NSF MARGINS Decadal Review Committee Report

Overview

The MARGINS Decadal Review Committee (DRC) met February 2 and 3, 2009, at NSF Headquarters to review accomplishments and planned future directions of the MARGINS Program at the 10-year point in its history. The DRC comprised individuals with both a broad and specialised range of expertise with no recent direct involvement in MARGINS. Our evaluation is based primarily on a thorough reading of the MARGINS 2004 Review Committee Report, the MARGINS 2009 Review documents (as written by current and past members of the MARGINS Steering Committee), the 2008 MARGINS Science Research "Nuggets" (as written by current and past MARGINS PIs), and various other documents, including Newsletters, Special Publications, and reprints of selected Nature and Science journal articles.

The review began with presentations by NSF's Assistant Director for Geosciences, Tim Killeen and MARGINS's Program Director Bilal Haq who reviewed the NSF priorities, funding levels and the charge to the committee. This was followed by presentations from Geoff Abers, chair of the MARGINS Science Steering Committee (SSC), on MARGINS accomplishments, data management, and outreach/education and by presentations from Julia Morgan, James Gill, Joanne Stock and Steve Kuehl on the four individual MARGINS initiatives. The presentations concluded with updates by NSF Program Officers Rodey Batiza, Shelby Walker, and James Whitcomb who updated the committee on other large-scale NSF projects such as IODP, Ocean Observatory Instrumentation (OOI), EarthScope, and continental drilling (ICDP) that might impact a future MARGINS program.

Accomplishments of the current MARGINS program

SEIZE

Knowledge of what controls energy release along active subduction zones through the seismic cycle is a fundamental question in the geosciences that has tremendous societal benefits in understanding earthquake and tsunami generation. The SEIZE initiative of the MARGINS program, in conjunction with the broader community and international collaborations, has played a major role in advancing our understanding of seismogenic zone processes at two focus sites (Costa Rica margin and the Nankai trough).

The SEIZE initiative has helped transform our thinking about slip behaviour at subduction zones. The range of data collected and more importantly the integration of these data have resulted in the following major accomplishments:

- New understanding of the updip limit of the seismogenic zone
- Identification of pore pressure transients associated with seismicity
- Detailed imaging of a 'megasplay' fault system from a 3D seismic data set acquired offshore the Kii Peninsula

- Carried out site surveys and groundwork for future deep drilling and observatories at Nankai trough in conjunction with the NanTroSEIZE program under IODP

The SEIZE program has provided a focus on seismogenic processes and successfully leveraged resources with international partners at both the Nankai and Costa Rica focus sites. It has also been a model program in the way that it has integrated the results from different disciplines, utilized large-scale oceanic facilities and engaged with the wider community. The program has made huge strides, for example, towards our understanding of earthquake rupture properties, the subduction channel and the linkages between deep mantle and shallow seafloor processes. This has been achieved through its integration of seismicity, GPS, experimental rock mechanics, sonar and swath bathymetry data sets, its involvement with IODP borehole-based studies and "state of the art" 3D seismic data acquisition, and its strong international collaborations, in particular, with Japanese, Nicaraguan, Costa Rican and German institutions.

Subduction Factory – SubFac

The overriding goal of SubFac initiative is to understand the intrinsically complex relationships between mass and energy fluxes through subduction systems. The three sub-themes of SubFac are: (1) the relationship of magma output and composition to forcing functions such as convergence rate, plate age, and sedimentary input; (2) the cycling of volatiles from the slab to the mantle wedge and ultimately to either the crust and surface reservoir or back into the deep mantle; and (3) the production rate of arc crust.

The SubFac initiative is at a relatively mature stage, and most of the proposed data have been collected for at least some parts of the focus sites in Central America and the Izu-Bonin – Mariana (IBM) arc systems. There has been considerable progress in both focus sites in integrating geological, geochemical and geophysical data with experimental studies and geodynamical models. The major accomplishments include:

- Development of numerical models to predict the thermal structure and flow field in the slab and wedge during subduction.

- Utilization of these models to examine the interconnectivity of hydrology, metamorphism, mantle wedge flow, and arc magmatism, so that ultimately the effects of various forcing factors can be understood.

- Improving understanding of many key processes within subduction systems, particularly with regard to mantle melting, volatile cycling, and material fluxes.

- Measuring the volatile contents of arc magmas and volatile fluxes out of arcs (using volcanic gas emissions), and demonstrating the relationship of these to progressive dehydration reactions in subducted materials and experimentally based melting models for the mantle wedge.

The SubFac initiative successfully integrated a multidisciplinary community of researchers, including many early career scientists and international partners, who have greatly contributed to the focus and success of the initiative. In this respect, the SubFac initiative has served as a model for the coordination and development of multidisciplinary science plans and the final integration of diverse datasets and approaches (field studies, experiments, and modeling) that truly cross the shoreline.

The determination of magmatic fluxes and arc crustal growth rates is an important goal of SubFac and requires comprehensive knowledge of arc crustal and upper mantle structure. Major active seismic campaigns were undertaken in both focus sites, leading to advances in understanding the volume and composition of arc crust, particularly in IBM. However, less progress was made in addressing the rates and fluxes of arc magmatism because of the inherent difficulty of determining volume and ages of plutonic rocks with sufficient resolution to achieve transformative breakthroughs. This is an area where studies of exposed crustal sections in ancient subduction zones may provide an important complement to the primary SubFac emphasis on recently or currently active systems and processes.

The SubFac initiative's success in tracking material fluxes from trench to mantle to volcanic arc is clearly a consequence of widespread community involvement, cross-discipline applicability and co-location of many projects, and the involvement of international partners. The initiative has spawned a series of IODP proposals that target fore-arc serpentinite diapirs, the nature of middle arc crust, subduction initiation, and the evolution of rear-arc magmatism and the nature of its slab-derived flux.

Rupturing Continental Lithosphere - RCL

The understanding of how continents break-up and new ocean basins form is a fundamental question in plate tectonics that has both scientific and societal implications. The RCL initiative of the MARGINS program, in conjunction with the wider community and international collaborations, has played a major role in advancing our understanding of the dynamics of initial rifting. The accomplishments at the Gulf of California focus site include:

- Documentation of the influence of pre-rift magmatism on subsequent breakup processes.

- Establishment of a correlation between mantle *P*-wave velocity structure and the degree of magmatism in a rift.

- Determination that strain localisation can occur before *or* after the onset of seafloor spreading.

- Integration of modeling with observations, leading to the dramatic effect of recognizing the importance of small melt fractions on mantle viscosity and the effect of rapid sedimentation on syn-rift and early post-rift magmatism.

- Integration of different techniques in a concerted effort to study tectonic complexities in the Gulf of California and the development of a highly effective and productive interaction with Mexican scientists.

Unfortunately, marine mammal issues in the Gulf of California have compromised the RCL initiative considerably. Some of the work in the Gulf of California is still at an early stage. The results from the major seismic refraction study are not yet fully published. The complete analysis of Mexican industry seismic reflection data is still outstanding and it is not clear that US workers will have full access to these data. Although a major seismic program in the Salton Sea has been funded, there remains a serious lack of mature IODP drilling proposals.

Probably the most important factor that has limited the impact of the RCL initiative has been the lack of effective access to its other focus site in the Red Sea. Some good preliminary work has been carried out, notably a compilation of existing regional geophysical and geological data and new sampling (for thermo-chronological studies) of the rim uplifts that flank the Red Sea. However, major gaps in data acquisition in the Red Sea itself have prevented this work from being developed into an integrated whole.

While some aspects of the major objectives of the RCL initiative have been addressed, success has been limited by data gaps, some of which may be addressed by ongoing and planned work. Of the four primary objectives, the role of magmatism and volatiles in rifting has been well addressed, but the stratigraphic response to rifting has been addressed very little. The other objectives (regarding strength evolution and strain partitioning) have been addressed to some degree. It is not clear that all these objectives can be fully addressed at one active rift, and a particular problem in the Gulf of California is its highly oblique pattern of extension and the lack of detailed stratigraphic age information.

Source to Sink - S2S

This initiative, with focus sites on the Waipaoa margin (North Island, New Zealand) and the Fly River – Gulf of Papua (Papua New Guinea), attempts to understand and predict, through field observations and numerical models, how sediment is produced, transported and accumulated across the land-ocean continuum. It has broad relevance to many societal issues including landslide initiation, coastal growth and erosion, and the prediction of submarine hazards (e.g., storms, tsunamis) and it is substantively impacted by anthropogenic effects (e.g., land use, climate change).

The S2S initiative also emphasises integration of land-based (e.g. geomorphology) and marine researchers (e.g. oceanography) and numerical simulation and modeling to predict relationships and sedimentation patterns and morphologies observed in the focus sites. Initial focus was on quantifying sediment fluxes with an eventual goal of determining how these processes build the stratigraphic record over a glacial cycle, as opposed to the longer-term tectonic cycles that characterise the evolution of continental margins. More recent work has integrated more traditional sedimentology with geochemistry in order to address carbon fluxes across the land-ocean continuum.

It is important to recognize that S2S was the last of the four initiatives to start and therefore has had the lowest number of projects funded to date. Despite this, cross-disciplinary efforts have allowed integration of models and field observations from both terrestrial and marine environments, and this integration has led to the following accomplishments:

- Demonstration that anthropogenic changes in land-use (deforestation) at the Waipaoa margin have caused a significant increase in sediment production that has led to a *rapid* ($\sim 10^2$ y) shift in the locus of deposition from the shelf to upper slope.

- Development and application of numerical models that predict the self-organization of the Fly River delta distributary channels in response to interaction of the measured fluvial and tidal regimes.

- Utilization of quantitative modeling that shows how sediment routing, involving both flood plain aggradation and/or incision, on the Fly and Strickland Rivers has responded to the rise in sea level since the Last Glacial Maxima (LGM).

Although the implicit goal of S2S has been to quantify the relationship of sedimentary processes that build the stratigraphic record over a glacial cycle, it has suffered as a consequence of lack of integration with the other, tectonically oriented, initiatives, which focus on longer-term margin evolution. The initiative has thus been focussed on Pleistocene to modern stratigraphy studies rather than whole margin evolution studies.

Management, Public Outreach, and Data Archiving considerations

The MARGINS program is managed by a Science Steering Committee (SSC) which comprises 11-15 academic scientists who are based at US universities. The chair is elected by the committee and normally serves a 3-year term. The chair heads up an office which currently comprises a Senior Coordinator, an Office Coordinator, and an Office Administrator. The office rotates with the chair and presently resides at the Lamont-Doherty Earth Observatory (LDEO) of Columbia University.

The DRC believe that the SSC does a very good job of managing the MARGINS program. The SSC has been led by a succession of active, mid-career, scientists (Sawyer, Taylor, Karner, Morris, Abers) who have robustly promoted the program at both the national and international level. The SSC has been particularly successful in facilitating the four initiatives through workshops and special MARGINS Theoretical & Experimental Institutes.

The DRC believes that the MARGINS office has been effective in disseminating results to the broader community, through its Newsletter, the Website, the encouraging special sessions at national meetings (e.g. AGU), through peer-reviewed publications and through various monographs and books. The office plays a

central role in coordinating international collaboration and serves as a point of contact to facilitate rapid event response.

The DRC applauds the MARGINS Education and Outreach Program and believes that it enhances the visibility and awareness of the program both within the broader geosciences community and to the general public. The committee was particularly impressed with the 'Mini-Lessons Program' concept and the quality of the Fellows in the Post-Doctoral Fellowship Program. The Distinguished Lecturers Program was also singled out for praise as an instrument for successfully communicating the results of MARGINS to the wider community.

Finally, the DRC was very impressed with the data archiving efforts of the MARGINS program. The decision to have the MARGINS data set hosted in the Marine Geoscience Data System at Lamont-Doherty is a good one that has been of mutual benefit to both groups. The committee is particularly impressed with the freely available *GeoMapApp* application that enables existing and new data from the MARGINS focus sites to be easily identified, displayed, and retrieved.

The case for a themed program

Community spirit and working to a common goal

The MARGINS program has been uniquely successful in developing a community spirit that transcends institutional and disciplinary boundaries and gives individuals the sense that they are working as a team towards a common goal. For example, the Sub-Fac initiative has successfully brought together geologists, geophysicists, and geochemists to work together on a fundamental problem related to the subduction of oceanic lithosphere, the melting of the asthenosphere, and the generation of magmas. Such synergies would have been difficult to achieve, we believe, through a 'core' program.

Crossing the shoreline

The MARGINS program involves work at the ocean/continental boundary and the program has been very successful at securing funds from both the Ocean Sciences and Earth Sciences divisions of NSF. Although individual scientists can, and frequently do, obtain funding in this way from core programs, co-funding is a time-consuming process that involves negotiations between program managers. Themed programs such as MARGINS have the advantage that they provide the NSF with a mechanism to co-fund geoscience in a way that encourages cross-fertilization between disciplines such as geomorphology and marine geology which have traditionally been separated by the continent-ocean divide.

International collaborations

The MARGINS program has benefited from new collaborations with non-US scientists, particularly in Mexico, Japan, Costa Rica, and Germany. While such collaborations are essential for logistical reasons and for acquiring work permits, it is clear that they have brought many additional benefits such as the transfer of skills through publications, mobility of researchers, and the optimal sharing of facilities.

These collaborations have also been important in the leveraging of funds. Such collaborations would be difficult to set up through a single PI funded by core programs.

Ships, Technology, and Modeling

The MARGINS program has also successfully utilized large observational platforms, "state of the art" technology, and analytical and modeling facilities. The acquisition of 3D-seismic data at the Nankai trough, for example, has provided a spectacular new image of the structure of an accretionary wedge. The new image powerfully demonstrates the potential of such data sets for future MARGINS research and their usefulness for the identification of localities for possible IODP drilling. Other major accomplishments have been in computation, especially the modeling of rifting, the thermal and mechanical regime of dense down-going slabs, and the stratigraphic response to sea-level change.

A new MARGINS Program – MARGINS-2010

The committee were unanimous in concluding that MARGINS has achieved a number of impressive results during its first 10 years of operation, including transformative breakthroughs in the majority of its initiatives. We believe therefore that NSF should give consideration to the setting up a new themed program, MARGINS-2010, to follow on from MARGINS. The new program should build on the strengths of MARGINS and take the study of the continental edge to a new level of integration, synthesis, and interpretation. The DRC recommends that the new program include:

SEIZE

The SEIZE initiative should go forward with a community workshop to define a science plan for the next phase of work, building on the success of the initiative. The guiding principles should include an interdisciplinary approach that links data acquisition and observatories with laboratory experiments and modeling as they apply to active seismogenic zones. As the SEIZE community indicated in their report, there have been recent events and new observations that have delineated significant new ideas and opportunities that should be exploited in future plans. In the MARGINS review report, the SEIZE initiative group identified several key questions that should guide their thinking including:

- What controls the observed wide spectrum of fault behaviours?
- What is the role of fluids in controlling fault rheology?
- What governs variations in the moment release of great earthquakes?
- What causes the observed temporal variations in seismogenic zone behaviour and plate boundary deformation in interseismic, coseismic, and post-seismic periods?
- What are the state of stress and absolute strength of subduction faults?

The DRC sees the value of focus sites that are undergoing active deformation, but it would like to suggest that we show some flexibility and incorporate limited, highly relevant geologic analogues (preserved seismogenic zones in the rock record) as well as other seismogenic zones that could provide key insights into the seismogenic process not possible at the current focus sites.

An outstanding issue that merits further study is the role of sediment on the incoming subducting plate in controlling the rupture history of large thrust earthquakes. The present focus sites provide "end-member" cases of a well-sedimented (e.g. Nankai) and sparsely sedimented continental margin (e.g. Costa Rica). The Costa Rica site has benefited from SubFac-type studies and so has the potential for us to fully evaluate the role of other factors such as the morphology of the oceanic crust, the sediment thickness and the structure of the forearc on earthquake rupture histories. Consideration should therefore be given to SEIZE transitioning to one or more other focus sites in the next 10 years.

Two possibilities are the Aleutian/Alaska and Cascadia subduction zones where 2-3 km of sediment lie on the subducting Pacific oceanic plate. The Aleutian/Alaska subduction zone repeatedly generates large "megathrust" earthquake events (Mw8-9.2—7 since 1906 and 5 since 1946) and matching local and transoceanic tsunamis. The record of past seismicity is stored along the coast, and presumably in offshore debris flows and turbiditic systems. Similar events, on the other hand, have not been instrumentally recorded along the Cascadia subduction. But, many past great and giant earthquakes, the last (Mw9.0) in January 1700, are recorded in the coastal geologic record and also in offshore turbidity current deposits and suggest a recurrence time of ~300 year.

SubFac

The Subduction Factory initiative has made impressive gains in knowledge through its conduct of focused, multi-disciplinary studies of the IBM and Central America subduction zones. In the near term, onshore and offshore investigations should continue in these focus sites to more completely achieve the original, overarching goals of sorting out forcing factors determining magmatic output, the long-term and short-term rates of arc productivity, and the flux of volatile and solid components through the subduction zone to be either retained in the forearc, cycled back to the oceans and atmosphere, or recycled to the mantle.

As a "next-step", it seems timely, productive, and perspective gaining to begin testing what has been learnt at the existing focus sites with new investigations at one (or more) additional subduction zone sectors. New regions should be chosen that exhibit varying degrees of volcanic vigour and high-magnitude seismicity but are distinguished from the existing focus sites by contrasting tectonic settings and input parameters and components. The MARGINS 2009 Review document identifies two candidate subduction zones, that of Cascadia and the Aleutian subduction zones, the latter consisting of its contiguous Aleutian island volcanic arc and that of the continental arc of Alaska. This brace of north Pacific subduction zones appear to offer special opportunities to address principal SubFac goals as well as to develop synergies with large-scale facilities such as OOI and EarthScope in the future .

The thick sediment at the Aleutian/Alaska and Cascadia subduction zones is nourished by trench-axis turbidite sedimentation over pelagic and hemipelagic sequences. Offshore Alaska these sequences bury older abyssal plain deposits. In contrast, the present IBM and Central America trenches are sediment starved, in particular by turbiditic sequences. Westward along the Aleutian subduction zone, the stratigraphic mix of sediment types entering the subduction channel varies laterally as does the age of the underthrusting crust from middle to earliest Tertiary. Younger, warmer, Neogene crust enters the sediment-charged Cascadia subduction zone. Although a magmatically productive arc during the Quaternary, Cascadia volcanism is presently less active. Equally productive in the late Cenozoic, eruptive activity remains vigorous along the Aleutian chain.

Addressing key SubFac goals, and also those of SEIZE, will require S2S-type studies of the flux of sediment from source areas to the Aleutian and Cascadia subduction zones during the past 2-4 myr. This is the time needed for ingested sediment to pass through the seismogenic zone and reach a sufficient depth in the mantle for complete dehydration and/or melting. Because the Aleutian and Cascadia arc systems are virtually intact, they also provide ways to peer into the rock record to decipher both long-term (~past 50 myr) and shorter term or episodic rates of arc magmatism.

The projects described above would address key outstanding questions that form part of the basis for a renewed SubFac program. These include the role of forearc serpentinite in the budget of volatiles and the interaction of 3-D mantle flow with fluids and melts, both along-strike and across-strike of the arc.

We therefore endorse the recommendation of the MARGINS Steering Committee 2009 Review document that the focus for the future of the SubFac initiative should be to test whether models developed in the current focus sites can be applied elsewhere, so that the effects of a wider range of forcing functions can be explored. We also recommend a renewed emphasis on investigating processes that control magma production rates and the flux of magma from the mantle to the crust. This is central to fundamentally important questions regarding crustal growth and material fluxes and also to societal relevant issues such as volcano eruptive behavior and frequency, return of subducted volatiles to the atmosphere and hydrosphere, geothermal energy resources, and the formation of base metal sulfide deposits.

In summary, the DRC recommends:

- Continuing the main goals of SubFac: namely magmatic output, magmatic productivity long-term and short-term, and component flux storing, cycling, and recycling.

- Continuing to address these goals at the existing focal areas (i.e. Central America and Iz-Bonin - Mariana) over the near term, but the winding down of these efforts as the original goals are met and as emphasis moves to one or more new focus sites.

- Taking the next step forward by addressing these goals at new focus sites that exhibit arc activity, but whose geological setting contrasts with the existing focus sites.

- The program consider the Cascadia and Aleutian/Alaska subduction zones as future possible focus sites, as suggested in the MARGINS 2009 Review.

Rifts, Sediments and Fluids - RSF

The centerpiece of this new initiative, for which we suggest the name "Rifts, Sediments and Fluids", or RSF, will be the *integration* of the fundamental building blocks of rifted continental margins: namely the tectonic mechanisms that are responsible for depocenters and the sediments that fill them. The final pieces are the role of post-depositional processes, such as compaction diagenesis, thermal maturation, and fluid flow.

We recognise that important ongoing and planned investigations in the Gulf of California focus site remain to be completed. These include the interpretation of seismic reflection profile data, the funded Salton Sea experiment, and possible future IODP drilling. We agree with the MARGINS 2009 Review document that the controls of magmatism and sedimentation on rifting are key issues and merit further investigation both in the Gulf of California and elsewhere. We feel that synthesis of field efforts and modeling studies in the Gulf of California should continue with funding gradually ramping down.

We suggest that the current MARGINS concept of studying only "active rifts at the locus of seafloor spreading propagating into continental lithosphere" may be somewhat limiting. There are few examples of this on Earth and arguably the best one, the Red Sea, is currently not available for political and safety reasons. The Gulf of California rift is highly oblique and what we learn about this rift is not easily transferable to other rifts. We perceive a need to study places where there are well-dated stratigraphic sequences to estimate rates of processes. We think that adequate stratigraphic control may be difficult to obtain in the Gulf of California, even if it is drilled in the future. This is because of the tectonic complexity and the likely difficulty of correlating structures between sub-basins. It also seems that while the Gulf of California is good for 2D transects, it will prove difficult to address 3D issues. These characteristics have inhibited the RCL initiative from transforming our view of rifting to the degree that was anticipated. We suggest therefore that the RCL concept be broadened to consider rifts that do not meet all of the above criteria. These might include old rifts, rifts in which seafloor spreading has not yet begun, and/or rifts that have only recently completed breakup. Specifically, we suggest that the community consider identifying one (or more) new focus site(s) and perhaps some ancillary sites where the study of rifting processes can continue. We encourage continued integration of observations with numerical models, which has been a strong aspect of the existing RCL initiative. We also recognize the critical role that the initial landscape, crustal structure, thermal and stress state, and later sedimentation and erosion play in rifted margin evolution. Greater integration of studies of erosion and sedimentation processes, and the role of stratigraphy in controlling rift evolution, are clearly required.

Finally, the important role that rift evolution, including heat flow and lithospheric dynamics, plays in controlling the overlying stratigraphy cannot be overstated. They are also an essential aspect in defining the associated petroleum systems that are common in rift basins. Therefore, a new RSF initiative that includes a significant sedimentary component has the potential to address important questions in both rifted margin evolution and energy resources.

In summary, the DRC recommends:

- That while there is certainly exciting science continuing to be done in the Gulf of California (ongoing and planned), funding for this focus site should probably begin to ramp down.

- That consideration be given to developing either additional focus site(s) and/or ancillary sites where some of the outstanding problems in rifted margin evolution can be addressed.

- That the new sites should address stratigraphy, sedimentology, and facies evolution.

- That large-scale tectonic studies (e.g. of crustal and upper mantle "architecture", strain rate history, sediment loading and flexure) be fully integrated with studies of stratigraphic processes.

Whither S2S?

The DRC does not recommend the continuation of the S2S initiative as a standalone entity within MARGINS-2010. The reasons for this are several, but mainly involve the apparent mismatch between past and ongoing S2S efforts and the overarching goal of MARGINS, namely to understand whole-margin evolution which involves time scales of millions of years. That does not mean that there is to be no role for studies of sedimentation and stratigraphy and sedimentology in MARGINS-2010, but only that those efforts should be integrated explicitly with the SubFac and RSF initiatives as we have outlined in detail above. The DRC also recognizes that source-to-sink studies of the type presently supported through MARGINS (i.e., mainly process-focused efforts that span a relatively short geological time span, but extend from mountainous regions to the continental slope) have tremendous scientific and societal relevance. In particular, the expansion of S2S studies to biogeochemically-relevant currencies, such as various solutes and organic carbon, would seem to facilitate future integration with other NSF initiatives such as the U.S. Carbon Cycle Science Program that would benefit from the source-to-sink perspective. Similarly, the committee strongly endorses proposed S2S efforts on glacial (e.g., Gulf of Alaska) or Arctic margins that are currently experiencing rapid changes associated with global climate change. Understanding how such margins respond to future global warming represents a tremendous scientific opportunity, but also has high societal relevance.

The role of Theory, Numerical Modeling, and Laboratory Experiment in MARGINS-2010

A stunning success of the MARGINS Program has been the strongly interdisciplinary approach that it has pioneered. This approach includes not only the traditional geoscience sub-disciplines, such as geochemistry, petrology, geomorphology, sedimentology, and seismology, but also both theoretical/numerical modeling and laboratory experimental studies. Continuing such interactions should be a defining aspect of any successor program. This is well recognized in the future directions and motivation for a successor program in the MARGINS 2009 Review document (Section 7) where rheology, crustal deformation, and melt/fluid flow play a central role in the studies envisioned. Rheology and Deformation as well as Fluids and Magmas have been described as a common thread between SEIZE, SubFac, and RCL and as overarching themes for a future MARGINS program.

In the SEIZE, SubFac, and RCL initiatives, seismic interpretation and modeling have played central roles that can be even further enhanced in future studies. In SEIZE, industry-standard 3D seismic reflection processing can be more broadly applied. Additional numerical models of deformation and fluid migration will be important to interpreting these and other observations. Laboratory measurement and their analysis will be essential to better understanding the material physical properties, such as seismic velocities, rheology, and permeability, needed for such models.

In SubFac, the large-scale physical and chemical structure of the mantle wedge is central to understanding processes of crustal genesis and emplacement. Experimental data on melting temperature and melt productivity in the presence of a water-rich fluid is one area where laboratory experiments are now providing new insights and essential input to models. Also, a better understanding of how water, melt, and temperature combine to affect seismic velocity and attenuation will be fundamental to drawing more refined inferences on the physical state of the mantle from tomographically-derived seismic velocities. Models of melting and melt migration depend critically on the results of such laboratory studies. Understanding these fundamental processes also requires the continued development and application of numerical models that can be compared with observations.

In RCL, observations as well as numerical models suggest important but still only partially understood couplings between volcanism, sedimentation, and lithospheric deformation. Future incarnations of RCL envisioned in the directions and motivation presented for the 2009 Review and, even more so, in the possible new directions envisioned by the Review Committee will involve state-of-the-art 3D seismic data processing. The goals will also depend on the development numerical models based on many of the same elements as models for mantle flow and melt migration in SubFac.

Computational capabilities are thus integral parts of all of the current programs and it is essential that this continue in MARGINS-2010. In particular, the new RSF initiative will bring forth the need for large-scale, 3D seismic data processing. This is one area where industry collaboration could and should play a strong role in future work. Computer software supported and developed in other NSF

programs may also play an important role. The goals of the original S2S program can benefit enormously from the theoretical framework that will evolve from interactions with the CSDMS program. The MARGINS 2004 Review noted that S2S should develop around such a theoretical framework, but this has still not been clearly articulated. The goals of all the current initiatives can benefit from computational capabilities provided by CIG. One specific example is the application of the CIG-created Gale code to RCL studies. This code could allow feedbacks between tectonically generated surface relief and erosional/depositional processes. It would be interesting to explore how a code such as Gale for modeling tectonic relief might be integrated with sediment transport and deposition following CSDMS developments.

Societal Relevance

We are living in times when the geosciences have never been more relevant to society. Firstly, the geosciences provides the context in which to understand the rate at which our planet is being modified by climate and environmental change, sometimes accelerated by man's activities. Secondly, it is geoscience knowledge that provides the rationale for discovery and exploitation of the resources (e.g. hydrocarbons, base metals and minerals, water, etc.) on which the modern world depends. We believe therefore that MARGINS-2010 should develop a strong, interlocking link with climate and environment, geohazard and energy issues.

Climate and the Environment

The new MARGINS program should consider how to bring aspects of the environmental response to global climate change into the experimental plan. For instance, how shorelines respond to rising sea-level may affect the lives of millions. On longer timescales, the CO_2 now accumulating in our atmosphere is removed from the environment in the form of carbon by deposition in the deep sea, and, as C_{org} and $CaCO_3$, is taken into the subduction zone. CO_2 is an important component of arc magmas and is released to the atmosphere by volcanoes, completing the cycle through the subduction factory. Climate change will be more extreme in higher latitudes, thus a migration of study sites out of the low to mid and higher latitudes would be appropriate. A full understanding of the response of continental margin sedimentary systems to climate change requires a historical perspective, so it would be useful to bring a longer record, perhaps part or all of the Pleistocene and older strata, to bear on the questions being examined.

Geo-hazards

Roughly 2 billion people live in close proximity to the shore and they may be in jeopardy for a number of naturally occurring reasons. To the extent that MARGINS-2010 can understand, quantify, and perhaps model these phenomena, people and societies can be appropriately forewarned of impending events. The obvious examples of these hazards include earthquakes and volcanoes. Convergent margins are being studied by the SEIZE initiative exactly because they are characterized by large thrust earthquakes that may cause significant damage to infrastructure with attendant loss of life. The physics of this kind of faulting, studied in multiple settings, is an important aspect of the anticipated research. Earthquakes may also trigger slope failures on either side of the shoreline and, at sea, tsunamis.

The huge destructive power of a big tsunami was demonstrated in a most frightening manner in December of 2004 when the largest Indian Ocean tsunami in the past 600 years was triggered by a great earthquake in the Sumatra subduction zone. Volcanoes that parallel the subduction zones are usually the type characterized by explosive eruptions (such as Anatahan, which erupted suddenly in 2003) that cause great damage locally and may have regional consequences associated with ash plumes. The very largest eruptions may cause a temporary cooling of the earth. The explosiveness of volcanoes is a function of the chemistry and volatile content of the magma, both topics of investigation of SubFac. These hazards may happen in seconds (earthquakes) or a few days (eruptions), others such as rising sea-level take longer. Severe storms and consequent flooding, when superimposed on conditions of higher sea-level pose enhanced threats to both the coastal environment and its inhabitants.

Energy and Resources

The continental margins contain vast quantities of sediments and are one of the world's last frontiers for resources. The SubFac and RSF initiatives of MARGINS-2010 can provide the knowledge base that will enhance our understanding of the processes that make this so. For example, the heat and fluids associated with the formation of subduction-related volcanic arcs is responsible for enormous deposits of base metals. Hydrocarbons are preserved at rifted continental margins both in more conventional sedimentary reservoirs, as well as in less conventional deposits such as carbon-rich clastics (proto-oil shales?), and the "black shales" of the middle and late Cretaceous. The methane hydrates occurring at shallow depths in many continental margins are a potentially huge, if diffuse, energy source. Other energy resources, like geothermal energy, characterize active margins in neo-volcanic regions.

Management

The MARGINS office

The DRC believe that the current and past offices have been very successful in effectively managing the MARGINS program. We agree that the 3-year rotation policy of the chair and the office, for example, is sensible and should be retained in MARGINS-2010.

We believe that while the MARGINS Newsletter is still valued by the community and is useful for community-building, consideration should be given to replacing it with an e-mailed pdf version in the future. It is also imperative that the office maintain an effective and current website. We approve the contents of the 'Related Documents' page of the website, but suggest that it may be improved with a larger collection of interesting/exciting images of active phenomena, which could be accessed for presentations or for incorporation into educational materials. If this is done, we recommend re-titling the page. Finally, we believe the cost of the MARGINS office, compared to that of the whole program (currently at ~6%), is appropriate.

The MARGINS Data Management/Portal

The DRC briefly discussed the permanent archiving of the data acquired during MARGINS but recognized that this was part of a much larger issue that extended to all the geosciences.

The current MARGINS data policy statement is that "expedition metadata should be archived within 60 days of the end of the field experiment, and data should be archived within 2 years."

The DRC felt that while the archiving of marine geophysical data (e.g. seismic) is well underway, there appears to be no plan for a central archiving of cores or physical samples. However, it was recognized that cores are a relatively small component of the MARGINS data-set and that they are currently well archived and accessible to PI's (for example: cores from the Waipoa Focus Area are archived in New Zealand). The program should consider methods of archiving or distributing key physical samples, so that other investigators could perform different chemical analyses on the same samples, for example, without having to replicate the field program or introducing uncertainty as to the similarity of the samples.

MARGINS Steering Committee

While the DRC recognises that the MARGINS steering committee has been largely successful, there have been instances (e.g. S2S) where we feel that the program might have been better monitored. We therefore would like to emphasise the need to:

- continually review progress towards each science plan
- encourage attempts to integrate and synthesize MARGINS data and results
- develop, promote and nurture national and international collaboration.

In order to facilitate the above charges, we suggest that the title of the new committee be changed to the MARGINS-2010 Steering and Oversight Committee.

We recognize that a number of issues are involved in deciding on the Steering Committee membership. We recommend that committee membership remain at about 12 individuals. We agree with the MARGINS 2004 Review Report regarding the composition of the Committee. The committee should be dominated by academic scientists and have the necessary diversity of expertise, and include a healthy mix of established leaders, younger scientists with new ideas, those who receive funding from the program and those who do not, and take into account gender and minority considerations. But, we also suggest that a member from industry with appropriate rifted margin/sedimentology expertise be added to the committee to encourage future collaborations and the exchange of data and ideas. We also suggest that members with additional expertise in climate/energy/geohazards be considered for the committee. Finally, we suggest that consideration be given to a member from the state/national surveys (e.g. USGS) who could add expertise in both these areas.

We approve the current procedure for selecting new members (with a widely disseminated invitation).

Education and Outreach

The DRC was generally strongly supportive of the MARGINS Education and Outreach effort, but believes that MARGINS-2010 should work to enhance the visibility and awareness of the program both within the broader geosciences community and to the general public. In particular,

- The DRC realize that the 'Mini-Lessons Program' was still on-going. However, it felt that some examples available on the website needed further maturation. In particular, all images required to carry out the lesson, must be accessible from the web; either from the Margins site or another web-site.

- The DRC supported the suggestion from the Margins office that Education and Outreach would be extended to include both undergraduates and graduate students. We follow the MARGINS 2004 report in suggesting that the Steering Committee may also consider adding a specific component directly applicable to community college and K-12 audiences, similar to that done by R2K and IRIS. We note that convergent margins involve exciting natural phenomena (in particular, volcanoes) that could provide a basis for introducing K-12 audiences to geoscience.

- The DRC wondered whether the MARGINS Post-Doctoral Fellow program should be expanded, but given the number of applications, agreed that it should continue in its current form.

- The DRC is anxious to build on and improve the outreach of the program and facilitate the involvement of young investigators. Specifically,

    a) We encourage the Steering Committee to choose one charismatic early career scientist for the Distinguished Lecturer Program (DLP) each year.
    b) We suggest that the Public Lecture of each Distinguished Lecturer is videoed and made available to all, on the website. Each video should permanently remain on the website, leading to a large body of available lectures as the Program matures.
    c) We recommend that as part of the application to host a Distinguished Lecturer, the institution should be asked to explain how the Public Lecture will be accessible to a broad and large public audience. The response should be used in the decision making for choosing host institutions.
    d) Lastly, we propose that the DLP should expand to include international institutions, especially those who will be collaborating in MARGINS-2010 research.

Review timescale

We judge that the process of preparing for this NSF review was a valuable exercise for the Steering Committee and others involved, requiring the collection of a

large amount of information and self-analysis of accomplishments that led to a better understanding of both the successes of the program and the remaining gaps and priorities/opportunities for future work. We especially valued the volume of Science Research 'Nuggets', which we think will be useful beyond this review. Recognizing that the work involved in the review process is large, we recommend that the current 5-year review timescale be retained.

MARGINS proposals; NSF review procedures

We strongly support the continued joint effort of NSF's EAR and OCE Divisions in convening a dedicated MARGINS panel review. This allows each proposal to be evaluated not only in terms of science but also in the context of other proposals submitted to MARGINS. This separate review, combined with the knowledge of the NSF program managers and guiding MARGINS documents, obviates the need for a separate relevancy panel.

Other issues

Demographics

The DRC recognises that the new MARGINS-2010 program will have elements that are similar to the current program. Therefore, there will be workers who will have been involved in both programs. This situation raises issues related to demographics. For example, the community involved in the SEIZE and SubFac focus sites have aged and so MARGINS-2010 should monitor and encourage the participation of early career scientists in these initiatives so that there is mobility and a replenishment of ideas.

Gender diversity

The DRC noted 14% (2 out 14) current MARGINS steering committee members are women. Over the 10-year history of the program women have comprised 20% (1 out of 5) of the steering committee chairs and 19% (10 out of 52) of the steering committee membership. The program has funded approximately 13% female PIs. Although our perception (without more data) is that this not unusually low compared to the representation of women as faculty and researchers at US institutions, we encourage the program to continue to be mindful of encouraging women to participate in the leadership of the MARGINS program, submit proposals, and to promote early career women.

Developing countries

The DRC recognises that the global world order is changing and that certain developing countries are likely to play an increasingly active role in the geosciences in the next decade. Most prominent is China, but other developing countries such as India, Brazil and Russia are emerging. MARGINS should follow these developments and where possible and appropriate make overtures to scientists and academies in these countries, some of which have excellent examples of margin systems in both the modern and rock record.

Summary of the main recommendations

- That the NSF set up a new themed program, MARGINS-2010, to follow on from the existing MARGINS program.

- That the new program is not restricted to active margins, but also addresses passive margins in the context of understanding how these margins are formed.

- That the new program continues to build on the focus site concept, but is flexible such that old sites can be wound down and new ones brought in as the science dictates.

- That the new program builds on the strengths of MARGINS and incorporates its SEIZE and SubFac initiatives and a new initiative which we dub a Rifts, Sediments and Fluids initiative (RSF).

- That the S2S initiative is not a standalone entity within MARGINS-2010, but is integrated explicitly into the SubFac and RSF initiatives.

- That large-scale computer modeling, laboratory experimental studies and studies of margin analogues in the rock record continue to be important elements of MARGINS-2010.

- That MARGINS-2010 continue to work productively with other large-scale NSF facilities and programs such as EarthScope, OOI, IODP and the new R/V *Marcus G. Langseth*.

- That the new program highlights links with societal issues such as climate, sea-level and environmental change, geo-hazards and energy and resources.

- That a new committee, the Steering and Oversight Committee, be set up to manage MARGINS-2010 which is dominated by academics, but includes representatives of the industry and the state/national surveys.

- That the Distinguished Lecture Program is expanded to include a highly visible, videoed, Public and University Lecture Series which is held in international institutions, especially those who will be collaborating in MARGINS-2010 research.

- That the current 5-year review timescale of MARGINS be retained in MARGINS-2010.

Composition of the NSF MARGINS Decadal Review Committee

Chair: Anthony Watts
University of Oxford

Members:
1) **David Rea**
2) **Dale Sawyer**
3) **Susan Beck**
4) **Michael Cheadle**
5) **Marc Parmentier**
6) **David Scholl**
7) **Tim Minshull**
8) **Paul Wallace**
9) **Janok Bhattacharya**
10) **Rob Wheatcroft**

March 4, 2009