Workshop Report

CHALLENGES AND OPPORTUNITIES IN ACADEMIC MARINE SEISMOLOGY

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Incline Village, Nevada—March 22-24, 2010

Sponsored by the National Science Foundation

Table of Contents

Executive Summary

In March 2010, over 70 marine seismologists met in Incline Village, Nevada to seek consensus on a path toward greater community participation in R/V *Marcus G. Langseth* cruises and broader use of data products, and to find new mechanisms for stabilizing—and to perhaps increase—funding within our community, which has dwindled over the past several decades. A key element of this workshop was the participation of a large number of young scientists—nearly 20 graduate students, post-docs and early career researchers—who helped provide constructive criticism of the status quo, and a unique perspective on the path forward. A programmatic view of current opportunities within Margins, RIDGE2000, IODP, Continental Dynamics, and Law of the Sea was highlighted, including new long-offset streamer studies, cutting-edge waveform tomographic techniques, and hands-on approaches to education/outreach within the K-12 and undergraduate environment. Breakout sessions discussing "Improving Access", "Science Opportunities", "The Proposal Process" and "Charting the Future" provided lively debates throughout the 3-day meeting, resulting in a remarkable degree of consensus on a myriad of important topics. Beyond the obvious desire to collect more 3D data volumes in the near future, this large segment of the marine seismology community strongly endorsed the notion of both PI-driven and community-based experiments, with the latter representing a strong break from business as usual. This new type of project would include immediate data access to all interested parties, rapid commercial processing of 3-D reflection data, and wider use of the initial and final data products in classrooms. Less clear was the role of contractor processing in non-3D and/or PI-driven experiments. Due to a perceived hiatus in public access to R/V *Langseth* 3D data in the near future, with some likelihood of a year or two long process on defining what constitutes a "community experiment", meeting participants strongly agreed to self-organize and submit 3D proposals that, at a minimum, would provide immediate community access to 3D R/V *Langseth* data (recently this concept has been coined an "open access" experiment). Scientists and educators alike left the Incline Village meeting with the sense that as a community the "corner had been turned", with the likelihood of greater access to multichannel seismic (MCS) data—and potentially a path forward toward building a dedicated program defined by significant growth of the user base over the next decade.

The R/V *Marcus G. Langseth*

Workshop Context

The recent acquisition of the R/V *Marcus G. Langseth*, the first-ever academic 3D seismic vessel, brings unprecedented opportunities for Earth imaging to the geoscience community. The *Langseth* is a National Facility, operated by Lamont-Doherty Earth Observatory (LDEO) and overseen by the Marcus Langseth Science Oversight Committee (MLSOC). With its four, 6-km-long streamers, dual, tuned airgun arrays, and ocean bottom seismometer launch and recovery capabilities, the Langseth produces 3D and 2D images of the Earth's crust and uppermost mantle with resolution and clarity that were unattainable a few years ago. Since its maiden scientific voyage in early 2008, the R/V *Langseth* has conducted nine expeditions, in sites from Taiwan to Costa Rica, all of which have been successful. However, along with these new capabilities come unprecedented challenges and costs. Under its current mode of operation, the R/V *Langseth* is hampered by a combination of factors, including a high day rate, long transits between funded work sites, and consequent delays in moving projects from the "funded" to the "scheduled" category. These factors have resulted in the R/V *Langseth* conducting relatively few scheduled programs (~4/year) in the first two years and a drop in proposal pressure to use the facility; the 2010 schedule took a turn for the worse, with only 1 funded program that went to sea. In addition, the long turnaround time from data acquisition to public release (in practice, often 5-10 years), coupled with the increased specialization required to acquire, process and interpret 3D data, suggests that R/V *Langseth* data are not achieving their full potential scientific and educational impact.

These challenges pose several risks to the marine seismic community, including low funding rates for *Langseth* proposals, a discouraged and shrinking user base, and low proposal pressure, in a potentially self-reinforcing cycle. If the scientific community is to have continued access to the remarkable new capabilities of the *Langseth*, this cycle must be broken and replaced with a healthier, more sustainable pattern of facility usage and community growth. However, this workshop was intended to also represent an opportunity to examine funding and accessibility of academic marine seismic imaging in the United States and seek improvements that will build our community, increase funding and educational opportunities, and generate more scientific discoveries. The ability to share this facility with international colleagues was seen as a critical step towards greater access for everyone.

To tackle these issues, over 70 scientists met for three days in March, 2010, in Incline Village, Nevada, with the goal of addressing three overarching questions:

- What are the exciting science goals that, over the next decade, will require a healthy Langseth facility?
- How can the process of soliciting, evaluating, funding, and scheduling work on the Langseth be improved?
- What modes of data access might help put Langseth products into more scientists' and educators' labs and schools?

These critical issues were discussed at the meeting through keynote presentations by invited speakers and breakout sessions in which working groups developed recommendations. Meeting participants included 21 faculty members, 23 research scientists, 16 students and postdocs, 2 representatives from industry, and 3 representatives of the National Science Foundation. Keynote presentations were given on the relationship of marine seismic imaging to major thematic programs (e.g., IODP, MARGINS, Earthscope, Continental Dynamics, US Extended Continental Shelf studies); recent advances in marine seismology (e.g., long-offset streamer studies, waveform tomography, P-cable);

educational opportunities for marine seismology; and science opportunities in marine seismology (e.g., mid-ocean ridges, ocean crust, rifted margins, subduction zone processes, gas hydrates, seismic oceanography). Breakout groups were convened to discuss aspects of "Improving Access" (e.g., data access and availability, expanding the *Langseth* user base, improving the educational footprint, and new models of data processing and release); "Science Opportunities"; and "The Proposal Process" (models of proposal preparation, nurturing, and evaluation). The workshop was preceded by a well-attended short course, sponsored by LDEO, on OpendTect®, a free, open-source, multiplatform software package for interpreting 3D seismic data.

Outcomes and Recommendations

Assessment

In the opinion of the Steering Committee, the meeting was an unqualified success. The scientific case for continuing to support the *Langseth* facility is unequivocal; many of the most pressing geoscientific issues facing our society rely on the ability to image the structure of the Earth's crust in three dimensions. These issues include geohazards (great earthquakes, submarine landslides, volcanism, and tsunami), energy (exploration and carbon sequestration), and climate change (paleoclimate and ocean imaging). The group convened at Incline Village strongly endorsed continued support of a robust marine seismic imaging facility.

Consensus

Importantly, consensus was reached on ways to improve the relevance, operation, impact, and access to the *R/V Langseth* facility. Below is a summary of the major recommendations; these were discussed and adopted by mutual consent of the assembled group in a plenary session on the final morning of the workshop. Scientific opportunities and an implementation plan, known as the *10+2*, will be released separately.

Funding:

- We strongly endorse creation of a new program at NSF to stabilize funding for work using the *R/V Langseth* facility.

Advanced Planning Cycle:

- We endorse an advanced planning cycle in which proposal calls are issued on a regional basis (e.g., North Atlantic, eastern Pacific) several years in advance. MLSOC should work with the user community and facility operator to determine the ship's projected areas of operation, possibly guided by pre-proposals (see below). The proposal review panel should be populated with appropriate scientific expertise according to the region.

Proposal Process:

- We endorse a separate panel for judging *R/V Langseth* proposals against each other, especially in the context of a new NSF program to fund the *R/V Langseth*.
- We endorse adoption of a pre-proposal process for work proposing to use the *R/V Langseth* facility. These pre-proposals would be judged by this new panel and confidential reviewers and would provide the information used for projecting the future areas of operation of the ship over the next ~3 years.

Training the Next Generation:

- We endorse recurring "training cruises" in which science berths are open to scientists wishing to gain at-sea experience on *R/V Langseth*. These could initially be aimed at early-career scientists but should be broadened to all interested scientists.
- We endorse, wherever practical, reserving 1-2 berths on each *R/V Langseth* cruise for early-career scientists via an open application process.
- We suggest lowering barriers to access through creation of a user "cookbook," at-sea training cruises, and a formal mentoring program to establish "junior leaders."

Hybrid model of community-selected and PI-driven 3D and 2D programs:

- We endorse a system that allows for both "community" as well as PI-driven 3D and 2D programs:

- We propose to allow for community 3D datasets to be acquired, perhaps in concert with training cruises. Identification of targets for 3D community datasets would occur at workshops open to all scientists. Following acquisition, 3D data sets would be commercially processed to an initial interpretable volume and publicly released (e.g., 6 months post-cruise). These data would then be available for an open competition for data interpretation and analysis proposals. A similar model should also be available (but not required) for processing and release of 2D data. A key component of this model must be a cultural change within NSF (and the reviewer community) toward funding data-analysis proposals, rather than the currently perceived bias toward data acquisition proposals.
- We also strongly endorse retaining a component of PI-driven proposals for using the *R/V Langseth*, with appropriate protections for PI's to conduct initial analysis under a data release moratorium of no more than two years.

Data Processing:

- We endorse commercial processing (to post-stack depth migration) for all 3D cruises.
- A similar option for commercial processing of 2D data should be available, but not required.
- NSF should explore establishing a long-term contract with a commercial processing house to lower processing costs.

Improving the Educational Footprint:

- We endorse (1) expansion of the *Langseth* website with a focus on public outreach and education, (2) K-12 presence through teacher workshops and teacher-at-sea programs, (3) a "Distinguished Ambassador" program to visit K-12 schools, (4) use of social networking sites to communicate *Langseth* activities and results to interested parties, (5) exploring use of *Langseth* transits for training/education cruises, and (6) training of undergraduate and graduate students in use of open-access 3D interpretation software to bring *Langseth* 3D data into college classrooms and graduate-level research programs.

Immediate Action:

- The workshop facilitated the formation of several self-organized groups to submit community-driven 3D proposals with "open data access" for the upcoming August 15 or February 15 deadline. The development and implementation of a new model for community datasets will require time to design, fund and implement. However, there was support for testing this new model and an understanding that in order for any community-driven 3D proposal to take place in 2012, it would need to be proposed in 2010. These self-organized groups provide an opportunity to explore options for implementing open data access and strong training components in R/V Langseth 3D programs.

Implementation

MLSOC will draft new policy and procedures, in consultation with NSF, for long range forecasting of ship operations, a pre-proposal process to guide long-range forecasting, and help flesh out various modes of operation for PI-driven, open-access and community experiments. MLSOC will keep the marine seismic community up-to-date throughout this process and ask for input where appropriate.

Participants

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Workshop Agenda

Monday, March 22		Speaker	Discussion Leader	Scribe
7:30	Breakfast			
8:30	Welcome; Goals of the Meeting	Kent/Holbrook		
8:50	NSF Opening Remarks	Smith/Carlson		
9:05	The R/V Langseth: Status and Future	Higgins		
9:20	**Relation to Thematic Programs**			
9:20	Marine seismology: Role in MARGINS studies	Morgan		
9:35	Marine seismology: Role in IODP studies	Tobin		
9:50	Marine seismology: Role in Earthscope studies	Trehu		
10:05	Marine seismology: Role in continental dynamics	Okaya		
10:20	Marine seismology: Role in Law of the Sea/USGS plans	G. Barth		
10:35	---Coffee Break ---			
10:50	**Talks: Advances in Marine Seismology**			
10:50	Review of R/V Ewing 3D Successes	Shipley		
11:15	Educational Opportunities for Marine Seismology	Reed		
11:30	Opportunities in Long-Offset Streamer Studies	Kent		
11:40	Opportunities in Long-Offset Streamer Studies	Singh		
11:50	Opportunities in Streamer Waveform Tomography	Nedimovic		
12:05	The first R/V Langseth 3D cruise	Carton		
12:20	Lunch			
13:20	**5-Minute Nuggets: Ideas from the Floor**			
14:20	**Breakout Sessions #1: Improving Access**			
	1A. Data access and availability		Carbotte	
	1B. Expanding the Langseth user base		Johnson	
	1C. Improving the educational footprint		Reed	
	1D. Data processing: commercial vs. in-house; 2D vs. 3D		Diebold	
15:20	---Coffee Break ---			
15:50	**Breakout Reports and Plenary Discussion**	Breakout Leaders		
16:50	**Poster Session**			
18:50	Dinner (Lakeside Room)			
	-- Guest Speaker: Dr. Jeffrey Thompson			
	-- Guest Speaker: Dr. Charles Goldman			

Tuesday March 23		Speaker	Discussion Leader	Scribe
7:30	Breakfast			
8:30	Recap/Plan	Kent/Holbrook		
8:40	**Science Opportunities in Marine Seismology**			
8:40	Mid-ocean ridges and ocean crust	Kent		
8:55	Rifted margins	Shillington		
9:10	Gas hydrates/methane systems	Gorman		
9:25	Subduction zone processes	Moore		
9:40	Seismic oceanography	Holbrook		
9:55	3D Imaging with the "P-cable"	M. Barth		
10:10	---Coffee Break ---			
10:30	**Breakout Sessions #2: Science opportunities**			
	2A. Ridges and ocean crust		Toomey	Wilcock
	2B. Rifted margins and continental crust		Louie	Driscoll
	2C. Subduction zones and geohazards		Legg	Singh
	2D. Hydrates, methane, and oceans		Barth	Trehu
12:00	Lunch			
13:00	**Recap of Science Opportunities**	Breakout Leaders		
13:30	**5-Minute Nuggets: Ideas from the Floor**			
14:30	**Breakout Sessions #3: The proposal process**			
	3A. Models of proposal preparation/nurturing/evaluation		Christeson	
	3B. Models of proposal preparation/nurturing/evaluation		Magnani	
	3C. Models of proposal preparation/nurturing/evaluation		Sawyer	
	3D. Models of proposal preparation/nurturing/evaluation		Mountain	
	NOTE: Have 4 randomly populated groups discuss the same issues			
15:30	---Coffee Break ---			
16:00	Breakout Reports and Plenary Discussion	Breakout Leaders		
17:00	**Optional Tour of Tahoe Center for Environmental Science**			
18:00	Dinner (open)			
19:30	Poster Session			

Wednesday March 24		Speaker	Discussion Leader	Scribe
7:30	Breakfast			
8:30	Recap/Charge to Breakout Groups		Kent/Holbrook	
8:50	Breakout Sessions #4: Charting the Future			
	4A. Crafting a consensus on proposal process		Gulick	
	4B. Long-range forecasting of areas of operation		Harding	
	4C. Training the next generation		Shillington	
	4D. Elements of a new NSF program		Shor	
10:20	---Coffee Break ---			
10:35	**Breakout Reports and Plenary Discussion**	Breakout Leaders		
11:35	**Recap/ The Path Forward**		Holbrook/Kent	
12:00	**Meeting dismissed/return to Reno-Tahoe Airport**			
	Steering Committee remains through Thurs AM to begin writing report			

Breakout Group Reports

Introduction

Much of the workshop was devoted to in-depth discussion by breakout groups of key issues facing the marine seismic community. The breakout topics were organized into four main themes: "Science Opportunities," "Improving Access," "The Proposal Process," and "Charting the Future." On the final day, the assembled group decided that the fourth topic, "Charting the Future," should be discussed in a plenary session rather than in breakout groups. The discussion on that morning led to the key items of consensus summarized on pages 3-4 of this report.

Below we include summaries of the key breakout groups on the topics of "Improving Access," "The Proposal Process," and "Charting the Future." The breakout discussions on "Science Opportunities" will inform the companion product of this workshop, the "glossy brochure" requested by NSF.

Improving the Educational Footprint

Chair: Don Reed

> The Issue: The 2D and 3D images of the earth created by Langseth data are ideally suited for education at all levels, from primary school to undergraduate education. Pictures of sediments, faults and magma chambers in these data are more intuitive for students than many other types of geological or geophysical data. However, at present, we are not exploiting the full potential of these data (and the results derived from them) for educational purposes. Some individual PI's or programs are developing educational materials from Langseth-type data, but the level of effort, type of products, and success varies.
>
> Charge to the group: Discuss possible educational applications of Langseth data and different possible mechanisms for developing the products and materials necessary for these applications.

High quality of seismic imaging in three dimensions, such as capable with the R/V *Langseth*, provides an invaluable asset for visualizing earth and ocean processes of significant societal relevance (giant earthquakes, volcanic eruptions, energy resources, shoreline encroachment). The dynamic nature of visualization, especially with animations and 3-D seismic interpretation systems, promotes a level of interactivity that facilitates inquiry-based learning, hypothesis testing, and exploration, all of which form the basis of K-12, undergraduate, and early graduate science education. Seismic imaging also puts a variety of data in geographical and geological context, allowing integration of multiple databases, on a variety scales (borehole, seismic velocity, heat flow, seismicity and geochemistry), which ultimately stimulates interdisciplinary education. The geographic breadth of *Langseth* activities provides a global framework for geoscience educational activities.

Different mechanisms will likely be necessary to reach the diverse groups in the U.S. educational structure, for example, K-12 educators and students may be most effectively reached through teacher workshops and teacher at sea programs, both of which have been successful in other ocean science outreach programs (Deep Earth Academy, IRIS, and COSEE). We also suggest a "Distinguished Lecturer or Ambassador" program to visit K-12 schools. Non-electronic means such as coloring books, puzzles, flipbooks, could be target to pre-K and K-5 students. Undergraduate and graduate education could benefit from classrooms at sea, filled with students from multiple institutions, and connected virtually to classrooms across the nation. Web-based products, based on *Langseth* activities, should target entry-level courses taught at a wide range of undergraduate institutions, from research institutions to comprehensive universities and community colleges. Moreover, the *Langseth* could serve as a Research Experience for Undergraduates (REU) site, which could be extend to a virtual cohort through active social networking.

In terms of an implementation strategy, we foresee growth of the current *Langseth* website with a focus on education and public outreach. In addition to web-based resources and announcements of teacher activities, links will be available to access resources at other geoscience education libraries, such as the Deep Earth Academy and the Science Education Resource Center. We also encourage the use of popular social networking sites, such as Facebook and MySpace, to develop a cohort of *Langseth* followers across a broad public audience. YouTube could provide access to *Langseth* at sea research activities through weekly video uploads. Twitter can be used for rapid communication of shipboard activities.

Lessons learned from existing outreach programs show that dedicated resources, both financial and human, for example, supported through ship operational budgets are required for a sustainable outreach effort. This effort should be designed to be scalable over time and take advantage of current geological events to capture the interest of the public. However, any program should avoid overlap with efforts underway elsewhere. For example, some activities, when and where appropriate, should combine resources with other geoscience outreach activities (Deep Earth Academy, Earthscope, COSEE, Ridge 2000, MARGINS successor program), especially where there is significant overlap in science.

Training the Next Generation of Scientific Leaders

Chair: Jackie Caplan-Auerbach

> <u>The Issue</u>: A central issue in ensuring the health of the *Langseth* facility is to continue developing the young scientists who will use the vessel in the future. At present, a relatively large community of trained 2D users exists (who will continue to propose appropriate 2D work on *Langseth*), but the user base of academic scientists skilled in 3D seismic work is small (and largely graying). Many of our best students choose career paths in industry and hence do not contribute to the growth of our science. The number of early-career scientists in active-source marine seismology is arguably not sufficient to sustain healthy growth in the field.
>
> <u>Charge to the Group</u>: Identify, discuss, and recommend mechanisms to train the next generation of active-source marine seismologists, to encourage retention of our brightest students within academia, and to enhance their access to the *Langseth* facility and its data.

The breakout group on Training the Next Generation reached consensus on structuring a five-year plan aimed at establishing plans for mentoring early-career scientists and for leadership training. The recommendations include the following:

<u>*Mentors & Mentorship:*</u>

- Establish a committee of 5-10 experienced scientist mentors per year representing different agencies (NSF, ODP) and scientific programs (Margins, Ridge, etc.).

- Hold semi-annual workshops to nurture science proposals by new and early-career principal investigators (mentors and 20-30 participants per workshop).

Leadership Training:

- Conduct annual training cruises, for 10-20 participants.
- Create an Associate Science Officer position. This person would participate in each seismic cruise, provide logistical and technical support, and assist in writing cruise report (2-3/year).

Measurable Results at the end of 5 Years:

- 5 training cruises
- 10-15 scientists trained as Associate Science Officers
- 25-50 active science mentors
- 50-100 scientists trained through training cruises
- Funded proposals by new and early-career investigators through the mentorship and proposal workshop program. (1 per workshop=10 funded proposals)

Expanding the *Langseth* User Base

Chair: Sean Gulick

The issue: Currently, the core users of the *Langseth* comprise a small group of specialists in 2D and 3D seismic reflection and wide-angle reflection/refraction data. However, the constraints on earth processes and subsurface structure provided by Langseth data are critical to a growing group of researchers and educators for a growing number of scientific and educational applications.

Charge to the group: Discuss different mechanisms for increasing both the number of specialists in marine active source seismology and the community of non-specialists that can take advantage of Langseth data and results.

This breakout group discussed ways to increase the user base of the facility beyond the "usual suspects" -- i.e., those PI's with extensive seagoing experience aboard the *Ewing* and/or *Langseth*. An important stepping stone toward this goal is making the Langseth operation more turn-key: the design, acquisition and processing of 3D data sets requires highly specialized training and experience that only a few people in the academic community possess. Broadening the community with those skill sets will require infrastructure and facility investments. In addition, several specific ideas for expanding the user base were endorsed by the working group, including:

- Issue proposal calls on a regional basis, with areas of operations known several years in advance.
- Establish a consistent proposal process that guides projects through several stages, from Planning Letters to Nurtured Proposals to Cruises.
- Include a dedicated "training" slot on all cruises, to give students and early-career scientists opportunities to gain experience aboard *Langseth*.
- Develop a "Cookbook" for *Langseth* users that describes the capabilities of the facility and guidelines for its use.
- Develop opportunities to enhance cross-training across disciplines and techniques.
- Establish a separate panel that reviews proposals within given regions of the global ocean, to ensure that the appropriate local expertise resides on the panels and to expand the number of scientists with exposure to the capabilities of the *Langseth*.

- Expand the opportunities for conducting general oceanographic research in the locations where *Langseth* is operating. Encourage cross-training of technical support staff for this purpose.
- Establish and enforce a more open data policy and encourage data sharing within the same profiles or volumes.
- Investigate opportunities for training cruises funded by non-NSF sources.

The Proposal Process

Chairs: Gail Christeson, Beatrice Magnani, Dale Sawyer, and Greg Mountain

The Issue: According to NSF program managers, proposal pressure to use the *Langseth* is lower than needed to sustain a healthy facility. Information provided to MLSOC on proposals submitted for *Langseth* in the past few years suggests that, so far, a typical year sees fewer than 10 proposals to use the *Langseth*. A basic tenet of successful facilities is that they are in demand by a broad cross-section of the community. So far, that is not the case for *Langseth*. It is not clear why proposal pressure has been low, though reasonable guesses include (1) the two-year delay in marine seismic operations during the transition from *Ewing* to *Langseth*, (2) the carryover of proposals funded for the Ewing but scheduled on *Langseth*, (3) the ill-timed ramp-down of key large programs, like R2K and MARGINS, (4) the perception that chances for proposal success are small, and (5) the small number of early-career scientists entering our field.

Charge to the Group: Discuss and evaluate possible new mechanisms for handling *Langseth* proposals, with goals of increasing proposal pressure and expanding the user base.

The four breakout groups on the proposal process discussed several ideas for improvements to the proposal submission and evaluation process, including a dedicated *Langseth* panel, pre-proposals for *Langseth* work, and mentoring new investigators through the process. The recommendations include:

- Dedicated funding stream. The *Langseth* provides a fundamental and irreplaceable capability to the geoscience community: the ability to image the Earth at high resolution. In view of that, a majority of participants felt that a dedicated funding stream for active-source seismology is long overdue: A "SeaScope," if you will (with apologies to EarthScope).
- Dedicated *Langseth* Panel. The majority view was that a separate panel to evaluate active-source seismic proposals would be a good thing; however, a significant minority view maintained that the current system might serve users better. The perceived advantages of a dedicated panel include: (1) A reduction of "sticker shock" on the part of panelists comparing active-source seismic proposals, which use an expensive national facility, with (typically) less-expensive MG&G proposals. The cost of the facility is fixed and beyond the control of PI's, but the perception is that it often works against proponents of marine seismic proposals. An analog would be the Continental Dynamics program; the projects funded there tend to be large, expensive programs, but the cost can take a back seat when CD proposals are only compared to each other. (2) Proposals to use the *Langseth* would be ranked against each other, thus providing the NSF programs clear guidance about which marine seismic programs should be prioritized. (3) A dedicated panel would guarantee that panels would have sufficient technical expertise to properly assess marine seismic proposals. A common perception among the seismic community is that MG&G panels rarely include more than one marine seismologist, and that in-

dividual may even be in conflict with proponents of some of the marine seismic proposals at panel. This can result in a lack of relevant technical expertise in the room when proposals are being ranked for funding, which would be solved by a dedicated panel. (4) Advanced planning of the ship schedule would be a plus and would enable dedicated panels to include scientific experts from the ocean basins under consideration for future work. (5) If the dedicated panel implied sequestered funds for marine seismology, that would be a a strong plus for the community.

A minority view pointed out several possible disadvantages to a dedicated panel system, including: (a) Program managers already take costs into consideration when making final funding decisions, so a dedicated panel might not be necessary. (b) With a *status quo* of only 2-3 seismic programs per year on the *Langseth*, why bother with a separate panel? (c) A negative analog might be R2K: in that community, a separate panel didn't solve problems. (d) We believe that our science can, and should, compete successfully against a broad range of MG&G proposals -- does a separate panel give the opposite appearance?

- <u>Pre-proposals</u>. The breakout group strongly endorsed a system encouraging (or requiring?) pre-proposals for programs intending *Langseth* use. Such a system would have many advantages, including: (1) The panel vetting pre-proposals would be a natural way to give PI's advice and feedback on their proposal -- both on the scientific merits but especially on the logistical/technical aspects of using the facility, which many PI's are less familiar with. Doing this at the pre-proposal stage prevents PI's from investing the time on a full proposal, if there is a fatal flaw in the acquisition design. (2) The pre-proposal panel need not entail travel to a live meeting, but could rather be done "virtually" via fastlane, as the Continental Dynamics program does. (3) A pre-proposal system encourages scientists with less *Langseth* experience to submit proposals, thus expanding the user base, particularly among new and early-career investigators. (4) The pre-proposals would give the MLSOC and NSF valuable information for long-term planning of *Langseth* operational areas. The breakout groups did not find any significant disadvantages to a pre-proposal system.
- <u>Mentoring/nurturing</u>. Nurturing of proposals through the entire process is closely linked to the issue of mentoring early-career scientists and thereby expanding the user base. Several ways of mentoring via the proposal process were suggested, including (1) reserving a slot on NSF panels for a graduate student, so that PhD students can gain experience with the system at an early stage; (2) encouraging and enforcing open data access policies, so that early-career scientists have access to *Langseth* data; (3) identifying mechanisms to incorporate scientists from smaller, MS-granting institutions into *Langseth* research projects; and (4) decreasing the time from proposal submission to field work, to increase incentives to write proposals for *Langseth* science.
- <u>Removing Barriers</u>. Several impediments, real or perceived, exist that might dissuade new investigators from writing proposals for *Langseth* science. Access to planning information is critical: the facility operator should put the user "cookbook" online, with guidelines and tools (e.g., spreadsheets or matlab scripts) to aid in cruise track planning for 3D and time estimations for both 2D and 3D. *Langseth* technical staff should be available at AGU to meet with potential users -- not just PI's of already-funded projects. Standardizing processing to a defined end product could increase the user base, but flexibility should exist to process data in house if desired. Finally, scheduling transparency could help in working with other programs, such as Earthscope, Continental Dynamics, GeoPRISMS, and the USGS Extended Continental Shelf program.

Long-Range Forecasting of Areas of Operation

Summary of Plenary Discussion, by Steve Holbrook

> The Issue: Given the relatively small number of funded proposals, NSF has a very difficult task designing sensible schedules for the *Langseth*. To take 2010 as an example, within a 12-month period the ship is scheduled to work in the Aleutians, Costa Rica, and the Lau Basin. This is highly inefficient, wastes program resources, and leads to unreasonable wait times for nominally "funded" programs (or to proposals being declined simply due to scheduling, rather than quality). Should we adopt a system of forecasting future areas of operation? For example, the community could decide that the *Langseth* will work in, say, the North Atlantic in 2012, the South Atlantic in 2013, the Indian Ocean in 2014, the western Pacific in 2015, and so forth. This would enable PI's to focus their efforts on proposals most likely to be scheduled (at the expense of potentially having to wait several years for the ship to reach the ocean basin of interest).
>
> Charge to the Group: Discuss and evaluate possible new mechanisms for long-range forecasting of areas of operation of the *Langseth*.

There was widespread consensus among the assembled scientists that long-range forecasting of *Langseth's* areas of operations should be a high priority. For the facility operator (LDEO), this would produce major benefits in cruise scheduling, planning of maintenance periods, and marine mammal permitting. For the user community, a forecast of operational areas would remove considerable uncertainty in deciding what to propose, and when to propose it ("should I submit my Atlantic project or my Pacific project?"). This can only increase proposal pressure, which will lubricate the entire system of *Langseth*-based science.

Implementation of a long-range planning cycle should be coordinated by MLSOC, NSF, and the facility operator. A key element in long-range planning is the submission of pre-proposals or "letters of intent" that would enable an overseeing body to gauge proposal pressure at a 3- to 4-year remove. The appropriate overseeing body could be MLSOC or a review panel, if a dedicated *Langseth* panel is instituted. The majority of participants felt that, partly for this reason, pre-proposals should be required (not optional) for all *Langseth*-based science.

Data Processing: Commercial vs. In-House

Chair: John Diebold

> The issue: A tremendous amount of time and resources are required to process seismic reflection data, particularly 3D data. The raw data require extensive disk space; several Tb of disk space are needed just to archive a typical 3D volume. Manipulation of these data is traditionally done with commercial software packages, many of which have expensive licenses fees and require training to use. Data processing also requires substantial computational power. These requirements limit the number of institutes and universities capable of analyzing seismic reflection data. Furthermore, processing a dataset involves a major time investment, some of which must be devoted to tedious, 'non-scientific' tasks (e.g., navigation, etc).
>
> Charge to the group: Discuss the pros and cons of different models for processing 2D and 3D seismic reflection data.

The group agreed that turnkey commercial processing could be beneficial, for several reasons. The first consideration is speed: commercial processing is expected to produce the fastest possible result, which will have major value in achieving rapid data release to the community. The second major consideration is reliability, as commercial processing is expected to be dependable, with little sensitivity to large data sets or variable throughput. Finally, industry processing should be of high quality, especially with the interaction of scientists in environments where industry might be less experienced (e.g., mid-ocean ridges).

Opinions as to the extent of commercial processing, however, varied, as well as whether processing of 2D data should be routinely done by a commercial shop. For 3D data, commercial processing All agreed that commercial processing to the point of CDP-gathered 3D data would be beneficial. Some propose that "standard" commercial 3D processing be carried out to the point that a post-stack migrated cube was ready for dissemination, and still others that all advanced processing should be done commercially. These varying opinions lead to the conclusion that the use of commercial processing should be a flexibly applied option – carried out to a level desired by the PIs and outlined in their proposal. This flexibility should include the choice of whether to outsource 2D processing as well. Costs for commercial processing may be ameliorated by the establishment of a relationship with some capable and interested commercial group.

When considering processing models that are viable in the academic world, some attention must be paid to the unavoidable tension between the need for rapid, openly available results, and the desire to train students in data processing. To date our community has erred on the side of protecting students' exclusive access to data, even if that meant long delays in releasing the results (not to mention the data). Given the expense of the *Langseth* facility, and the relatively few projects that can be conducted, that balance must now shift toward more open access, and some form of rapid, scheduled processing (whether by a commercial or academic outfit) must become the norm. Nevertheless, we must build flexibility into the new model, so that people who want to process everything themselves should be able to do it (though not under the protection of data exclusivity that exceeds 1-2 years). One possibility for striking a balance between the need to train students and the need for rapid data release is to develop arrangements with commercial processors to take students as interns to help with processing; perhaps this should be built into any long-term contracts that might be negotiated between NSF and a commercial contractor for processing of *Langseth* data. A further concern is the loss of substantial expertise in 3D processing in the community if we farm all processing out to contractors. We must retain some in-house expertise in academic institutions, both for teaching, and to interface with contractors in 3D processing of *Langseth* data.

Data Access and Availability

Chair: Suzanne Carbotte

> The Issue: Results (and data) from seismic cruises are often not available to the community within a reasonable time frame – for large seismic programs, intervals of five years (or more) post-cruise are not uncommon before data are published and publicly released. This may be understandable – seismic data are time-consuming to plan, acquire, process, and interpret, and the time scale of the typical PhD student is often compatible with the desire to stick to the usual two-year moratorium on data release. However, keeping seismic data as the private property of a small number of PI's and their students for five years or more may not be acceptable any longer, and it may be counter-productive, given the challenges facing our facility and our community. If we are to enhance the

impact of *Langseth* data – e.g., by putting it (and the tools to use it) into the hands of more educators and classrooms across the world – we may need to consider new models of data access.

Charge to the Group: Determine, discuss, and evaluate mechanisms and policies for maximizing access to, and impact of, marine seismic data.

In assessing new models of data access and availability for the marine seismic community, it is useful to review the current state of seismic reflection data access. Field data collected from NSF supported programs are all transferred directly from *Ewing*/*Langseth* to the online Academic Seismic Portal at LDEO and should be routinely released after 2 years unless the PI requests extension from NSF. Processed data is managed at the Academic Seismic Portal at UTIG. More of this data is kept with proprietary restrictions. There are various problems with submission of processed data -- for example, most grants end before data is fully processed. But this is evolving and the culture is changing, with more people coming around to support open access. In the future NSF would like to see all processed data that forms the basis for publications going into the database.

There is also an extensive national archive of marine seismic surveys that have been "rescued" from industry, and this data rescue has had extensive use in the classroom. While these data are quite valuable, there are errors and problems with some of the data. Unresolved issues remain of how to get feedback on these errors into the system to improve the data base.

A New Model: Open Data Access.

A major thrust of this workshop is to evaluate ways to get *Langseth* data into the hands of more researchers and teachers. One end-member model that would accomplish this is to make all data open-access, with no restrictions, as in done with IRIS data. Such a system, on its own, would have both pros and cons. The advantages include: (1) growing the community by enabling more users; (2) broadening the impact of *Langseth* data; (3) raising the profile of *Langseth* science; and (4) generating more interest and potentially greater funding for our science. These are compelling reasons to consider an open-access model.

As an exclusive model, however, the open-access model has drawbacks. Chief among them is maintaining incentives for PI's to do hard work necessary to make *Langseth* science happen: to write proposals, plan survey designs, and conduct data acquisition. Further issues surround data processing. For seismic data to be useful to a broader community it must be processed to a basic level; putting raw shots out there will not widely broaden use, as the level of expertise required to use such data is still high. Commercial data processing could address this, but if we use contractors to process data, we may lose the capability to train the next generation of reflection seismologists; processing shouldn't be a black box to our students. While some in this breakout group support open-access models for all data categories, the majority favor a continued role for PI-driven projects with some period of exclusive data rights.

We recommend a model that includes three classes of data access:

1. **Community programs**. This category includes large programs that, by virtue of their broad interest, are most appropriately planned by a wide community, e.g. in thematic workshops. Many (or most) 3D programs will likely fall into this category. An analog for this model might be NSF's EarthScope program.

2. **Open-access programs**. These programs, which combine elements of the PI-driven and community models, will stem from proposals written by small groups of PI's, but will produce open-access data for full release to the community. This would be an entirely new data model.
3. **PI-driven programs**. This category describes the current modus operandi of our community: PI-driven projects, with exclusive data rights for PI's within a moratorium period (currently two years). An analog in the onshore seismic community is PASSCAL experiments.

Due to their high cost, 3D programs should fall mostly into the "community" or "open-access" category. 2D programs could equally well fall into the open-release categories but might be PI-driven in some cases. Community and open-access programs should share several characteristics with regard to data processing and release: (1) A standard-processing product (e.g., pre-stack migrated stack) with appropriate QC should be made openly and immediately available to the public within months (not years) of the cruise. (2) Pre-stack data should be immediately available following the cruise. (3) Data publications should be an important component -- for example a *G-Cubed* data brief, which other scientists could cite when using the data set (this would give project leaders a reward in the Science Citation Index for acquiring a broadly used product). Additional elements could be considered that might alleviate concerns about, e.g., protecting graduate student projects -- for example, user login could be required to download data, with correspondence required between the requestor and the PI's about intended data use.

White Papers: Operational Issues and Planning

Here we include White Papers submitted to the workshop, both by workshop participants and by other interested parties. The White Papers fall into two broad categories: (1) discussions of operational issues, long-range planning, and community growth, and (2) expressions of interest in specific future field programs. In this section of the report we reproduce papers in the former category; potential future surveys are presented in a later section.

An Open-Access 3D Training Cruise for Early-Career Scientists

Steve Holbrook, Paul Johnson, John Diebold

How many of us became "hooked" on marine geophysics on our first cruise – that first thrill of real-time, at-sea science that led us to say, "this is what I want to do"? Unfortunately, for the Langseth community, that opportunity is available to far too few early-career scientists. Under the current system, young scientists can only gain Langseth experience by (1) having the good fortune to work with an advisor who has a funded Langseth program; (2) being invited to join a successful team; or (3) writing a successful proposal themselves. This is a high entry bar. Moreover, the Langseth has introduced an entirely new capability into the U.S. academic community: 3D seismic imaging. The design, acquistion, processing, and interpretation of 3D seismic surveys are substantially more complex than for 2D seismic data. While a relatively large community of trained 2D users exists the user base of academic scientists skilled in 3D seismic work is small (and graying). One possible remedy to this situation would be for our community to endorse the concept of open-access training cruises aimed at early-career scientists (graduate students, postdocs, and assistant professors/scientists). We envision a program that would provide hands-on experience in 3D data acquisition aboard the Langseth and shore-based short courses in seismic processing and interpretation. Together these experiences could provide a cadre of ~20 early-career scientists trained in 3D reflection seismology and experienced in at-sea data acquisition. Participation would be open: participants would not be principally from the PIs' home institutions, but rather selected from nationwide applications. The opportunity would be widely advertised, and the selection process open and fair (perhaps overseen by MLSOC). The Cascadia margin would be an obvious place to conduct such a training cruise, for numerous reasons: (1) The area hosts varied high-value scientific targets, including a subducting plate boundary, an accretionary prism, and an active fluid flow regime (e.g., a shelf methane venting system, a slope gas-hydrate system). (2) Other scientific programs are devoting major resources and infrastructure to studying the area, including MARGINS, Earthscope, and OOI. (3) The study area is close to shore, enabling at-sea crew transfers using small vessels. (4) The study area lies in U.S. waters, simplifying permitting issues. Since a 3D survey inevitably only samples a small portion of a margin, siting of the survey would be a major question and would best be decided by a mini-workshop of interested parties. The figure below shows one possible site, off Grays Harbor, WA, but other sites could be considered as well, across other parts of the Cascadia margin. A 3D box crossing the trench, forearc, and shelf (10 km wide by 115 km long) could be acquired in 60 days (with 37.5 m cross-line CMP spacing), i.e., two legs of Langseth. Each month-long leg could be split into two-week participation mini-legs for 6-8 participants each, separated by an at-sea boat transfer, so that ~25 scientists could gain at-sea experience. An interpretation workshop ~6 months post-cruise, using an industry-processed initial 3D data set, would train all participants to interpret the 3D volume they helped acquire. More sophisticated post-cruise short cruises on pre-stack data analysis could also be envisioned. To ensure the success of our community participation model, we would adopt two key post-cruise data policies: rapid commercial processing of the 3D data, and an open data policy. Commercial 3D processing would guarantee a fully interpretable product for use in the post-cruise 3D interpretation workshop, timely release of data (within 6 months of the cruise), and rapid dissemination of research results. The data policy would be fully open, with all 3D seismic data, including the industry-processed 3D volume, released immediately upon receipt. This would promote broad use of the data set, for both research and teaching. If successful, such training cruises could become a recurring feature of community training. Conducting one such cruise every, say, 3 years would enable virtually every interested early-career scientist to "learn the ropes" on the Langseth. This would have a strong positive effect on the influx of young scientists into our community.

Challenges Facing the Langseth Community – What's "Broken?"

W. Steven Holbrook (member, MLSOC)

The *Langseth* facility faces significant challenges in the years ahead, some of which could even threaten the continued existence of the facility. These remarks are a subjective distillation of a meeting that took place in August, 2009, in Denver, among members of the MLSOC, representatives of NSF, and several members of the seismic community, to enumerate and begin to address those challenges. (Minutes of the meeting are available here: http://www.unols.org/meetings/2009/200908mls/200908mlsmi.html) The March 2010 "Futures" workshop is a direct result of that Denver meeting. During the two days of discussion in Denver, several key challenges facing the marine seismology community were identified. Here I summarize the major issues that were discussed, along with some possible solutions. Note that these possible solutions are merely ideas to kick off discussion; my mention of them here does not imply advocacy or endorsement. (That's for the community to decide.)

• **Facility cost and funding limitations.**

The Problem. There are two related funding challenges facing the Langseth user community: the day rate for using the vessel, and science funding within NSF-MG&G. Both funding sources, as currently structured, are insufficient to fund a robust Langseth schedule (for either 2D or 3D operations). Projected day rates for Langseth for 2010 are about $67 K/day for 2D and $84 K/day for 3D operations; this makes the Langseth second only to the drill ship in costs among U.S.-supported research vessels. (As a point of comparison, the day rate of Atlantis, including Alvin, is ~$50 K/day.) Given these costs, and the available funds at NSF for science support, Langseth is only being supported for ~6 months per year.

Possible Solutions. Since we can't make the ship cheaper to operate, we need to develop strategies to increase funding for the operation. Several options need to be discussed, including (1) increasing support levels within NSF for Langseth operations (this will require a solid scientific justification); (2) broadening the user base within NSF beyond MG&G and ODP, perhaps to include Earthscope, Continental Dynamics, and Physical Oceanography; and (3) diversifying the portfolio of Langseth users beyond NSF, to include other federal agencies, international users and partnerships, and industry. One product of this workshop is intended to be a "glossy brochure" that will highlight the scientific justification for increased support within NSF for the Langseth facility.

• **Proposal pressure.**

The Problem. According to NSF program managers, proposal pressure to use the Langseth is lower than needed to sustain a healthy facility. Information provided to MLSOC on proposals submitted for Langseth in the past few years suggests that, so far, a typical year sees fewer than 10 proposals to use the Langseth. A basic tenet of successful facilities is that they are in demand by a broad cross-section of the community. So far, that is not the case for Langseth. It is not clear why proposal pressure has been low, though reasonable guesses include (1) the two-year delay in marine seismic operations during the transition from Ewing to Langseth, (2) the carryover of proposals funded for the Ewing but scheduled on Langseth, (3) the ill-timed ramp-down of key large programs, like R2K and MARGINS, (4) the perception that chances for proposal success are small, and (5) the small number of early-career scientists entering our field (see below).

Possible Solutions. Possibly, if some of the other problems listed here are solved (more funding for ship time, community growth, etc.), the proposal pressure problem might take care of itself. We might, however, wish to consider several other, more targeted, changes, such as instituting a pre-proposal process, encouraging consortia of PI's to write proposals in a given area, holding community workshops to determine areas of high priority and to populate consortia, and/or having a process of mentoring Langseth proposals akin to that in IODP (so that proposals can be "mentored to maturity" rather than face a simple up/down decision at panel).

• **Scheduling and transits.**

The Problem. Given the relatively small number of funded proposals, NSF has a very difficult task designing sensible schedules for the Langseth. To take 2010 as an example, within a 12-month period the ship is scheduled to work in the Aleutians, Costa Rica, and the Lau Basin. This is highly inefficient, wastes program resources, and leads to unreasonable wait times for nominally "funded" programs (or to proposals being declined simply due to scheduling, rather than quality). (This, in turn, probably feeds the "proposal pressure" problem.)

Possible Solutions. This one might be relatively simple to address. We could adopt a system of forecasting future areas of operation – for example, the community could decide that the Langseth will work in, say, the North Atlantic in 2012, the South Atlantic in 2013, the Indian Ocean in 2014, the western Pacific in 2015, and so forth. This would enable PI's to focus their efforts on proposals most likely to be scheduled (at the expense of potentially having to wait several years for the ship to reach the ocean basin of interest). Thorny issues might include how to decide the rotation of ocean basins, and how to include a rapid-response capability.

• **Growing the community.**

The Problem. This problem can be summed up by the following quote from a "person of importance" at NSF: "If the Langseth continues to just serve a small number of PI's, it won't be viable." The problem of community growth encompasses several related issues: (1) increasing the number of early-career scientists specializing in active-source marine seismology, (2) growing the community of non-specialist users of the facility, and (3) increasing the impact of Langseth data and results among scientists and educators.

Possible Solutions. Several potential actions might help here. In order to "lower the bar" for access to the Langseth, a 3D data processing facility (or subcontractor) could be developed to produce rapid, turnkey 3D volumes. Training programs (perhaps a series of workshops) on 3D processing and (especially) visualization/interpretation could build a broad community of users empowered to use Langseth data (especially 3D data). An open-access "training cruise" to give students and early-career scientists experience on the Langseth might help empower new users to write Langseth proposals. One or two berths might be set aside on all Langseth cruises for open application by students and early-career scientists. A system of proposal-mentoring might do the same.

• **Data access, outreach, and impact.**

The Problem. Results (and data) from seismic cruises are often not available to the community within a reasonable time frame – for large seismic programs, intervals of five years (or more) post-cruise are not uncommon before data are published and publicly released. (And I am certainly not one to throw stones here…) This may be understandable – seismic data are time-consuming to plan, acquire, process, and interpret, and the time scale of the typical PhD student is often incompatible with the desire to stick to the usual two-year moratorium on data release. However, keeping seismic data as the private property of a small number of PI's and their students for five years or more may not be acceptable any longer, and it may be counter-productive, given the challenges facing our facility and our community. If we are to enhance the impact of Langseth data – e.g., by putting it (and the tools to use it) into the hands of more educators and classrooms across the world – we may need to consider new models of data access.

Possible Solutions. A processing center, especially for 3D data, could produce rapid, turnkey 3D images, at least for initial scientific results. This could enable PI's to get initial scientific results out within the initial moratorium, while still achieving timely data access to processes results. Production of classroom activities using Langseth data (e.g., akin to the MARGINS-in-the-classroom activities), perhaps together with software training programs, would enhance outreach and educational impact.

• **Maintaining flexibility and protecting the individual PI.**

The Problem. Adopting solutions to some of the problems enumerated above may produce unintended consequences, which we must be mindful of. If we adopt faster data release, do we risk jeopardizing PI's who have put significant effort into planning, proposing, and acquiring the data? Planning crustal-scale transects requires a huge investment of time and effort – especially onshore-offshore transects where siting and permitting are required. Can we continue to expect PIs to put in this effort if they perceive a substantial risk of just "giving their data away?" How do we balance the needs of the community against the right of an individual PI to enjoy the fruits of their labor?

Funding Issues

Richard Hobbs, Durham University, UK

The big issue is funding - the 3D capability has to be priced at a rate that can be sustained by NSF and other funding councils through barter or direct payment. So the issue is how to defray the costs of the Langseth: 1) retain ownership but operate a 6-8 month commercial/4-6 month academic cycle with the commercial activity subsidising the academic work? 2) set up an international 3D consortium (eg IODP)? 3) sell the Langseth to a commercial operator at a 'reduced' cost but have an agreement for N months academic work per year.

Of the options I favour the latter. OK we academics get reduced time (maybe only 4 month per year) but the risks are taken by the commercial company and they also ensure the equipment is maintained and the crew appropriately trained etc. But given the expected cruise sucess rate is 2-4 per year then this could be sustained, also it would look better for there to be a small backlog of 5* science waiting to use the facility than to have a 'white elephant' tied up for 8 months of the year because there are no funds to operate it.

The danger is is the commercial owners cannot run the vessel at a profit they will scrap it (this is currently happening to a vessels of a similar specification).

Mentoring Langseth Proposals

An Experiment to Broaden the Seismic User Community

James A. Austin, Jr., University of Texas Institute for Geophysics

Concerns have been raised about the "graying" of the user community supporting Langseth-type 2D and 3D seismic operations. The number of proposals funded is not large, but a more significant long-term issue might be a declining number of (competitive) proposals submitted to use this dedicated seismic facility. In particular, designing 3D surveys is complex, requiring a dual knowledge not only of the scientific target(s), but of the imaging requirements and limitations intrinsically and usually uniquely related to those targets. This complexity may have discouraged some potential users from proposing interesting and important work for Langseth.

A possible remedy comes from the realm of scientific ocean drilling, one of the primary recipients of Langseth seismic survey products. More than a decade ago, the science advisory structure of the Ocean Drilling Program recognized that the program would be well–served by helping drilling proponents write the most competitive proposals possible. The Science Steering and Evaluation Panels (SSEPs) were set up in 1997 not only to review but to provide constructive advice to proponents, in a manner somewhat like the traditional role of NSF review panels. However, unlike NSF panels, SSEPS reviews were not anonymous. Quite the contrary; named "watchdogs" assigned to each reviewed drilling proposal provided constructive input, and were (and continue to be) available to answer proponent questions and to aid in an iterative nurturing process (sometimes over years). Certainly, the drilling program remains a highly competitive environment; only a small number of proposals submitted are drilled. However, the proposal submission/review atmosphere changed, from adversarial to supportive, and the flow of drilling proposals has remained strong, despite recent economic constraints on the drilling activity itself.

A similar solution could be attempted for Langseth proposals, in one of several ways:

1) A group of experienced seismic users could be identified (by NSF? the user community at this workshop?) that would be willing to act as mentors to less-experienced PIs contemplating a proposal submission to use the facility. In the drilling program, SSEPs members have been volunteers; they have not been reimbursed except for their expenses. That could be the model here, but another option is for this mentoring group to get some (1 month/year?) of salary support from NSF in return for their service. Their names would be published widely, and they could either be assigned or picked by potential proponents. Potential complexities exist. How to mentor without prejudice? Who would choose the partnerships – NSF (unlikely, as they are the recipient of the proposals)? MLSOC (more likely, as they are charged with monitoring the progress/health of Langseth)? Some re-presentative user group yet to be identified?

2) MLSOC members, or another designated (by this workshop?) subset of the community, could "co-write" all submissions for Langseth, assuring a minimum standard for follow-on standard NSF review. But how would these individuals function – as volunteers (with limited terms, to minimize work load)? Or as paid partners, perhaps as part of the cost to NSF of the facility itself?

3) An "interim" panel convened by NSF, receiving "draft" proposals in advance of actual submission. This "proto" panel would act as a nurturing body, very much like the SSEPs have acted through the years. Given present NSF practices, these individuals could serve set terms, and receive both honorariums and expenses in return for their service.

All of these scenarios have attached complexities, which could be discussed at the workshop, but any of them might result in a healthier flow of proposals to use Langseth, and that would be a worthwhile goal.

Infrastructure for 3D Seismic Data Processing

Dale Sawyer

The following builds on my experience with proposing to acquire and process a large 3D MCS dataset. In sequential submissions, I have proposed 1) using an industry contractor to process the data, and 2) having the processing done within academic institutions. There are excellent scientists in our community who strongly favor one of these approaches or the other. I have learned that is quite easy for reviewers to castigate either approach, and if a proposal goes out to 5-7 reviewers, there will always be one or two folks in each camp. Catch-22.

Industry processing

Pro's

Processing can be done comparatively quickly (often a few months); Data is available in standard forms for convenient dissemination to scientists and the broader user community; Processing done by experienced personnel; Processing companies have very powerful/fast computers.

Con's

Usually comparatively expensive; Price can vary dramatically based on level of industry activity (i.e., not predictable at time of proposal submission); Academic scientists and students get little or no experience with processing; Agency money leaves the academic research community.

Academic Processing

Pro's

Scientists and students learn every step of the processing. Usually less expensive Agency money stays in the academic research community.

Con's

Scientists and students must learn every step of the processing. Due to relative inexperience, the processing must often be repeated from scratch one or more times. Processing usually takes years and may never be really finished. Dissemination to the wider community is often slow and then not in a convenient form for most potential users

The hybrid solution:

In my current proposal for 3D acquisition in the deep Galicia Margin, I am getting around this quandary by splitting the processing into 1) basic processing (navigation, trace editing, filtering, wave shaping, velocity analysis, stacking, and post-stack time migration) and 2) advanced processing (pre-stack time and depth migration, and innovative techniques). I argue that it is not educationally valuable for graduate students to do basic processing, but that it is very valuable for students to do advanced processing. The former is very dull, requiring little thought, but nevertheless critical for all following work. In the absence of new academic processing capability, I believe that we can farm this out to commercial processing companies. The latter, advanced processing, is processing integrated with interpretation. This is what we should want our students to learn by doing. This hybrid model involves both industry and academic processing, puts painfully mundane but critical tasks in the hands of experienced people hired for that work, and puts students on the geologically and geophysically interesting task in the hands of academic researchers and students. A win-win!

An Academic Processing facility:

My real preference is for NSF to set up a National academic reflection seismology processing facility. This facility would employ a few experts on all aspects of 3D seismic data processing (they could easily do 2D as well) and would be equipped with good computation and software resources. Some users, scientists and students, would interact with the facility at a distance, while others would choose to visit the facility for short or long periods. The experts would work with the science teams performing the processing work, providing training and advising as required. The experts would also make sure that required standard data products were prepared for public dissemination on the agreed release date. This approach allows many academic institutions to share the costly "experts" while still getting high quality advice on how to process their data efficiently and well. It makes moot the ongoing commercial vs. academic institution debate that makes it hard to get a proposal through NSF. It gets the discussion of proposals back to the science where the discussion belongs.

Long Range Planning

Dale Sawyer

I suggest that there are a number of advantages to longer range planning for the basic Langseth cruise track. My concept of long range planning is to construct an approximate regional track for the ship 4-5 years into the future. The level of detail would be parts of oceans, i.e. North Pacific, East Pacific, Central Atlantic, Mediterranean, and etc., and chunks of time in about 3-9 month increments.

1. This would provide clear windows of opportunity for proponents to submit proposals for regions coming up in the next 2-5 year period.
2. It would make it easier for the program to plan cruise level track, potentially minimizing transit times.
3. The amount of time spent in each region would of course need to be adjustable according the number of excellent proposals received. I do not want to see any mediocre science scheduled just to fill in a regional program.
4. This approach would remedy the dilemma of a proponent whose proposal gets high marks and could be funded, but cannot be scheduled because the work is in a region with no other highly ranked proposals.
5. If the IODP would also adopt this same concept of long-range planning, it might be possible to coordinate Langseth program areas to inform planning of drilling and planned drilling targets. This would strengthen future US participation in IODP as well as strengthening IODP as a whole.
6. If the long-range plan could include an element of circumnavigation over a period of 6-8 years, then any investigator could have a shot at doing work in any of the world's oceans.

Potential for USGS Use of R/V Langseth: An Optimist's View

Ginger Barth, United States Geological Survey

Workshop conveners have asked, "Is there any demand within the USGS to use R/V *Langseth*?" The answer is, "Yes, but with some important caveats." The up-side of the situation is that USGS scientists can identify a rich variety of mission-relevant scientific work that could be carried out on R/V *Langseth*. The down-side is that major USGS marine field programs are limited by high cost as well as challenges of scheduling, permitting and staffing. At this time, only the USGS Law of the Sea programs are planned on R/V *Langseth*.

Mission Science.

The USGS has mission-driven science on its agenda that could be carried out using *Langseth*. Three of the six USGS science directions prescribed in the current agency strategy involve, or could very appropriately involve, marine geophysical pursuits. These mission elements focus on energy and mineral resources for the future, climate variability and societal impacts, and natural hazards facing the nation (http://pubs.usgs.gov/circ/2007/1309/). At this time, the Secretary of the Interior and the USGS Director are focused in part on the importance of scientific characterization and stewardship of US territory beyond the coastlines (McNutt, M., 2010, "USGS Support for a National Ocean Policy: From the Coasts to Deep Ocean", Sea Technology, V51:1, p16-17.). From the agency's mission perspective, USGS has work to do in the offshore.

See:http://seatechnology.com/features/2010/0110/USGS_oceanPolicy.html

Research plans and regions of interest. Within this mission framework, USGS demand for marine seismic exploration can be viewed in two categories of relevance to the R/V Langseth discussion - (1) Law of the Sea work under the guidance of the interagency Extended Continental Shelf task force, and (2) blue-water and challenging-environment work that is not primarily designed for ECS definition. A third category (3) work in near-shore environments, is something that the USGS does well and frequently using portable acquisition systems from smaller vessels.

Law of the Sea

The USGS Law of the Sea work is an atypical project with a long planning time line (ideally all data acquisition within ~5 more years, and project target completion within ~8 years) and assured funding. It is broad in regional scope but has highly specific objectives related to definition of the extent of US-owned seabed. The Law of the Sea seismic acquisition work is the only currently planned USGS field program that identifies R/V *Langseth* as a preferred platform. Law of the Sea seismic programs require only 2D MCS and OBS or sonobuoy support. The USGS has no plans to acquire 3D MCS data in association with Law of the Sea.

The USGS is a primary partner, along with US Department of State and NOAA, in the multi-agency Extended Continental Shelf (ECS) project tasked with establishing the full extent of the US "continental shelf" (i.e. regions of sovereign rights particularly including economic and conservation rights to the seabed and subsoil). The Convention on Law of the Sea (UNCLOS) provides the algorithms for defining this region beyond 200 nmi, based primarily upon identification of the morphologic transition from continent to deep ocean floor and the thickness of sediments beyond the "foot of the slope." UN technical guidelines specify the data requirements, which echo the state of the art from the time that final wording of the treaty was accepted in 1982. Bathymetric data and 2D seismic reflection data with velocity control are the minimal requirements.

The ECS task force has agreed to a division of responsibilities that assigns seismic data acquisition operations to USGS and bathymetric data acquisition operations to the NOAA/University of New Hampshire Joint Center for Coastal and Ocean Mapping. With regard to R/V Langseth, the USGS is therefore only able to speak for the potential seismic work under Law of the Sea.

The ECS Project has identified a dozen regions with potential for extended continental shelf along the margins of the US and its Pacific Islands (http://continentalshelf.gov/). Of these, new seismic reflection data are required for the Arctic, the Bering Sea, the Gulf of Alaska, the Atlantic margin, and possibly also the Northern Marianas region and the Line Islands south of Hawaii. Targeted OBS refraction data are also needed in each of these regions, with differing specific objectives for each margin area. The Arctic work is being accomplished in partnership with the Geological Survey of Canada, employing both the Canadian icebreaker CCGS Louis St. Laurent and the US icebreaker USCGC Healy for cooperative seismic and multibeam acquisition. The remainder of the ECS seismic work is not yet specifically scheduled, but informational ship time requests for four programs on R/V Langseth have been submitted. These programs will be funded through the USGS using specific ECS Project funds with the approval of the ECS interagency task force.

In an idealized future, these non-proprietary ECS-specific seismic studies would be a starting point for natural follow-on inquiries, many of which would be central to USGS mission elements including resource and hazard characterization. For USGS, follow-on field programs of this sort would fall into the next category.

Other Blue-Water Seismic Work

Other blue-water and challenging-environment marine seismic acquisition could occur in association with ongoing and emerging USGS research focus on energy and marine mineral resources, climate, and - most notably - catastrophic tsunami, earthquake, and submarine slide hazards. However, major projects of this type are not a part of current USGS field plans due to funding limitations and other obstacles discussed below.

The focus of most USGS energy research is on US margins where industry data is already available, or where industry partnerships might make sense for new acquisition. Current USGS energy, resource, and climate studies focus largely on shallow subsurface and/or near-shore problems, requiring high-resolution seismics, often in combination with sampling and seafloor imaging. The current USGS programs do not require the support of an academic vessel with R/V Langseth's MCS capabilities.

In an idealized future, two areas of noteworthy exception may be the deep-water Bering Sea and the Arctic margin of Alaska. In these remote areas, where regional geologic context is less well established and desirable programs might involve deep-penetration seismic studies as well as 2D or limited 3D seismic resource and hazard investigations, R/V Langseth would be an obvious platform to consider.

USGS responsibility to characterize the geologic framework and processes that define the distribution of hazards leads logically to a renewed interest in the source regions for catastrophic and tsunamigenic earthquakes. Again in an imagined, idealized future, the USGS might pursue these issues through integrated marine geological and geophysical investigations including seismic programs in the Gulf of Alaska, Caribbean Puerto Rico trench and Hispaniola regions, Arctic Beaufort margin, and/or Cascadia. The goals of such programs would be to update and improve understanding of the regional geologic context and to survey targets of particular relevance for understanding the mechanisms that trigger catastrophic events. The technical needs of this type of program would be well aligned with the capabilities of R/V Langseth. To reiterate, these would be areas of scientific interest and mission relevance, but at this time, USGS has no plans (and no funds) to lead Langseth-scale field programs in these areas.

Feasibility.

The above is an optimist's picture of some of the appropriate scientific work on the USGS horizon. In practice, USGS project scientists encounter many impediments to making use of a large UNOLS vessel like R/V Langseth.

Cost of platform

Currently, very little large-vessel work is being done by USGS scientists. The biggest obstacle to USGS use of R/V Langseth or any global-class UNOLS vessel is cost. The USGS does not have its own funds to run seagoing cruises on such platforms. The price-tag on a month-long Langseth MCS cruise dwarfs, by a factor of ~20, the operating budget of a generously-funded USGS marine research project. The Coastal and Marine Geology centers do use some USGS funds to conduct cruises on smaller coastal and regional vessels, but even the frequency of these cruises has been reduced over the years. As a result, USGS marine researchers must necessarily focus on partnering w/ NSF PI's, with other agency or industry leads, or on proposing small piggy-back projects to gain access to large vessel capability. Such partnerships are not always appropriate for the types of projects the USGS pursues, particularly those completed government-to-government, on an interagency basis.

The USGS already has a cooperative arrangement with the OBS instrument facility in Woods Hole. USGS supports the OBSIP maintenance of 15 instruments, in exchange for priority access. Absent this arrangement, per OBSIP website information, USGS would be at the back of the line for instrument access, following NSF-funding priority order. Even with this arrangement, OBS instrument costs (e.g. range of ~$100K-200K for use of 10 instruments including shipping, materials, and field support for a month) come in second only to ship costs for those seismic field programs requiring OBS instruments.

Permitting

The expense, lead time and expertise required for marine mammals and endangered species permitting (MMPA/ESA) present another major challenge for USGS-led active-source seismic work. At this time, the USGS does not have personnel with appropriate biological expertise for in-house completion of the full EA/IHA process. The USGS can lead the full process, as for the Arctic Law of the Sea programs, but requires external funding to cover the expert contractor costs, which can exceed $100K depending on the complexity of the cruise and its location. For smaller active source cruises, only the USGS Menlo Park office has substantial in-house experience completing requests for NMFS Letters of Concurrence, particularly in the California coastal zone.

Value for dollar

Given the real budget constraints on any USGS field program, scientific value for the dollar is critical. The two key questions regarding R/V *Langseth* are (1) Do platform capabilities match our needs? And (2) Is R/V *Langseth* a cost-effective choice?

As outlined above, USGS needs for academic 3D seismic data are minimal for the foreseeable future. The USGS has identified the need for 2D seismic reflection acquisition, and for refraction surveys that include OBS for some scientific projects. R/V Langseth high-volume source array and long streamer are very appropriate tools to meet these anticipated USGS data needs, particularly in the blue-water settings indicated for Law of the Sea work.

Other competitive options exist for some USGS seismic requirements. The Scripps portable system, which can be deployed from vessels with day-rates lower than that of R/V Langseth, may be an option for some USGS resource and hazard projects. The option of less-expensive P-cable rather than conventional 3D is being explored for some Atlantic and Carribean objectives. For high-energy seismic work in relatively accessible areas, such as the Atlantic margin, industry contract vessels may also be available and competitive for USGS projects. Industry vessels also bring the advantage of a contract guarantee of successful data acquisition.

For USGS marine work other than high-energy seismics, the high day rate and low transit speed makes R/V Langseth generally unattractive, even as a ship of opportunity. USGS science could benefit from flexibility in the platform pricing scheme to allow, for example, collection of underway swath bathymetric data on a transit-of-opportunity for less than the full day-rate.

In sum, while USGS looks forward to employing R/V Langseth capabilities in the Law of the Sea 2D seismic work, the cost effectiveness of the Langseth platform is not uniformly obvious for future broader USGS program, if such USGS program were to develop.

Scheduling

The UNOLS schedule is usually set well before the beginning of a given federal fiscal year, but USGS operations funding certainty is only assured several months after the start of most fiscal years. This funding delay can be particularly acute when interagency funding agreements are involved. Although USGS gets two-year money, most USGS funds must be spent (or obligated) within a single fiscal year. USGS researchers are caught with not enough planning time to take advantage of ship-of-opportunity or project add-on situations (i.e. not enough time to coordinate permitting, instruments, and personnel.) This mismatch between agency fiscal cycles and UNOLS scheduling cycle adds another obstacle to accessing larger vessels and remote locations.

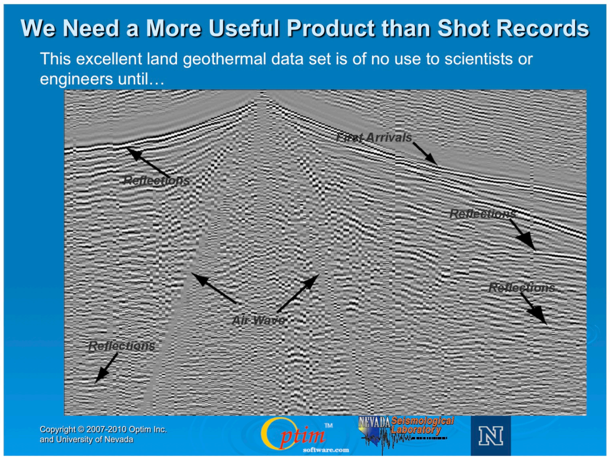
On the flip side, for the atypical program with a longer planning timeline, example Law of the Sea, the ship schedule uncertainty makes planning equally awkward. Law of the Sea has diverse seismic program needs in the Pacific and Atlantic - which program should we have on the front burner? More predictable regional availability of R/V Langseth and more available information regarding which NSF programs are funded to drive the schedules, might facilitate more efficient planning for both major and add-on programs.

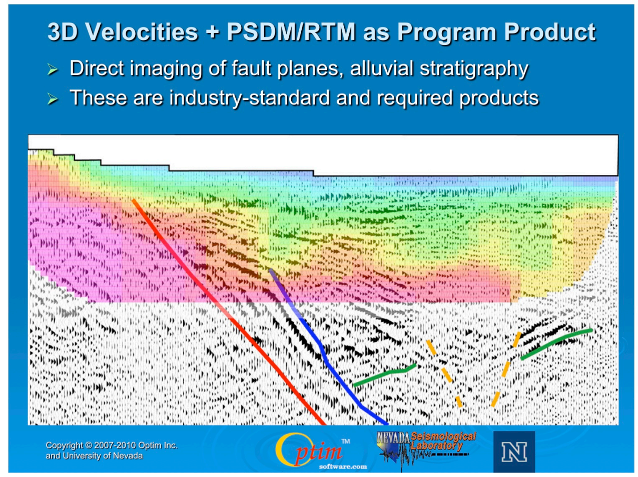
Staffing a program

A final challenge for USGS blue-water program on R/V Langseth is staffing. Over the past two decades, USGS expertise has followed USGS program toward more high-resolution and near-shore work. Many of the staff who operated the major deep-water seismic programs of the 1970's and 1980's are now retired (and have not been replaced). Back on land, the USGS has the expertise and software to routinely process 2D marine data within small but complementary technical groups in Woods Hole, Denver and Menlo Park. The USGS currently supports interpretation of industry-standard 3D data at only one of our centers and is not staffed for production-mode processing. The USGS has in-house expertise in analysis of underway geophysical data (gravity, magnetics, multibeam bathymetry). However, given the passage of time since the large-team USGS marine exploration programs of the 1970's, the on-staff science expertise is currently extremely limited for large programs of deep-water geologic studies of the sort that R/V Langseth is best suited to support.

These issues mirror similar ones in the larger marine community. The intermittent demand for expert marine and processing technicians and the small pool of new scientist specialists in active-source seismology affect not only the USGS, but also academic institutions and the private sector. These issues reflect the overall vitality of the marine seismology community.

A "turn-key" facility approach has been suggested, to allow R/V Langseth use by a wider portion of the marine community. Such a system might provide support for field program planning and permitting, seismic data acquisition, expert processing, and 3D visualization. In concept, such a community facility would cover the gaps in individual programs. For USGS, it might alleviate the problems of intermittently-required technicians and limited staffing for production-mode data processing - in a hypothetical future with a renewed USGS focus on deep-water





UNOLS vessel. Only if the challenges of high cost, scheduling, permitting, staffing, and internal scientific priorities can be addressed will the USGS be in a position to make use of R/V Langseth's active-source seismic capabilities on something beyond an occasional basis for programs other than ECS.

Acknowledgment.

Views expressed reflect the benefit of discussion and comment by J. R. Childs, P. Hart, D. R. Hutchinson, C. D. Ruppel, D. W. Scholl, and U. TenBrink.

Need for 3D Velocity Models + PSDM/RTM as a Program Product

John Louie

Really a "white slide" showing how well modern velocity modeling and PSDM can do in a seismically difficult onshore environment: direct imaging of fault planes in bedrock below the lateral heterogeneity of a Basin and Range geothermal prospect below an alluvial valley. I propose that all 2d and 3d Langseth seismic data be automatically processed to the prestack depth migration/reverse-time migration stage (with PI involvement) as a Program product, paid for by the program instead of by the PI's grant. Excellent results could then be released 6 months after the cruise as images that are immediately interpretable by geologists.

It is my position that poststack imaging, or any imaging without development of excellent velocity models controlling lateral velocity variations, would be of limited utility to anyone outside the marine seismic community. Resolution of 3d velocity problems is required for the correct imaging of faults and other features that enable the geologists and oceanographers to appreciate the data. This problem is exacerbated in basement terranes. Of course, the cruise PI and students will be involved in the processing, even (especially) if the processing is done commercially.

Thoughts on a future operating model for the R/V Marcus Langseth

Dave Goldberg

I would like to offer 2 thoughts on the management of MGL activities in the future that will streamline and improve seagoing operations. The growing intensity of pre-cruise planning and permitting activities, the potential for future non-NSF-funded research cruises, and the administrative complexity of the current funding structure give ample reasons for considering a more efficient operation. In short, MGL would benefit greatly from a more programmatic approach, that is, one that operates the MGL as the unique flagship facility that it is in the academic fleet, remains responsive to the NSF research community using any proposed science model that is advanced from this workshop, and still allows the operator to effectively pursue external contract work which will likely continue to be desirable.

I believe that there are 2 fundamental changes in the administration and management of MGL activities that should be considered:

I. Advanced Planning Cycle

By far, the most critical change is to allow longer lead-time for operational planning of all at-sea projects. Operational planning 18-24 months in advance of cruises would be minimally needed. One method to achieve this, as discussed in the meeting white paper, would be to specify an approximate ship track for out-years cruises and thus encourage proposals to be submitted in specific geographic locations well in advance of ship scheduling. Another approach would be to specify pre-selected programs for MCS work via community-based reviews and then schedule these projects annually for the out-year(s) and thus optimize ship time. Both approaches have implications for the scientific proposal and review process. But, with either approach, sea-going projects have more time to advance delicate US State Dept and mammal mitigation permitting processes, make technical preparations, and offer clear operational efficiencies through reduced transit times and more ship days for research. Another important consideration is that an Advanced Planning Cycle will allow the operator to schedule non-NSF funded programs with minimal impact on NSF research cruises. This would be extremely difficult to achieve without knowledge of the geographic area of operations and the schedule of NSF cruises well in advance.

II. Simplified Funding Structure

With the expense of MCS cruises and the complexity of the UNOLS scheduling procedures, a Simplified Funding Structure at NSF for Langseth operations would offer several advantages. First, the complexity of multiple proposals, reviews, and awards for MGL operations would be reduced to one, annually, that encompasses all elements of the activity for NSF, including ship operations, technical support, marine mammal observations, and equipment. This basic simplification would allow greater efficiency on-shore, reduced overhead for MGL operations, and change the currently distributed scientific award structure for MCS cruises to a more programmatic one. The need for scientific proposal development and review remains critical, however, and could begin with a new model advanced from this workshop. Based on any model, however, the selected science projects should be built into a single annual Program Plan by the operator and then submitted for NSF approvals 18-24 months in advance of the start of the ship schedule.

A second advantage of a Simplified Funding Structure will allow similar administration of both NSF and non-NSF funding programs, both of which seem likely to be needed to support operations in the foreseeable future. Each would have a singular contract or cooperative agreement that encompass all elements of MGL operations each year and for each project or program.

High-Resolution 2D and 3D Marine Seismic Reflection Profiling

Mark Legg

Academic goals in marine seismic reflection profiling are to advance geoscience knowledge through research by applying state-of-the-art technology and to develop and refine that technology. Of equal importance, academia must educate future scientists and engineers in use of marine seismic reflection technology to advance geoscience knowledge through research, identify and mitigate geological hazards, locate and develop energy and mineral resources, and provide marine science and engineering expertise for the development and growth of national and global societies. Although 3D seismic reflection profiling is one of the most advanced technologies used in marine geoscience, there remain significant requirements for 2D seismic profiling and use of other advanced technologies in academic marine geosciences. In particular, high-resolution multi-channel seismic (MCS) profiling, both 2D and 3D, is needed for a wide range of investigations for inshore, coastal, and deep ocean environments. For example, geological hazards studies must locate and map active faults, landslides and other slope instability, petroleum, natural gas, and hydrate/clathrate accumulations and seeps, hydrothermal and volcanic systems with high-resolution to understand processes involved in their development and to develop strategies for hazard mitigation. Likewise, high-resolution seismic stratigraphy is needed for fine-scale investigation of sedimentary processes and climate change. In coastal areas, society needs better understanding of the interaction between fresh water aquifers and seawater intrusion to protect vital groundwater resources–high-resolution seismic techniques can provide important data to examine these systems.

Beyond the expensive large vessel with multi-streamer 3D seismic profiling systems, such as provided by the R/V Langseth, there is great need for seismic profiling on smaller vessels to work in coastal and inshore areas with high-resolution technology. These vessels may include boats associated with academic institutions performing the research or local vessels of opportunity. Although much of the equipment necessary for advanced high-resolution MCS profiling exists in the academic community, to carry this to a higher level such as hi-res 3D survey, academia needs to coordinate resources, as has been done with the Langseth, to provide a pool of advanced technology for future projects. Such technology would include sufficient numbers of short group interval (<12.5-m) streamer sections so that multiple high-resolution streamers could be deployed, portable systems for navigation of the areal arrays used in 3D surveys, and hardware (or specifications for hardware) necessary to deploy multiple streamer and multiple energy source arrays. Other advanced marine seismic technology that could be used for both 2D and 3D profiling include multi-component ocean bottom cable (OBC) systems, that would allow converted wave surveys, downhole arrays that could allow vertical seismic profiling (VSP) in wells-of-opportunity, and "matched" sets of energy sources that could be used in "flip/flop" 3D seismic source configurations. One new hydrophone streamer technology that is being developed is the "P-Cable"–a system that tows from 12 to 24 eight-channel streamer sections from a semi-rigid cross-line cable and paravane system.

An important question to be faced by the academic marine seismic community is whether limited budgets could be better served by investing in "portable" systems such as P-Cable, OBC, and so forth, and rely upon less expensive vessels in the UNOLS fleet or ships of opportunity rather than to try to fully fund the R/V Langseth with NSF or other academic budgets. The problem of availability for vessels specifically equipped for full-scale deep penetration 3D seismic profiling exists, however, as demand and competition for geophysical exploration fleets grows, either due to increased exploration efforts as energy needs expand or due to reduction in the size of these fleets due to dwindling economies.

Industry funding for deep seismic studies of rifted margins

Harm J.A. Van Avendonk[1] and Donna J. Shillington[2]

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Marine seismic studies of continental extension and breakup have been of great importance to our understanding of the rheology of continental lithosphere and the development of seafloor spreading in young ocean basins. At present, the role of magmatism in continental breakup is still a topic of debate. There is also great uncertainty in the evolution of the thermal structure and isostasy of margins in the millions of years after breakup. This last problem has become of great interest to energy companies since exploration for hydrocarbons has largely moved into deep water over the last decade. The p-T history of the highly extended lithosphere, which affects the maturation of oil and gas, cannot be understood here without a good model for the late-stage structural, thermal and magmatic development of continental rifts.

Since the deep-crustal structure of rifted margins has become important for hydrocarbon exploration, partnerships between academia and energy companies are starting to deliver data sets that improve our insight in rifting processes. European countries, in particular, have developed successful programs with joint industry and government funding to investigate the nature of continental extension at ancient margins. Likely, these studies do not cover all aspects of continental breakup (such as the nature of incipient seafloor spreading). Nevertheless, the US science community could also benefit from a greater role of industry funding in studies of continental rifting, albeit in a different way. To obtain a seismic image of the processes that attended continental rifting requires that we gather seismic reflection and refraction data along 2-D lines across passive margins, encompassing the transition from unstretched continental lithosphere to the oldest oceanic crust. The width of most passive margins is roughly 400 km in the rifting and spreading direction. The R/V Marcus Langseth, which has the capability to deploy a long multichannel streamer and ocean-bottom seismometers, is an excellent vessel for such regional (2-D) marine seismic experiments.

The primary mission of the R/V *Marcus Langseth* is to support NSF-funded investigations of diverse geological processes. In that capacity, this vessel and its predecessor the R/V *Maurice Ewing* have played a key role in the marine geoscience community. The need for such marine seismic data will not diminish in the future. However, the acquisition of marine seismic data is expensive, and current NSF funding levels are not sufficient to cover Langseth operations throughout the year. Industry funding could help fill some of the gaps in the cruise schedule. While NSF-funded science should take priority, industry funding for marine rifted margins studies would have two important broader impacts:

1) Industry-funded studies would expand our knowledge of the modes of deformation during continental rifting, the accommodation of sediments, and the vertical motions during and after rifting.
2) A full cruise schedule for the R/V Marcus Langseth would make it easier to keep highly qualified personnel on the ship. It may also help ease the financial burden of transits between NSF-funded scientific cruises.

The development of industry seismic proposals for the R/V Marcus Langseth will require the initiative of individual scientists and institutions. For the reasons mentioned above, the US marine geoscience community will benefit if these efforts succeed. The main challenges that we would need to address are the planning of industry-funded cruises in the schedule of the R/V Marcus Langseth, permitting of marine seismic operations, and the degree of data confidentiality.

Recent developments in hydrocarbon research have created the right circumstances to obtain industry funding for studies of rifted margins. The Gulf of Mexico and the South American and African margins of the South Atlantic are areas where energy companies have already shown an interest to collaborate with academic scientists. However, there is a similar need for deep crustal structure in exploration frontier areas around the globe. Industry seismic projects may therefore fit relatively easily in the future schedule of the R/V Marcus Langseth.

Some brief thoughts on best use of Langseth

Joe Cartwright, 3DLab, Cardiff University, Wales, UK

Scope

As a long-term 3D seismic user, I thought it would be useful to add some comments for consideration at the workshop. I will restrict my comments to scientific rather than operational. I'm sure most of this is 'old hat' so please excuse me stating the obvious.

Global resource of 3D seismic data

One of the major problems I see facing the programme is to justify highly expensive acquisition and processing of 3D seismic data against the backdrop of much greater accessibility of industry datasets. I estimate there is now a cumulative 3D coverage of >3 million square kilometres of 3D seismic data. Many nations have a policy of opening this data to academics after a few years, and most keen academic geophysicists can lay their hands on data if they try hard enough. A question for your community therefore is why acquire new data in small survey volumes when large industry volumes lie fallow from a research point of view?

Industry 3D: a Panacea? The vast bulk of this industry data has been acquired on petroliferous sections of passive continental margins, so obviously there are many science questions that cannot be tackled with the existing coverage, but there are plenty that can. This partly answers my own question (above), but not entirely. Money is tight, so why not put new data acquisition on hold until we (the geophysical community) have ploughed a merry furrow through all that gorgeous industry data, often acquired in large enough survey dimensions to capture whole basins. I'm being provocative here, but the taxpayer has a right to know.

Some topics that are being actively pursued (mainly in labs outside the US) using industry 3D seismic are:

1. gravity tectonics on margins- many groups on this 2. salt tectonics (e.g. McClay Group, Brun/Cobbold in Rennes, Aachen- janos Urai's group 3. interactions between magmatism and basins (e.g. Norway, Oslo Group) 4. sediment transport processes in margins (Leeds, Aberdeen, IFP, Brest etc) 5. Faults and fault propagation (Manchester, Cardiff, Edinburgh, Dublin, Imperial, Royal Holloway etc), including rift basin evolution (Manchester, Imperial, Aachen) 6. Fluid flow in basins (Berndt in Geomar, Bunz in Tromso, Cardiff, Durham, Gay in Montpellier) 7. Silica Diagenesis (Durham and Cardiff) 8. Mass transport deposits and massive submarine failures (Cardiff, Aberdeen, Manchester, UT Austin) 9. basin scale processes (Cambridge, Manchester) e.g. source –to sink (Imperial – Allen). 10. Hydrates (Meinert in Tromso, Henriet in Gent) but US groups are way ahead on this topic… 11. CO2 storage: BGS, Statoil and their academic partners, Cardiff, Edinburgh, Heriot-Watt groups. 12. There are many more, but this needs a proper review to avoid being unfair to groups that are just getting started.

Not wanting to be too blunt about this, but a quick search for papers based exclusively on 3D seismic for the past two decades written by academics, and dealing mainly with geological processes/observations would show the US has a small fraction of the outputs (<20%). So why not collaborate more?

I think there are obvious barriers for US – based academics getting a 3D seismic programme up and running, mainly because the system for obtaining Industry seismic in the US is so much tougher than, say in Europe. So for me the answer is through collaboration.

I would say that some funding mechanism could be sought that allows US groups to collaborate with those elsewhere, particularly to ease the access to data. Data sharing is the way forward.

Survey size and science challenges

If the case is to be made to keep Langseth going, then a key issue is surely the trade-off between survey size and transit time. So think of some science questions that would benefit from larger survey sizes, where for example not one vent field is captured but say 10, and crucially where many complimentary or disparate themes can be tackled in the single large area. In active margins, don't aim to survey just one piggy back basin and one thrust, but try and image a whole segment of the thrust and fold belt with say a 2,000km2 area.

Calibration

In general, I would advocate that any proposal ought really to have an ODP or IODP site in its bounds. Firstly, this gives hugely added value to the ODP/IODP results, and the well calibration would multiply the benefit of the seismic many-fold, allowing all sorts of follow-up work such as calibrated inversions etc.

Some topics

Fluid flow in sedimentary basins is close to my own interests (so I'm not objective here), and there has been so much great work done on hydrates and venting that surely more will come from your community by deploying Langseth. But a cautionary note: there are now vast swathes of industry data that addresses this topic of focused flow and of hydrate distribution. Mud volcanoes might be an extension of fluid venting as a theme, but there are many large industry surveys in the Caspian, Nigeria, the Nile Cone and NW Borneo that image MVs, so I recommend against pursuing this.

Igneous-sedimentary interactions (hydrothermal) might be usefully explored more in young spreading centres. Equally, any basin forming processes or basin deforming processes (e.g. fault propagation) are best researched in areas where the process is vigorous and active currently. So where would you go to really look at new ocean crust formation, or at sites of active lateral fault propagation? Can they be tackled with smallish survey areas?

Faults and fault related processes are probably a good general theme to pursue, but it's probably only worth doing this in areas of active faulting, where there might be a fruitful link between fault growth, fault segmentation and seismological studies.

In the same thematic area of magmatism and basins, a possible target might be a submarine shield volcano. I have seen several examples where excellent internal structure of the volcano (including vents) can be seen from the reflection geometry. The mechanism of volcano growth might be tractable in this way.

One negative aspect of modern palaeoceanography is the over-reliance on the evidence from a single core to characterise the bottom flow regime in often large scale contourites. Perhaps there is a role for Langseth in shifting awareness that cores plus seismic means a lot more than just core alone. It might be interesting to do a 3D survey in a major gateway, and to look in detail at the distribution of moats, mud waves and other current indicators through the glacial-interglacial periods of the Late Pliocene to Recent.

Concluding Remarks:

This next phase for your community strikes me as being critical: under an ever toughening backdrop of funding allocation, can big science justify itself? Globally, there will be immense pressure on academics to (a) prove they are using tax dollars wisely, and (b) seek alternative models for working on problems that have societal relevance.

I do believe that the answer is a re-balancing, with greater links with Industry to conduct joint experiments and share risk, but also greater usage of industry data for data mining of a host of less spectacular scientific problems (perhaps) but that are equally as valuable as the high risk-big science goals. By doing so, and raising profile through publication, conferences etc you can then leverage the continued use of the Langseth for research on the fundamentals.

I think I would advocate setting up a US Centre for 3D Seismic Research (US3D?!), with nominal costs, but not virtual, and with one employee: someone who can go around knocking heads together from Industry and Academia, and putting key players into a position where they can collaborate if they like each other. We all know that the best collaboration is not forced, or imposed from top down, but equally, in busy lives getting busier, it's sometimes nice when someone else does some of the leg work. A good question for this person's interview would be: "How would you go into Exxon and ask them what their priorities are for using 3D seismic data in a research mode?" If they can do that, they could really help build critical momentum for the whole community.

What's Working

John Mutter

Steve Holbrook and others have offered some suggestions for the future of marine seismology based around an analysis of what is not working. I would like to offer some thoughts using what is working as a starting point.

The ship

In late June 2008 *Marcus G. Langseth* sailed from Manzanillo to the 9°50'N Integrated Study Site on the East Pacific Rise to acquire the first multi-streamer 3D seismic survey in the history of academic marine seismology. It was far from easy. We encountered many difficulties but by the end of the summer we had accomplished acquisition of 3,781.95 km of sail line data comprising 888 CMP lines. The *Langseth* towed four solid Thales/Sercel streamers each 6 kilometers long having 468 hydrophone groups at 12.5 meter spacing. The streamers were separated by paravanes to 150 meters spacing so that the total spread was 450 meters wide. The style of acquisition and data quality achieved during this survey met or exceeded standards used in current oil exploration. 3D coverage was achieved in two areas, of which the larger comprises a set of 94 across-axis lines at 300 m spacing between 9°57' N and 9°42' N, made up of two complete racetracks and the northern lines of a third racetrack that was not completed. The Langseth fields the most complex and demanding seismic acquisition system available today to the global research community – and it works. What's more, it works very well. The vessel has a global range – it can accomplish 3D surveys towing two sources and fours streamers up to 6 km long, opening the door for 4D work, high-resolution surveys thanks to its excellent seismic sound source, long-offset 2D or 3D surveys with streamer length up to 8 km. The technical staff operating the vessel has been recruited from the exploration industry and is the best in their field. The ship's officers and crew are superb. Scientists proposing to use the Langseth can be confident that they will acquire data of a quality well in excess of that possible from any previous vessel, data that will meet all requirements necessary for them to reach their diverse research objectives.

Processing

The US community has achieved considerable skill in seismic data processing. The era of in-house scientist-generated processing software has all but passed except for quite specialized purposes, like the very valuable SioSeis that is available onboard Langseth for quasi real-time stacking at sea. Many institutes have installed commercial processing packages and are running them successfully. Our rate of throughput is quite a bit slower than commercial processing mainly because we devote less personnel to the task (including for IT support), this personnel has quite variable levels of experience (with graduate students receiving training in processing as part of their PhDs), and our hardware is generally not as advanced as that in processing centers at companies. However, the product generated is equal in quality to that produced by commercial processing. Furthermore, we understand what goes into it much better than if an outside group provided it. That may not be a huge advantage if the trade-off is a very long time to generate this product, but the positive aspect is that data processing is carried out with the research objectives in mind and we generally know exactly what we are looking at in the processed output. Though less quickly than one would like, the data processing component works too.

Our science.

Understanding of the Earth form science is advancing at a faster rate than it ever has. It wasn't so long ago that we were asking questions in the general category "what's there?" We now are asking questions of a different class, much more like "what processes are operating there?" We haven't reached a phase in which we would be cleaning up the details. Questions posed in terms of processes are much more complex and hence difficult to answer than the original exploratory set of questions. But we now have the tools to address such fundamental questions. It thus seems to me that the system on which advancement of our science relies has worked. The heart of that system is a competition, a marketplace of ideas in which the best succeed. For most of us the market is the NSF proposal system with peer review as its basis. The system has its flaws (I have had my full share of bizarre reviews) but no one has come up with a better one. No market is perfect but they do work. It is important that everyone has access to the market and that information about the market is equitably available to all. Markets need to be regulated and can still fail. But in the absence of a competitive marketplace we risk a tragedy of the commons in which everyone shares a common resource but there is no incentive to preserve or improve it. That is far worse.

Making things work better.

It seems that the Langseth is destined to be relatively expensive to operate, though day rates are not a good way to compare between vessels – Alvin wouldn't look like such a good deal if we compared data rates rather than day rates (one day of Langseth 3D data acquisition typically results in ~120km of sail line data excluding line changes). We have the obligation to ensure that the very best science comes from Langseth's operation and our workshop task is to determine how to do that.

The only proven way to ensure the best science is produced is a healthy open competition – the marketplace of ideas. If the logistics of ship operations are re-arranged it is still essential that we preserve a competitive system of funding for research. Flawed as it might be, it is the only thing that works.

One of the concerns expressed is that too few people are benefitting from marine seismic research, just a few PIs who have special knowledge of how to write proposals and who plan the surveys and collect data then sequester the information for a long time. As a result proposal pressure and success rates are low. That is, not enough people are participants in the market and not enough reward is gained for being in the market. The long sequestration interval causes new information to be restricted so it does not benefit anyone who wants to build on existing knowledge to create and offer new ideas. Markets fail if information about them is restricted. But the answer is never to scrap the market; rather it is to stimulate it and make it work more efficiently and to the greatest benefit. The large delay is mostly due to processing times associated with large data volumes. It is a mistake to think that PIs benefit from this sequestration period – we all have to produce results to get new proposals funded as well as for career advancement: the sooner the results are out, the better. But making processing faster is actually very simple -- it requires a greater allocation of resources, whether in academic settings or through commercial contracts or a combination of the two. Producing results and making data available are two different things as Steve pointed out. Everyone must benefit. It is reasonable for those who win in the marketplace of ideas to be the first beneficiaries but it is not reasonable that they be the only beneficiaries or that the benefit to others is delayed for an unreasonably long time. So we need to shorten the processing time and require as part of the award that data be made available after a reasonable but short period post-acquisition.

We also need to be able to reward young people for success in an appropriate manner. Perhaps because acquisition is considered expensive, science budgets tend to get squeezed. Senior scientists can barely support themselves, let alone a group of students, post-docs and junior scientists (especially those on soft money) at a level more than a minimum amount that allows them to go to sea on the cruise, help process data and attend a couple of AGU meetings. Jamie may be right that young people need mentoring but first they need to be paid. ODP suffered significantly from lack of post-cruise funding and that is turning into a risk for our field also. It is part of the reason results come out so slowly. Today there is insufficient funding to build a cadre of young scientists in our field. Proper allocation of resources into grants can solve that problem.

Then there is the issue of the time between proposal success and data acquisition. This problem dogged ODP as well and was a significant disincentive for anyone to try to build a career on ODP science. Dave Goldberg's suggestions for operations and funding seem very reasonable and would help to get the most out of vessel operations while maintaining an open, though geographically segmented, market in which people compete for work in predesignated regions. And it might even save money and enable greater allocations into science support for young researchers if the funding streams for research and operations were more closely tied.

In summary

We must preserve a market place of ideas. Collective farming may produce more crops but it doesn't produce better crops.

We need to stimulate the market by reducing barriers to entry, make participation more rewarding, and make the benefits more rapidly available to all participants.

We need to manage the functioning of the market better by more efficient vessel operation.

White Papers: Possible Future Surveys

Advanced Seismic Investigations of Oceanic Core Complexes and Detachment Faulting Along the Mid-Atlantic Ridge

J. Pablo Canales, Woods Hole Oceanographic Institution

Oceanic core complexes (OCCs) are known to form by exhumation of large lithospheric sections by long-lived detachment faults along the flanks of ultra-slow to intermediate-spreading mid-ocean ridges (e.g., 1). These faults have been historically known as low-angle normal faults (e.g., 2) because they typically dip ~15°-30° where they break the seafloor (3). However recent research suggests that their orientation at depth could be much steeper (e.g.,4). When active, oceanic detachment faults may constitute the sole extensional boundary between separating tectonic plates (3), and in some instances they can accommodate extension for up to 3 Myr. Exposed fault planes at the seafloor can form corrugated, dome-shaped massifs ("megamullions") or smooth-surfaced broad hills sub-parallel to the spreading axis (e.g., 5).

OCCs and detachment faults are increasingly attracting the interest of a diverse group of geoscientists and biologists because they represent or provide access to a significant number of fundamental scientific processes that are currently being actively debated and investigated:

(1) A fundamental process in the generation of oceanic lithosphere that can be responsible for >50% of lithospheric accretion along slow and ultra-slow spreading centers.
(2) Tectonic windows providing access to deep-seated rocks and processes, allowing studies of mantle flow, melt generation and migration, strain localization, and crustal accretion at mid-ocean ridges.
(3) A system that provides a unique setting for sustaining both long-lived, high-temperature hydrothermal circulation as well as low-temperature, hydrogen-rich, serpentinite-related hydrothermal systems, and their associated mineral deposits and micro- and macro-biota.
(4) A fault zone, containing weak hydrous alteration phases, that localizes strain over extended periods of time (in some instances up to a few million years), with associated flexure and rotation of the footwall.
(5) A key to understand continental metamorphic core complexes formed in settings of extreme tectonic extension, as well as to detachment faults associated with extensional magma-poor continental margins.

Geological and geophysical investigations to date reveal that OCCs are structurally and compositionally highly heterogeneous due to the temporal and spatial variability of lithospheric accretion processes along slow-spreading ridges like the Mid-Atlantic Ridge (MAR) (e.g., 6, 7, 8). Thus, advancing our understanding of the structure and evolution of oceanic core complexes, detachment faulting, and associated geological, chemical, and biological phenomena will require integrated, advanced seismic investigations such as 3D multichannel seismic reflection imaging, 3D wide-angle seismic reflection/refraction, and waveform tomography, that can accurately take into account large variations in elastic properties of the subseafloor as well as the complexity of the rough terrain that generally characterizes the MAR.

A forthcoming AGU Chapman Conference on "Detachments in Oceanic Lithosphere: Deformation, Magmatism, Fluid Flow, and Ecosystems" (www.agu.org/meetings/chapman/2010/dcall) has the goal of identifying the relevant scientific questions related to this topic that remain unanswered, put forward new questions, and define both scientific experiments and an approach strategy to address those questions. We anticipate that advanced seismic investigations of OCCs and the role of the R/V M. Langseth in such investigations will be an important topic of discussion during the Chapman Conference. We encourage participants of the workshop "Challenges and Opportunities in Academic Marine Seismology" to express their interest and thoughts on the potential and limitations that current Langseth capabilities have to advance research on OCCs, and more generally, to advance our understanding of the formation and evolution of the oceanic lithosphere accreted along the MAR.

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3D MCS and Wide-angle Seismic Study of the Galicia S Detachment

Dale Sawyer, Juli Morgan, Tim Reston, Tim Minshull, Dirk Klaeschen,and Donna Shillington

We propose to study the rifted continental to oceanic crust transition in the Deep Galicia Basin west of Spain. This margin and its conjugate are among the best studied magma poor rifted margins in the world and the focus of studies of the faulting mechanics and modification of the upper mantle associated with such margins. Over the years, a combination of 2D seismic reflection profiling, general marine geophysics, and ocean drilling have identified a number of interesting features of the margin. Among these are the S reflector, which has been interpreted to be a detachment fault overlain with fault bounded, rotated, continental crustal blocks and underlain by serpentinized peridotite, and the Peridotite Ridge, composed of serpentinized peridotite and thought to be upper mantle exhumed to the seafloor during rifting.

Specifically we propose to use the RV Langseth to collect a 3D seismic reflection box, a dense 2D box, and an OBS long offset seismic program, 80 km long and 25 km wide over the Deep Galicia Basin, and extending through the crust and S detachment into the upper mantle. With these data, we will characterize the last stage of continental breakup and the initiation of seafloor spreading, relate post-rifting subsidence to syn-rifting lithosphere deformation, and learn about the nature of detachment faults.

We propose to examine three hypotheses:

Hypothesis 1: The S detachment was active at a low angle (<20º; Reston et al., 2007). If true, this would be a major discovery, because the existence and mechanics of low-angle faults have been extensively debated. The evidence for such activity is found in possible syn-faulting sedimentary wedges observed in 2D pre-stack depth migrated profiles over the S detachment.

Previous work has suggested that syn-rift wedges are rare or non-existent over the S detachment (Wilson et al, 1996; Wilson et al., 2001). Reston et al. (2007) attribute their success in identifying them to the power of pre-stack depth migration to properly image complex stratigraphy. They combine observations of the shape of the faults and the configuration of the syn-faulting wedges to argue that the wedges were deposited during low angle fault movement on the S detachment. This interpretation assumes that the 2D profile is oriented in the extension and fault movement direction, and that the stratigraphy has no out-of-plane dip. We will test this hypothesis by mapping the 3D geometry of the fault and of the overlying stratigraphy and by determining the extension direction.

Hypothesis 2: Differences between the degree of extension estimated from fault heaves in the upper crust and whole crustal and lithospheric extension estimated from wide-angle seismic data and subsidence can be explained by polyphase faulting (Reston, 2005). Reston's (2005) model suggests that crustal blocks associated with the S detachment were exposed to several cycles of (1) breaking a new set of normal faults, (2) extension on that set of faults, (3) eventually rotating the blocks and the faults until they are no longer properly oriented for further motion, and (4) breaking a new set of normal faults. He then suggests that extension recorded in all but the last cycle of extension is not easily recognizable; thus the observed brittle extension is far less than the total extension. This is particularly true for highly extended crust which will have experienced more cycles of refaulting.

Reston presents a palinspastic restoration of the fault blocks along profile GP 101 that takes into account the two series of faults that are interpreted to have cut the crust under the Deep Galicia Basin after the continental crust had already been thinned to 15 km during the formation of the Galicia Bank and Interior Basin. While this restoration lends support to the inferred complex sequence of faulting, a 2D restoration can only assume that the motion out of the plane of the section is negligible. We will test this hypothesis by 3D palinspastic restoration of the crustal blocks, and by improved (3D) imaging of the syn-faulting sediment packages. Conclusive demonstration that polyphase faulting is or is not the cause of the apparent extension discrepancy at this margin will have profound implications for models of rifted margins worldwide.

Hypothesis 3: The crustal blocks above the S detachment have formed in a "rolling hinge" manner (Buck, 1988; Manatschal et al., 2001; Lavier and Manatschal, 2006). In this hypothesis, the transition from rifting to seafloor spreading occurred on a concave downward normal fault dipping to the west. The footwall of this fault was pulled progressively out from under the hanging wall. Fault bounded blocks of the hanging wall material were plucked off and transferred to the footwall. This hypothesis requires that the tilted fault blocks overlying the detachment (S reflector) formed and then ceased movement progressively from east to west. We will test these models using high quality imaging of the fault network in the extension direction and perpendicular to it, identifications of fault motion indicators, detailed stratigraphy over fault bounded blocks of continental crust overlying the S detachment, and the ability to obtain relative timing of the locus of extension by correlating reflectors from basin to basin throughout the area.

Potentially affecting each of these hypotheses are recent interpretations of large scale landsliding affecting the west and south sides of the Galicia Bank (Sawyer et al., 2005; Clark et al, 2007). These interpretations are built upon the relative lack of clear syn-rifting sediment in the basins of the Deep Galicia Basin. This interpretation argues that the S detachment may be the surface-of-separation of a westward directed landslide from the Galicia Bank down into the Galicia abyssal plain. Reston et al, (2007) presented the best evidence for rotated syn-rift strata in the fault bounded basins of the deep Galicia basin. These observations challenge the landslide interpretation, but because of uncertainty about the 3D stratigraphy and structure in basins, they do not completely exclude it. The 3D MCS data that we propose to collect would nail this issue one way or the other.

We are collaborating with scientists from the UK, Germany, Spain, and Portugal. For the acquisition, European colleagues will contribute commercial basic data processing of the 3D seismic data, the use of 80 Ocean Bottom Seismographs, the use the RV Poseidon to deploy and recover the OBS's, and a ship swap for 20 additional days of RV Langseth time. The UK proposal has already been funded at a level of £1,133,000.

The proposed survey will support future IODP drilling in the Deep Galicia Basin as well as in the conjugate Flemish Cap Basin. Conjugate studies involving excellent seismic characterization of stratigraphy and tectonics combined with drilling to determine dates and rates are critical to advancing our understanding of continental breakup processes.

Future Surveys: Constraining the dynamics of Subduction Initiation off the South Island, New Zealand.

Michael Gurnis[1], Joann Stock[1], Robert Clayton[1], and Rupert Sutherland[2]

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Subduction initiation is a vital, but poorly understood phase of the plate tectonic cycle. Computational studies and interpretation of the Mesozoic and later plate tectonic history suggest that subduction initiation profoundly alters the force balance on plates. If that is the case, then our picture of the dynamics of plate tectonics is incomplete. If we hope to make fundamental advances in understanding the forces driving and resisting plate motions, then a detailed picture of subduction initiation is needed. Fortunately, nearly half of all presently active subduction zones initiated during the Cenozoic, providing multiple opportunities to better understand the process through geophysical and geological studies.

The best examples where we know subduction started and has since evolved into fully self-sustaining subduction zones, including the Eocene initiation of the Izu-Bonin-Marianas (IBM) and Tonga-Kermadec, are problematic. The transition to a full-fledged subduction zone overprints much of the record needed to constrain the dynamics. The relative plate motions are sufficiently ambiguous, especially for the IBM, that they cannot be reliably used as a constraint on the history during the incipient phase. On the other hand, there are some potentially incipient subduction zones that are so young we do not know if they are going to develop into fully fledged subduction zones, such as the Gorringe Bank, the Owen Ridge, the Hjort Trench, or the Mussau Trench.

Thus, to find key evidence to constrain geodynamic processes, we must study a subduction zone that has partially proceeded through the nucleation stage. The Puysegur Trench and Ridge of the Macquarie Ridge Complex, just south of New Zealand, is slowly transitioning from a forced to a self-sustaining subduction system. The Puysegur region could be a natural laboratory to study the kinematics of this vital phase of plate tectonics, potentially uniquely so in the world, especially when considered in terms of the well-constrained convergence history. Many of the constraints on dynamics can be determined by further field work and analysis.

Detailed marine geophysical survey of the Puysegur Trench and Ridge could be mounted to test the hypothesis that this incipient subduction zone is slowly making a transition from a forced to a self-sustaining state. The R/V Marcus Langseth is an ideal platform to carry out seismic refraction, with OBSs, and multi-channel seismic surveys to collect structural and geological tests on geodynamic models. For example, refraction lines would be used to constrain the crustal thickness and velocities of the lower crust and upper mantle, whereas MCS lines would reveal the velocity and structure of the upper crust. Appropriately designed MCS surveys could be linked to the detailed sequence stratigraphy already completed closer to New Zealand.

Shelf-Slope 3D Survey for Sea-Level and Sedimentary Objectives

Craig Fulthorpe, Jamie Austin, Greg Mountain, Ken Miller, Mladen Nedimovic, Don Monteverde

Sedimentary architecture, even on passive margins, is strongly three dimensional. This reflects sediment supply and transport pathways, underlying tectonism, differential compaction, and along-strike processes such as long-shore drift and ocean currents. Efforts made to study this three dimensionality using 2D seismic data have yielded tantalizing, but incomplete, results. For example, shelf and slope incisions have proven to be impossible to map using profiles spaced ~2 km apart. However, such dispersal systems must be understood in order to define the processes responsible for the lithologies recovered by scientific ocean drilling and to define the extent of shelf exposure during relative sea-level falls, which will likely assist estimation of eustatic amplitudes.

The New Jersey margin has been the focus of intensive and ongoing ODP/IODP drilling for sea-level objectives since 1993 (Legs 150, 150X, 174A, 174AX and Expedition 313); extensive 2D seismic grids have been collected in support of that drilling. However, experience has highlighted the need for 3D seismic coverage to maximize returns from drilling. Such 3D data can only be collected by the scientific community, because commercial 3D seismic data are available only on margins of interest to the oil industry and have not been collected off New Jersey. The alternative to working in areas of oil industry interest, where 3D data are available, is also valuable and should be pursued. However, commercial 3D surveys generally lack the ground truth in the critical (for sea-level studies) Neogene section that has been and is provided by continuous ODP/IODP coring.

Survey design will be critical. Areal coverage, in both dip and strike directions, is important for sedimentary objectives. This need arises because of the requirement to constrain known complex variability within a representative portion of the margin that includes examples of all key sedimentary processes. Compromise and innovation may be necessary, both to minimize cost and to avoid navigational hazards off the east coast U.S., e.g., fishing gear near the modern shelf-edge.

Building on the results of IODP Expedition 313 would be especially relevant to the societal need of understanding the cause and impact of shoreline flooding. Roughly a dozen cycles of glacio-eustatic variation were sampled at three sites; environments from open shelf to shoreface to paleosols were recovered. Three-dimensional registration of these samples would provide an unprecedented data set and yield insight into the impact of encroaching shorelines during times of rising sea level such as we are experiencing today.

Having made such a huge investment in drilling over nearly two decades at sites across the New Jersey shelf and slope, it would a great pity not to follow through with imaging equal to the complex and fundamental geologic objectives that drove us to drill in the first place.

Subducted seamounts and great earthquakes: Comparing Chile and Cascadia

Anne Tréhu, Oregon State University

Subducted seamounts are ubiquitous in the ocean basins and have profound effects on the accreationary complex where they enter subduction zones. There are both empirical and theoretical reasons to believe that as seamounts are dragged deeper into the subduction zone they will result in heterogeneous friction on the plate boundary. However, whether they will act as strong or weak patches on the plate boundary that hinder or facilitate slip remains uncertain, with examples of both types of behavior discussed in the literature.

The excellent imaging of the rupture history of the recent Chile earthquake enabled by new analysis techniques applied to high density seismic arrays like USArray provides an opportunity to test whether rupture history during a great event is correlated with the presence of subducted seamounts and/or variations in plate boundary reflectivity. These models (e.g. http://seismology.harvard.edu/projects/chile) indicate that the earthquake had a complicated rupture history characterized by patches of high moment release. A seismic experiment incorporating 2 and 3D seismic imaging using the R/V Langseth and both seafloor and onshore seismometers could determine whether these patches correspond to deeply subducted seamounts and whether those seamounts are attached to the subducting plate or represent decapitated seamounts that have been transferred to the overriding plate. Seismic imaging would also map spatial variations in plate boundary reflectivity associated with changes in fluid pressure on the megathrust and other associated faults. While there have been a number of ambitious active-source seismic experiments on the Chile margin in the past 2 decades, none (that I know of) have been in the rupture zone of the recent earthquake.

Lessons learned from such an experiment could be applied to developing a more detailed predictive model for what can be expected from the next great Cascadia earthquake, where great earthquakes have been inferred from the paleoseismic history. Existing active source seismic data indicate the presence of subducted seamounts beneath the central segment of the subduction zone (Tréhu et al., 1994; Fleming and Tréhu, 1999). Geodetic data indicate that interseismic coupling varies along strike (e.g. McCaffrey et al., 2007; Burgette et al., 2008), with the change in coupling spatially correlated with the presence of the subducted seamounts and a strong crystalline upper plate backstop, which may inhibit seamount subduction. Low angle thrust earthquakes have also recently been indentified in this region (Tréhu et al., 2008; Williams et al., 2009). Further north, offshore Washington, topographic roughness is suggested on the subducting plate and/or within the accretionary complex (Flueh et al., 1998). Further downdip, temporal and spatial variations in episodic tremor and slip behavior are currently being documented, which also appear to correlate with variations in upper and lower plate structure. Existing active source data, which are more than a decade old, along with potential field data and high resolution bathymetry, provide an excellent framework for designing a targeted experiment to image subducted seamounts and variations in plate boundary reflectivity in several contrasting segments of the plate boundary as part of a larger scale effort to understand megathrust slip processes.

Experiments in both Cascadia and Chile provide excellent opportunities for collaboration with other NSF (e.g. MARGINS, EarthScope) and international initiatives.

Global mantle dynamics and active-source marine seismology

Jun Korenaga (Yale University)

The thermal and chemical evolution of Earth after the magma ocean period has been controlled, to first order, by mantle dynamics (e.g., Korenaga, 2008). The mantle is parental to both continental and oceanic crust, regulates core cooling and thus the secular evolution of the geomagnetic field, and plays an important role in the global cycle of volatile elements. Yet, many aspects of mantle dynamics remain enigmatic, creating a considerable bottleneck in our understanding of the evolution of terrestrial planets at large. Here I list two of such outstanding problems in geodynamics, to which future experiments in marine seismology could potentially make fundamental contributions.

1. The generation of plate tectonics

The operation of plate tectonics is what distinguishes Earth from other terrestrial planets, but it is perhaps the most puzzling aspect of mantle dynamics. Because the viscosity of silicate rocks is strongly temperature-dependent, the top thermal boundary layer (or lithosphere) is supposed to be too stiff to allow the bending of lithosphere, without which subduction thus plate tectonics cannot take place. Given our understanding of mantle properties, the most natural mode of convection is so-called stagnant-lid convection; the entire surface of a planet is covered by a rigid spherical shell and convection takes place only beneath it. It is thus easy to explain why Venus and Mars exhibit stagnant-lid convection but difficult to explain why Earth doesn't. In order to generate plate tectonics, there must exist some additional mechanism to compensate temperature-dependent viscosity, but what this mechanism could be is still under intense debate (e.g., Bercovici, 2003).

An important point here is that the central issue is the rheological property of oceanic lithosphere (as opposed to continental lithosphere); oceanic lithosphere needs to be somehow permanently damaged during its evolution so that it can deform easily at subduction zones. Such rheological evolution may be tracked down by imaging the fine-scale structure of oceanic lithosphere (e.g., Korenaga, 2007), but such information has been a blind spot in conventional geophysical remote sensing. Most of previous active-source studies with ocean bottom instruments are limited to crustal structure. Surface wave tomography can probe deeper but with much lower resolution. A recent active-source experiment at lithospheric scale (the FAIM experiment; Lizarralde et al., 2004) provided promising data, but because translating the structural information into the rheological information is not straightforward, it will be important to further accumulate lithospheric-scale marine seismic data at multiple localities in order to better interpret them. Active-source marine seismology, particularly in conjunction with magnetotellurics, could provide essential structural data (that are otherwise impossible to obtain) to test various hypotheses on the generation of plate tectonics.

2. Relation between mantle convection and terrestrial magmatism

Large-scale mantle circulation associated with plate tectonics can readily explain mid-ocean-ridge magmatism and arc magmatism, both of which take place at plate boundaries, but we need additional mantle dynamics to explain hotspot magmatism and the formation of large igneous provinces (LIPs) such as continental flood basalts and oceanic plateaus. Whether hotspots and LIPs are due to the upwelling of mantle plumes or not has been debated extensively in the past, partly because the origins of hotspots and LIPs are intimately coupled with the structure and evolution of the mantle. A deep isolated reservoir at the core-mantle boundary has often been provoked to explain isotopic heterogeneities observed for ocean island basalts and flood basalts, but this idea is based mostly on the following two assumptions: (1) hotspot magmatism is caused by deep mantle plumes, and (2) mantle convection can quickly homogenize chemical heterogeneities. In light of recent progress in mantle dynamics, however, both assumptions need to be carefully reconsidered, and it is no longer obvious how geochemical observations at the surface and mantle convection in the deep Earth may be related. In particular, it is important to recognize that chemically heterogeneous mantle is an unavoidable consequence of mantle convection with plate tectonics (e.g., Korenaga, 2008), carrying a number of important implications for the origins of anomalous magmatism such as LIPs.

Deciphering the formation mechanism of large oceanic plateaus would be critical in this line of effort, and active-source marine seismology is expected to play a vital role here as well, for the following reasons: (1) the formation of oceanic plateaus represents at least an order-of-magnitude greater magmatism with respect to currently active hotspots; (2) it is straightforward to interpret the crustal structure of oceanic plateaus in terms of the state of their parental mantle, because most of them were formed far away from continents so do not suffer from continental contamination, and also because they remain largely intact after formation; (3) they were formed by mantle dynamics in the ancient past (many of them are older than 100 Ma), which is very difficult to constrain otherwise, because mantle tomography tells us only the present-day state of the mantle; and (4) many of large oceanic plateaus are yet to be investigated by contemporary seismic techniques, so we have a vast amount of untapped information with considerable impact on global geophysics and geochemistry.

For both themes, 2-D seismic experiments would be sufficient and also realistic given the scale of a survey area, so it would help to create a balanced mixture of 2D and 3D experiments for R/V Langseth, while addressing a wide spectrum of scientific questions.

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Investigating the Structural Evolution of the Panamanian Margins and the Panama Canal Basin, with Implications for Construction and Tectonics of the Central American Isthmus

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The Central American Isthmus, comprised of the Costa Rica – Panama Microplate, is a structurally complex area that continues to be affected by four converging plates. To the southwest there is subduction of the Cocos Plate and Cocos Ridge beneath the isthmus at 90 mm/yr. Further east there is oblique subduction of the Nazca Plate, creating transform faults as well as the Columbia Trench. The Caribbean Plate is subducting from the north and, coupled with convergence of the South American Plate from the southeast at a rate of 31 mm/yr, has caused the development of the North Panama Deformed Belt (NPDB) along with deformation and "bending" of the volcanic arc since the Middle Miocene (Jackson et al., 1996). The NPDB and Caribbean subduction zone also represent historically the most seismically active region of the microplate.

However, focus can be drawn within this microplate to the Panama Canal Zone, where interactions between the Chorotega and Choco blocks, controlled by complex regional tectonics, have resulted in an extensive NE-trending sinistral fault/shear zone (Lowrie et al., 1982; Pratt et al., 2003). This shear zone, described as the Gatún Fault Zone or the Canal Fracture Zone (De Boer et al., 1988; Jackson et al., 1996), has primarily controlled the evolution and sediment infill of the Canal Basin in the low-relief center of the isthmus. High-resolution seismic work by Pratt et al. (2003) show that Miocene to recent sedimentary rocks within Limón Bay on the Caribbean side of the isthmus are faulted, but the origin of these faults, their broader-scale significance, their relation to the Panama Canal fracture zone, and the seismogenic- hazard potential of the fracture zone are not well understood.

Targeting the margins of the Isthmus of Panama, from the South Panama Fault Zone across the Gulf of Panama, through accessible portions of the Panama Canal (i.e., Lake Gatún), to the North Panama Deformed Belt (Caribbean subduction zone) would inform interpretations and models of orogenic processes, continental accretionary evolution, and interactions of complex subduction-zone tectonics on crustal blocks. Such an ambitious survey would be natural and, in a sense, more cost-effective during consideration of a transfer of the RV Marcus G. Langseth between the Atlantic and Pacific basins via the Panama Canal.

To take greater advantage of marine seismic operations, onshore deployments of PASSCAL recording systems would be coordinated with offshore shooting, allowing for greater seismic coverage of this structurally complex zone within the Central American Isthmus. A significant target of interest would be the subducting Caribbean Plate that has been suggested to pass underneath Gatún Lake at a depth of 35 km (Pratt et al., 2003). Detection of this slab, which potentially is within the imaging capabilities of the RV Marcus G. Langseth, might explain the interactions occurring at a deep-rooted level, along with potentially tying this to the more near-surface structures observed.

Marine (and onshore–offshore) imaging of the Central American Isthmus on the margins, and in accessible parts of, the Panama Canal Zone (Lake Gatún) will provide invaluable information to understand better the structural evolution of this complex region over the past 15 Ma. Such a target is of high importance due to the global impact that the formation of the isthmus has had on ocean circulation and climate patterns (Jackson et al., 1996). Determining details of the development of Panamanian continental crust, along with better understanding of orogenic processes and the complex effects of subduction-zone tectonics on crustal blocks, will also allow for increased understanding of how global circulation patterns are affected by tectonic activity.

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Mapping magma in motion with 4D seismics

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Although geological processes operate over very long time scales they are typically the sum of a multitude of short-period increments. The formation of oceanic crust is one example -- the upper layers are built from discrete dyke injection and eruption events. At fast spreading ridges, a simple calculation based on average dyke width and spreading rate information suggests that repeat injection/eruption events must be occurring on the order of every few years. Direct evidence of eruption cycles, though sparse, confirms those calculations are reasonable: at 9°50'N on the EPR, documented eruptions occurred in 1991 and again in 2005/06. Ridge-crest hydrothermal circulation, driven by heat from the mid-crustal magma lens, is known to be highly variable in time with both vent structures and vent chemistry varying over very short periods. While such rapid evolution does not imply an equivalent time scale of magma system dynamics (hydrothermal circulation is sure to be intrinsically unstable, showing rapid variations even with slowly varying boundary forces) magma beneath the ridge axis is likely to be in essentially constant motion and/or evolution.

Almost nothing is known at present about magma dynamics associated with an eruption at a submarine volcanic system. We have a fairly good sense of the length of ridge segment involved in the recent eruptions at 9°50'N on the EPR, as recorded in surface features such as eruptive fissures and lava flows, but we do not know the correspondence to the magmatic system at depth. Does the erupted lava all originate at a relatively isolated region of the magma body or is there an elongate magma sheet at depth that will become a new dyke propagating to open a surface fissure? What form does the prelude to an eruption take? Does the magma body change geometry before an eruption by getting larger, say? Or instead does the liquid fraction progressively increase and the pressure rise until the eruption occurs? Does the magma body deflate after an eruption?

Seismic time-lapse imaging techniques have been widely used in the oil industry to track the depletion of hydrocarbons in a producing field, often during advanced recovery operations. They are now also used to track the location of carbon dioxide pumped into saline aquifers and other formations as part of carbon capture and storage for CO_2 emissions mitigation . These techniques can be readily applied to study magma dynamics[1]. Most importantly the acquisition capability of the R/V Langseth has sufficient resolution and repeatability that repeat seismic surveys can be performed to study changes in shape and properties of the axial magma body. The 2008 3D cruise to the 9°N area of the EPR where the eruptions took place made the first set of images for this purpose. A repeat survey to produce time-lapse images could be planned for around 2012 giving sufficient time for changes in the magma system to have taken place. Monitoring of the ridge to detect any precursors to eruptions such as increases in microseismic activity would help identify the most critical time for a repeat survey.

[1]The February issue of The Leading Edge http://segdl.aip.org/tle is a special issue on CO_2 sequestration with several articles on 4D techniques for monitoring.

MCS in the Ross Sea and West Antarctic margin

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Sea ice constitutes the obvious challenge to obtaining marine seismic reflection data at the Antarctic margin. Many MCS targets of potential importance along the Antarctic margins have been accessible only by icebreaker during sea ice minimum (January-February). Other targets have been completely inaccessible due to ice conditions. Because sea ice conditions worldwide are now changing, the marine MCS community should regularly reexamine the feasibility of work in the polar regions. Annual cover of Arctic sea ice is currently dropping. Average annual Antarctic sea ice has been slightly increasing since 1979, but it has been decreasing rapidly in the Amundsen-Bellingshausen Sea (ABS) sector of the West Antarctic margin (Turner et al., 2009). It has also been decreasing overall for the month of January (Turner et al., 2009, Figure 1) including in the southern Ross Sea (sRS) sector. Turner et al. attribute these changes to increased storm intensity due to the expanded ozone hole, which has been countering the warming effect of increased greenhouse gases. It is not known how long this trend will last.

As sea ice diminishes in ABS and sRS, numerous 2D and 3D MCS targets may become accessible. For example, the fossil subduction zone (Aluk/Phoenix plate subducting under West Antarctica) present along the ABS may provide a detailed snapshot of the geological record of subduction termination due to ridge-trench collision. The zone of interaction of the fossil Bellingshausen-Aluk plate boundary with the overriding Antarctica continental plate (Eagles et al., 2004) may be studied, as well as the engimatic volcanism that later blanketed the same region, and various continental margin basins that accommodate an unknown amount of plate boundary deformation. In the sRS, the Central Basin and a rift east of Iselin Bank appear to have accommodated mid-Tertiary separation of East and West Antarctica. The details of their timing and motion will be best elucidated by high resolution seismic surveys of the faults and sedimentary strata. The Adare Trough seafloor crust grades southward along strike into transitional crust, or extremely thinned continental crust (Cande et al, 2000) but the structural details of this continent-ocean transition remain elusive. Numerous other targets involving sedimentation and glacial history, important for understanding the climate record, would also benefit from an improved 2D or 3D MCS capability.

Although MCS data have been collected by a number of vessels from different countries, the current US research capability consists of a 48-channel, 1200-m oil-filled streamer and analog data acquisition system belonging to the USAP icebreaker R/VIB Nathaniel B Palmer. Available seismic sources are arrays of up to 6 GI guns (210 cubic inches each) or Bolt guns (ten available from 1000 to 80 cubic inches). This system is deployed when open water can be maintained behind the ship so that the air guns and streamer do not get caught in the ice. Borrowed or leased MCS systems could also be deployed from this ship. It is well recognized that this capability needs upgrading and it is our understanding that the Antarctic research vessel operators may be in discussion with UNOLS about possible shared equipment pools (ARVOC minutes, 2009). In addition, a new polar research vessel is being planned. Until this ship is available and has its own MCS system, several possible configurations of MCS data collection should be considered depending on the ice conditions and ship availability. These include: use of the 3D capability of the Langseth as regions become ice-free; deployment of a P-cable system from the Nathaniel B Palmer or its replacement; use of the Langseth in 2D mode; or, at a minimum, upgrading the Palmer to a digital acquisition system and streamer. If community effort is made to obtain a P-cable system for use on UNOLS or other research vessels, it would be ideal if the Antarctic research vessels can be included as participants in the instrument pool.

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Onboard marine geophysics classes during ship transits

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From 1997 to 2008, NSF Office of Polar Programs funded collaborative research projects from Caltech and Scripps (PIs: Joann Stock and Steven Cande) to collect underway geophysical data during appropriate transits of the R/VIB Nathaniel B Palmer. The main goals of these activities were twofold: first, to add to the very sparse geophysical data base of the Antarctic plate and surrounding plates, in order to improve plate reconstructions; second, to provide student training by offering formal classes in marine geophysics, when practical, aboard ship. Our experience may be useful as an example of possibilities for classes in marine geophysics aboard the Langseth, which could take excellent advantage of transit time.

We taught formal classes on board the ship three times: NBP0102 (17 days, Cape Town to Punta Arenas); NBP0207 (25 days, Port Hueneme to Lyttelton) and NBP0607C (14 days, Lyttelton to Lyttelton). These transits were chosen because they were not too long, did not require Antarctic medical clearances for the participants, and were expected to have reasonably calm sea conditions compared to many of the other transits used for the regular data collection. The courses consisted of one hour per day of formal lecture; homework assignments involving the data being collected; watchstanding time for each of the students; and ping editing assignments for each of the students while at sea. Each student was expected to read references prior to coming on board and to do a short presentation during the class. In addition, each student chose one part of the data set to analyze, and wrote up a research report for the major part of the class grade. Course instructors were: J. Stock and R. Clayton (Caltech) on NBP0102; J. Stock, R. Clayton, and M. Gurnis (Caltech) on NBP0207; and J. Stock, R. Clayton, B. Luyendyk (UCSB) with collaborator B. Davy (NZ- IGNS) on NBP0607. We generally had 12-15 students, a mix of graduate students and well-qualified undergraduate students. The number was limited by the available berth space for the science party.

Geophysical systems used were: gravity, magnetics, swath bathymetry, 3 kHz echo sounder with subbottom penetration, XBTs/XSVs, and single- or multi-channel seismic reflection. For each cruise, existing data were reviewed and a cruise track was chosen that would permit collection of new data to study one or more geophysical problems of interest. For the first two classes, we were limited by needing to cruise at nearly full speed (10 knots) during the allotted transit time; this meant we could only do two days of single-channel seismics (at 5 knots) during each of the two cruises. The limitation of single-channel seismic was dictated by the numbers of marine technicians and support personnel available. The third cruise was an equipment testing cruise, primarily designed to test several different MCS streamers, sonobuoys, GI guns, and Bolt gun configurations for use later that season on a separately funded MCS research cruise in the Antarctic. Therefore, for that class, we were able to do much more MCS seismic data collection. Note that the Palmer is a multipurpose research vessel, not a dedicated seismic data collection vessel. This means that some of the geophysical systems (magnetometer, reflection seismic equipment) had to be brought on board especially for our use.

Students who participated in the formal classes, over the course of this project, came from Caltech, UCSD, UCLA, Pasadena City College, UT El Paso, Interamerican University (Puerto Rico), Colorado College, UCSB, and Cal Poly Pomona (i.e., mainly non-oceanographic institutions). Several students went on to use their class reports as a basis for undergraduate or graduate thesis papers. Undergraduate participants often enjoyed the experience and subsequently applied to graduate programs in marine science. Others found that this class experience led to more shipboard experience and ultimately to employment opportunities relevant to their cruise participation. The students were selected by advertising to schools in southern California (so that the students could attend some class meetings at Caltech prior to cruise departure). Students could come from more distant locations if a faculty member at their institution was willing to work with those students to oversee any part of the project that needed to be completed after the cruise was over. Although most oceanographic institutions give their students course credits for going out to sea as watchstanders on geophysical cruises, it is my understanding that there is not usually formal class instruction during such cruises, nor do they target the population of students from non-oceanographic institutions. This is understandable, because on a dedicated science cruise, particularly a full-time MCS cruise, there is just too much going on to be able to fit in formal class teaching, and having more experienced students on board is an advantage. However, teaching activities can be designed to fit in well on transit cruises.

We found that there is great value in being able to teach a class on marine geophysics (including both theory and data acquisition) while at sea. This was a very efficient and rewarding use of transit time, from the educational perspective and also from the value of the scientific data that were obtained. It was also clear from our experience on both the class cruises and the data collection on the other transits, that it is generally possible to design a cruise track that will collect new data relevant to one or more interesting tectonic problems. I suggest that similar efforts be considered for use of the Langseth transit time. Obviously there would have to be some consideration of what level of seismic data collection is feasible during transit cruises, as well as what other systems might be available.

Additional details of the curriculum offered during Caltech's onboard marine geophysics classes can be found at: http://www.gps.caltech.edu/~jstock/Ge211.html and links therein.

Setting up the Stage for Project MoHole: Seismic Studies of Fast-Spread Ocean Lithosphere

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The mid-ocean ridges and the new oceanic lithosphere that they create are the principal pathway for energy and mass exchange and physical/chemical interactions between the earth's interior, the hydrosphere, and the biosphere. Bio-geochemical reactions between the oceans and oceanic crust occur throughout its lifetime, and hence the ocean lithosphere records the inventory of global thermal, chemical and biological exchanges. The MoHole, an initiative to drill an ultra-deep hole in an intact portion of oceanic lithosphere, through the crust to the Mohorovičić discontinuity (Moho), and into the uppermost mantle is a long-standing goal of scientific ocean drilling. It remains critical to answer many fundamental questions about the dynamics of the Earth and global elemental cycles; its fundamental goals include:

Determine the bulk composition of the oceanic crust to establish the chemical links between erupted lavas and primary mantle melts, understand the extent and intensity of seawater hydrothermal exchange with the lithosphere, and estimate the chemical fluxes returned to the mantle by subduction,

Test competing hypotheses of the ocean crust accretion at fast spreading mid-ocean ridges, and quantify the linkages and feedbacks between magma intrusion, hydrothermal circulation and tectonic activity,

Determine the geological meaning of the Moho in different oceanic settings,

Determine the in situ composition, structure and physical properties of the uppermost mantle (and its variability), and understand mantle melt migration,

Calibrate regional seismic measurements against recovered cores and borehole measurements, and understand the origin of marine magnetic anomalies,

Establish the depth extent of deep biosphere and hydrological/geobiological processes in the lithosphere.

More detailed scientific rationale for the MoHole can be found in recent workshop reports:

- http://www.iodp.org/mission-moho-workshop

- http://www.interridge.org/WG/DeepEarthSampling/workshop2009

A forthcoming workshop to be held in Kanazawa, Japan, in June 2010 (http://earth.s.kanazawa-u.ac.jp/~Mohole) will indentify 2-3 potential MoHole sites in the Pacific where the scientific community will focus geophysical site survey and post-drilling research efforts over the next few years. The type, resolving power, and coverage of geophysical data needed for site selection and to accomplish the post-drilling scientific goals will be amply discussed during the workshop.

In particular, seismic surveys are expected be a fundamental component of MoHole critical to accomplish the goals of this ambitious project. These surveys will be more efficiently conducted through international collaborations involving several platforms of different characteristics. Among these platforms, the R/V Langseth will undoubtedly be a key resource because of her state-of-the-art seismic capabilities. We envision Langseth contributing to acquisition of one or more of several types of seismic data needed to support Project MoHole, which include:

1. 3D multichannel seismic (MCS) data. MCS reflection imaging of the oceanic Moho is often degraded by in- and out-of-plane energy scattered by the rough igneous basement [e.g., Kent et al., 1996]. Among the many benefits of 3D MCS data and 3D processing techniques is the possibility of accurately collapsing the scattered wavefield to its source location; therefore significantly improving image quality. In addition, obtaining geometrically accurate images of steeply dipping faults that may cut an entire crustal section (and therefore perhaps affecting the physical properties of the Moho) [e.g., Nedimović et al., 2009] will also require 3D MCS data/processing. The potential benefits of combining 3D MCS with 3D borehole VSP for a project of these characteristics need to be explored.

2. 2D long-offset (>=8-km streamer) MCS data. In recent years 2D MCS data collected with 6-km-long hydrophone streamers have resulted in seismic images of the lower oceanic crust, Moho, and sub-Moho structure of unprecedented quality and detail, contributing to a better understanding of the geological processes that form the lower crust and Moho [Canales et al., 2009; Nedimović et al., 2005]. Acquiring MCS data with an 8-km-long streamer, as current Langseth capabilities allow, will further improve imaging of lower crustal and uppermost mantle features, as well as enabling amplitude-vs-offset studies of the physical properties of such deep targets. An added value of long-offset MCS data is their potential for conducting high-resolution waveform tomography studies to obtain the fine-scale seismic velocity structure of the upper- and mid-crust in the vicinity of a deep drill hole, thus contributing to a better integration of drilling sampling/results and regional geophysical data.

3. 3D large-scale Ocean Bottom Seismometer (OBS) data. Langseth offers a superb powerful airgun array for active-source 3D wide-angle refraction/reflection OBS experiments. Using traveltime tomography techniques, these type of data allow resolving the 3D P- and S-wave velocity and anisotropy structure of the crust and uppermost mantle at scales of several kilometers, which will help interpretation of drilling results and placing them in the appropriate tectonic context.

4. 2D high-resolution OBS data. Data acquired with a large number of densely spaced OBSs, in conjunction with Langseth's excellent seismic source, can be used for high-resolution determination of the

velocity structure of the Moho transition zone (MTZ) in the vicinity of a drill hole using waveform tomography approaches [e.g., Operto et al., 2006]. At long source-receiver offsets (~15-40 km), the MTZ seismic signature is a high-amplitude wide-angle reflection ideal for frequency-domain waveform tomography studies [e.g., Brenders and Pratt, 2007].

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