MARGINS 2009 Review

7. Future directions and motivation for a successor program

7.1 Motivation for a Successor to MARGINS

Scope and Origin of This Chapter

In early 2007, the MARGINS Steering Committee (MSC) in discussions with NSF considered several possible models for timing and preparation for the MARGINS Decadal Review. Discussions addressed planning for the future, and the extent to which planning activities should precede the Review, or follow it. It seemed appropriate to move toward a Review immediately: several major field programs have been funded and data have been collected or well underway, many major publications have recently emerged, education and data management activities are established, and many recommendations made in the 2004 Review have been addressed. One consequence is that preparatory activities (such as the writing of this document) have been conducted quickly and limited to MSC or small working groups, as time did not allow major, community-based planning workshops to be held. The writing of community-backed Science Plans will await recommendations from the Review Committee, and subsequent large meetings, many associated with Synthesis workshops now being planned. One benefit of this approach is that future planning meetings can be held with knowledge of the Review recommendations.

Planning-related activities include:

- MSC meetings in 2007 and 2008, including an augmented planning & writing meeting in 2007;
- Open Letter from MSC to Community, outlining the planning process, Nov. 2007;
- Mini-Workshop at AGU on RCL future, Fall 2007; (See Supplementary Documents)
- Open planning sessions at major meetings: Costa Rica SubFac/SEIZE in June 2007, IBM in November 2007, and SEIZE synthesis in September 2008; (See Supplementary Documents)
- On-Line Discussion Forum, January-October 2008;
- Working Groups convened for successors to S2S (March 2008) and RCL (April 2008).

It is hoped that the results of this approach convey well the sense of excitement for a MARGINS successor, and some of the opportunities that lie ahead.

Vision

Continents evolve at their margins, so in order to study the evolution of the continents, experiments must cross the shoreline and span disciplinary boundaries. Many of the opportunities for major transformative breakthroughs in solid earth Geoscience lie at the shoreline, as do some of the best opportunities for fundamental research to impact humanity. The critical systems are complex and their connections more so, requiring a broad, interdisciplinary program focused on interconnected geological systems. MARGINS has succeeded thus far by successfully building interconnected, open and multidisciplinary communities focused on a common goal, be it an understanding of the generation of great earthquakes, the long-term material exchanges between surface and deep earth, the connection between erosion and the sedimentary record, or an understanding of the breakup of continents.

Given this vision, a successor program is likely to rely upon several principles:

- Emphasis on interconnections between different systems (e.g., subduction zones, rifts, continental shelves, rivers) that provide insight into major scientific problems.
- Analyses across time scales, from tens of Myrs that control crustal evolution to seconds over which earthquakes rupture. We are discovering that intermediate scales control many processes and transients (strain events, fluid pulses, sediment delivery events, flux melting of the mantle wedge, etc.).
- Integration of signals, processes and observations from the Earth's surface to deep mantle. This interplay governs system behavior, and requires coordinated study from a wide range of expertise.
- Studies that cross the shoreline – while NSF structure separates terrestrial from marine endeavors, it is clear that many of the critical processes shaping the continents take place through the interplay of these two realms.
- Emphasis on integration and synthesis – MARGINS has supported a wide range of individual and small group efforts, but its most obvious success (and need) is the integration of these efforts across disciplinary lines, and the synthesis of their results into new, transformative scientific paradigms.

The current MARGINS program also emphasizes active process studies, and concentration of field efforts at focus sites. Both of these decisions have proved to be good ones, and to some extent they are embedded in the principles outlined above. However, it is time to reevaluate these decisions. For example, the appropriate successor program may include study of passive margins or ancient arcs where the processes of interest have gone to completion, and perhaps a more thematic approach that emphasizes cross-comparison between sites. These issues and some possible models are discussed more fully in section 7.3.

Questions that could drive a successor program: Arising from present Initiatives

Each Initiative Summary outlines several new opportunities and the evolution of thought within the current Initiatives, driven by discoveries made over the last decade. These are elucidated in the Initiative Summaries above, and are summarized here:

RCL

1) How does melt rise through, and alter the rheology of, the thinning continental plate?

Magmatism plays a role in controlling rift behavior from both the top-down as well as the bottom-up. Melt generation extracts incompatible elements, dehydrating and strengthening the mantle beneath rifts. Conversely, melt retention can result in weakening of the mantle. Magma intrusion alters the thermal and mechanical structure of the lithosphere. New field observations and theoretical work are critical to determine mantle permeability structure and its influence on the 3-D pattern of melt migration beneath rifts.

2) How is strain partitioned horizontally and vertically between mechanical stretching and magma intrusion from rift inception to breakup, both (1) across and along the length of rift zones, and (2) in the long-term and during discrete rifting events?

Recent research results demonstrate fundamental feedbacks between faulting, magmatism, and lithospheric thinning. The superposition of tectonic and magmatic processes results in across and along-axis variations at a variety of spatial scales, necessitating a fully 3-D approach. Rifting is achieved through a cyclical process. Tensile stresses from far-field plate motions accumulate over decades before being released during relatively short-lived "rifting events", whose succession eventually achieves continental rupture and plate separation.

3) What are the feedbacks between vertical tectonics, climate change, and sediment flux from rift onset to breakup?

Sediment fluxes and sedimentation may act to amplify or damp rifting, depending upon the character of the rift drainage network, the rate of uplift and erosion of the rift margins, and the loci of deposition. The accommodation space created with the formation of a new rift basin promotes erosion, alteration and deposition of sediments that represents a substantial terrestrial to marine carbon flux; flanking uplifts pose barriers to atmospheric circulation, leading to climate change. New research directions exploring the interplay of surface processes, climate, sedimentation, and tectonic processes in rifts require a cross-discplinary, cross-shoreline MARGINS perspective.

S2S

1) How do we upscale physical processes from the time scale of individual events (e.g., floods or storms) to the time scales that create landforms and the strata of sedimentary basins?

As the spatial and temporal scales of the system increase, our ability to develop and test approximations for sediment flux equations diminishes accordingly. Progress here requires a multi-disciplinary approach combining field observations, modeling, and experiments designed to inform and test these approximations. Given the inherent complexities, the issue of upscaling is likely to remain a key area of research in the coming decade.

2) What controls the timing and magnitude of sediment escape from the shelf to the deep ocean?

Shelf sediment trapping or bypassing depends on the complex interplay between sediment transport processes and longer term changes in sea level, sediment input, and tectonics. Work in the Waipaoa Focus Site indicates that relatively small perturbations in these controlling factors can have profound effects on shelf bypassing over very short (decadal to century) time scales. Beyond refining stratigraphic models of margin development, a mechanistic understanding of shelf bypassing is also a key to understanding carbon cycling and burial on the margin.

3) How do the source-to-sink components of Arctic landscapes respond to rapid climate change?

Global climate change, particularly the increase in temperature at high latitudes, is altering Arctic landscapes at an astonishing rate. The rapid thawing of permafrost is profoundly changing the appearance of these lake-dominated landscapes, with tens of meters per year of shoreface retreat along reaches of the Arctic Coast, allowing direct observation on annual to decadal time scales. The effects of this thermally driven landscape alteration on Arctic ecology and on global carbon cycling are poorly understood.

4) How do the sediment budgets of lowland river reaches drive the production of landform and sedimentary formation complexity that characterizes the landscapes and sedimentary records of these environments?

Since they lie at the exits from continental-scale drainage basins near sea level, lowland river reaches are also among the most sensitive continental environments to alterations of climate, crustal deformation, sea-level rise, and human resource management. Prediction of future states of these vast transport and storage systems is emerging as a widespread need as societies begin to recognize the significance of subtle and gradual changes for the long-term habitability of these landscape zones.

<u>SEIZE</u>

1) What controls the observed wide spectrum of fault slip behaviors; specifically their spatial distribution and their variation throughout the seismic cycle?

Detailed observations in a variety of fault zones, but in particular, subduction zones, indicate that fault slip also occurs during silent earthquakes, episodic tremor and slip, low frequency earthquakes, and very low frequency earthquakes. It is unclear how these slower time constant events relate to coseismic slip during normal earthquakes. What processes or properties facilitate them, e.g., rock composition, stress change, pore fluid release or migration, etc.?

2) What is the role of fluids in controlling fault rheology?

It has been hypothesized that metamorphic dehydration, pore pressure, and their distribution affect slip behavior and fault strength, but direct tests of many of these hypotheses remain to be conducted. Fluid release and pore pressure evolution, possibly mediated by sediment composition and thickness, basement topography, or thermal structure, may play defining roles in controlling fault rheology.

3) What governs along-strike variations in moment release in great earthquakes, and similar variations in interseismic locking?

Variations in seismicity and interseismic deformation along- and across-strike have been correlated with lower plate roughness and age, upper plate structure and lithology, and contrasting properties and processes within the fault zone. Are these correlations universal or local? Are there other factors, for example, pore pressure distributions, that strongly influence or control these variations, and if so, how?

4) What causes the observed temporal variations in seismogenic zone behavior and plate boundary deformation in interseismic, coseismic, and post-seismic periods?

Integrated onshore-offshore surveys, e.g., at Nicoya, Nankai, Cascadia, and elsewhere, demonstrate distinct fault behaviors and surface deformation in each setting, often varying along strike. Are these indicative of where these margins lie within the seismic cycle, and if so, what controls their behaviors? Comparative studies along several margins at different stages within the seismic cycle can help to establish a unified understanding of evolving processes at subduction margins.

SubFac

1) What happens to volatile elements in the slab and mantle wedge between the bottom of the seismogenic zone and the onset of melting in subducting crust (200-750°C), and what is the geodynamical result?

This critical gap requires the interaction between two of the four current MARGINS initiatives. The new SEIZE models for the downdip end of the seismogenic zone provide inputs to SubFac, which could be tested against volcanic outputs and laboratory constraints on pressure-temperature-compositional variations in mineral stabilities and element partitioning in the slab.

2) What is the role of serpentine on the input budget of volatiles and dynamic behavior of the slab and mantle wedge?

Serpentine is a critical mineral with a large carrying capacity for H_2O (> 12 wt%) and unique seismic and rheological properties. During the course of the MARGINS program, serpentine has emerged as a possible central control on the behavior of the subduction system at intermediate depths, and new approaches need to be developed to quantify its abundance in the mantle section of the downgoing slab, the nose of the mantle wedge, and in the forearc crust.

3) How is the volcano at the surface connected to the processes that happen at depth in the slab?

MARGINS has contributed to a new view of magma plumbing systems, with composite seismic images of the root zones of volcanoes extending through the crust, into the mantle, and maybe even sourced in the slab. Thus, new efforts need to be focused at the scale of individual volcanoes (<50 km), including higher resolution seismic imaging, detailed geochemical and geochronological time series of eruptive products, and volcano-scale seismicity and deformation studies.

Questions that could drive a successor program: Cross-cutting themes

Much of the success of the present MARGINS has come from developing true cross-disciplinary communities where none existed before. One of the main tasks in building a successor program will be to identify and mitigate other barriers to discovery, including those between the existing four Initiatives. An April 2008 Planning Group meeting, and subsequent MSC meeting, identified three exciting opportunities that cross-cut the present Initiative structure, where much potential is seen for major breakthroughs. These are described in chapter 8, and briefly described here:

Rheology and Deformation

Continental rifting proceeds through a combination of elastic-plastic deformation in the lithosphere and viscous flow in the underlying asthenosphere. Similarly, deformation in the descending plate and the overlying mantle wedge at subduction zones is controlled by the behavior of the crust and mantle, as well as the fault zone rheology along the subduction interface. The response of the plates to erosion and redeposition also depends on and influences plate rheology. The Earth's rheology, therefore, forms a common thread between all MARGINS initiatives.

Magmas and Fluids

The production and transport of fluids, including magmas, is a fundamental process controlling the thermal, compositional and mechanical evolution of continental margins and the mantle. The similarity of scientific objectives and approaches across the MARGINS initiatives provides opportunity for synergetic studies of these systems. Melt generation in rifts and subduction zones is the primary mechanism of continent formation, and these systems regulate volatile exchange between deep Earth and its surface. These systems influence the long-term chemical evolution of the Earth, and control rheology and deformation at many spatial and temporal scales.

Sediment Fluxes

The S2S approach provides a framework for understanding and predicting the fluxes and chemical transformations of sediment and solutes in Earth systems. The complex interplay between sediment transport, climate and tectonic processes dictates the partitioning of inorganic and organic sedimentary constituents across the margin. Deformation creates and modulates the highlands and basins, with faulting, magmatism, and ecological processes acting as barriers or conduits to sediment transport. Recent observations indicate other feedbacks, for example between sedimentation and rift magmatism. These systems are climate-modified and modify climate. Furthermore, erosion and sedimentation play an important role in subduction and the cycling of material to the deep mantle. The theme of sedimentation, climate, and deformation has the potential to bring in numerous new researchers to the MARGINS community.

Example: Integrated Subduction Zone Studies

Both the SEIZE and SubFac Initiatives chose Central America as a focus site, leading to adjacent and sometimes collocated observations. The result are synergies between studies that explore the systems that regulate large thrust earthquakes and those that generate magmatism; fluid cycling, thermal structure, plate kinematics and large-scale deformation all play a role in both systems. This example explores some of the benefits of integrating studies from multiple MARGINS initiatives in one site.

Thematic Approaches from Planning Groups and Community Contributions

At the series of workshops and planning meetings, several concepts have been developed for a future program in a series of short summaries. While not a substitute for full science plans developed with broad community input, they represent some of the more exciting opportunities envisioned on the part of the various planning groups. These are encapsulated in a series of "mini-white papers", including one Eos article submitted to the On-Line Forum. The white papers are included in the Appendix. They include:

From an S2S Planning Group meeting, a Source-to-Sink Working Group Plan

From an RCL Planning Group meeting, three thematic plans:

When and How does Magmatism Affect Rifting?
Sedimentation, Climate and Surface Processes in Rifting
Lithospheric Strain in Space and Time

Contributed to the web forum:
U.S. Passive Margins: Are We Missing an Important Opportunity?
(*by R. Stern and S. Klemperer, reprinted from Eos*)

These documents, together with the Opportunities for the Future described above, in the Initiative Summaries, and the Overarching Theme descriptions, show several productive and significant ways in which a successor to MARGINS could have a transformative impact on Geosciences over the next decade.

7.2 Opportunities for a Successor Program: Societal Relevance

The great 2004 Sumatra earthquake, Hurricane Katrina, global warming and the high price of fuel have all highlighted the importance of understanding the solid earth at continental margins. What MARGINS can contribute are the fundamental scientific underpinnings of any educated approach to these and other critical societal concerns. Some have always been part of MARGINS, for example SEIZE aims to understand the controls on rupture of the planet's largest earthquakes, but we envision a greater and more integrated role for several issues in the future.

Geohazards

Much of the world's population lives along coastlines, and many of the natural hazards that affect society occur at this critical interface between the oceans and continents. Examples include great earthquakes, tsunamis, explosive volcanism, marine and terrestrial mass wasting events, great storms, and the floods and sediment-transport events that accompany them. Given its focus on active margins and active processes, the MARGINS program and its successor are poised to make major contributions to our scientific understanding of such hazardous phenomena, their causes, and their consequences. Seismogenic zone studies, focused on the properties and processes that govern the planet's largest earthquakes, define an obvious connection, particularly with the world's attention following the devastating 2004 Sumatra earthquake and tsunami. Seismic surveys carried out over continental margins subject to earthquakes can reveal the internal structure, fault activity, and slip history that can generate large tsunami. Direct sampling and instrumentation of active fault zones can help constrain the mechanisms and limits for seismogenic slip. Earthquake frequencies and distributions can be interpreted through onshore and offshore paleoseismology, for example, extracted from the trench turbidite record as shown effectively for the Cascadia margin. At the defined SubFac Focus Sites, MARGINS already has provided critical data on eruptive histories of volcanoes, and has constrained the geochemical evolution that might influence eruptive behavior. Moreoever, ash layers that accumulate in oceanic trenches are the key to dating turbidite records used to reconstruct subduction zone earthquake histories.

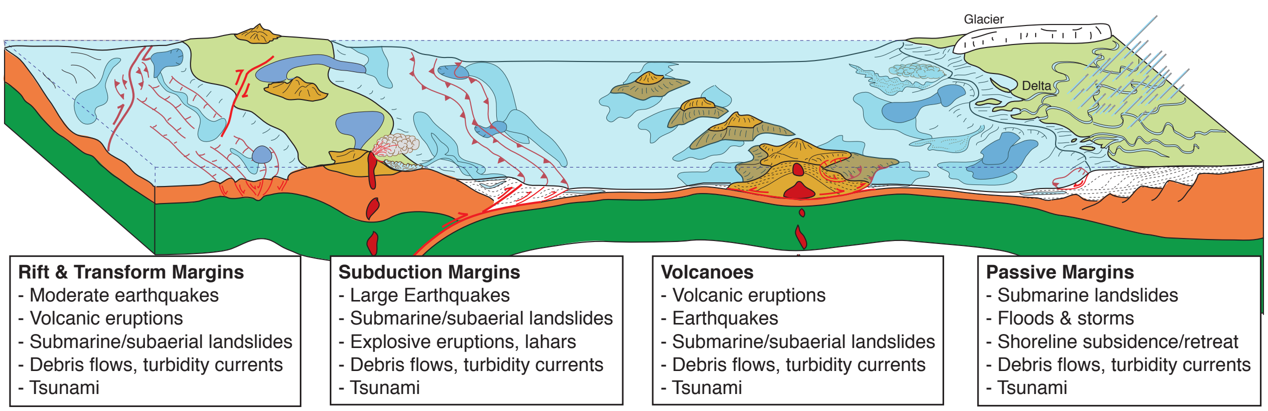

Figure: Continental and volcanic margin settings in which geohazards may be generated, and potential opportunities for a successor program to MARGINS (Modified from Morgan et al., 2008).

A successor program to MARGINS could significantly expand linkages to geohazards and other societal issues. One approach is through studies of active coastal and slope processes. For example, S2S emphasizes the erosion, transport, and transfer of sediments across the shoreline, and their storage in the marine setting. Major flooding and storm activity drives the production and transport of sediment, and can also influence its offshore distribution. Possible new directions for S2S research addressing coastal subsidence and Arctic shoreline retreat have direct relevance to climatic changes and their impacts on society. Slope instability and consequent landsliding on all types of margins can be initiated by floods, storms, earthquakes, and eruptions, and a MARGINS successor provides the means to study the mechanisms of mobilization and transport, and potentially, precursory phenomena indicative of failure.

Natural Resources

Increasing demand and dwindling supplies of world oil and gas reserves, especially those most accessible, raise concerns about our ability to meet future petroleum demands. Given that much of the petroleum lies in nearshore environments, and virtually all of it was created on continental shelves, understanding these zones will be critical for future oil and gas exploration and exploitation. Future efforts to further exploit known reserves, to better explore nearshore settings, to push farther offshore into deeper water settings, and for future exploration into "frontier" margins will all benefit from a better understanding of the structure, tectonics, depositional environments, thermal histories and stratigraphy of continental margins. Both the RCL and S2S Initiatives of the existing MARGINS program address aspects of continental margin development that apply directly to understanding the geologic context of petroleum reservoirs. The proposed Ocean Drilling Consortium project, a proposed Joint Industry Project for continental shelf drilling with IODP, if funded, offers tremendous leverage for a successor MARGINS program to achieve the research goals for continental margin geology and simultaneously directly support development of energy resources.

In addition, submarine active margins are sites where large deposits of precious and base metals continue to be formed. Almost half of current global mineral exploration is for gold and the largest new deposits are associated with hydrothermal vents in Subduction Factory environments, such as the caldera of Lihir volcano and at 1500 m depth in the northeast Manus Basin, both in Papua New Guinea. The metals in these deposits are mostly derived from subduction zone magmas and volcanic rocks, and are transported in saline fluids similar to those responsible for metasomatizing arc magma sources and for the explosive eruption of arc volcanoes. Consequently, the origin and setting of the metal deposits is directly related to the origin and evolution of mantle, crust, and fluids in subduction zones at many scales.

Climate Change

The systems approach of the MARGINS initiatives provides vital constraints on the complex interplay and feedbacks between tectonics, sediment generation and transport, and global climate change. Compressional and extensional tectonics may lead to both broad plateau uplift that deflects continental-scale drainage networks, and that serves as a topographic barrier to atmospheric circulation, with feedbacks to the ocean circulation pattern. At the scale of ~100 km, individual fault-bounded rift basins, volcanic arcs, and thrust fault systems may capture or deflect continental-scale drainage networks. Continental rupture culminates in the formation of new ocean basins that fundamentally change ocean circulation, with clear atmospheric feedbacks and climate change. Because of the mix of organic rich muds, narrow oceans, and moderate to rapid sediment rates, early-stage rifts are the ideal setting for formation of large gas hydrates which later may be destabilized. In addition, thermal uplift may disrupt the connection between seaways, thereby further altering ocean circulation and climate.

The effects of global climate change, particularly the increase in temperature at high latitudes, are altering Arctic landscapes at an astonishing rate. The rapid thawing of permafrost is profoundly changing the appearance of these lake-dominated landscapes and allowing tens of meters per year of shoreface retreat along reaches of the Arctic Coast. The effects of this thermally-driven landscape alteration on Arctic ecology and on global carbon cycling are poorly understood. The net effect of repeated glacial cycling is the rapid accumulation of thick (hundreds of meters) sediment wedges on Arctic margins; these sedimentary successions preserve a high-fidelity record of the interaction between climate and tectonics throughout the Pleistocene.

Over time scales of years, some of the most profound effects on the climate come from explosive volcanic eruptions that eject aerosols high into the atmospheres. While most of these effects diminish after a few years, the largest historic eruptions have had profound consequences. New gas and volatile measurements from arc volcanoes are helping to elucidate these processes.

International and multi-institutional partnerships

One of the great successes of MARGINS has been the catalyst for partnerships with large international programs (see previous chapters). These have provided many opportunities both for U.S. and foreign scientists, and have led to efficient use of resources beyond NSF's direct contribution. They have also led to major discoveries, as evidenced by the multinational nature of author lists in recent Science and Nature papers. The major partnerships (e.g., GEOMAR, IFREE) will continue, and new opportunities for partnerships will be sought.

Within U.S. and NSF programs, the most obvious opportunities for further partnership are with MREFCs such as EarthScope, OOI and ODP/IODP. These facilities are well suited to the science goals of MARGINS. For example, future subduction studies could take advantage of EarthScope resources on land, and OOI-cabled observatories offshore to greatly enhance observations requiring high-resolution and long time series. In a new development, major computational infrastructure initiatives have come on-line (CIG, CSDMS), and provide new opportunities for development of hypotheses, and for integration and synthesis of observations. Chapter 6 provides details of how these connections might be achieved.

Education, Training and Public Outreach

Because the processes taking place at continental margins are easily accessible or envisioned, and involve organized but complex systems, they form a natural center for broad science education. The current program emphasizes undergraduate education as an area where MARGINS could make the biggest impact. One likely next step is an emphasis on training of new graduate students, for example through short courses. Also, at the undergraduate level, MARGINS could play a role in coordinating REU-supplement training with the goal of developing a cadre of educated, well-informed students and future scientists, to become leaders both in research and education.

This approach seeks to complement EPO efforts made by related programs such as IODP and EarthScope, which tend to emphasize K-12 content and teacher training, as well as broader public outreach through museums and similar venues. The MARGINS emphasis on undergraduate and early graduate education should strengthen the overall educational profile of the solid earth sciences. One goal for the next several years would be to develop clearer ties between these complementary programs, and establish plans for coordination.

7.3 Implementation of a Successor Program

At the various planning workshops, there has been much excitement about the scientific opportunities for a future program and discussion about how to best structure a MARGINS successor. Although consensus could be reached on broad scientific goals and general principles of a program, implementation issues will need to be resolved through community planning workshops following input from this review committee. Nonetheless, a successor program would likely carry forward several elements:

- Increased emphasis on integration and synthesis, including partnerships with new computational programs in Geosciences.
- A continued, but relaxed Focus Site model with increasing thematic foci, the specific structure of which would need to be worked out in community planning workshops and may vary with theme or initiative.
- Continued emphasis on active systems in most cases, with evaluation of passive margins as suitable sites to best study rifting dynamics and certain sedimentary processes.
- A focused program with science funding separate from NSF core programs, that supports experiments which cross the shoreline, interdisciplinary communities, and integration and synthesis activities.

These elements and the issues behind them are elucidated below.

<u>How do we make integration and synthesis work?</u>

The major recommendation of the 2004 Review was an increased emphasis on Integration and Synthesis, something that clearly should continue. Some can be accomplished by regular, interdisciplinary meetings, AGU sessions, volumes, newsletters, and through other communications tools that the program has developed. There are many examples of interdisciplinary groups forming real integration of their results (e.g., geochemical and geophysical studies of melting; geological and geodetic studies of strain at different time scales). However, it seems likely that real, transformational synthesis will require more than the occasional meeting and short course, and that significant work will be required on the part of some PIs or centers. In the last year MSC has been explicitly encouraging the community, through open letters (available via listserv, newsletter, electronic forum and web page), to develop proposals that emphasize integration and synthesis. A few such multi-PI proposals have been submitted to integrate disparate observations in more organized ways. Many of the concrete examples of synthesis that have been discussed highlight a component of geodynamical modeling to form quantitative hypotheses that could be tested by a variety of observation. One way to encourage this is to build stronger partnerships with CIG and CSDMS, the recently-funded infrastructures that support modeling efforts. To develop these partnerships, the MSC membership now overlaps that of the CIG and CSDMS Executive Committees or Steering Committees. It seems likely that a successor program will be structured to encourage such partnerships. Similarly, continued use and development of database tools will be a priority, including a new emphasis on access to derived products (analyses, inversions, etc.) as well as growth in raw data.

Focus Sites vs. Thematic approaches

Focus sites in the current MARGINS program have been very successful, both at concentrating resources and as a vehicle for building new cross-disciplinary communities. At this stage, it is natural to ask whether this model should be continued, perhaps at new sites, or whether instead the large focus site experiments have fulfilled their promise and the program should migrate to other more thematic approaches. This is a complex problem, with several considerations:

- Clearly some changes will be needed, since some sites have proven their worth and others have run their course in other ways. It is important for continued growth of the community and the science that significant work can be done outside the existing focus sites. Even should the Focus Site model persist in some form, the default is that all of the current focus sites should lose special status unless strong arguments can be made to the contrary, and a new selection process would be needed.
- Some of the critical questions are best tackled by comparative global studies. Results from the first decade within the Focus Sites provide an excellent baseline for understanding several systems, but in many cases comparative studies would be needed to evaluate their global significance. Also, a more flexible approach to sites may make event response more feasible (e.g., a re-coordination of efforts to events like the Sumatra earthquake).
- Given the availability of new near-U.S. facilities (EarthScope, OOI, etc.) and basic logistical considerations, it seems wise to have at least part of the program's focus near North America. Besides rifting regions in the southwest, areas of interest include Cascadia, the rifted Atlantic margins, and the Alaska-Aleutian subduction system.
- Certain kinds of observations (strain accumulation, etc.) require very long-term time series, and some kinds of data collection (riser drilling) require more than a decade from concept to completion. In general, forming well-posed and testable hypotheses becomes easier when baselines of data already exist. Hence, some aspects of the program benefit strongly from continued observation at current focus sites.
- In some instances, a case can be made for even narrower focus – e.g., large resources aimed at a single volcano, or just near the shoreline at a single river system. The operative scale of some processes is often much less than an entire margin.
- International partnerships have been set up at some sites, and there is much value (scientific and resource-wise) in maintaining them.
- Certain sites make easier natural synergies between different initiatives, and sites that meet multiple needs could be encouraged. The Central America focus site is an excellent example, where the current MARGINS program operated there through both the SubFac and SEIZE initiatives. Other sites that encourage such synergy should also be sought, for example to better integrate sediment transport with tectonic process efforts.

The current consensus within MSC is to retain some level of Focus Site designation, but to relax the exclusivity such that critical field studies could be conducted in other, comparable settings. The exact solution may vary between parts of the program, depending upon scientific needs. For example, the lengthy NanTroSEIZE drilling schedule is likely to keep Nankai as a critical site for seismogenic zone studies over the next several years, and long-baseline time series at collocated observatories may be needed to adequately sample the seismic cycle. On the other hand, groups of sediment-transport scientists have developed a model for single, large collaborative projects that compete for focus sites every 2-4 years, and global sampling of arc volcanic volatile output may be the best way to establish global budgets. Studies of Cascadia and Alaska seem natural follow-ups to current SubFac and SEIZE efforts, and make optimal use of EarthScope and NEPTUNE/OOI-cabled observatory facilities.

Active processes or not?

The current MARGINS Science Plans make the argument that processes are best studied where they are currently active, on active margins. Direct measurements of active deformation (geodetic, seismic, neotectonic), thermal state, and uplift-driven erosion generally can be observed only in active settings, and the geologic record frequently overprints evidence of past activity in complex ways. Nevertheless, direct observation of deeply-exposed material or other processes reflective of geologic time are best observed in ancient environments. Also some processes, such as the opening of a major ocean basin, happen relatively rarely in earth history and must be observed where they have gone to completion. Passive rifted margins such as the Atlantic are the only practical places to sample the full rupturing of a continent to form a major ocean basin. These margins are not "dead" in that subsidence, sedimentation and hydrologic processes continue to shape them. Some concerns remain about the ability to conduct a broad multi-disciplinary observational program in such areas, where many signals associated with active deformation may be absent. While no firm consensus exists on this issue, community workshops may help decide whether or not certain aspects of the program such as rifting are better studied if passive margins are included.

In an interesting development, recent proposals have been floated for petroleum-industry sponsorship of U.S. scientific drilling. The current proposals feature drilling at several passive margin sites, in locations of interest to the industry but also with considerable value to studies of rifting. Such plans could be of great benefit to a MARGINS successor.

Why not "core"? The case for a stand-alone program

Hopefully this document as a whole makes clear why MARGINS describes a suite of scientific problems and approaches that cannot be handled through normal NSF core programs. The systems that govern evolution, deformation, material and energy cycling at continental margins are complex, and in order to achieve transformative breakthroughs in our understanding of them, a focused yet broadly interdisciplinary approach seems necessary. More specifically:

- MARGINS projects typically involve a mix of on land and marine investigations and focus on geologic processes spanning the shoreline. The relevant mix of projects should be constructed as dictated by scientific goals without regard to which side of the shoreline individual projects sit.
- MARGINS projects are commonly strongly interdisciplinary. MARGINS will include synthesis activities as an essential part of any continuation. Individual panels focused on scientific excellence in a single field may not fairly evaluate broader complex interdisciplinary, land-sea, and synthesis programs. They also may have difficulty evaluating the importance of critical work done away from field sites, such as experimental or theoretical studies that make integration possible.
- Such a program can function well only when a well-educated, informed interdisciplinary

community exists. In order to build and sustain such communities, some infrastructure is required to promote communication, cross-disciplinary education, and foster integration and synthesis. Regular thematic workshops, Newsletters, web pages, a Steering Committee and other facilities provided by the Office require programmatic support.

- Broader impacts such as the relevance of MARGINS science to geohazards and natural resources are easier to nurture, coordinate, and explore in a focused program than when relying solely on PI-initiated proposals.

MARGINS has demonstrated several other benefits of a focused program, including the ability to engage and leverage major international partnerships, to provide a framework for science that uses major infrastructure facilities, and to develop broad education and outreach efforts from numerous individual research projects. Furthermore, the facilities for data archiving, rapid public release policies, and development of educational access tools are more difficult to support outside of a focused program, yet have contributed significantly to its success.