Broad Characteristics of an Academic Active-Source Seismic Capability to Replace that Previously Provided by R/V *Marcus G. Langseth*

The aim of this document is to describe, in the broadest possible terms, the desired characteristics of an academic active-source seismic capability to replace the capabilities currently provided by R/V *Marcus G. Langseth*. The path forward for identifying and selecting replacement capabilities includes a focused workshop in early 2019, and it is our hope that this document will be helpful in the preparation for that meeting.

Brief history. The National Research Council report *Sea Change: 2015-2025 Decadal Survey of Ocean Science* recommended that NSF divest ownership of R/V *Marcus G. Langseth*, citing the unsustainable cost of running that facility. NSF and the marine-science community have been working since that time to be responsive to the Sea Change recommendation by seeking a replacement capability, similar to *Langseth*'s, that could be sustained with support from NSF of up to $10M per year. One of the first activities was an October 2015 workshop in Washington, D.C. During that workshop, the capabilities of a 'removable' seismic system that could be added to an existing global-class ship were described, an overview of the availability and cost of seismic vessels within the exploration industry was presented, and a survey of existing seismic capabilities of international research organizations was presented. In 2017, NSF issued a solicitation (NSF 17-563) for the provision of marine seismic capabilities to the U.S. research community. Proposals were submitted and reviewed, but a suitable replacement was not found through the solicitation. NSF held to the position stated in the solicitation that "If no acceptable proposals are received, NSF will divest from R/V Marcus G. Langseth". A Dear Colleague Letter (NSF 18-061) announcing the outcome of the proposal review and the resulting intent to divest was released in April, 2018.

<u>Statement of goals</u>: The marine geoscience community broadly, and the marine seismic community in particular, seeks a **sustainable** replacement for the active-source seismic **capability** currently provided by *Langseth*, and NSF is **committed** to supporting such a capability.

This statement of goals is most useful if all interested parties have a common understanding of the key highlighted terms: sustainable, active-source seismic capability, and committed. With a common understanding of these terms, options for a replacement can be judged against both their sustainability and capability, and consideration of both of these criteria places strong constraints on viable options for a replacement capability.

The easiest term to define in this context is **committed**, which relates specifically to NSF's commitment to supporting the seismic capability. NSF has been clear since 2015 that they view this capability to be important to the broad portfolio of science that NSF-OCE supports, and that they can commit up to $10M annually in total to support this capability contingent on the demand for the capability in highly-rated research proposals. NSF has also indicated that this commitment is contingent on the sustainability of the replacement capability and the availability of funds to the Division overall.

The most nuanced term is **sustainable**. This term encompasses several components, including the replacement itself, the active-source seismic community, and NSF's science portfolio, all of which must be sustained. Sustainability involves subjectivity and probability, it impacts every conceivable replacement option, and NSF's commitment to a solution depends on the sustainability of the replacement model.

A **sustainable** active-source seismic capability is one that can, with a financial commitment of up to $10M/year from NSF, 1) support enough cruises to maintain a healthy community, and 2) maintain the providing facility at a high-quality standard, with stable costs, and with predictable availability. A healthy community is one that is not shrinking and is perhaps growing, where science return on the dollar is reasonable, and where NSF-OCE broad science needs are being met.

The 'community' and 'portfolio' components of this sustainability definition imply particular characteristics for the provision of the capability, in particular predictability and global reach. A healthy user community requires frequent and predictable access to data provided by the capability. A robust and dynamic science portfolio requires the ability to acquire data in the largest possible variety of settings.

The term **capability** encompasses the technical requirements of the replacement; in particular, the type and quality of seismic data that the replacement can provide and the physical infrastructure and technical expertise needed to acquire those data. The definition of this term is thus equivalent to a description of those technical requirements. The three main components of the physical infrastructure, apart from the host vessel, are the source, the receiving elements, and the data logging and navigation systems. Of these, the source and receiving elements place the major constraints on the operational model of the replacement.

The requirements on the source can be bounded by experience with R/V *Maurice Ewing* (*Langseth*'s predecessor), the track record of *Langseth*, and by outcomes of the October 2015 workshop. The 'removable' option discussed at the workshop involved the installation of a compressor on an existing global-class U.S. Academic Research fleet (ARF) vessel, and the physical constraints of that installation limited the air production to 3300 in^3 at a 10 s rate at 2000 psi. This energy level (equivalent to two of the four airgun strings currently on *Langseth*) was deemed to be too small, as it would substantially limit the types of science questions that could be addressed. At the same time, there is consensus that *Langseth's* well-tuned 36-element, 6600-in^3 array is not limiting for the science targets regularly proposed by the community, and that the *Langseth* source is far superior to that of the larger-volume (20 element, ~8500 - 10000 in^3) Ewing array. The general satisfaction with the *Langseth* source suggests that it should represent the standard. The source wavelet is well characterized in terms of energy level and compactness, bandwidth, and reproducibility; and the navigational accuracy of the source elements is also well documented. Any replacement source capability should meet this standard.

The requirements on the receiving elements are most easily described if we assume that these elements will consist of towed streamers of hydrophones. It is possible that some variety of seafloor-node technology may play a role in the replacement, but it seems more likely that they will not; and in any event the requirements for nodes will be similar to those for streamers in terms of source/receiver offset, element spacing, and positional accuracy.

Considering streamers, key questions are what maximum source/receiver offsets are required for 2D MCS acquisition, is a persistent 3D capability required and if so how many streamers and at what length. Since the beginning of operations on *Langseth*, the rate of 3D acquisition has averaged one dataset every other year. It seems unlikely that this rate will increase substantially, and at that rate it is difficult to argue that a persistent 3D capability is required, though the great value of the science resulting from existing 3D surveys argues strongly for continued access to a 3D capability. It should be noted, however, that a 2D versus 3D requirement may not represent as substantial a threshold on complexity as one might expect. For example, considering an industry model for the provision of the capability, all viable industry vessels are 3D capable. For a model that involves a vessel within the U.S. ARF, a requirement for 2D acquisition with a single 12- to 15-km-long streamer imposes nearly the same infrastructure requirements (in terms of space and reels) on the vessel as the additional requirement of a persistent

3D capability involving a 4x4-km streamer configuration, assuming standard seismic-ship layouts. In this case, a long-streamer 2D requirement implies a relatively low-cost step to a persistent 3D capability.

The maximum required streamer length for 2D MCS acquisition may thus place the most limiting constraint on a streamer-based replacement option. There is not a single, correct value for this length. In principle, longer offsets are always better, but there are practical considerations and risks that limit maximum streamer lengths to ~15 km. A useful rule of thumb is that reasonable velocity information can be obtained from reflection travel times to boundaries at a depth comparable to the maximum source/receiver offset. Streamer lengths of 12-15 km would thus provide high quality imaging with velocity information through most of the world's oceanic crust, to depths that span important regions of the seisomogenic zone within subduction systems, and to any depth that could plausibly be drilled for scientific purposes. There is ample justification to require that the replacement be capable of acquiring data comparable (in terms of shot and group spacing and maximum source/receiver offset) to what can be acquired with a towed MCS streamer of 12-15 km length.

Capability Requirements
R/V *Marcus G. Langseth's* replacement capabilities should thus have the following technical characteristics:

• A seismic source that meets or exceeds the standard of *Langseth's* 36-element, tuned array in terms of energy level, wavelet compactness, bandwidth, and reproducibility;

• An ability to acquire 2D MCS data comparable (in terms of shot and group spacing and maximum source/receiver offset) to what can be acquired with a towed MCS streamer of 12-15 km length;

• A state-of-the-art data logging and navigation system, including GPS and acoustic based positioning of source and receiving elements, and data sampling rates capable of capturing the full bandwidth of the seismic pulse; and

• Continued access to a 3D seismic capability at a rate consistent with historical averages.

These capability requirements imply access to both physical and expertise infrastructure. Discussions regarding a replacement capability have focused on physical infrastructure. We note here that access to expertise infrastructure is also important, as was also noted in reviews of proposals to solicitation NSF 17-563 that aimed to provide access to industry seismic capabilities. Access to expertise infrastructure would include, at a minimum, activities such as full engagement of PIs in the technical planning of data acquisition, at-sea training for early career scientists, and participation of students in cruises. Deep knowledge of the methodologies and art of acquiring marine seismic data is important for the analyses of these data and for the evolution of methodologies. Maintaining this knowledge is thus important for sustaining the community and its ability to expand analytical capabilities.

Joint Requirement of Sustainability and Capability
A number of particular options and models have been discussed for the provision of marine seismic capabilities to the U.S. research community following NSF's divestment of *Langseth*. The joint consideration of both sustainability and capability requirements places strong constraints on the viability of these options, and we advocate that both of these requirements are given full weight in discussion of replacement options. Without prejudice, we provide some example considerations. A model that involves structured access to exploration industry seismic ships would satisfy the capability requirement, but it is unlikely to have sufficient predictability in cost and availability nor sufficient global reach to satisfy the sustainability requirement, and there are significant questions about the potential for at-sea training. A model that relies solely on infrastructure controlled by non-U.S. research organizations would also likely be limited in predictable availability and also global reach. An option

involving a vessel wholly within the U.S. ARF would have global reach and predictable availability. However, a seismic facility on such a global vessel may not have stable or predictable costs with a primary dependence on NSF funding if the vessel is highly specialized toward primarily seismic data acquisition. A highly specialized seismic vessel would require the balance of support for this facility to rely on exploration industry work, the availability of which is difficult to predict. A capable and sustainable active source seismic facility on a US global-class vessel would thus likely require specific non-seismic capabilities to be sustainable.