The Need to Continue the Robust Relationship Between Seismic Imaging and Scientific Ocean Drilling

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February 2017

Executive Summary

The NAS "Sea Change" report to NSF/OCE has ushered in an ongoing balancing act between PI-driven science and critical supporting technical infrastructure, which includes the dedicated seismic platform *Marcus G. Langseth*, in the U.S. Similar stresses are affecting imaging capabilities in Germany, the UK, Japan and China. As a result, a healthy future for seismic imaging in the world's oceans is at risk; programs like IODP, the latest incarnation of the international collaboration in support of scientific ocean drilling, depend in part on such a global imaging capability. In response to warning coming from within IODP, international groups both inside and outside the drilling program have met to consider paths forward. More fiscal resources are not yet available, but the view of these groups is that more efficient scheduling and coordination of international imaging assets will optimize their functioning, and in the process support the continuation of IODP. A recent development in the U.S., execution of the Terms of Reference for a new international imaging oversight body, the Marine Seismic Research Oversight Committee (MSROC), suggest that such collaboration and coordination are possible, if an MOU mechanism among the known national purveyors of imaging can be developed.

Charting the Future of Marine Seismic Science

In the wake of the 2015 "Sea Change" report to the Division of Ocean Sciences of NSF (https://www.nap.edu/catalog/21655/sea-change-2015-2025-decadal-survey-of-ocean-sciences), the U.S. ocean sciences community continues to assess the dynamic balance between funding PI-driven science and important technology infrastructure. This process is being mirrored around the world, as nations conducting ocean research deal with rising infrastructure costs. There is perhaps no better example of this trend than the challenge facing seagoing seismic imaging, which requires substantial, expensive infrastructure and operational support, but is also crucial for other ongoing endeavors, most notably the Integrated Ocean discovery Program (IODP). Although there is general acknowledgement that seismic imaging is the primary tool to "see" the sub-seafloor realm, threats to degrade or eliminate imaging capability as a result of rising costs would lead to serious limits on the international science community's ability to make fundamental observations that are both critical for basic science progress and a long-standing prerequisite for scientific ocean drilling. What is needed, besides more money, is more efficient international coordination and scheduling of seismic infrastructure assets – ships and their ported seismic systems. If such coordination and scheduling can be achieved, high-quality marine seismic imaging will continue to play the vital role it now plays in hypothesis-testing in the global ocean environment. The goal of an international focus group* meeting at Lamont-Doherty Earth Observatory (L-DEO) on November 21, 2016, was to begin to consider this challenge, building upon related discussions at the September, 2016, IODP Forum meeting in Brazil.

In 2018, the enduring international collaboration that is the scientific ocean drilling program will be 50 years old. That effort, comprised of multiple phases (Deep Sea Drilling Project, Ocean Drilling Program, the Integrated Ocean Drilling Program, and the International Ocean Discovery Program), represents the most successful such collaboration in the history of the Earth sciences. And from the outset, the success of these drilling activities has been contingent on the ability to see into sub-seafloor environments to identify targets, plan safe drilling operations, and provide geologic context beyond the drill hole. Multi-channel seismic (MCS) imaging has been a staple of drilling-related imaging efforts since the early 1970s, and now both high-quality 2D and 3D images, from a variety of sources, support scientific ocean drilling efforts (Figure A).

However, the increasing costs of both imaging platforms and installed imaging systems is now putting that longstanding and highly effective relationship at risk. IODP's Science Evaluation Panel warned in 2015 that despite improvements in imaging acquisition and processing capabilities, more IODP proposals were being submitted (and some scheduled and drilled) with sub-par imaging in support (see the next section). Increased scheduling efficiency of imaging capabilities, modulated through evolving international mechanisms, will be critical to provision of quality images for scientific drilling in the future. The purpose of this white paper is to begin a discussion towards development and provision of those mechanisms.

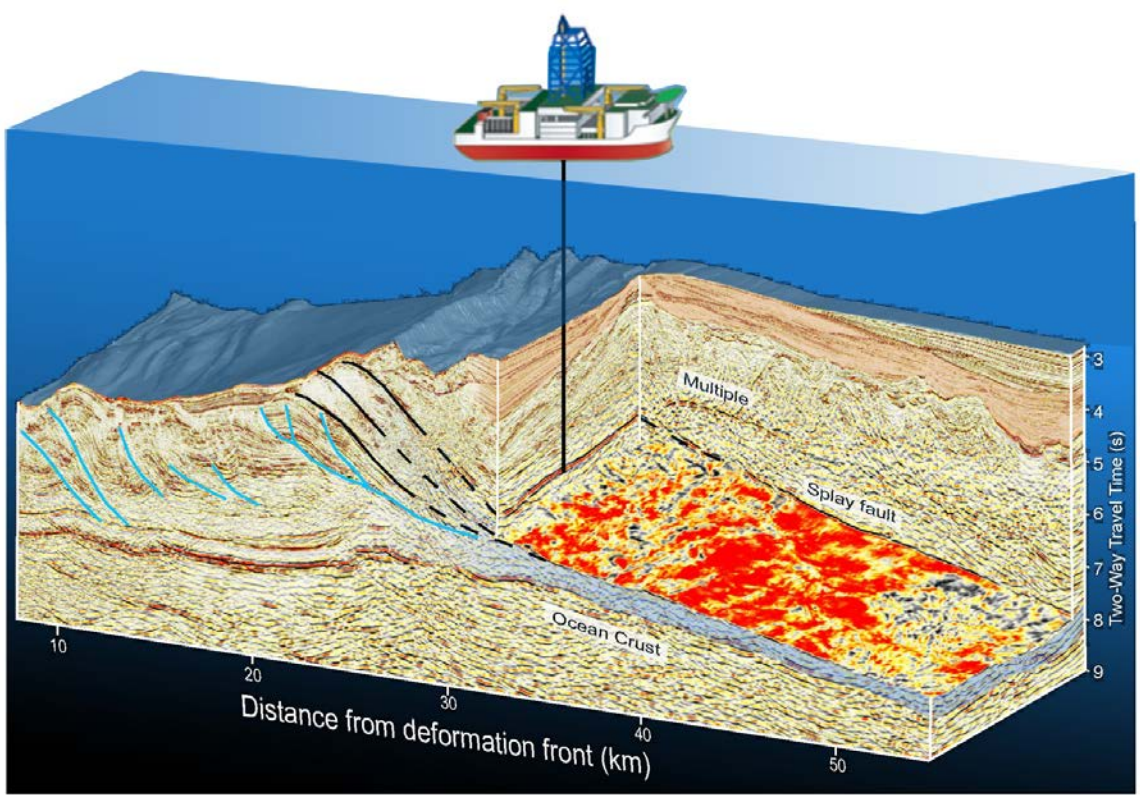

Figure A. A 3D seismic image of the Nankai Trough accretionary prism along the southwestern Japan margin, a plate boundary which has been a focus of multiple scientific ocean drilling efforts for *decades. The cut-out area looks into the plate-boundary megathrust, where it intersects a major splay-fault system, shown with dipping black lines. Blue lines show thrust faults within the upper plate/accretionary wedge. The vertical black line shows the location of the deep riser drilling site (part of the decadal NantroSEIZE drilling program) that is designed to penetrate the splay fault at ~5 km below seafloor. IODP efforts to drill to that target continue. (Seismic image is from Bangs et al., 2009.)*

The Role of the IODP Forum, 2015-2016

The Forum is the part of the current (2013-2018) phase of scientific ocean drilling dealing with philosophical consensus-building; Forum discussions help to maintain IODP as a program rather than just a collaboration. In 2015, the Science Evaluation Panel (SEP), the primary scientific review body (from both science AND data points of view) of IODP, sent the following statement to the Forum:

> *The IODP Science Evaluation Panel (SEP) wishes to convey concern regarding the increased pressures on the acquisition of academic active-source seismic data, some of which by design is conducted in support of scientific ocean drilling. Continued reduction in the international marine geoscience communities' ability to collect seismic data in areas of scientific interest is jeopardizing the scope and impact of IODP science. The SEP consensus is that the IODP should stress the importance, both to member country funding agencies and environmental permit organizations worldwide, of high-quality subsurface images for science and safety in connection with expected continuation of IODP. Furthermore, SEP looks forward to IODP playing a role in bringing sound science to ongoing discussions of mitigation for (seismic- based) noise in the marine environment.*

At its 2015 meeting in Australia, the Forum discussed the SEP consensus, and produced one of its own, along with an accompanying Action Item:

> ***Forum Consensus 15-06****: The Forum appreciates and seconds the SEP statement on marine seismic site survey data importance and acquisition challenges, and stresses the vital importance of the linkage between seismic data and drilling in IODP.*

> ***Action Item:*** *Progress toward addressing the challenges related to international coordination and acquisition of IODP-related seismic data will be an important focus at the 2016 Forum meeting.*

At its 2016 meeting in Brazil, the Forum brought both U.S. and non-U.S. (Japan, UK, Germany) seismic experts for a follow-up discussion, and produced another consensus (*note: underlining not in original, but for emphasis here*):

> ***Forum Consensus Item 16-06****: The international marine seismic imaging community has moved toward conducting IODP site surveys in more cooperative ways with combined resources. The IODP Forum endorses that trend and encourages that community to explore options for more efficient and cost-effective use of existing seismic imaging assets and survey funding across all IODP partners. <u>The Forum suggests that the initial steps should include a formal meeting of the international seismic imaging stakeholders within</u>*

the next year to develop a framework and justification for utilizing existing resources more efficiently in support of IODP, ICDP and other scientific requirements.

A November 21, 2016, focus group meeting at L-DEO represents (in part) the follow-up to this 2016 Forum consensus. Seismic imaging clearly remains a priority for scientific ocean drilling, and the international ocean drilling community supports all reasonable actions to keep such imaging capability, provided by multiple partner nations, healthy.

The Importance of Seismic Reflection Imaging to Marine Geology and Geophysics, including Scientific Ocean Drilling (IODP)

Improving seismic imaging for IODP goes hand in hand with a comprehensive marine geology and geophysics program. Understanding fundamental deformational, seismogenic, magmatic, sedimentary and oceanographic/paleoclimatic processes is a primary goal of core marine geology and geophysics programs broadly, and IODP specifically. A comprehensive understanding of these processes requires scientific ocean drilling, predicated on high-quality imaging of sedimentary, crustal and (occasionally) upper mantle fabric and structure. Subsurface geophysical imaging is also essential to plan properly to drill, by identifying sites that will hit science targets deemed desirable by IODP's decadal Science Plan (https://www.iodp.org/about-iodp/iodp-science-plan-2013-2023), to assess and avoid attendant drilling hazards, and ultimately to provide scientific and geological context for the results of drilling, over both short and long terms. In the oceans, seismic reflection and wide-angle reflection/refraction data are the best and most cost-effective, and often the only, means to image the sub-seafloor realm. No other suite of geophysical methods is capable of comparably detailed imaging in support of efforts to ground truth the geologic foundations of the global oceans.

Seismic reflection data are an essential component in addressing all of the major research themes in the IODP Science Plan, by providing constraints on Earth structure, stratigraphy and attendant physical properties over large areas, at horizontal resolution scales as small as ~5 m, and to depths up to 10's of km, that complement the results obtained from drilling (Figure A). Consequently, combining reflection/refraction data and drilling results can produce more transformative science than either approach used in isolation. For example, considering the Science Plan's "Earth in Motion – processes and hazards on human time scales" initiative, seismic data provide detailed information on fault geometries to depths up to ~50 km, along with *in situ* physical properties within and around fault zones within drilling windows, including (but not limited to): pore-fluid pressure, the structure of landslide complexes and underlying conditions associated with such gravitational instabilities, and sedimentary patterns associated with both landslides and fault zones, which can be used to construct timing and style(s) of deformation. For the "Earth Connections – deep processes and their impacts on Earth's surface environment" initiative, geophysical constraints are required to assess upper mantle properties at depths inaccessible to drilling, along with the distribution and character of magma bodies, faults and other structures that provide pathways for fluids from the deep Earth to the surface, some of which are currently being addressed by IODP. For the "Biosphere Frontiers – deep life, biodiversity, and environmental forcing of ecosystems" initiative, seismic reflection data constrain the distribution of magma chambers and associated plumbing systems of circulating fluids important to sub-seafloor life.

Finally, for the "Climate and Ocean Change – reading the past, informing the future" initiative, seismic reflection data characterize basinal and continental margin stratigraphic successions, which are crucial to understanding the "frozen tape recorder" of paleooceanographic/paleoclimatic change in the oceans globally.

Imaging constraints from reflection (and occasionally refraction) seismology are required by IODP for drilling approval and also essential prior to drilling for safety reasons. For example, 2D and 3D constraints on subsurface structures allow scientific ocean drilling to avoid seismic hazards, like active faults, structural closures and associated overpressures. Such situations occur in ocean basins, along continental edges, and in island arcs, all important current drilling arenas.

Finally, marine seismic reflection data acquisition can be optimized for a wide variety of science goals and targets, including goals and objectives for IODP. For example, long streamers and large air gun arrays in some modern seismic acquisition systems make it possible to constrain detailed seismic velocity structure to depths up to ~10s of km, which can then be used to recover detailed geometries of targeted subsurface features and provide constraints on *in situ* properties, like pore-fluid pressure, melt content, composition, etc. Cutting-edge analysis methods, such as full waveform inversion, make it possible to use such long-streamer data to provide velocity models in unprecedented detail, even for shallow targets. Features at scales as small as ~1 m can be constrained with available high-resolution systems. For complex environments (e.g., see Figure A), 3D seismic reflection imaging provides unprecedented constraints on geometry. All of these techniques mean that imaging is crucial to put drilling results in their proper geospatial, regional focus. There can be no effective scientific ocean drilling program capable of achieving primary science objectives moving forward without a continuing, healthy, international marine seismic effort.

A New Future for U.S.-based Marine Seismic Science…

In the wake of the "Sea Change" report, the future of marine seismic science in the U.S. is currently in transition, with the stated objective to become more inclusive in planning, facilities and techniques. Consequently, this is an opportune time to expand our thinking about the international portfolio of facilities at hand to accomplish the goal of increasing access to marine seismic imaging, which will in part support IODP. On December 1, 2016, the UNOLS Representatives approved a revision to the UNOLS Charter), thereby allowing for the establishment of the Marine Seismic Research Oversight Committee (MSROC, https://www.unols.org/committee/marine-seismic-research-oversight-committee-msro), inherited from the MLSOC (*Marcus Langseth* Scientific Oversight Committee). The revised UNOLS Charter includes the Terms of Reference for the MSROC, ANNEX IX *(see Appendix I)*. Approval of the revised UNOLS Charter effectively means that the MSROC will take over and replace the MSLOC as of December 11, 2016.

In the interim, members of the MSLOC, including the Chair, will serve as interim members of MSROC for up to three months, from December 1st, 2016. However, all will be required to submit new applications to become inaugural standing members of MSROC. A request for nominations for new members has been posted by the UNOLS Office to the community at large; the deadline for nominations was Jan. 18th, 2017. Applications will be reviewed by the UNOLS Council and final selection will be made by the Council before mid-March, 2017. Important facets of MSROC include: 1) a formal liaison with IODP, and 2) international participation.

…And A Cooperative International Concept

The key to increasing the availability of seismic reflection/refraction data for academically driven marine geology and geophysics globally, both for supporting scientific ocean drilling and beyond, is an increase in cooperation among countries with substantial marine seismic programs and capable linked seagoing facilities. Efficiencies in cooperation can result from collaborative planning, using facilities in regions where they are available, in order both to avoid long (unproductive) transits and deviations from generally used operations to acquire needed data. The advantage of such planning collaboration, to all programs, is the potential to deliver a wider array of facilities to a larger number of locations than can be achieved by any one (national) program alone.

Such an international collaboration requires several specific implementation efforts, all of which can be administered by an oversight body. We suggest that MSROC could be that body. First, there is a need to match capabilities of particular facilities with seismic acquisition needs and plans, e.g., submitted IODP drilling proposals, to assure that seismic imaging goals can be achieved with available facilities and that resources are indeed being used efficiently and effectively. Second, long-range (multi-year) planning among all parties involved is critical to assure sufficient time to develop seismic programs and coordinate with international partners and other, larger international science programs, such as IODP, Geoprisms, and the Subduction Zone Observatory (to name a few). Third, having adequate Memoranda of Understanding (MOUs) between the interested/participating parties will be critical to assure that operating terms and expectations are understood, in order to develop a framework of substantial and effective cooperation. The primary goal of the oversight body will be to develop initial guidelines for cooperation, and then to implement a long-term plan. We propose that the MSROC provide a substantial component of that oversight, in coordination with additional representatives of interested international parties (to be identified; potential representatives attended both the September 2016 Forum meeting and the November 2016 focus group meeting at L-DEO). The key to success is establish MOUs that define what it means to share facilities among international parties and facilitate opportunities for all involved. To that end, we propose to use and build on Europe's Ocean Facilities Exchange Group (OFEG, www.ofeg.org) plan of cooperation and facilities bartering system as a possible model, for developing terms that could be used to include a broader international community.

Moving Ahead with International Cooperation in the Context of the MSROC

The focus group which met at L-DEO on November 21, 2016, including representatives from the UK and Germany, was unanimous in its support for continuing the provision of, and efficient global scheduling of, large-scale (meaning non-portable) imaging systems and linked platforms, in order to advance seismic imaging in support of scientific ocean drilling.

The group considered the following plan to implement the avowed primary objective:

- Put together an international group of seismically cognizant representatives, ideally also with drilling experience; this group could build on MSROC;
- Have this group meet on a regular basis (but not less than once a year) to develop efficient imaging scenarios in support of scientific ocean drilling; IODP presently

develops its multi-platform drilling schedules several years in advance, in response to a well-respected, community-driven, proposal-submission model;

- This group will be chaired on a rotating basis by an internationally respected leader of both imaging efforts and scientific ocean drilling expeditions; that chair will be reimbursed in some measure (to be determined) for his activities;
- Ideally, this group will be under the purview of the international funding agencies that support both imaging and scientific ocean drilling, perhaps through the IODP mechanism of MOUs.

The group took note of the fact that the MLSOC was being replaced by a new entity, the MSROC (https://www.unols.org/committee/marine-seismic-research-oversight-committee-msro), and that the MSROC might fulfill many of the envisioned oversight group's goals. However, MSROC is presently under the umbrella of UNOLS, and that could not apply to the new drilling-centered seismic imaging/scheduling entity.

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