To: The Deep Submergence Research Community
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Date: November 26, 2002
Subject: A perspective on two decades of deliberations regarding deep submergence facility requirements and suggestions for the future

Dear Colleagues:

I hope you are well and that you will take a few moments to read this as you are traveling to San Francisco, in advance of the DESSC meeting at AGU on December 5. There are two main reasons for drafting these words: one is to provide a historical perspective on deep submergence facilities and the other is to provide my assessment of a reasonable path to ensuring the necessary deep submergence capabilities for all facets of the research community. First, I have greatly valued my collaboration with many of you and the research community in general over the past few decades in our collective efforts to improve the National Deep Submergence Facility (NDSF) at WHOI - a focus of my activities for the past decade and more. In reviewing two decades of documentation regarding the incremental and steady improvement in UNOLS and NDSF oceanographic capabilities, I found that the federal agencies and the community can be proud of the consistent progress that has been made to better the facilities that marine scientists use to collect data at sea and conduct their research. The interplay between scientists, federal agency representatives and facility operators has been constructive and focused, the result being US researchers have at their disposal state-of-the-art ships, data acquisition systems and deep submergence vehicles. The 1999 Ocean Studies Board report on UNOLS echoes this view.

History always provides a vantage point for determining the future. I present below a brief review of the historical record that I believe will help properly assess the current status of deep submergence facilities in the US and the future requirements. If you feel you already know this, skip the "History" section and proceed to the "Future".

A Brief History

First, it should be clear that many individuals and groups at numerous US institutions have played key roles in deep submergence technology development since the 1950s following the war effort. In the case of deep submergence, the construction of *Alvin* for US Navy strategic interests in the early 1960s, and its eventual integration into US oceanographic facilities in the mid 1970s following the FAMOUS program to the Mid-Atlantic Ridge, ushered in an era where scientists could routinely propose to do basic research and conduct experiments in situ on the seafloor. The literature is replete with seminal publications stemming from the early work with *Alvin*. The key point to note is that in the early 1980s it became clear that Lulu, the first *Alvin* support ship, was proving to be a very limiting factor to the global scientific investigations that needed to be conducted with *Alvin*. The 1982 Submersible Science Study (SSS), funded by NSF, ONR and NOAA was key in providing the justification for conversion, in 1983, of R/V Atlantis-II to be the new *Alvin* support vessel. A-II provided increased berthing, lab space, endurance, and multi-beam mapping capability for pre-dive surveying. Also significant was the modification of *Alvin* to a single point lift and installation of a special A-frame for launching and recovering the submarine. That A-frame is still in use today on R/V Atlantis. The 1982 SSS report is perhaps the first committee report convened and funded by the federal agencies that pertains specifically to US deep submergence scientific facilities. The report date is April 1982 - the start of our 20-year historical perspective on these topics. Also in the SSS report are recommendations that, it turns out, have been consistently reiterated over the past 20 years. These include: increasing the depth range of *Alvin*, ensuring capabilities to launch and recover remotely operated vehicles and autonomous vehicles from the *Alvin* support ship, and improvements to *Alvin's* sensors and imaging systems.

The next NSF, ONR and NOAA funded study was in 1986, conducted under the auspices of UNOLS. That study, entitled "*Alvin* '86 A Report on the Program's Status", provided an assessment of both the current and future science to be carried out with *Alvin* and the status of the facility at Woods Hole. The key points to note from that study are: 1) the science being accomplished was excellent and

the prognosis for continued productivity was very good, 2) technological improvements to *Alvin* were necessary in various areas (navigation, imaging/lighting, sonar, data logging, payload and manipulators) to optimize science operations, 3) foreign governments (France, Japan and Russia) were developing deeper diving submersibles and the US should initiate efforts to both keep pace with improved technology and attempt to gain access to foreign submersibles so that US scientists can have access to the deep ocean >4000m with a submersible, 4) the "*Alvin* Review Committee" should be revamped, and 5) a Submersible Science Study Committee (SSSC) should be sponsored in 1986-87 to assess shallow submergence science and facility needs as well as investigate the specific research imperatives for science at depths greater than *Alvin's* then depth limit of 4000m.

The SSSC report, conducted in 1987-88 and published in 1990, focuses on four issues: 1) the immediate need for funding much-needed improvements to *Alvin's* science and imaging sensors, 2) gaining access to depths greater than 4000m, 3) providing better access to shallow water submersible facilities for research, and 4) establishing a permanent submersible science committee. Note these recurring themes regarding improvement to facilities and needing access to greater depths, which remain valid to this day. The early 1990s are also important because they ushered in an era of viable remotely operated vehicle (ROV) technology and capabilities. With specific regard to ROVs used in the academic community, in 1994, *ROV Jason* was integrated into the NDSF, along with the *Argo II* and *DSL-120* sonar mapping systems, thereby creating a significantly improved national deep submergence capability with access to depths as great as 6000m. In addition, in 1994, *Alvin's* titanium sphere was recertified to 4500m - hence improvements in depth capability for US scientists have been steadily implemented. The take-home message for me is that the open collaboration between federal agencies, engaged scientists and facility operators has served to define and implement the necessary improvements for the entire community to the present.

Since the mid-1990s there have been several additional committees, workshops, reports and technical publications focusing on the evolving deep submergence technology in ROVs and autonomous underwater vehicles (AUVs), as well as the continuing needs for human-occupied vehicles (HOVs) for basic research in the deep ocean and seafloor. Briefly, these include: the "Global Abyss" report of Sept. 1994 that followed a large community workshop in Oct. 1992, various issues in Marine Technology Society Journal (e.g., v24, #2; v26, #4), a 1996 NRC study funded by the US Navy ("Undersea Vehicles and National Needs"), a workshop in 1997 on assessing the Navy's *SeaCliff* and possible use for science, the Oct. 1999 DESCEND workshop that produced an executive summary in Dec. 2000, a 2000-2001 US Navy sponsored working group to investigate a new, deep diving nuclear research sub. (RAND report), and most recently a NOAA and NASA sponsored LINK workshop (May 2002) that addressed, in part, future shallow and deep submergence facility needs. Most of the references to these studies (or summaries of them) can be found at the UNOLS web site or can be requested from the UNOLS office.

The past ~8 years of deliberations concerning future deep submergence facility requirements, summarized in the reports cited above, are important because they set the stage for the current debate that is in progress at both a federal agency and advisory board level, and within the community. A balanced capsulation of those reports with regards to deep submergence science facilities is:

1) The science community has seen the important benefits of modern ROVs and more of them are required to augment US vehicle capabilities and provide access to globally diverse study areas at depths to 6500m.
2) AUVs are currently demonstrating superb mapping capabilities and their importance to a wide-range of deep submergence science. Accelerated development, construction and operational support for more AUVs with diverse operational characteristics are necessary.
3) There continues to be a need for in situ observation and sampling of seafloor processes and terrains for biological, chemical and geological investigations- a new US submersible should be built with a depth range of 6500-7000m to provide improved HOV capabilities for the next several decades.
4) Innovative deep ocean sensors and instrumentation are required for the diverse array of ocean floor observatories and other basic research programs that are being planned.

These four community-wide recommendations are well documented in the recent reports and reiterated throughout the last ~8 years of deliberations. One recent, direct result of this community consensus and federal agency collaboration is the construction of the new 6500m rated *Jason II* ROV; placed in service in Sept. 2002 and successfully conducting science operations. This is a very recent example where the community spoke with clarity and justification, the federal agencies responded with funding, and, in this case, NDSF at WHOI implemented the technology and placed the vehicle in service for science.

The Future

A key to understanding both the current status of deep submergence facilities in the US and the current debate (see Eos Forum article, "Being There: …", v83, #46, Nov. 12, 2002) regarding the proper mix of deep submergence vehicle systems for future US basic research programs in the deep ocean is this: for 20 years the federal agencies and the science community have collaborated superbly on identifying and solving problems related to the provision of fundamental facilities to conduct deep-sea research. Fact: the US science community has at its disposal an integrated NDSF comprising complementary vehicle systems including a 4500m rated *Alvin*, 6500m rated *Jason II* ROV, and upgraded *Argo II* and *DSL-120A* sonar mapping systems (also rated to 6500m). In addition, ROVs like MBARI's *Tiburon* (4000m depth rating) and the Canadian *ROPOS* (5000m depth rating) continue to provide important capabilities to a subset of scientists in the US, and they will undoubtedly play an important role in the coming decades of deep seafloor science. These very complementary facilities and the high-resolution imaging and mapping capabilities they provide, continue to be one key reason why US scientists enjoy broad and technically sophisticated access to the deep seafloor for their research. I submit that no other country does this to the extent and with such open access as the US. I don't mean to suggest that we should be complacent--not at all. But this panoply of capabilities and vehicle systems is important when considering the future and how we approach the problem of ensuring continued US leadership in ocean floor research and deep submergence technology.

So, given both the historical record and the current status of deep submergence facilities in the US is there a substantive need for pitting *Alvin* against the modern class of ROVs? Are HOVs like *Alvin* still required for seafloor research? Can ROVs, in fact, do everything that a submersible like *Alvin* does? Are there substantial cost-benefits of proceeding down one path versus another? Does the community require a diverse suite of vehicle systems to support the wide range of scientific and engineering problems to be addressed in the next few decades? These are important questions that the community needs to speak clearly about and achieve consensus on if we are to present a unified platform to the funding agencies for the required facilities. I believe much of that consensus and justification has been provided by the last 8 years of meetings and reports - but a review and synthesis of those findings will no doubt be helpful and perhaps this document can serve to precipitate that.

One issue that has not been fully discussed is the cost-benefit of HOV versus ROV. I believe that part of the polarization on this topic has developed because of false assumptions. Based on reasonable estimates one can place the capital cost of building a new 6500m *Alvin* at ~$18-20 million (the current New *Alvin* Design Advisory Committee is tasked with developing the functional specifications for a new HOV and will be reporting at the DESSC meeting). The new *Jason II* ROV cost ~$3 million to build. However, I contend that one cannot, from these figures, conclude that the capitalization costs of HOV to ROV are ~6:1. They are not; because *Jason II* doesn't provide 3D cognitive vision and the degrees of freedom and other capabilities that *Alvin* does. If one were to cost-out what it would take to build an ROV with full virtual reality (something that does not currently exist in any ROV system) I submit that the capital cost ratio would be much less- probably approaching 2:1 or 1:1. But from a long-term budgetary perspective, it is not the one-time capital costs of facilities that are key. The operational costs are the most important driver. With regards to the historical record for NDSF, it has been demonstrated that the daily facility cost for either *Alvin* or *Jason II* is equivalent: ~$10,500./day.

In 1994, when ONR, NSF and NOAA provided the framework for integrating *ROV Jason*, *Argo II* and the *DSL-120* sonar into the NDSF, it was clear that the message of the 'Global Abyss'

report - for improved facilities, inclusion of ROVs and AUVs, and deeper capabilities - had been well received and was being implemented. Since the mid-1990s significant improvements to all of the NDSF vehicle systems have been made, largely through support provided by you the community, and funded by the federal agencies and implemented by NDSF at WHOI. During the past few years, we have been seeing in the published literature the important science benefits of complementary deep submergence vehicle systems - high resolution sonar to guide seafloor mapping and sampling, ROV capability that provides global reach, ROV and submersible joint investigations, and continued improvements of *Alvin's* core sensor and imaging systems to the point where they have produced exceptional imagery for a diverse range of multidisciplinary science and outreach efforts. I personally see that a continued suite of complementary vehicle systems will produce the best science and provide the necessary facilities to meet the research and engineering challenges of the next few decades.

The current debate over the importance of human access to the deep ocean is not new. It is my view that in situ observations will continue to be important for a wide range of research and engineering for at least the next several decades. At the same time, the advent of increasingly capable ROVs and AUVs has greatly expanded the nature of seafloor and oceanographic investigations in ways that could only be dreamed about 20-30 years ago. Should we have abandoned piston coring ~15 years ago because hydraulic piston coring could be done from the drill ship? As absurd as that question is, clearly the answer is no; we would have a much poorer understanding of a whole class of oceanographic and climate related processes were it not for the core material in various repositories. So, do we not need *Alvin* because there are quite capable ROVs in operation? Can ROVs really carry out *all* of the same types of science as HOVs? I believe the answer to these questions is an unqualified no - for reasons mentioned in the just published Eos article on this topic that I hope you all take the time to review.

The pitting of *Alvin* versus ROVs is ultimately damaging to the health of the deep submergence facilities that our community will rely on for the next several decades. Structuring the debate in this way ignores an axiomatic scientific principal—that multiple, complementary instruments or facilities are often required to solve basic scientific problems. For instance, no one would argue with the need for a diverse fleet of oceanographic research ships that include coastal vessels, intermediate range ships for regional studies, drilling vessels or platforms, global class vessels, and ice-strengthened vessels capable of polar investigations. One cannot understand all aspects of a research problem, or specific multidisciplinary dynamic interactions and their manifestations within earth or ocean processes by using only one instrument. The same is true for deep submergence vehicle systems. The multidisciplinary problems that are now, and will continue to be, studied for the next several decades in core and program-specific science, and observatory experiments in the deep ocean require an array of complementary vehicle systems – HOVs, ROVs, tethered systems and AUVs.

There is no doubt that ROV and AUV technology will continue to advance. I believe it is also important to make improvements to HOVs, building on those that have been implemented during the past 20 years, which have produced a body of scientific results that can be measured in many hundreds of important scientific papers. There has been considerable deliberation on this topic over the past 8 years and we are on the threshold of both opportunity and responsibility with regards to planning for deep submergence facilities for the next few decades- a process that takes at least 3-5 years from concept to funding, construction and delivery. Ocean floor observatories will no doubt require a step-function in vehicle capabilities and specialized features for both installation and maintenance. Ocean floor observatories and the science to be conducted from them, as well as those associated with basic research and exploration are placing increasing demands on our current fleet of deep submergence systems. The community, federal agencies and facility operators should collaborate on what has been a very successful method to improve deep-ocean vehicle capabilities. Discussions, meetings, workshops and reports have been written which reflect recent sentiment. I believe the broad oceanographic community seeks improved and expanded capabilities, not one type of vehicle system versus another. I look forward to discussing these important topics with you at the DESSC meeting on Dec. 5 and working with you for improved and expanded facilities for deep submergence research.

Best Regards,
Dan Fornari