (nsf-margins.org) websites. An analysis of the attendance of the workshops demonstrates that the GeoPRISMS community is diverse, youthful, vibrant, and growing. The total number of participants in GeoPRISMS meetings is 1050 (compared to 1559 for all of MARGINS) with 680 unique individuals (compared to 1001 for MARGINS). The number of female participants is 32% (compared to 24% for MARGINS). More than 65% of the attendees of GeoPRISMS workshops had not attended any MARGINS meetings. The percentage of international participants is down from 36% (MARGINS) to 21%, which reflects the refocusing of early GeoPRISMS research to three primary sites in the US (Cascadia, Alaska-Aleutians, Eastern North American Margin) and the paucity of meetings held abroad. The organization of meetings in the US, at locations that are affordable and near airports with competitive routes, has also significantly reduced the per-person cost for the meetings compared to those held during MARGINS.

The large number of individuals who have attended GeoPRISMS meetings is much greater than that supported directly by GeoPRISMS funding. This testifies directly to the broad impact that the GeoPRISMS Office activities have had on community building and facilitating GeoPRISMS science.

Support for Science and Implementation Plans and for the Mid-term Review

The Office provides significant support for the writing and dissemination of the GeoPRISMS Science and Implementation Plan and for the production of these mid-term review materials. The Office supports the meetings that lead to the production of the documents, provides teleconferencing facilities, data gathering and compilation of statistics on meeting participation, citations to papers resulting from MARGINS and GeoPRISMS funded research, as well as the final production of the review documents. The Michigan Office also formatted the Amphibious Array Workshop report and recommendation that resulted from the October 2014 Snowbird meeting (organized by IRIS).

AGU Activities: Mini-Workshops

The GeoPRISMS Office has popularized the concept and expanded the reach of the AGU mini-workshops that were initiated late in MARGINS. There is nothing 'mini' about the workshops themselves; the term relates to the budget, which can be kept low as the meetings take place in San Francisco during the Fall Meeting of the American Geophysical Union. The Office only provides funds for the meeting venue and food. It does not provide support for travel or accommodation. Each year a call for mini-workshop proposals is advertised through the website, listserv, and newsletter.

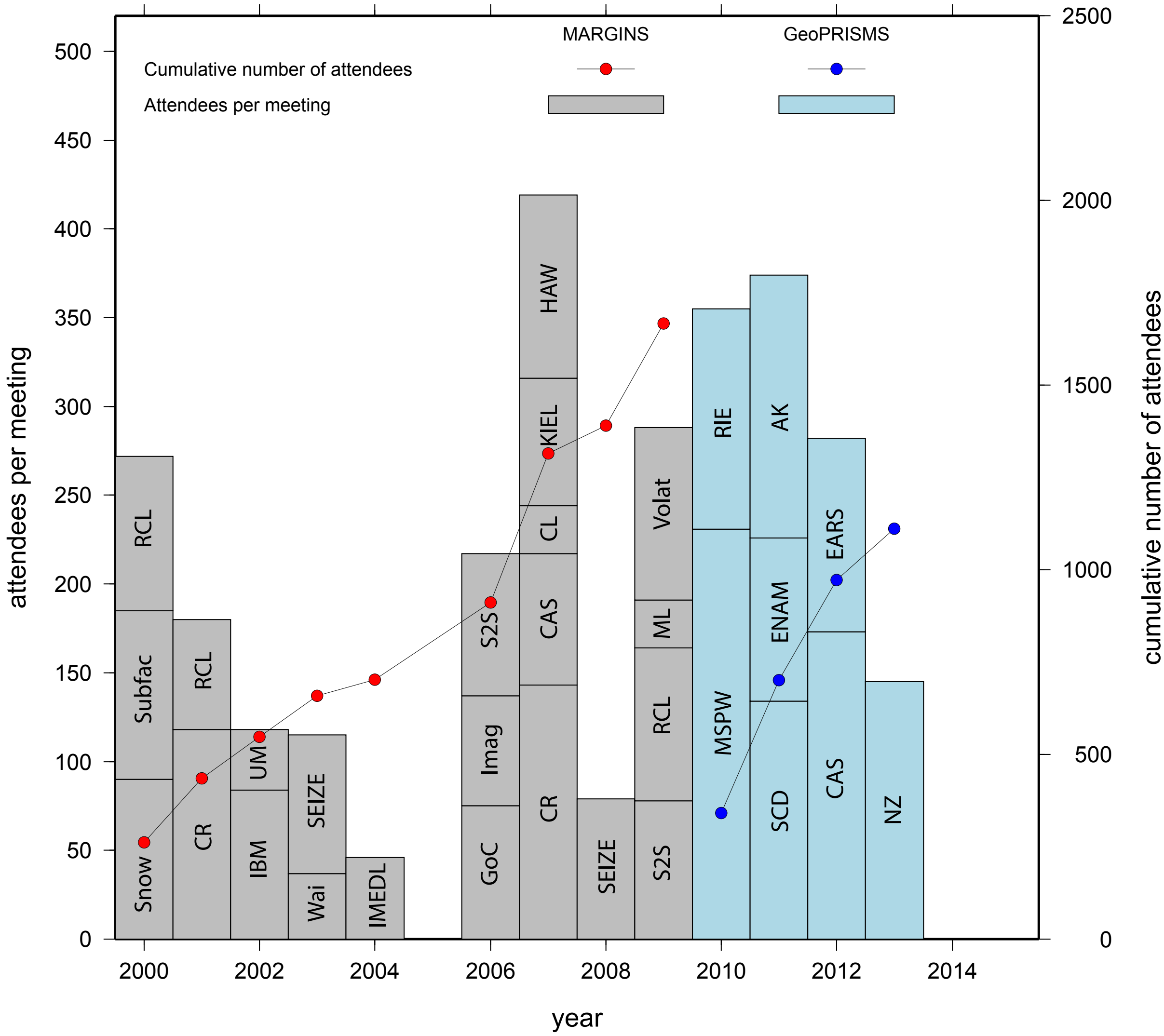


Figure 4.5. Attendance per meeting and cumulative attendance for MARGINS and GeoPRISMS meetings. 2000: SEIZE=SEIZE TEI (Snowbird, UT; January), Subfac=Subfac TEI (Eugene OR, January), RCL=Gulf of California workshop (Puerto Vallarta, Mexico, October). 2001: CR=Central America SEIZE/Subfac workshop (Heredia, Costa Rica, July), RCL=Red Sea workshop (Sharm-el-Sheik, Egypt, March). 2002: IBM=Izu-Bonin-Marianas workshop (Honolulu, HI, September), UM=Subfac modeling workshop (Ann Arbor, MI, October). 2003: Wai=Waipaoa focus area workshop (Gisborne, New Zealand, May), SEIZE=Seismogenic zone revisited TEI (Snowbird, UT, March). 2004: InterMARGINS workshop on modeling the extensional deformation of the lithosphere (Pontresina, Swiss Alps, July). 2006: GoC=Lithospheric rupture in Golf of California workshop (Ensenada, Mexico, January), Imag=workshop in interpreting upper mantle images (Woods Hole, MA, May), S2S=Source and sediment dispersal workshop (Eel River system, California, September). 2007: CR=Subfac/SEIZE integration workshop (Heredia, Costa Rica, June), CAS=integrated collaborations in Cascadia and Walker Lane/Salton Trough (Monterey, CA, March), CL=education mini-workshop (Arlington, VA, April), KIEL=Global data network meeting (Kiel, Germany, May), HAW=Subfac at Izu-Bonin-Marianas (Honolulu, HI, November). 2008: next decade of SEIZE workshop (Mt Hood, OR, September). 2009: S2S Synthesis meeting (Gisbourne, New Zealand, April), RCL=RCL Synthesis workshop (Charleston, SC, April), ML=Mini-lessons workshop (Palisades, NY, May), Volat=Subfac TEI on volatiles (Mt Hood, OR, September). 2010: MSPW=MARGINS Successor Planning Workshop (San Antonio, TX, February), RIE=RIE Implementation workshop (Santa Fe, NM, November). 2011: SCD=SCD Implementation workshop (Bastrop, TX, January), AK=Alaska/Aleutians site planning workshop (Portland, OR, September), ENAM=EarthScope/GeoPRISMS workshop for ENAM site (Bethlehem, PA, October). 2012: CAS=GeoPRISMS/EarthScope site planning workshop for Cascadia (Portland, OR, April), EARS=planning workshop for East African Rift System (Morristown, NJ, October). 2013: NZ=Planning workshop for New Zealand primary site (Wellington, New Zealand, April).

The GSOC evaluates and ranks the proposals. The mini-workshops are then scheduled, with the number and timing of the meetings dependent on the available budget and cost of venues.

Analysis of the attendance numbers demonstrates the high impact of these modest-cost activities with nearly 700 individuals attending over 4 years (Figure 4.6). The average cost per attendee is generally less than $100 per participant. Combined with the workshops discussed above we have had nearly 1800 individuals (931 unique) attend GeoPRISMS meetings.

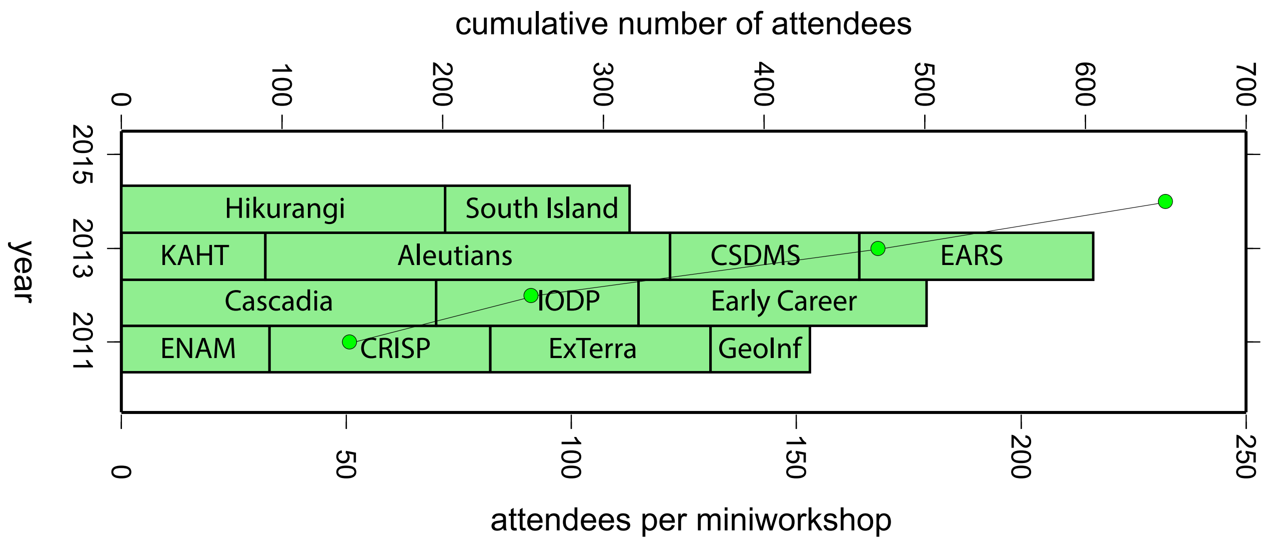


Figure 4.6. Attendance at GeoPRISMS Mini-workshops at the Fall AGU. 2011: ENAM=East North American Margin; CRISP=Costa Rica Seismogenic Project; ExTerra=Exhumed Terranes; GeoInf=GeoInformatics. 2012: Cascadia=Marine Geophysics at Cascadia; IODP=IODP opportunities in SCD; Early Career=GeoPRISMS/EarthScope luncheon. 2013: KATH=Kermadec Arc Havre Trough; Aleutians=logistics preparation workshops; CSDMS=opportunities with the Community Surface Dynamics Modeling System; EARS=planning and logistics.

AGU Activities: Townhall Meeting

The Office organizes a Townhall Meeting at each Fall Meeting of the American Geophysical Union, typically on the Monday evening of the AGU week. The Townhall is generally attended by some 150 participants who have the chance to mingle with GSOC members and NSF representatives, listen to talks on GeoPRISMS activities and science talks, and view the posters of students that are competing for the Best Student Presentation.

AGU Activities: Best Student Presentation

Each year we have a competition for best student presentations. We give two awards (one for best poster, one for best talk) and up to two honorable mentions in each category. The Office invites judges from the GeoPRISMS community, former awardees, and GeoPRISMS postdocs. At least three judges are assigned to each presentation. The evaluations are compiled and used by the GEAC to rank the presentations. More detail on the student presentation competition is provided in the Education and Outreach section.

Distinguished Lecturer Program (DLP)

The Office organizes a program to bring GeoPRISMS science to undergraduate and graduate institutions within the US. Each year we have up to eight distinguished speakers who travel to three or four institutions each. Speakers sign up generally for two years and receive an honorarium of $1000 per year. The Office invites applications to the DLP in the early summer via website, newsletter, listserv, Facebook, and through printed brochures that are sent out to 750 institutions. The Office coordinates the speakers' schedules with the schools that are awarded a distinguished lecturer within the constraints of the speaker's availability and interests in addition to the diversity of the schools visited. The Office also provides travel logistics and reimburses the speakers for their travel. The schools are responsible for accommodation and local expenses. More details on the DLP are provided in the Education and Outreach section.

4.3 Data Management - GeoPRISMS and MARGINS Data Portals

The MARGINS and GeoPRISMS Data Portals host data collections for each program and provide a range of data-related services to the community. To support interdisciplinary science goals, the MARGINS Data Portal (http://www.marine-geo.org/portals/margins/) was established in fall 2003 in response to a program call for a dedicated data system that would facilitate the open and timely exchange of data. The GeoPRISMS Data Portal (http://www.marine-geo.org/portals/geoprisms/) came on-line in 2011 (Figure 4.7), leveraging the same data system infrastructure. The Portals and related resources are developed as part of the NSF-supported Interdisciplinary Earth Data Alliance (IEDA) facility based at Lamont-Doherty Earth Observatory.

To overcome traditional challenges in determining what field programs had been conducted in an area, who was involved, what kinds of data were collected, and who holds the data,

Figure 4.7. The MARGINS and GeoPRISMS Data Portals share a common web interface and include links to program information, data, bibliographies, and dedicated searches.

the Data Portals provide services that include web-based, searchable integrated catalogs containing field expedition and modelling/lab experiment information, links to the diverse terrestrial and marine data sets generated under MARGINS and GeoPRISMS awards, a bibliographic database, and PI tools for data management. The GeoMapApp data exploration and visualization tool (http://www.geomapapp.org/) provides additional access points to field program data and information and to other data sets of relevance to the community. Efforts promoting greater sharing and interaction with domestic and international data centers have also been pursued.

System Description

The backbone of the MARGINS and GeoPRISMS Data Portals is an integrated metadata catalog and data repository that provides information on field programs (who, what, when and where), inventories of sensor data and samples, and links to download associated data files which reside either within the Data Portal system or at distributed repositories such as IRIS and UNAVCO.

To accommodate the varied needs of scientists for accessing the broad range of data generated under the MARGINS and GeoPRISMS programs, two main access tools have been developed. One is a browser-based tool that offers a customized filtered search using a range of parameters such as geographical bounds, data type, and investigator name. It is available in both map-based and text-based formats (Figure 4.8).

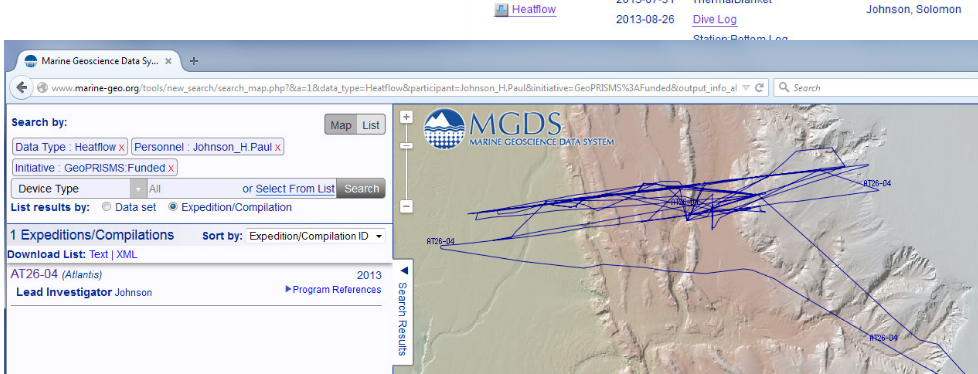


Figure 4.8. Screen shots showing the GeoPRISMS Data Portal web search interface with the text-based search on top and map-based search at bottom. In this example, a search was done for Cascadia heat flow data related to investigator H. Paul Johnson. The search returned a downloadable data set gathered from thermal blankets during GeoPRISMS-funded cruise AT26-04.

The second access tool, GeoMapApp (http://www.geomapapp.org/), is a platform-independent graphical application that allows users to visualize, explore, manipulate, and extract data holdings within a map interface. For each MARGINS and GeoPRISMS Focus Site, highlighted menus allow quick access to program-funded data sets and tables that can be viewed and compared with thousands of other built-in data sets such as sonar (multibeam, side-scan), focal mechanism solutions from the Global CMT catalog, deep-sea drilling holes, and locations of samples and stations from program-funded field expeditions (Figure 4.9).

In addition to the search tools and GeoMapApp, the Data Portals employ standards-compliant web services to provide data holdings in flexible formats that allow users greater choice of data visualization and analysis tools such as ArcGIS and Google Earth.

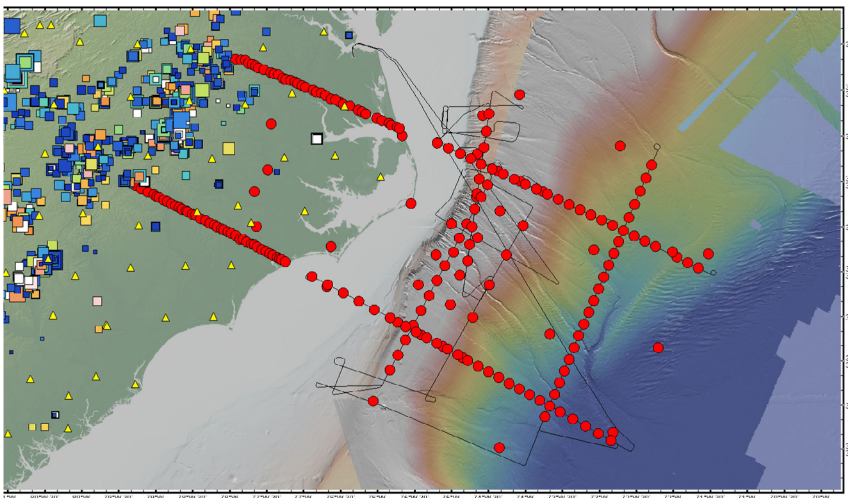


Figure 4.9. In this image of the ENAM primary site, generated from GeoMapApp, red circles give locations of land seismometer and seafloor OBS instruments used as part of the ENAM Community Seismic experiment. ENAM-CSE multi-channel seismic lines were collected during R/V Langseth's cruise MGL1408 (track line in black). The high-resolution Law of the Sea east coast bathymetry grid is plotted for the downslope areas, with artificial illumination from the north. Note the incised channels on the slope, and the large wave forms in the east. Small yellow triangles mark the position of EarthScope USArray stations. On land, squares denote the location of EarthChem geochemistry samples, which in this image are colored on MgO content and scaled according to Al_2O_3 values.

PI Services

The Data Portal offers a Data Management Plan tool and a Data Compliance tool to help PIs with NSF proposal data management requirements (see Appendix A10 for the NSF MARGINS and GeoPRISMS Data Policies).

More than 360 individual PIs have generated over 1,100 data management plans using these tools. On-line submission and registration web pages allow PIs to register rock sample information (through SESAR) and to contribute data sets with a range of formats. The ability to cite data sets in a manner similar to the citation of a published article has undergone rapid development in recent years. To help promote data sets as a formal part of the scientific record, digital object identifiers (DOIs) are assigned to many data sets cataloged in the GeoPRISMS and MARGINS Data Portals. Data DOIs allow data sets to be discovered programmatically through systems such as DataCite. Information on downloads of contributed data sets is provided to investigators via e-mail letters that are sent at regular intervals.

IEDA provides small grants to help PIs rescue data (e.g., by digitizing analog records). MARGINS researcher James Gill received an IEDA Data Rescue grant in 2013 to help consolidate and preserve geochemical data collected in the IBM focus site.

Available Data

Currently, the data collection includes information and data for almost all MARGINS-funded field programs (22 terrestrial, 63 marine) covering projects ranging from sampling of volcanic rocks on Guam, deployment of ocean-bottom seismometers in the Gulf of California, sediment coring in the PNG and New Zealand Focus Sites, to earthquake microseismicity and tomographic experiments across Central America. Available data sets for the land programs include rock and sediment sampling studies (analytical geochemical and radionuclide data), geodetic and active/passive seismometer experiments (access via links to IRIS, UNAVCO, and UTIG), and lacustrine fieldwork. Data sets submitted for the marine expeditions are equally broad-ranging and include bathymetry, side-scan sonar, seismic reflection and OBS data, gravity and magnetics data, water column physical and chemical properties from XBT, MAPR, CTD, and ADCP devices, sound velocity data, Alvin and Jason ocean floor photography, heat flow, and rock, fluid, and sediment sampling information. A significant proportion of the information and data from MARGINS-funded programs was contributed in the 2011-2012.

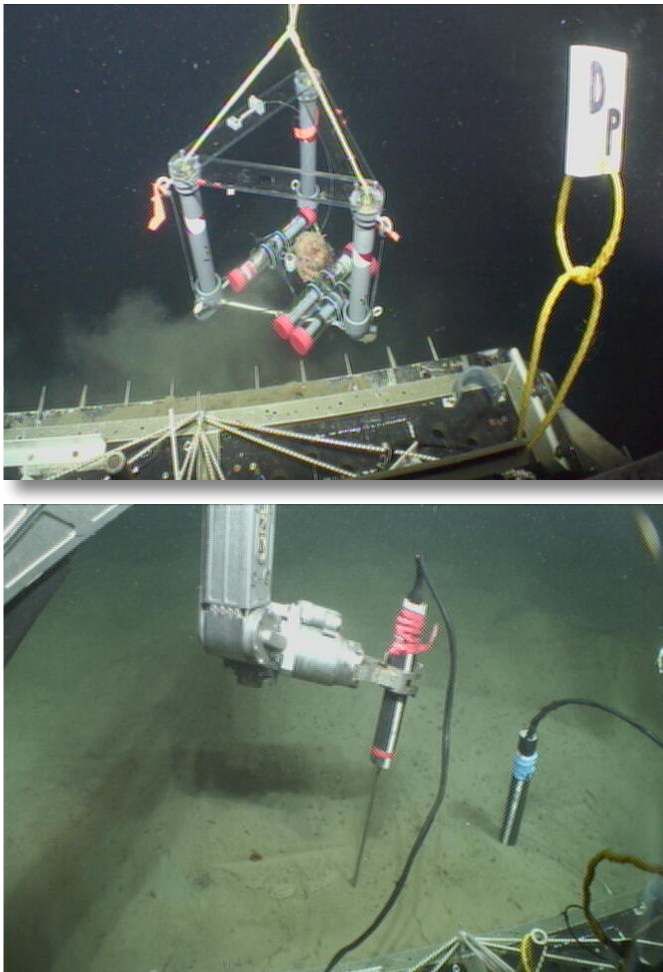


Figure 4.10. Jason II Virtual Van video frame grabs for the 2013 Johnson-Solomon-Harris Cascadia GeoPRISMS-funded Atlantis cruise AT26-04. (Top) Recovery of a Mosquito fluid flow sensor from the seafloor. (Bottom) Image of the Jason II arm used to deploy a pair of heat flow sensors with each unit typically left in the sediment for 20-30 minutes before recovery.

At present, the GeoPRISMS data collection provides information and data for more than twenty GeoPRISMS-funded and closely related programs. Submitted data sets include a geodetic velocity field of the East African Rift System, a 3-D shear wave tomographic velocity model for Cascadia (accessed through IRIS), multi-channel seismic reflection, CHIRP sub-bottom profiling data and high-resolution bathymetry on the Aleutian, Cascadia and ENAM margins, and heat flow, water column data, and Jason II dive photos in Cascadia. Deployment/recovery field information (Figure 4.10) and links to data for the Cascadia Initiative OBS project are also provided. Instrument location information and data from GeoPRISMS projects has also been added to GeoMapApp, under the Focus Sites tab (Figure 4.11).

In addition to compiling and serving data for MARGINS- and GeoPRISMS-funded programs, a significant focus of the

Data Portal has been to develop access to other field and derived data sets relevant for MARGINS and GeoPRISMS research. These include geodesy, DSDP/ODP drilling data, high-resolution land topography, regional geophysical datasets from the NGDC, SIO, and LDEO collections, and the Global CMT catalog (formerly Harvard CMT), all of which can be accessed through GeoMapApp. Another example is the cleaning of swath bathymetry data from more than 60 Cascadia cruises for inclusion in the Global Multi-Resolution Topography (GMRT) synthesis that forms the base map for all of the Data Portal map clients as well as for GeoMapApp.

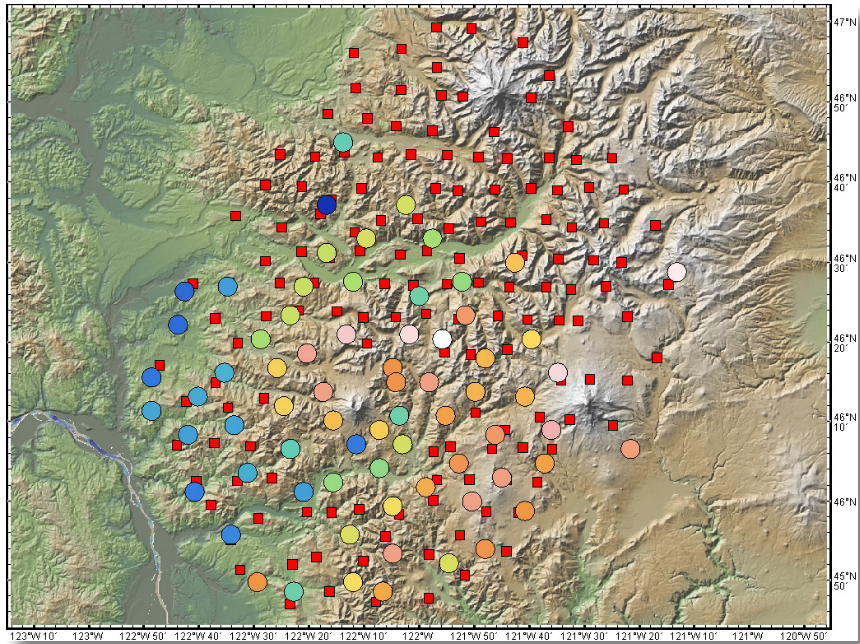


Figure 4.11. For the multi-institution Cascadia iMUSH project, MT instrument positions are shown as red squares, and seismometer locations are plotted as circles that are colored with station elevation (warm colors = higher). Links to IRIS are provided. Background map is the USGS NED 10m high-resolution relief model. Image created using GeoMapApp. Built-in menus provide links to GeoPRISMS data sets and related information and to other externally-funded data sets of interest for each primary site.

Collaborations with domestic and international data centers and institutions including IODP, IRIS, UNAVCO, JAMSTEC (Japan), and BGR and GEOMAR (Germany) were initiated by the Data Portal and have fostered the development of Open Geospatial Consortium standards-compliant web services for dynamic access to distributed data holdings. These contacts have also resulted in access to several high-quality regional datasets contributed by US-based and international collaborators, including bathymetry and magnetics grids for Central America, bathymetry from the Nankai-IBM area, and bathymetry and acoustic backscatter data for a areas surveyed as part of the US Law of the Sea project.

Bibliography

Citation details for publications stemming from GeoPRISMS awards and from closely related projects have been added to an on-line web-accessible bibliographic database (Figure 4.12). Parameters including title, author, journal and year can be used for searches, and each paper is listed with links to the article, data, and field expedition where appropriate. On-going collaborations with the Elsevier publishing company have resulted in links from electronic journal articles to the downloadable geochemical and geophysical datasets held within the Data Portal collection. Participation in the newly-established COPDESS group is helping foster links between data repositories and journals, as a means of improving the convenience with which readers can access data.

The GeoPRISMS bibliographic database with information (where available) about funding has been expanded greatly in preparation for this review and currently contains more than 1,100 citations. The MARGINS database contains nearly 600 citations. Plans are underway to merge the GeoPRISMS and MARGINS bibliographic databases.

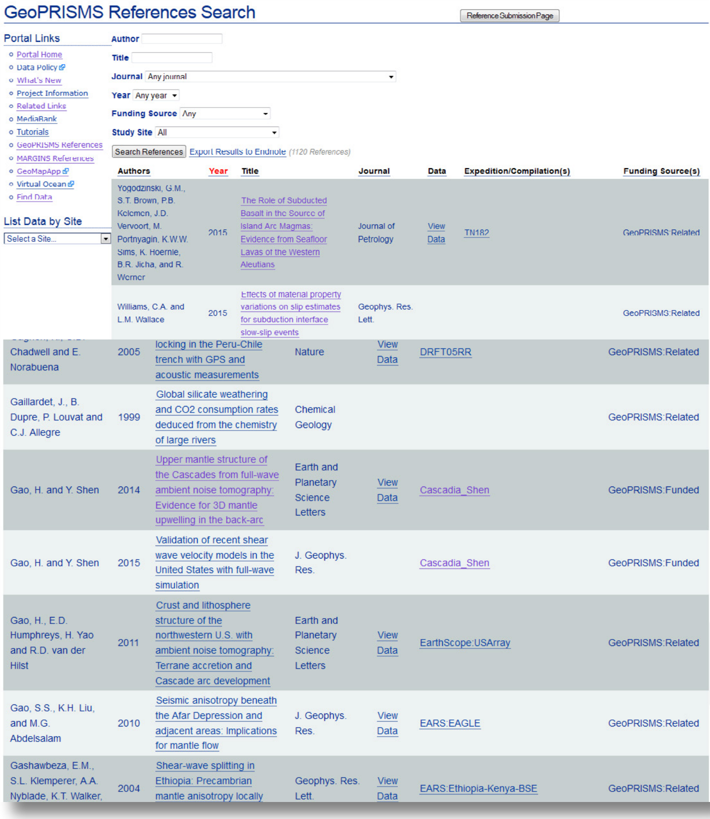


Figure 4.12. Screen shot of part of the GeoPRISMS bibliography. Filtering can be done using keywords. Search results can be sorted by clicking any of the column headers. Links to articles, data, and field program information are provided.

Community Outreach

Interaction with GeoPRISMS Office staff and with GeoPRISMS PIs is an integral part of the work of the Data Portal team. Communication with individual PIs helps with the flow of data and information into the Portal. IEDA representatives attended each of the GeoPRISMS Planning and Implementation workshops, helped convene a GeoPRISMS-sponsored mini-workshop at AGU, and ran a GeoPRISMS-specific GeoMapApp webinar (Figure 4.13).

To help keep community members abreast of recent developments, a report about the Data Portal is written twice yearly for inclusion in the GeoPRISMS Newsletter, and the GeoPRISMS Office e-mail listserv is used to disseminate important Data Portal events. A News section on the Data Portal web page lists recent activity and contributions. A formal presentation is also given by Data Portal staff at each GeoPRISMS Steering and Oversight Committee meeting.

Members of the GeoPRISMS and MARGINS communities have participated on the IEDA User and Policy Committees and have taken part in workshops and surveys led by the Data Portal team. Community members have also been polled to help uncover existing datasets of interest to GeoPRISMS, and to help guide future developments of data-related services.

An IEDA exhibit booth at AGU and attendance at other national and international meetings helps the IEDA Data Portal team stay closely in touch with MARGINS and GeoPRISMS community members.

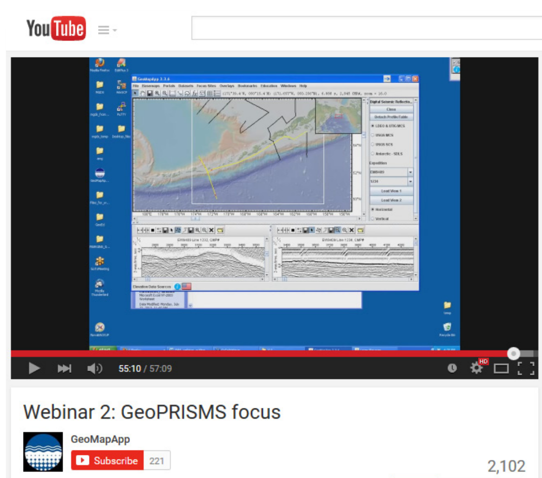


Figure 4.13. A snapshot from the GeoPRISMS-focused webinar shows multi-channel seismic profiles across the Aleutian arc. The webinar, created in July 2013 and available on YouTube™, has been viewed more than 2100 times.

5. Education, Outreach, and Human Resource Development

The GeoPRISMS community, with support from the GeoPRISMS Office, is actively engaged in Education and Outreach (E&O), with the goal of developing a better-informed public and well-trained student population. The Decadal Review Committee (DRC) made a number of recommendations to continue, enhance, and expand MARGINS E&O activities. These included further development of the MARGINS mini-lessons, continuation of the Postdoctoral Fellowship Program, and expansion of the Distinguished Lectureship Program (DLP) to include visits abroad, video-taping of lectures, and inclusion of early/mid-career scientists as speakers. We have largely followed these recommendations as described below. The DRC also recommended expanding E&O efforts towards K-12 institutions, a recommendation that has not been pursued due to lack of Office resources (see section 4.2). Effective K-12 outreach requires significant effort and evaluation, necessitating a full-time dedicated E&O staff person within the GeoPRISMS Office. The GeoPRISMS Education Advisory Committee (GEAC) also strongly endorsed maintaining the focus on undergraduate education and early-career investigators, due to its greater potential for near-term impact.

Even without a dedicated E&O staff person, GeoPRISMS has been able to maintain a vibrant E&O program that is geared towards the general public and towards undergraduates, graduate students, and postdocs. GeoPRISMS E&O activities include the following:

- GeoPRISMS Distinguished Lectureship Program
- GeoPRISMS Best Student Presentation Prize competition at Fall AGU Meetings
- GeoPRISMS Townhall and Student Forum at Fall AGU Meetings
- Student Symposia and field trips prior to all GeoPRISMS Planning Workshops
- Other student, postdoc, and early-career investigator training:
    - Broad calls for participation (e.g., "Apply to Sail") to students and postdocs for marine and terrestrial field campaigns (Cascadia Initiative, ENAM seismic experiment, iMUSH)
    - Data processing and interpretation workshops as part of community experiments
    - GeoMapApp tutorials (offered by Andrew Goodwillie, GEAC member) at GeoPRISMS Workshops
    - Joint GeoPRISMS-EarthScope Early-Career Investigator Luncheon at the Fall AGU Meeting 2013
    - GeoPRISMS Best Presentation Prize winners invited to judge presentations
- Ongoing mini-lesson development
    - New NSF DUE TUES grant (joint between GEAC and SERC)

- Contributions from individual GeoPRISMS PIs as broader impacts
- Introduction of student-oriented "Field Blogs" in the bi-annual GeoPRISMS Newsletters
- Presentations in Education sessions at Fall AGU meetings
- Participation in EarthScope E&O Summits
- Efforts to initiate a GeoPRISMS REU Program (proposal unsuccessful)
- Outreach to the scientific community, educators & funding agencies
    - GeoPRISMS sponsored sessions at AGU
    - Bi-annual GeoPRISMS Newsletter (with new and modern layout)
    - GeoPRISMS Listserv Announcements
    - Social Media (Facebook, and Twitter)
- Outreach to the public and policy makers:
    - AGU Exploration Station - AGU Fall Meeting 2011
    - NSF-organized Geohazards Forum on Capitol Hill, September 2011 (Figure 5.1)

Several of these E&O components are developed in more detail below. Chapter 4 provides also some more details on the Newsletter and AGU activities.

Figure 5.1. GeoPRISMS representatives at the Hart Senate Building for the Geohazards Forum (September 2011). From left to right: Donna Shillington, Maya Tolstoy (both at LDEO), Harold Tobin (University of Wisconsin at Madison) and Alison Henning (GeoPRISMS Office).

5.1 Distinguished Lectureship Program (DLP)

The Distinguished Lectureship Program enables scientists working on GeoPRISMS-related projects to visit schools and institutions around the US to communicate the excitement of GeoPRISMS research. The program aims to bring the speakers to a diverse set of audiences, ranging from traditional PhD-granting institutions to four-year colleges, museums, and other venues for public lectures. Since 2010 we have had ~300 applications for DLP speaker visits. There have been a total of 39 speakers who gave 139 presentations. These presentations range from standard academic lectures to special lectures in Earth Science courses and evening lectures in museums.

Attendance at individual lectures ranges from tens to a few hundred. The largest attendance thus far (242 people) was at a talk given by Liz Cottrell (Smithsonian Institution) at the IMAX theater in Tallahassee, FL (Figure 5.2). Host schools and institutions are encouraged to videotape the presentations, which are then posted to the GeoPRISMS website for external viewing.

Figure 5.2. DLP Speaker Liz Cottrell at a public lecture in front of 242 participants at the local IMAX Theater during her visit at University of South Florida in February 2015. Photo credit: Shuying Yang.

Speakers are invited by the GeoPRISMS Office Director following recommendations and ranking by the GSOC. We choose speakers from across the GeoPRISMS spectrum of disciplines, with attention to gender balance and distribution between early/mid-career and more established scientists. The current DLP speakers are listed in Figure 5.3 and the locations of the lectures since 2010 are shown in Figure 5.4. A full list of MARGINS and GeoPRISMS distinguished lecturers is in appendix A9.

The impact of the DLP is high. Based on the feedback from speakers and schools (90% complete), we estimate that more than 7000 people have attended lectures discussing GeoPRISMS research. This high impact comes at a modest cost. The average cost to GeoPRISMS per lecture is about $800 (including honorarium) resulting in an average cost per attendee of only $16. Nevertheless, in recent years we had to scale down the program from eight to six lecturers due to increases in travel costs (particularly airfares) within a fixed budget. Budget limitations also forced us to limit visits to institutions abroad (as recommended by the DRC) and thus far we have held only one such lecture.

5.2 MARGINS (and GeoPRISMS) Mini-lessons

The MARGINS Mini-Lesson Project, initiated by MARGINS Director Geoff Abers, was reinvigorated during GeoPRISMS by means of a successful NSF DUE grant issued to Julia Morgan at the Rice GeoPRISMS Office. Mini-lessons are modular learning materials that use data resources, visualizations and other information resources to examine and understand fundamental earth processes. This latest project is designed to develop the next generation of data based mini-lessons and to integrate a decade of successful MARGINS research into the upper level undergraduate geoscience curriculum. The project brings together members of the GeoPRISMS Education Advisory Committee (GEAC), prominent scientists from the MARGINS and GeoPRISMS community, as well as curriculum

Distinguished Lectureship Program

Distinguished scientists involved with GeoPRISMS science and planning are available to visit US colleges, universities, museums, schools, and other institutions. The distinguished speakers will present technical and public lectures on subjects related to the two GeoPRISMS science initiatives:

Subduction Cycles and Deformation • Rift Initiation and Evolution

Elizabeth Cottrell

Dr. Elizabeth Cottrell is a curator in the Department of Mineral Sciences at the National Museum of Natural History, Smithsonian Institution where she serves as the Director of the Global Volcanism Program. Liz conducts experiments at high pressures and temperatures to understand the evolution of Earth's mantle, from the time of planetary accretion and core formation to today. Currently she is focused on understanding how oxygen, hydrogen, and carbon cycle between mantle reservoirs and how this influences the petrogenesis of Earth's crust and the deep carbon cycle.

Availability: Fall 2015 and Spring 2016

Public Lecture: *Volcanoes: Windows to the Deep*

Technical Lecture: *Oxygen Cycling Through Subduction Zones and the Generation of Continents*

Bradley Hacker

Dr. Bradley Hacker is a Professor in the Department of Earth Science at UC Santa Barbara. His research focuses on field, laboratory, and theoretical study of tectonics using a combination of metamorphic petrology, structural geology, mineral physics, and geochronology. Particular topics of interest include continental subduction, continental collision, and ophiolite emplacement. Applied tools are chiefly electron-backscatter diffraction, electron-probe microanalysis, and laser-ablation inductively-coupled-plasma mass spectrometry.

Availability: Spring 2016

Public Lecture: *Earth's Tempo: The Bleeding Edge of Geochronology*

Technical Lecture: *Differentiation of the Continental Crust by Relamination*

Beatrice Magnani

Dr. Beatrice Magnani is a seismologist at Southern Methodist University whose overarching research theme is the formation, evolution of continents, and continental dynamics. Dr. Magnani employs controlled-source seismology to image continents at a wide range of scales and resolutions, from the lithosphere to the near surface. Her research interests include the Eastern North American passive margin structure and evolution (ENAM Community Seismic Experiment Project), seismic oceanography, and GIA investigations in the Patagonian Andes.

Availability: Fall 2015 and Spring 2016

Public Lecture: *The legacy of ancient plate boundaries in continental intraplate deformation*

Technical Lecture: *From plate boundary to intraplate: understanding the role of paleotectonic structures in continental intraplate deformation*

Andy Nyblade

Dr. Andy Nyblade is Professor of Geosciences at Penn State University. He uses seismic recordings of earthquakes to interrogate earth structure in continental settings to understand deep earth processes linked to rifting, plateau uplift, volcanism, basin evolution, mountain building, crustal genesis, and craton formation. For the past 10 years, he has led the AfricaArray initiative to build science capacity in Africa and the U.S. through coupled data gathering, research, and education programs. He has worked extensively throughout eastern and southern Africa for over 25 years, where much of his research has focused on imaging the African superplume.

Availability: Fall 2015 and Spring 2016

Public Lecture: *The formation of the Great Rift Valley in East Africa: Is there a Connection with Human Origins?*

Technical Lecture: *Cenozoic Rifting, Plateau Uplift, and Volcanism in Eastern Africa and the African Superplume*

Robert J. Stern

Dr. Robert J. Stern is Professor of Geosciences at the University of Texas at Dallas. His research focuses on three complementary themes: 1) How modern arc crust forms above subductions zones and evolves into true continental crust; 2) How new subduction zones form; and 3) When and why Plate Tectonics began on Earth. He, his students and collaborators emphasize geochemical and isotopic data sets to investigate examples around the globe, both on land and beneath the sea. Active areas of study include modern examples of arc and backarc basin igneous activity in the Izu-Bonin-Mariana, Japan, Central American and Aleutian arcs, and ancient examples in Afro-Arabia and Iran.

Availability: Fall 2015 and Spring 2016

Public Lecture: *Geoscientific Investigations of the Southern Mariana Trench and the Challenger Deep*

Technical Lecture: *Convergent Plate Margins, Subduction Zones, and Island Arcs*

Laura Wallace

Dr. Laura Wallace is a Research Scientist at the University of Texas Institute for Geophysics. Laura uses geodetic methods to investigate deformation of the Earth's crust at plate boundaries with a particular focus on subduction zones. She undertakes research at various locations in the western Pacific. She is particularly interested in understanding the physical mechanisms that control subduction thrust earthquakes and slow slip events. She is currently leading a large-scale international project to deploy ocean bottom seismometers and seafloor geodetic instruments to investigate slow slip events offshore New Zealand. Prior to her arrival at the University of Texas, Laura was a research scientist at GNS Science in New Zealand for nearly a decade.

Availability: Fall 2015 and Spring 2016

Public Lecture: *The slow slip revolution: Leading to a better understanding of earthquakes*

Technical Lecture: *Sticky or Slippery? Controls on subduction megathrust behavior at the Hikurangi subduction margin, New Zealand*

Interested in Hosting a GeoPRISMS Distinguished Speaker?

Any US institution interested in inviting a DLP speaker may apply via the GeoPRISMS website: *http://geoprisms.org/education/distinguished-lectureship-program/* Applications are due by August 1, 2015 for speakers visiting in Academic Year 2015 - 2016 (Fall 2015 - Spring 2016). Please note that spots are limited as speakers are only available to visit approximately four institutions apiece. Institutions catering to the general public or not currently involved with GeoPRISMS research are strongly encouraged to apply, including those granting undergraduate or masters degrees, as well as those with PhD programs. Institutions may request a technical and/or public lecture. Public lectures outside of established geoscience departments (including libraries and museums) are encouraged to apply, with help from the GeoPRISMS Office to coordinate. The GeoPRISMS Office will cover airfare for speakers' travel and will coordinate travel and off-site logistics. Host institutions are responsible for the speaker's local expenses (i.e. hotel and meals) for the duration of the visit.

GeoPRISMS Office, University of Michigan
2534 C.C. Little Building | 1100 North University, Ann Arbor, MI, 48109-1005 | +1 734-255-1228
May 2015, Academic Year 2015-2016
The Distinguished Lectureship Program is funded by the National Science Foundation

Figure 5.3. DLP brochure announcing the 2015-2016 lecture program

experts from On the Cutting Edge, a community of geoscience faculty dedicated to improving teaching and student learning. This integration of leading scientists and curriculum experts produces high quality science curricula informed by current educational research and practices.

The original set of mini-lessons was developed under an NSF Course, Curriculum and Laboratory Improvement (CCLI) grant "Using MARGINS data in the Classroom" and resulted in a mix of mini-lessons spanning MARGINS science. An NSF DUE Transforming Undergraduate Education in Science Technology, Engineering and Mathematics (TUES) grant "Bringing NSF MARGINS/GeoPRISMS Continental Margins Research into the Undergraduate Curriculum" was initiated in 2012 and provided the opportunity to synthesize key results of the full decade of MARGINS research, while integrating the existing mini-lesson collection, in order to define a more coherent suite of lessons across the initiatives. Both efforts have been strongly supported by the Science Education Resource Center (SERC - directed by Cathy Manduca) at Carleton College. SERC also houses the MARGINS mini-lessons in their online portal, ensuring ready access and support for a broad range of potential instructors.

The project launched in Spring 2013 and was led by Julia Morgan (Rice), Ellen Iverson, Cathy Manduca (both at Carleton College), Andrew Goodliffe (Alabama), Jeff Marshall (California State Polytechnic Pomona) and Jennifer Beck (EvalArts Consulting). A broader description of the initiative is provided in a recent GeoPRISMS newsletter provided by Julia Morgan and members of the GEAC. The curriculum development teams draw from a wide spectrum of educators and researchers, listed in Table 5.1.

The mini-lesson authors participated in a series of webinars and virtual workshops, as well as

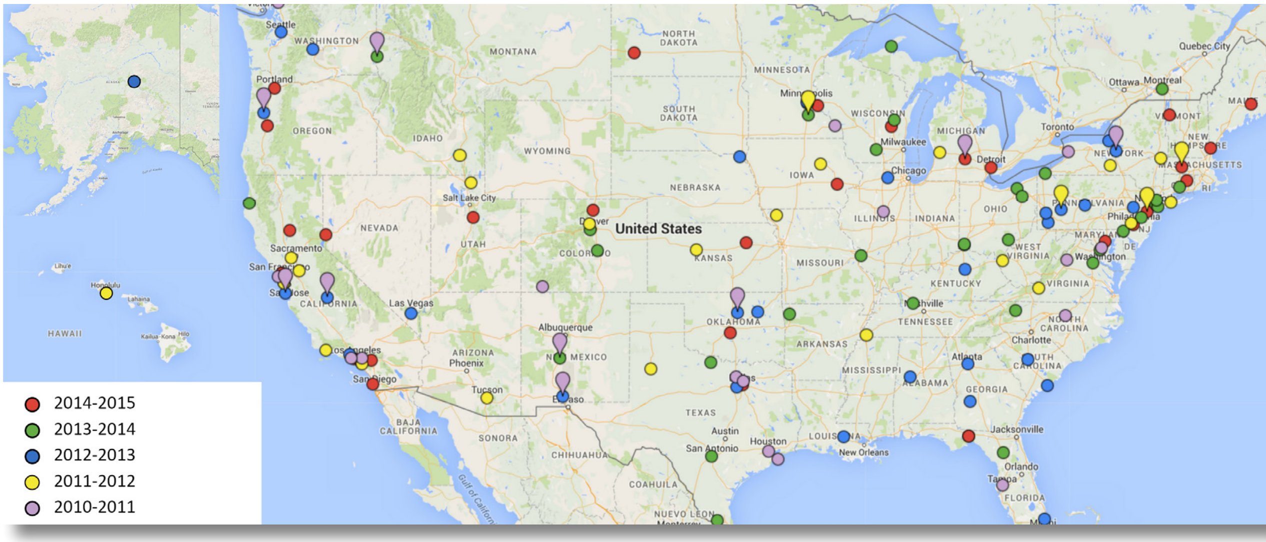


Figure 5.4. Locations of institutions visited by DLP speakers from 2010-2015.

two face-to-face workshops, during which the structure, content, and pedagogical framework of the mini-lessons was laid out (Figure 5.5). Outside educators were invited to try out the mini-lessons during their development. Their feedback and subsequent peer reviews were crucial for the final refinement of the mini-lessons. The development approach, time-line and availability of the new mini-lessons suite has been presented in several AGU Educational sessions and in presentations at the GeoPRISMS Townhall, in addition to SERC exhibits and Newsletter and listserv announcements. This latest MARGINS mini-lessons project wraps up this summer 2015, when the mini-lessons will finally be released to the public by way of the SERC portal. The MARGINS Mini-Lesson Program has paved the way for the future development of GeoPRISMS Mini-Lessons, defining a model and framework that can be employed by GeoPRISMS PIs as part of their broader impacts. This

SubFac: *Chemical cycling in subduction zones* (Robert Stern, UT Dallas; Ben Edwards, Dickinson College; Sarah Penniston-Dorland, University of Maryland; Chris Kincaid, University of Rhode Island).

SEIZE: *Seismogenic processes at subduction zones* (Casey Moore, UC Santa Cruz; Jeff Marshall, Cal Poly Pomona; Eliza Richardson, Penn State; David Pearson, Idaho State; Sue Cashman, Humboldt State).

RCL: *Rifting processes and feedbacks* (Scott Bennett, USGS Golden CO; Rebecca Dorsey, University of Oregon; Andrew Goodliffe, University of Alabama; Jack Loveless, Smith College; Lisa Lamb, University of St Thomas).

S2S: *Sediment erosion, transfer, and deposition* (Steve Kuehl, Virginia Institute of Marine Science; Lonnie Leithold, North Carolina State; Kathleen Surpless, Trinity University; Adam Hoffman, University of Dubuque).

Table 5.1. Curriculum development teams for the current MARGINS mini-lessons project

will ensure that the latest and best continental margins science can be rapidly incorporated into the undergraduate curriculum.

5.3 Student and Postdoc Opportunities

Figure 5.5. Class demonstration quantifying heat flux during a Carleton workshop on the MARGINS mini-lessons project. Photo credit: Anaïs Férot, GeoPRISMS.

Student Symposia

A significant addition to the new GeoPRISMS Program is enhanced training and engagement of early-career investigators, with particular emphasis on students and postdocs, who will become the next generation of GeoPRISMS scientists. In keeping with this goal, a series of student-centered activities was introduced in association with the primary site implementation workshops. The main component was a one-day Student Symposium scheduled immediately prior to the workshop. Students typically arrive one day early to the meeting, attend a half day of introductory talks on the geology of the primary site, given by experts, discuss their own research through poster presentations (which were then displayed throughout the workshop), and then attend a half-day geologic field trip in the local area (Figure 5.6). The primary goals of these symposia included (a) providing all students with a common background knowledge in preparation for subsequent discussions during the workshop, (b) facilitating interactions between students and senior scientists in a friendly setting, (c) providing an informal forum in which to present their research and hear from their student colleagues, and (d) developing a student cohort that would carry through the workshop and beyond. Students and postdocs also were invited to participate in several other workshop activities, including a best poster competition, a student career dinner, and scribing or leading break-out discussions. Overall, student feedback was extremely positive and the program resulted in a high level of student participation in workshop activities (Table 5.2).

Primary site	Total attendance	Student symposium attendees
Cascadia	173	37 (21%)
Alaska-Aleutians	148	22 (15%)
EARS	108	28 (26%)
ENAM	92	16 (17%; includes postdocs)
New Zealand	145	23 (16%)

Table 5.2. Student participation in the primary site planning workshops

Figure 5.6. Student field trips ahead of the EARS (right) and New Zealand (bottom) site planning symposia. Photo credit: Anaïs Férot, GeoPRISMS.

Student opportunities in GeoPRISMS-funded research projects

The field work and marine cruises associated with GeoPRISMS-funded projects provide unique opportunities for graduate student training, as well as introducing undergraduates to science in the field, and allowing postdocs to hone new skills and supervise field activities. The field work and cruises bring students together with more senior PIs, technical support staff and crew, and provide unique experiences learning how to conduct high quality and interdisciplinary science in the field. For example, many students, typically from the PIs' home institutions, have participated in PI-driven research projects. However, several community experiments and projects with long or involved deployments have enabled broad calls to students and postdocs across the community to participate in field work or cruises. This model was particularly successful for the Cascadia Initiative (with the Apply to Sail program hosted by GeoPRISMS), the ENAM community experiment, and the iMUSH project to geophysically image Mount St. Helens.

For the Cascadia Initiative, "Apply to Sail" invitations led to approximately 50 applications per year to fill a limited number of positions. Over five years of operations, a total of 41 graduate students, 25 undergraduates and 3 postdocs participated in the instrument deployment and recovery cruises (Figure 5.7).

Figure 5.7. Left: Samantha Bruce (Adjunct Instructor, College of Charleston) with starfish in front of ROV Jason during a Cascadia Initiative cruise. Bottom: A student checks the status of short period seismometer (photo by Gary Linkevich).

Cruise reports and blogs are available through the Cascadia Initiative Expedition Team website and a summary of student experiences was published in the GeoPRISMS Fall 2013 newsletter.

The ENAM Community Seismic Experiment (CSE) provided 79 students and young scientists the opportunity to participate in seagoing and/or land-based field work during several field campaigns (see Nugget by Shillington et al.). These included four different cruises (to deploy and recover OBS instruments and carry out the active source seismic experiment; Figure 5.7) and two campaigns on land. Their experiences were captured well by the student report published in the Fall 2014 Newsletter and on the ENAM CSE field blog with many of the blog posts written by participating students. The PIs of the ENAM CSE organized two data processing workshops with a multi-channel seismic workshop at the University of Texas (20 participants) and a seismic reflection workshop at Lamont-Doherty (14 participants). The interest for the workshops and field opportunities was high. The UT workshop alone drew nearly 80 applications, while there were 17 applications for 5 spots on the broadband OBS recovery cruise in March 2015.

There was also strong student participation in the iMUSH field deployments, as featured in the Spring 2015 newsletter. There were more than 250 applications to participate in the active seismic component. From these applications 48 graduate students, 10 undergraduates and 2 postdocs were selected. These students and postdocs came from 29 US institutions and 7 European universities (Copenhagen, Hamburg, Bristol, Lausanne, Free University Berlin, Technical University Berlin and ETH). The passive broadband seismic deployment and retrieval involved 8 graduate students, 6 undergraduates and 1 postdoc. The nodal seismic deployment further involved 8 graduate students and 1 postdoc. The MT component involved a further 8 graduate students, one of whom was chosen from an open application that had 12 interested students.

The GeoPRISMS/EarthScope-sponsored MAGIC project has taken a different approach to student participation in field work. Instead of hosting an open call for applications, the PIs on the

MAGIC project are developing relationships with colleges and universities located near seismic stations (see Nugget by Long and Benoit). The PIs have engaged with faculty and students from 10 institutions, most of which primarily serve undergraduates, who helped install and service stations or host stations on their campuses. In addition to this outreach effort, the MAGIC project is making a particular effort to involve undergraduates in their field campaigns; approximately a dozen undergraduates from Yale and the College of New Jersey have participated in MAGIC field work, benefiting from working closely in the field with PIs, graduate students, and postdocs.

In summary, projects that are sponsored or closely related to GeoPRISMS provide significant opportunities for field experience and hands-on training to a large number of graduate students, undergraduates and postdocs. The calls for applications to sail or to participate in field work are popular and competitive. This provides the essential human resource development necessary to maintain a scientifically well-educated workforce and for the entrainment of new talent in interdisciplinary research on the oceans and on land.

Best Student Presentation Prize Competition at the Fall AGU meeting

The GeoPRISMS Office organizes an annual competition for the best student presentations at the Fall meeting of the American Geophysical Union in San Francisco. This is a continuation of the competition begun during MARGINS and is designed to communicate the breadth of GeoPRISMS science, but also to extend the reach of the program to early-career researchers. Students are invited through newsletter, listserv, website, and Facebook announcements to apply to compete in the program. They submit their abstracts, CVs and short statements of motivation and relevance to GeoPRISMS science, prior to the meeting. Students are not required to work on GeoPRISMS- (or MARGINS-) funded research but their work should fall within the general scope of the GeoPRISMS science objectives. All applicants are also invited to present their research in poster format at the annual Townhall and Student Forum (typically held on Monday evening during AGU week), which offers a friendly and informal opportunity to interact with colleagues and senior scientists (Figure 5.8).

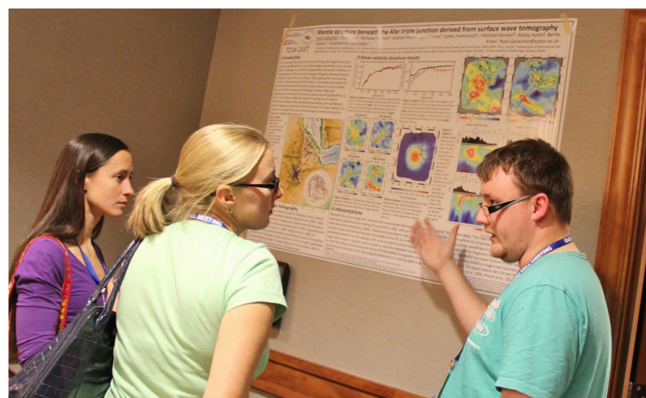


Figure 5.8. Applicants for the Best Student Presentation competition can present their work in poster format at the Townhall and Student Forum at the annual Fall AGU meeting. Photo credit: Anaïs Férot, GeoPRISMS.

Presentation judges are selected from a large pool of former MSC / GSOC and MEAC / GEAC members, former or current postdoctoral fellows, and previous award winners. The recommendations of the judges are evaluated by the GEAC, which decides on the best presentation (one each for oral and poster presentations) and up to two runners-up in each category. The winners receive a cash prize of $500 and are profiled, along with the runners-up, in an article on the website and in the newsletter.

The number of applications grew steadily through 2013 (Figure 5.9) before a sudden decline in 2014. Typically there are slightly more female than male applicants and more posters than talks are submitted. In the early years of GeoPRISMS, MARGINS-funded research dominated the submissions but the two GeoPRISMS initiatives have gradually started to dominate the submissions, with more submissions from SCD than RIE. The decline in applications in 2014 appears to be anomalous, and may relate to website or listserv issues leading up to the application deadline. We anticipate an uptick in applications this coming year, particularly with the increase in GeoPRISMS science being carried out.

The list of student presentation award winners since 2010 is provided in Table 5.3. Sixty percent of the winners are female. A full list of winners and runners up is provided in appendix A6.

	Poster	*Talk*
2014	Andrew Parsons (Leeds)	Kristina Walowski (Oregon)
2013	James Muirhead (Idaho)	Megan Newcombe (Caltech)
2012	Samer Naif (UC San Diego)	Maryjo Brounce (Rhode Island)
2011	Manahloh Belachew (Rochester)	Christie Regalla (Penn State)
2010	Kristin Morell (Penn State)	Linda Chernak (Brown)

Table 5.3. GeoPRISMS Student Presentation Award winners

5.4 Postdoctoral opportunities

The NSF program solicitation for GeoPRISMS encourages applications for GeoPRISMS Postdoctoral Fellowships, which are aimed at providing opportunities for early-career scientists to solidify research skills, build a track record, establish peer relationships, and acquire professional self-confidence. The GeoPRISMS Postdoctoral Fellowship Program issues grants to PIs to support postdoctoral researchers at institutions in the US for up to two years, typically within five years after receipt of their Ph.D. The table below provides the names of the funded postdoctoral researchers or fellows during GeoPRISMS so far. Seven out of the nine postdocs (78%) are female. All who completed their postdoc appointments have since moved into faculty or research positions, and thus are now in the position of training new GeoPRISMS investigators.

FY15	Shuoshuo Han	University of Texas
	Aurore Sybrandt	University of Idaho
FY13	Taryn Lopez	University of Alaska Fairbanks
	Sabine den Hartog	Penn State University
FY12	Abijit Ghosh	University of California at Santa Cruz (now at UC Riverside)
	Haiying Gao	University of Rhode Island (now at the U of Massachusetts).
FY11	Ellen Syracuse	University of Wisconsin Madison (now at Los Alamos National Laboratory)
	John Naliboff	University of California at Davis (now at the Geological Survey of Norway)
	Hiroko Kitajima	Penn State University (now at Texas A&M University)

Table 5.4. Postdoctoral scholars supported by GeoPRISMS including (where appropriate) their current affiliations.

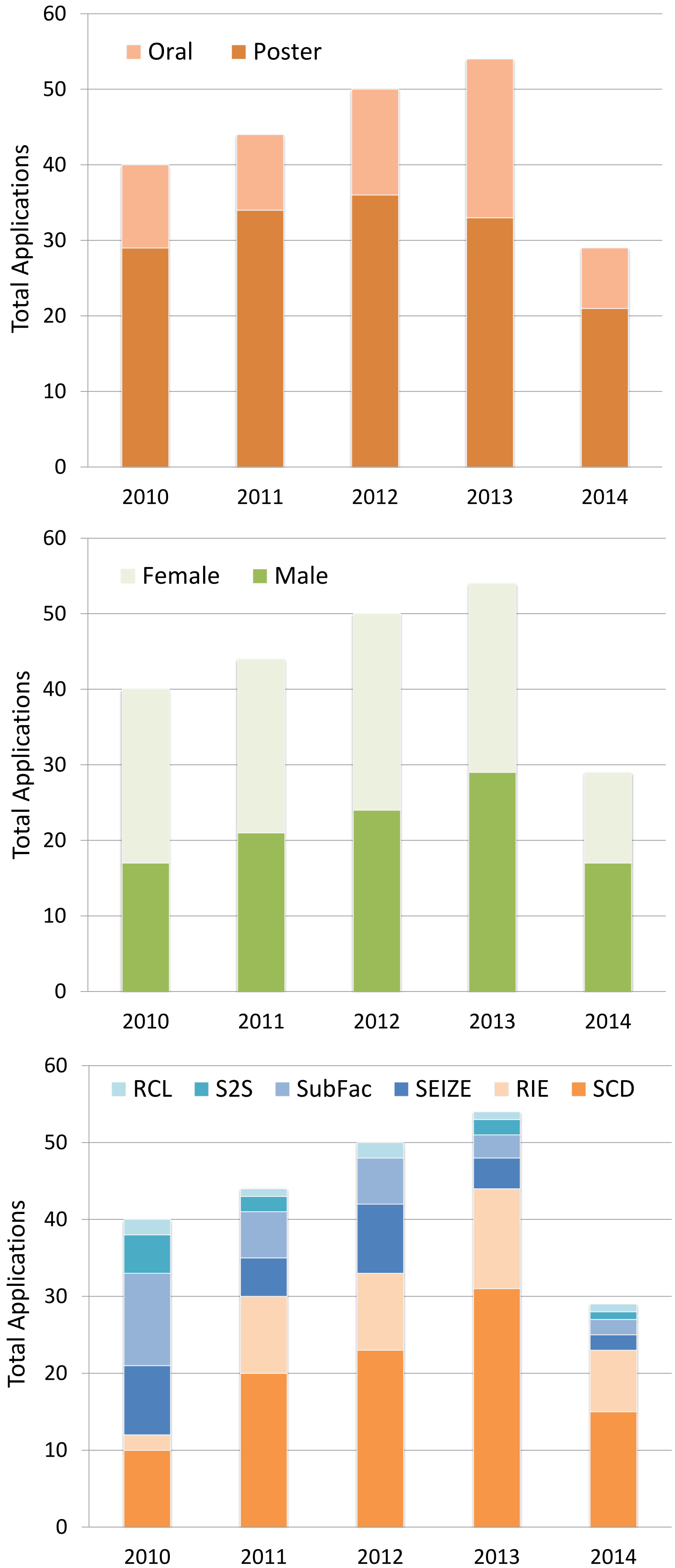


Figure 5.9. GeoPRISMS Best Student Presentation statistics (2010-2014)

6. Other Impacts

6.1 Building an Interdisciplinary GeoPRISMS Community

During its first five years GeoPRISMS has substantially grown its community base, building upon and expanding beyond the original MARGINS community. This is reflected in the excellent attendance at GeoPRISMS workshops (with nearly 1,000 unique individuals attending), including a high percentage of graduate students (~20%), postdocs, and early career investigators (a further 15-20%), who represent the next generation of GeoPRISMS researchers. The GeoPRISMS Science and Implementation Plans are the products of formal and informal contributions from large numbers of scientists, including those listed in these documents and all attendees of the planning workshops. As necessary for a program of this nature, the community is highly interdisciplinary and collaborative, enabling strong team-based research efforts, including the planning and execution of community experiments and expeditions. The community-building activities are tightly interwoven with GeoPRISMS research activities and define the entire GeoPRISMS research enterprise.

6.2 International Collaborations

International collaboration and exposure remains an important aspect of GeoPRISMS. Significant international work has been conducted in the last 5 years as part of MARGINS-funded work at the focus sites abroad, including Central America, Gulf of California, IBM and Nankai, as indicated by the citations listed in Chapters 2 and 3. The GeoPRISMS primary sites that have been open for large field projects thus far have all been within the US. By design this has led to a reduction in international exposure. The Program has sought to maintain strong relationships with potential collaborators, both on US-focused projects, and in anticipation of future research. In particular, the Cascadia primary site has provided clear opportunities for collaborations with Canadian researchers, with emphasis on geodetic and seismic observations along this active margin, as well as cooperation on offshore cabled infrastructure, including NEPTUNE-Canada and the US Ocean Observing Initiative. Interests in comparative studies of Eastern North American Margin (ENAM) structure also enabled collaborations with Canadian scientists. Collaborative research projects, shared development and use of infrastructure, and research training are key elements of ongoing and proposed projects in East Africa and New Zealand, with significant international collaborations anticipated in upcoming years. To ensure these long-term international collaborations persist, all GeoPRISMS planning workshops sought to engage active international attendance. International participation in the mini-workshops focusing on EARS and NZ was high.

The Office Directors have also been actively engaged in developing international partnerships, which includes presentations highlighting the Program and research objectives at international meetings in Europe and Japan; participation in planning meetings that led to the UK NERC Consortia infrastructure for studies of the interaction of volatiles between the deep Earth, the hydrosphere and atmosphere; and partnerships in projects funded through national funding agencies in Japan and Europe, as well as those provided by the European Union.

Thematic studies in the GeoPRISMS Science and Implementation Plans have also enabled valuable international collaborations. The ExTerra group of researchers, interested in the thematic study of exhumed terranes, has flourished with the support of GeoPRISMS and other NSF programs. ExTerra has developed its own community-driven Field Institute approach to conducting scientific research in the field, with their first field institute focusing on the Salinian arc in California (Figure 6.1). A ~$4M ExTerra Field Institute and Research Endeavor (E-FIRE) proposal has just been recommended for funding through NSF PIRE (Partnerships for International Research and Education). This project develops a new paradigm for collaborative geological research by conducting collaborative fieldwork to collect materials held in shared, open-access depositories; facilitates broad interactions through workshops; and allows student exchanges among research laboratories in the US and abroad to foster international training. The E-FIRE project will build on a partnership with the EU-sponsored Marie Curie Training Network "Zooming In between Plates" with lead-PI Philippe Agard (Université Pierre et Marie Curie, Paris). This project will lead to international field institutes to trace the cycle of rocks and fluids through the subduction process, as recorded in the Western Alps, which is a premier example of a fossil subduction zone.

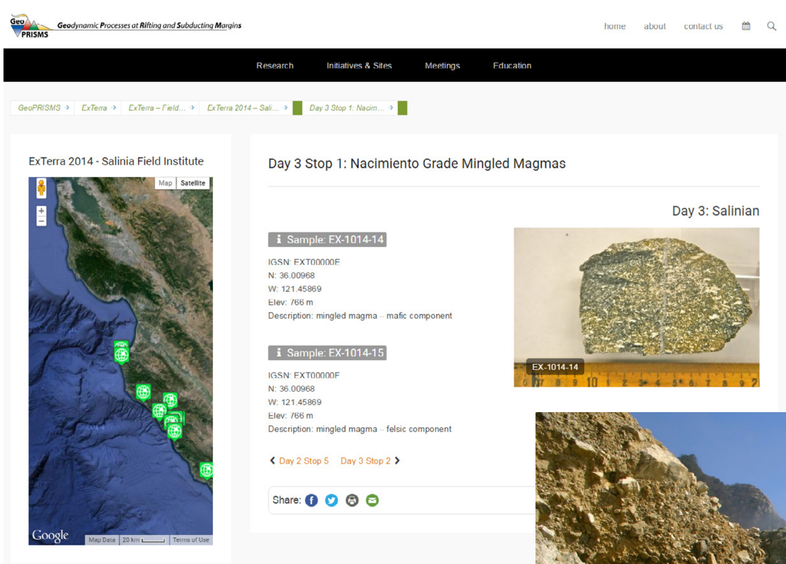


Figure 6.1. Left: Meta-data for rocks collected as part of the first ExTerra field institute in the Santa Lucia mountains (central coastal California). Below: Exposure of the late Cretaceous Salinian arc along the California Coast.

6.3 Relationship to Facilities and Other Programs

There is a great deal of synergy between GeoPRISMS goals and efforts and other NSF-sponsored facilities and programs. In particular, GeoPRISMS research efforts are successfully leveraging data from EarthScope facilities, including USArray and the Plate Boundary Observatory (PBO). The PASSCAL program of IRIS provides critical support for PI-driven seismic deployments that support GeoPRISMS science. A large number of GeoPRISMS projects rely on data provided by the IRIS and UNAVCO data centers, which in turn distribute data collected through GeoPRISMS funding. The Computational Infrastructure for Geodynamics initiative provides codes and computational support for GeoPRISMS-related modeling projects. A number of GeoPRISMS-supported data collection initiatives with offshore components, including work in Cascadia, ENAM, and Alaska/Aleutians, have relied heavily on infrastructure maintained by other NSF programs. This includes ship time resources supported through the UNOLS fleet and instrumentation maintained and coordinated through groups such as OBSIP (Ocean Bottom Seismograph Instrument Pool; which is in itself a collaborative effort among IRIS, Woods Hole Oceanographic Institution, Lamont Doherty Earth Observatory, and Scripps Institution of Oceanography).

GeoPRISMS relies particularly heavily on synergy with the EarthScope initiative in the Cascadia, ENAM, and Alaska-Aleutians focus sites. GeoPRISMS research in Cascadia has benefitted from both seismic and geodetic data collected in the Pacific Northwest by EarthScope and by the Cascadia Initiative. In the ENAM primary site, data from a number of USArray components are proving critical for GeoPRISMS science; this includes seismic data from the seismic Transportable Array (TA) and Flexible Array (FA) studies, in addition to data from the recently established Central and Eastern US Network, an intra-agency collaboration that takes advantage of the opportunities provided by the deployment of the TA in the eastern US. The magnetotelluric (MT) component of USArray will provide an exciting opportunity for GeoPRISMS science in ENAM over the next few years, as the MT TA deploys in the eastern US, and FA data are collected along the MAGIC seismic line. These data will provide an opportunity for imaging the conductivity structure of the rifted ENAM margin in unprecedented detail. Finally, with the focus of USArray data collection turning towards Alaska, where the PBO has operated for a decade and will continue to operate through the end of the EarthScope program in 2018, there are ongoing opportunities to leverage EarthScope data collected in Alaska-Aleutians for GeoPRISMS science. In addition to the leveraging of EarthScope resources, GeoPRISMS researchers are exploiting the synergy between EarthScope and GeoPRISMS science goals in the three US-based GeoPRISMS focus sites. Scientific results from EarthScope projects are informing GeoPRISMS science questions and vice versa. As a demonstration of this cooperation, three of the five primary site planning workshops were sponsored jointly by GeoPRISMS and EarthScope, enabling cooperative project planning and coordinated data collection efforts.

GeoPRISMS, like MARGINS before it, will benefit from scientific ocean drilling (now through the International Ocean Discovery Program, IODP) and there is significant overlap between the guiding science questions of the two organizations. Given the long lead time for implementing IODP-related projects, many drilling proposals originally submitted during MARGINS have been

Figure 6.2. Drill ship Chikyu leaving Yokohama harbor. Photo by Katsuyoshi Michibayashi.

SCD-related expeditions

Exp 348: NanTroSEIZE Stage 3 – Plate Boundary Deep Riser 3 (Sep 2013–Jan 2014)
Exp 338: NanTroSEIZE Stage 3 – Plate Boundary Deep Riser 2 (Oct 2012–Jan 2013)
Exp 343: Japan Trench Fast Drilling Project (Apr–May, Jul 2012)
Exp 333: NanTroSEIZE Stage 2 – Inputs Coring and Heat Flow (Dec 2010–Jan 2011)
Exp 332: NanTroSEIZE Stage 2 – Riserless Observatory 2 (Oct–Dec 2010)
Exp 326: NanTroSEIZE Stage 3 – Deep Riser Hole (Jul–Aug 2010)
Exp 322: NanTroSEIZE Stage 2 – Subduction Input (Sep–Oct 2009)
Exp 319: NanTroSEIZE Stage 2 – Riser/Riserless Observatory 1 (May–Aug 2009)
Exp 328: Cascadia A CORK Observatory (Sep 2010)
Exp 334: Costa Rica Seismogenesis Project (Mar–Apr 2011)
Exp 344: Costa Rica Seismogenesis Project 2 (CRISP) (Oct–Dec 2012)
Exp 340: Lesser Antilles Volcanism & Landslides (Mar–Apr 2012)
Exp 341: Southern Alaska Margin (May–Jul 2013)
Exp 352: Izu-Bonin–Mariana Fore-arc (Jul–Sep 2014)
Exp 351: Izu-Bonin–Mariana Arc Origins (May–Jul 2014)
Exp 350: Izu-Bonin–Mariana Rear Arc (Mar–May 2014)
Exp 362: Sumatra Seismogenic Zone (planned for FY16)
Exp 366: Mariana Convergent Margin (planned for FY17)
Exp TBD: Hikurangi Subduction Margin (FY18)

RIE-related expeditions

Exp 349: South China Sea Tectonics (Jan–Mar 2014)
Exp 367-368: South China Sea Rifted Margin (planned for FY17)

Table 6.1 GeoPRISMS related IODP expeditions accomplished only in the past six years. The Expeditions listed in Table 6.1 have directly addressed MARGINS- and GeoPRISMS-related scientific questions.

Although few of these expeditions visited or will visit the selected GeoPRISMS primary sites, they serve the thematic studies component of the program very well, providing valuable comparative observations to the chosen primary sites. As results are obtained from offshore studies in the primary sites, we can anticipate new GeoPRISMS-inspired IODP proposals to be submitted.

6.4 Geohazards and GeoPRISMS

GeoPRISMS focus on continental margin processes leads to a direct relationship to improved understanding of geohazards, including the effects of climate change, slope processes and stability, as well as earthquake and volcano hazards. Several research efforts are directly designed to address such questions, including the Cascadia Initiative (CI) and the iMUSH project. The CI is an onshore/offshore seismic and geodetic experiment that takes advantage of the Amphibious Array to study questions ranging from megathrust earthquakes and volcanic arc structure and processes. The CI was highlighted in Vice President Biden's list of "100 Recovery Act Projects that are Changing America" under the heading "Research to Avert Disaster: Understanding Earthquakes in the Pacific Northwest – Oregon, Washington, Northern California". Several projects are characterizing the eruptive history and volcanic products of Cascade and Aleutian volcanoes, contributing to our understanding of volcanic hazards in both settings. The iMUSH project is focused on clarifying the internal structure of Mount St. Helens, which erupted catastrophically in 1980 and continues to be the most active volcano in the lower 48 US states. GeoPRISMS related projects underway or planned in the Alaska-Aleutians and New Zealand primary sites also directly address subduction zone geohazards, guided by the scientific questions outlined in the GeoPRISMS Science and Implementation Plans. In both Cascadia and Alaska-Aleutians, close collaborations with USGS scientists ensure that GeoPRISMS results are put to best use in mitigating earthquake and volcanic hazards in the US.

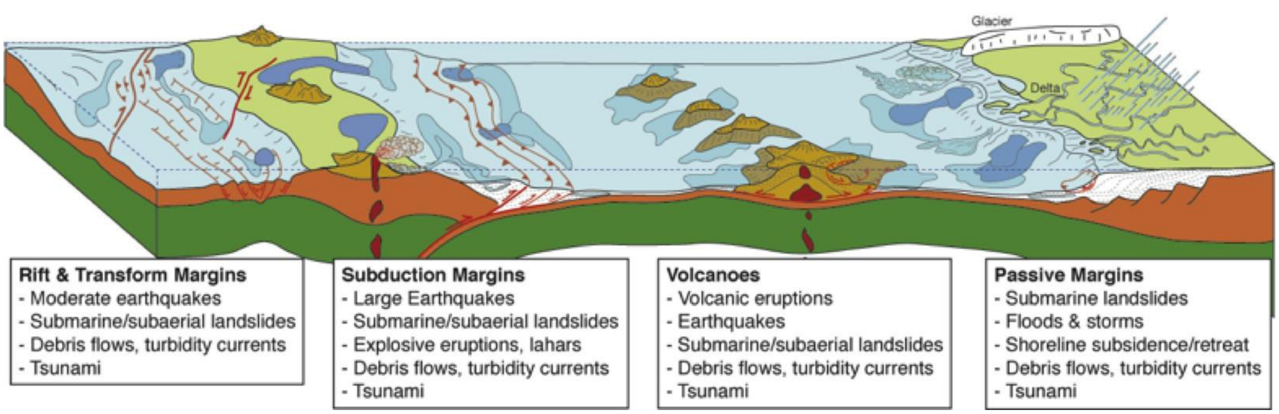


Figure 6.3. Representative geohazards that can originate along continental and volcanic margins. From GeoPRISMS Draft Science Plan, modified from Morgan et al. (2009).

Research within the RIE initiative also addresses geohazards at rifted margins. In particular, the ENAM community seismic experiment yielded a rich trove of MCS data imaging sedimentary strata on the shallow continental margin, which also record large prehistoric landslides. Analysis of these data will allow improved assessments of slope stability in these settings, as well as the mechanisms of erosion, transport, and transfer of sediments across the shoreline, and their storage in the marine setting. In the EARS primary site, analysis of the unusual Malawi earthquake sequence has yielded new interpretations about the distribution of active faults in the rift valley, with significant implications for local earthquake hazards (see nugget by Gaherty).

6.5 Energy and Economic Resources

An improved understanding of continental margins will have a substantial impact on our access to and utilization of resources, including water, habitat and in particular, energy and mineral resources. Upon the recommendation of the DRC, Lori Summa (ExxonMobil) joined the GSOC as a representative of the oil and gas industry, providing valuable perspectives on the connections between GeoPRISMS research and economic objectives. Several of the planning workshops, in particular for ENAM and EARS, drew other industry representatives, including participants from African oil and mining companies. The ENAM community seismic experiment continues to be of great interest to companies keen to understand energy resources buried along this ancient passive margin, although efforts to expand the data collection through industry investments were unsuccessful. The open-access nature of the acquired data of course allows for both academic and commercial use. Seismic reflection and heat flow studies along the SCD primary site margins also better image hydrate deposits which allows for a better understanding of the causes and consequences of climate change.

Global mineral exploration may benefit from ongoing research at active convergent and rifting margins, focused on understanding the origin and evolution of mantle, crust, and fluids in subduction zones at many scales, goals that figure prominently in GeoPRISMS. Further partnerships are anticipated in association with EARS and ENAM studies, and possibly at the three SCD primary sites.

6.6 Human Resource Development and Outreach to Local Communities

The GeoPRISMS Office and broader community engage in many education and outreach activities that contribute directly to the training of graduate students and postdocs as described in Chapter 5. Another contribution to human resource development arises from engagement with local communities, in particular, in areas where residents otherwise may have few resources or limited exposure to the science that impacts their daily lives.

A few examples include: 1) field activities in Alaska during the 2011 survey of the Alaska Megathrust (by PIs Shillington, Keranen and others) provided unique opportunities to engage residents and school children in smaller communities during placement and recovery of instruments; 2) the Malawi earthquake study (see nugget by Gaherty) led to the installation of a local seismic network and involved on-site training of African scientists who will use it; 3) the large number of African scientists and students that attended the EARS Planning Workshop in 2012, fostering new collaborations that can help to develop scientific resources in Africa; 4) the MAGIC experiment, taking place in the eastern US, is inviting local college students to participate in geophysical field activities, giving them exposure to research experiences that may guide them into geoscience careers; and 5) the participation by GeoPRISMS scientists in the EarthScope-hosted Interpretative Workshops for Eastern North America and Alaska that provide outreach to professionals in museums and national or state parks who interpret science for school children or the general public.

7. Summary and Outlook

The previous chapters document a strong GeoPRISMS science and community effort. Many significant data collection efforts are underway or have just been completed at Cascadia, the Eastern North American Margin and Alaska-Aleutians. The early scientific reports and papers based on research that started just four years ago predict a high scientific impact of GeoPRISMS-funded research.

In the SCD initiative, the primary scientific topics are being addressed through field work and thematic studies. The offshore work at Cascadia highlights the thermal structure and tectonic deformation of the fore-arc and plate boundary. Slow earthquakes here are shown to have higher seismic efficiency than previously thought. A number of interdisciplinary projects combine geophysical and geochemical work to investigate magma transport from mantle to volcano at multiple locations in Cascadia and the Aleutians. Significant geochemical and petrological work is improving our understanding of the initiation and evolution of the Aleutian arc. Laboratory experiments constrain the conditions of earthquakes and slow slip at depth. Numerical models provide new insights into the nature of outer-rise faulting and intermediate-depth seismicity. Links between surface processes, sediment production, and subduction are being investigated through numerical modeling and laboratory analyses in the three primary field areas.

In the RIE initiative, field and thematic approaches are addressing several of the key initiative questions. We have new insights into the causes of late-stage volcanism at ENAM. A significant amphibious seismic community experiment has just concluded and has provided significant training opportunities for graduate students and postdocs. An interdisciplinary project is underway to better understand the geological evolution of the U.S. east coast. New seismic hazards assessments are being completed in Malawi. Significant work funded through EAR to PIs from the GeoPRISMS community has led to better constraints on the kinematics and dynamics of rifting and the role of magma and plumes in rift initiation and evolution.

The community has grown significantly by broad outreach to and entrainment of new talent through activities organized by the Office and overseen by the GSOC. The focus on early career scientists (including students) in MARGINS and GeoPRISMS has led to a profound shift in the demographics of GeoPRISMS PIs and the broader community. We will continue to strongly engage early-career scientists with focused activities at the Fall Meeting of the AGU as well as at this Fall's SCD Theoretical and Experimental Institute (TEI) and the RIE TEI planned for 2016. These mid-term meetings will also set the stage for significant synthesis work at the primary sites and lead to progress in thematic studies.

Moving forward, there are several topics that require careful consideration as the Program enters the second half of the decade.

There are concerns about whether the science goals can be accomplished with the significant reduction (40%) of its sequestered budget, which has been hit hard by the lack of growth in the budget of NSF GEO and the federal sequestration. In a conversation with the NSF, the GSOC has firmly supported continuing the approach laid out in the Science and Implementation Plans. It has rejected calls to find ways to explicitly reduce the scope of the program, by, e.g., eliminating one or more of the primary sites. Appendix A8 contains the full response to questions by NSF. GeoPRISMS is not just a funding opportunity but also a broad community effort and PIs are actively encouraged to obtain funding sources outside of the sequestered budget. Many GeoPRISMS PIs have been successful at this. The reduced budget will lead to fewer or smaller GeoPRISMS grants, but the GSOC recommends this budgetary pressure should be resolved by proposal competition. Ideally, the EAR and OCE divisions would work together to bring funding levels back up to pre-sequestration levels.

The Sea Change report ("Sea Change: 2015-2025 Decadal survey report of Ocean Sciences", The National Academies Press, 2015), which has subsequently been endorsed by NSF, highlights several GeoPRISMS science initiatives as key areas of inquiry for OCE to pursue in the next decade. It also recommends significant reduction in funding for OCE infrastructure to preserve the ability to conduct science. This reduction is likely to have both positive and negative impacts on GeoPRISMS science. On the one hand, the reduction in funds to IODP and the Academic Fleet will cause some delay on projects by having fewer available ships or cruises. The reduction in funds for OOI may limit the impact of future smaller projects at Cascadia. On the other hand, the increased availability of funds for PI-driven science will benefit individual PIs either through more OCE-funding or, again ideally, increased contributions from OCE to the sequestered GeoPRISMS budget.

The availability of ARRA funds for the acquisition of hardware for the Amphibious Array led to significant investment in the Cascadia Initiative, which is in essence a large-scale community experiment with its offshore implementation managed through the CIET. The ENAM Community Seismic Experiment was encouraged by NSF and was formulated following a community workshop. Both efforts are relatively new approaches to data-driven science within MARGINS and GeoPRISMS, where collected data is immediately made available to the academic community. It will be useful to evaluate the community science model following these two experiments and weigh the benefits (open data, community efforts toward a common goal) and disadvantages (significant work by PIs without actual funding for science, no priority access to the data). While the GSOC has not formally evaluated these community experiments, informal discussions with lead PIs has suggested that some design improvements can be made in future experiments, including careful consideration of the length of time PIs commit themselves to the initial project and of the demographics of the PI team – the CIET is principally composed of senior PIs whereas the ENAM CSE is principally conducted by early- and mid-career PIs.

The impact of the phased funding model for primary sites needs to be evaluated. While the phased funding approach has economized and focused funding for large data acquisition efforts, there is the potential for imbalance in the impact GeoPRISMS funding has on research at the five primary sites. A few examples of factors that may contribute to this imbalance are changes in available funding due to the sequestration in FY13 (which negatively affects the later primary sites), a delay on the (otherwise very positively evaluated) shared logistical support for fieldwork in the Aleutians, and limited funding success for EARS proposals in its first year. Another contributing factor to imbalance between primary sites is that with the phased funding approach some sites (e.g., Cascadia and New Zealand) will have been open for proposals without competition from proposals for another primary site, effectively allowing PIs working at Cascadia and New Zealand to compete for a larger pool of funds. The first stage of the phased funding model will end next year when New Zealand is open for the second year. This mid-life review of GeoPRISMS therefore provides an opportunity to consider the best use of GeoPRISMS funding in the remaining years, which may include revisiting some of the primary sites.

Moving forward, the GeoPRISMS community is strongly involved in important discussions regarding the future of facilities such as SAGE and GAGE operated by UNAVCO and IRIS, which will be recompeted in the near future, as well as plans for new scientific approaches to continental margins science. One of the most prominent of these, that has substantial implications for GeoPRISMS science, is the concept of the Subduction Zone Observatory (SZO) that has been described in IRIS and UNAVO plans as a possible follow-up and extension to EarthScope. It has the ambitious scope to cover most of the subduction zones in the Pacific (and specifically those in the Northern and Eastern Pacific) and combine a multi-disciplinary facility with an active, international, shoreline-crossing and interdisciplinary community studying convergent margins and their associated hazards. Two SZO Townhall meetings at AGU have engaged a wide community. We note that the 2014 Townhall was attended by a significant number of GeoPRISMS PIs and had an attendance that was 43% female and 29% early career. We expect that the future SZO discussions will focus on integration between the EarthScope and GeoPRISMS science objectives with broad geophysical and geochemical facility support and strong interaction with the USGS and international partners. A proposal for a planning workshop for the SZO initiative is currently under development with participation from the IRIS and UNAVCO Directors, the GeoPRISMS and EarthScope Chairs, and the Chair of the IRIS Board of Directors.

In closing, we are happy to report that the GeoPRISMS community is alive and well. Many PIs are engaged in GeoPRISMS-funded projects; many more scientists and students engage in closely related research and participate in GeoPRISMS community initiatives; and the general public is exposed to new findings about the structure of continental margins. It is still too early to be able to fully synthesize or quantify the progress towards the science goals, but initial reports from funded projects demonstrate the high quality of exciting new interdisciplinary, collaborative and shoreline crossing work, and set the stage for another five years of quality GeoPRISMS research. We expect that the research productivity will accelerate in a similar fashion to that from MARGINS-funded work before it and continue to have an impact long after the final GeoPRISMS funding decisions have been made.