UNIVERSITY-NATIONAL OCEANOGRAPHIC LABORATORY SYSTEM

UNOLS

DEEP SUBMERGENCE SCIENCE COMMITTEE

SEACLIFF
WORKING GROUP REPORT
July 1997

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SEACLIFF Working Group Report

Executive Summary

Routine access to the deep ocean and seafloor has allowed the U.S. oceanographic community to make important biological, geological and geochemical observations and discoveries which have had significant impact on our understanding of oceanographic and Earth processes. This scientific and technical knowledge has provided important benefits to strategic, educational and public interests. Nonetheless, scientists have explored only a small portion of the deep sea and ocean floor, and it is now clear that a spectrum of deep submergence tools and vehicles are required to address the research questions of the last frontier -- Inner Space, into the 21st century. The compelling nature of science and exploration in the abyss requires deep submergence vehicles that can provide scientific access to ~9000 meters depth. We need to initiate development and continue refinement of these vehicles and their capabilities using modern technologies to make this a reality within the next decade.

The DEep Submergence Science Committee (DESSC) and a working group, comprised of leaders in the marine science community, were recently tasked to deliberate on the effective utilization of the U.S. Navy's submersible SEACLIFF and on the facility needs of the U.S. academic, deep submergence community. These deliberations provide a tremendous opportunity because they require the marine science community and federal funding agencies to make important short-term and long-term decisions regarding U.S. leadership in deep submergence science and technology, and the facilities required to maintain that leadership position.

The facts and scientific rationale discussed below, coupled with the U.S. Navy's decision to decommission SEACLIFF, provide an important opportunity to define and plan the future vehicle composition of the U.S. National Deep Submergence Facility to meet the projected scientific objectives of the early decades of the 21st century. DESSC and its SEACLIFF Working Group believe there are a number of critical areas which must be addressed if the U.S. is going to continue to be a leader in the science and technology of deep ocean research. They are:

- focused, cost-effective, and technically capable national deep submergence facilities and operators,
- an integrated mix of vehicle systems including human occupied vehicles (HOVs), remotely operated vehicles (ROVs), tethered mapping systems and autonomous underwater vehicles (AUVs),
- a stable, federal funding base to support science, technology and enabling vehicle and ship facilities in the deep ocean with a lead federal agency to help advocate for a U.S. Inner Space program in the 21st century.

The clear consensus of the SEACLIFF Working Group and the community that responded to a DESSC questionnaire regarding the future of deep submergence science is that:

1. there are many important science questions to be answered and objectives to be met at depths greater than 4500m,
2. there is a critical need to maintain the excellent HOV capability which now exists in ALVIN to 4500m,
3. there is support for having a 6000m HOV capability provided the costs are not prohibitive and the impact to conducting science in the more traditional depth range of ~2500-4000m is not negatively impacted, and
4. we should support the critical need for new ROV and AUV development, specifically the development of a science dedicated ROV with a 9000m depth capability that should enter service within the next five to seven years.

The SEACLIFF Working Group supported DESSC's preliminary response to Dr. F.E. Saalfeld (December 5, 1996) which stated that given the current federal funding constraints and the level of technical knowledge necessary to operate deep diving submersibles, it would not be prudent at this time to consider developing additional National centers for operating deep submergence vehicle facilities. Community response indicates there is strong support for HOV depth capability to 6000m, and to 9000m for ROVs, to allow for research over a wide range of tectonic, sedimentologic and geographic environments. The Group acknowledged the continued need for an HOV at abyssal depths and in general, supported the concept of engineering an HOV using some combination of ALVIN and SEACLIFF equipment to create a 6000m HOV. However, the Group could not rank or seriously consider any of the more viable options for utilizing SEACLIFF because costs in time and money for the conversion were not available at the time of the meeting, and a detailed technical feasibility study has not yet been done, nor have any commitments for increased funding for the National Facility to accommodate conversion/utilization of SEACLIFF been made.

Based on the information available at the meeting, the Working Group's responses to the specific options listed in the October 1996 letter from Dr. F.E. Saalfeld of the Office of Naval Research (ONR) are:

OPTION	WORKING GROUP RESPONSE
1. Deactivate SEACLIFF.	Unwise use of facility.
2. Transfer to other than WHOI.	No
3. Decline SEACLIFF.	No
4. Accept SEACLIFF, retire ALVIN.	No
5. Accept SEACLIFF, retain ALVIN.	No
6. Accept SEACLIFF, operate ALVIN.	No
7. Modify SEACLIFF using ALVIN.	Serious Reservations-Probably No
8. Modify ALVIN using SEACLIFF sphere and parts to create a 6000m HOV.	Possibly - but needs further technical evaluation and identification of funding sources.

WHOI OPTION	WORKING GROUP RESPONSE

8A. Use SEACLIFF parts to improve ALVIN, keep SEACLIFF sphere for future upgrade.	Yes-Many advantages for current ALVIN capabilities.
9. Redesign of vehicle using ALVIN and SEACLIFF equipment.	Possibly - but needs further technical evaluation and identification of funding sources.

The Working Group agreed that Woods Hole Oceanographic Institution (WHOI) and DESSC must work together with the Navy to gather more specific information regarding the costs that options 7, 8, 8A, and 9 represent, and what the science capabilities of a merged vehicle are expected to be. A proposed ONR funded engineering study by WHOI of these options was recommended.

The Working Group also discussed additional strategies to provide more frequent access to areas of the ocean floor below 4500m in the near future. There was clear support for the increased use of ROVs and this was supported by the results of the survey. With the financial constraints that exist for deep submergence facility support at the present time, the Working Group strongly recommended pursuing Option 8A and using the funds saved, along with new funding, to develop a new ROV for science with a depth capability of 9000m and greater sampling and payload capability. This would allow the scientific community to access virtually all of the areas of compelling scientific and technical interest, and would represent a military contribution to the betterment of science and public welfare.

Introduction

This report presents the findings of a Working Group established by the DEep Submergence Science Committee (DESSC) of UNOLS, which deliberated on issues pertaining to the retirement of the U.S. Navy deep submergence vehicle SEACLIFF, and how that facility, and the equipment associated with it, can best be used to serve academic deep submergence research and other national needs. This Working Group was organized in response to a request in October 1996 from Dr. F.E. Saalfeld (ONR) for information and guidance from DESSC regarding the effective utilization of SEACLIFF which will be retired in FY98 as well as an assessment of deep sea scientific research objectives for the next few decades. Following this request, DESSC provided a preliminary response (December 5, 1996) regarding long range scientific objectives and the projected requirements for deep submergence vehicle systems and facilities to meet those needs. In accordance with DESSC's overall plan to include the perspectives and requirements of the deep submergence research community in this planning process, a more formal and comprehensive assessment of these issues was carried out by the SEACLIFF Working Group which was comprised of experienced users of deep submergence facilities, including some DESSC members (***Appendix I***).

To ensure maximum community input to the deliberations, a questionnaire was distributed by mail and via electronic mail in February 1997 to over 400 members of the research community (***Appendix II***). The questionnaire was designed to compile some specific responses on key issues related to deep submergence vehicle access to the sea floor for academic research, research directions in the 21st century, and it posed several questions pertaining to the options presented in Dr. Saalfeld's letter to Dr. Perfit and DESSC regarding SEACLIFF retirement and transitioning to the academic community.

The working group met on March 20, 1997 in Washington, DC, and its tasks were to:

1. deliberate on the future facilities needs for deep submergence research,
2. review the results of the deep submergence/SEACLIFF questionnaire distributed by the UNOLS Office,
3. discuss how SEACLIFF and its associated equipment can be integrated into future academic research facilities requirements for deep submergence,
4. discuss the scientific and financial impacts of pursuing various SEACLIFF retirement options,
5. and draft a Working Group response to Dr. Saalfeld of ONR, and other federal agencies which support deep submergence research, on the various options proposed by ONR for disposition of SEACLIFF, and future research directions and facility requirements for deep ocean research.

Future Deep Submergence Research Directions

Working Group members discussed current and future research directions for deep submergence science and important objectives to meet at depths between 4500m and 6000m. The disciplines involved in deep submergence research are varied and the scales of investigation range many orders of magnitude from micron-sized bacteria to segment-scales of the mid-ocean ridge (MOR) system, 10's to 100's of kilometers long. These processes occur at depths between ~1500 m in the mid-water environment and shallow volcanic edifices and ~9000m-11,000m in the deepest trenches.

The most recent, comprehensive assessment of future deep sea research objectives for the coming decades was presented in a report titled: The Global Abyss: An Assessment of Deep Submergence Science in the United States (UNOLS, 1994) which was prepared by DESSC and included contributions from many individuals working in different disciplines of deep ocean research. That report, which presents a balanced, multidisciplinary view of deep sea research - present and future, makes a compelling argument that deep submergence science is mature enough to identify many important biological, chemical, geological, and engineering problems that require human presence, in situ and remotely, in the abyss. Most of the world's sea floor, whether along the global ~60,000 km of mid-ocean ridge crest, or in mid-plate or convergent margin abyssal terrain, has yet to be explored or mapped in detail using near-bottom techniques. Consequently, multidisciplinary deep sea research embodies all the challenges of frontier science with the potential of making startling discoveries which can have important societal and strategic impact into the 21st century.

Such was the case in the mid- to late 1970s with the discovery of deep ocean hydrothermal communities and hot vents. These discoveries revolutionized our concepts of deep ocean chemistry, biology, and geology. They also propelled deep submergence science, and the related fields of deep sea microbiology, biochemistry and biotechnology, in new research directions. Discovery in 1991 of the immediate after-effects of a submarine eruption on the East Pacific Rise crest (Haymon et al., 1993) and similar observations along the CoAxial Segment of the Juan de Fuca Ridge in 1993 (Embley et al., 1995), the Gorda Ridge and Loihi Seamount in 1996, have provided further impetus to investigate the processes which begin the biological colonization of the sea floor and lead to the creation of 75% of the Earth's crust.

Associated with these discoveries are recent hypotheses predicting the existence of a deep, hot biosphere in the ocean crust (Deming and Baross, 1993), conceptual approaches to monitoring crustal accretionary and deformational processes using ocean floor observatories (Spiess et al., 1995), and models of fluid circulation and heat flow through the ocean crust that provide us with a better understanding of the chemical and thermal exchange between the solid earth, the hydrosphere and the biosphere (Kadko et al., 1995). In addition, tectonic and geotechnical studies of oceanic trenches, continental margins and oceanic islands related to catastrophic slope failure and seismic/volcanic hazards, all are important research topics at depths >4000m that will be the focus of fundamental deep submergence research well into the 21st century. Jointly, deep submergence and oceanographic studies play a significant role in understanding global CO_2 levels and climate change, understanding mid-water and benthic oceanographic processes and their impact on world fisheries stocks, determining new solutions for solid waste disposal in the oceans, and expanding opportunities for biomedical technology.

The effects of subduction of the oceanic lithosphere beneath both continental and oceanic lithospheric plates are the targets of recently focused interest in the marine geological and the MARGINS initiative (MARGINS Report, 1996). It is in these extremely active tectonic localities that continental crust begins to form, the most destructive earthquakes and tsunamis are generated, and vast quantities of hydrocarbons accumulate. The chemistry of fluids from the subducting slab at convergent margins and the vigorous biological communities that they support at depths >4000m are also new areas of chemical and biological research. While we have amassed a great deal of information regarding subduction of lithospheric plates through land-based seismic and volcanologic studies, subduction phenomena represent an aspect of the formation of the Earth's surface that we have never been able to systematically study in detail.

In the mid-plate regions, the problems of lithospheric aging, hot spot volcanism, and the phenomenon of formation of new subduction zones can only be addressed with vehicles capable of reaching depths >~5000 m. Deep ocean trenches at established convergent margins occur at depths of greater than 11 km and have only been visited in a cursory manner with bathyspheres such as the TRIESTE. The great depths of the trenches preclude investigation with nearly all of the existing techniques and available deep submergence vehicles. The new discoveries of active serpentine mud volcanoes and complex suites of rocks within the overriding plates in these convergence zones can only be explored fully if deep submergence vehicles capable of mapping and sampling at depths between 4000m-9000m are available. Finally, the actively spreading backarc basins of convergent margin regions are the sites of production of a unique oceanic lithosphere and form some of the potentially richest reserves of metallic ores on Earth. The study of the formation of lithosphere and metallogenesis in these basins is very poorly understood and without detailed, in situ investigations, models which will allow us to extrapolate what we find in arc and backarc environments to interpret subaerial exposures will remain inadequate.

In summary, studies of mid-ocean ridge processes, deep sea biological and microbiological communities, subduction and crustal recycling, climate change, oceanic volcanism, and the exchange of chemicals and energy transported by fluids through the oceanic crust and at convergent margins are all areas which require deep submergence vehicles capable of a wide variety of mapping and sampling tasks. Clearly the spectrum of scientific problems, and environments where they must be investigated, require access to the deep ocean floor to depths at least as great as ~9000m, with a range of safe, reliable, multi-faceted, high-resolution vehicles and sensors, operated from support ships that have global reach and good station-keeping capabilities. Providing the right complement of deep submergence vehicles and versatile support ships from which they can operate, and the funding to operate those facilities cost-effectively, is both a requirement and challenge for satisfying the objectives of deep sea research in the coming decades.

Questionnaire Results

A copy of the questionnaire developed by DESSC that was mailed to 420 members of the deep submergence/oceanographic community is presented in ***Appendix II***. The tabular and graphical summaries of the questionnaire are presented in ***Appendix III***. Approximately 25% of those polled responded. The greatest number of responses came from marine geologists and biologists followed by chemists and geophysicists. The most frequently listed research areas were the mid-ocean ridge and continental shelf/slope regions which combined, accounted for over 50% of the total. The survey showed that while eighteen different remotely operated vehicles (ROVs) had been used, the most extensively used deep water vehicles were Jason, the Canadian ROPOS, and the Navy's ATV. Approximately 50% of the people who responded to the survey indicated that they had not used ROVs in the past five years whereas 78% had used a human occupied vehicle. ALVIN was by far the most frequently used HOV, and represented over 50% of the total use of those responding to the survey. Twelve different HOVs were listed as having been used, some of which were shallow water (<1000m) vehicles.

The survey showed that there is a good deal of interest in having access to a maximum depth range of 6000m by deep submergence vehicles for the next twenty years; 37% felt this should be the maximum depth range versus 26% that supported 4500m. Most respondents indicated that HOVs were very important to critical for depths to 4500m (85%) and many (56%) thought there would be an HOV need to 6000m. At depths greater than 6000m, HOVs were considered less important as a scientific tool; although 25% felt they were very important to critical. Individual comments by respondents stressed that there is no substitute for human presence in the deep ocean and there are important needs for HOVs up to 4500m particularly at sites in the ocean where long term, time-series experiments of a multi- and inter-disciplinary nature are occurring. Work in the Western Pacific will require an HOV with deeper depth capability than 4500m. While it was suggested that international assets should be considered for accessing deeper depths, it was also noted that U.S. scientists have little control in determining where foreign submersibles operate and very limited access to them. ROVs should be used for work at the deeper depths when feasible, and development efforts need to be made to make these vehicles more science capable.

Scientists were evenly divided between regarding whether it is critical or not important in responding to the degree of importance of having an HOV that operates between the depths of 4500m to 6000m. Many of those who felt it was critical worked on the deeper mid ocean ridges and in the Western Pacific. Also, many were concerned that with the retirement of SEACLIFF we will lose our national and strategic capability for HOV access to 6000m. Many of the people indicating that HOVs were not important at depths greater than 4500m felt that most of the scientific tasks could be handled by ROVs. When asked to what extent current and future science objectives could be met at depths >4500m, most indicated that between 50% and 100% of their work could be done by either HOVs or ROVs. Fifty-one percent indicated that HOVs could accomplish greater than 75% of their objectives at depths greater than 4500m in comparison to 47% who felt that ROVs could do it. Smaller payload capabilities of many ROVs compared to HOVs was a common concern (although development of new strategies for elevators is helping to mitigate the ROV payload problem), whereas limited bottom time was a problem noted for HOVs. Some respondents indicated that both HOVs and ROVs are needed as deep submergence tools. It was also noted that at greater depths bottom time of HOVs is much more limited compared to ROVs. Many felt that less than 10% of their work could be accomplished by AUVs, and voiced concern about their limited payload capabilities. The lack of popularity of the AUVs was largely due to the admitted unfamiliarity with AUVs and the fact that many of these vehicles have not yet been proven as mature science tools.

Category B of the questionnaire focused on options available for SEACLIFF upon retirement from the Navy. Many responded to the questions posed by answering "unsure" because they were unfamiliar with SEACLIFF's capabilities or they were concerned with the financial implications of the option and felt they could not answer with confidence. Many felt that SEACLIFF and ALVIN should be merged with the result being a 6000m depth capable submersible. Others indicated that the submersibles should not be merged and that the systems should be kept intact as is. Still, others were concerned about SEACLIFF's capabilities and strongly recommended that ALVIN's capabilities be preserved.

The majority of responses (53% NO, 7% YES) indicated that SEACLIFF should NOT replace ALVIN, citing SEACLIFF's poor track record and ALVIN's proven capabilities. They did not want to compromise ALVIN's performance for increased depth capability. It was noted that SEACLIFF has less capability in sampling and as an observation platform. Responses were mixed (24% YES, 44% NO, 32% UNSURE) on whether or not SEACLIFF should be transferred to another facility of institution. Those opposed to transferring SEACLIFF to another facility indicated that this would place a risk on both facilities and would strain funds available to the deep submergence facility. A centralized operation was noted to be more cost-effective. Those in support of this option felt that two facilities would add versatility in scheduling and greater access to the sea floor.

Responses were very positive (59% YES, 14% NO, 27% UNSURE) for transferring SEACLIFF's equipment to WHOI for use in enhancing ALVIN and preserving the titanium sphere for later use. Most found this to be the best alternative and most cost-effective option. Those opposed to this idea suggested building a new class of 6000m HOV or keeping SEACLIFF available if funding could be found.

Status of WHOI's Engineering Study re: SEACLIFF/ALVIN Conversions/Upgrades

Dudley Foster reported that WHOI has been evaluating the technical feasibility of the various options regarding the future of SEACLIFF that were provided to DESSC in a letter from Dr. Saalfeld. WHOI reviewed Options 4 through 8, since these involved the acceptance of SEACLIFF by the Federal Agencies, and the Working Group had dismissed Options 1-3 as not viable. The Working Group understands that WHOI will submit an initial response to ONR in the near future. WHOI plans to follow the initial written response with a detailed engineering/cost study of the preferred option(s) which will result in a full report to ONR in the fall. The Working Group was very supportive of this study because they felt it was difficult to decide which option was best without knowing the cost to the community and the down-time for ALVIN that would result from any conversion/upgrade effort and how that might be integrated into one of ALVIN's triennial major overhauls. The proposed ONR-funded engineering study by WHOI of these options was strongly recommended by the Working Group.

It is the Working Group's understanding that following the WHOI engineering study, ONR will evaluate the options and provide their recommendation to the Navy by December 1997. Dudley reported that the Navy plans to do a reduced scope overhaul on SEACLIFF and they are in the process of working on decommissioning details. They are also in the process of identifying SEACLIFF's vehicle components that are inventoried in their supply system. It is unclear what will be done with these spare items when SEACLIFF is decommissioned. The Working Group was unanimous in its opinion that surplused sensors and operational equipment from SEACLIFF and TURTLE should be transferred to the academic community for use at the National Deep Submergence Facility at WHOI, or other UNOLS operators of deep submergence systems like Scripps Institution of Oceanography.

Dudley began the discussion with Option 4, which calls for a one-for-one replacement of ALVIN with SEACLIFF. He first reviewed the modifications necessary for ATLANTIS. These include modifications of the A-Frame main lift winches and rams and the cradle. The hanger would need to be made larger (which, given the structural problems of installing a hanger on R/V ATLANTIS may be difficult and costly). The deck structure will not require any changes. SEACLIFF alterations would include modifications to make the vehicle more science capable; including replacement of SEACLIFF's manipulators. The batteries would need to be replaced with NiCads because SEACLIFF currently uses AgZn batteries which are expensive to buy and maintain. The vehicle would need to be modified to a single pilot configuration. If not included with the vehicle, imaging equipment would be needed. Other items to be addressed include overhauling SEACLIFF, spare parts requirements and expendables needs. If SEACLIFF is to replace ALVIN, WHOI roughly estimates that the vehicle would be ready by the year 2001. The learning curve for pilots and technical personnel for use and maintenance of the vehicle would also need to be considered.

Option 5 calls for accepting SEACLIFF and operating ALVIN and SEACLIFF simultaneously. This option would require an additional support vessel and A-Frame. Two complete support crews would be needed, although there may be some economy in shore staffing. SEACLIFF modifications would be the same as those required in Option 4. The ATLANTIS modifications identified for Option 4 would also be required for Option 5. SEACLIFF modification for science and overhaul would be required. An additional maintenance crew would be required to retain the vehicle certifications during "off duty" periods. Time would be necessary for changeover between the two vehicles and science equipment. The A-Frame and cradle would need adaptation. Sea trials and training would be required after any extended lay-up of a vehicle. Spare parts for SEACLIFF would be needed. The realities of present funding constraints and science demands for two HOVs also needs to be considered.

Option 6 indicates that SEACLIFF and ALVIN would be operated alternately. All the above mentioned SEACLIFF modifications for science and overhaul would be required. The ATLANTIS modifications identified for Option 4 would also be required for this option. An additional maintenance crew would be required to retain the vehicle certifications during "off duty" periods. Time would be necessary for changeover between the two vehicles and science equipment. The A-Frame and cradle would need adaptation. Sea trials and training would be required after any extended lay-up of a vehicle. Spare parts for SEACLIFF would be needed. This option is logistically difficult to accept.

Option 7 recommends modifying SEACLIFF using ALVIN equipment. Suitable ALVIN equipment may include its propulsion system, manipulators, video/lighting/imaging systems, power distribution, data logger, science basket concept and weight droppers. Conversion issues include engineering planning/funding and documentation. Both vehicles would be off-line during the conversion. Spare parts quality and quantity need to be defined. The manpower needed to handle the conversion may have an impact on ROV operations. Eighteen to 24 months are estimated for the conversion. The Working Group had serious reservations about this option because it involved replacing the most capable deep diving submersible in the world with a scientifically less capable vehicle.

Option 8 calls for modifying ALVIN with SEACLIFF's sphere and components. Suitable SEACLIFF components might include the variable ballast system, sonars, hydraulic system, unique Navy spares, UQC and similar equipment, instrumentation (depth, heading, voltages and altimeter), explosive bolts and syntactic foam. Conversion issues would be same as those identified for Option 7. The conversion would take approximately eight months to complete.

The Working Group also discussed another possibility, "WHOI Option 8A," which calls for upgrading ALVIN with SEACLIFF parts while saving the SEACLIFF sphere for a possible later installation in ALVIN to upgrade it to 6000m depth capability. This option would be relatively low cost, initially, and SEACLIFF equipment and parts would be available for upgrading ALVIN. There would be a long-term economy because much of the equipment (e.g. VB components, sonar system, hydraulic system, altimeters, explosive bolts, foam, UQC, electronic instrumentation etc.) could be used both now by

ALVIN and in the future by the modified submersible. The possibility of pursuing ONR Options 7 and 8 at some time in the future would be preserved by following WHOI Option 8A.

WHOI also considered an Option 9 which was not suggested by ONR. This option involves a frame-up redesign for a new submersible which would combine the best features of both ALVIN and SEACLIFF. The submersible would retain ALVIN's science capabilities and SEACLIFF's 6000m depth capability. The vehicle would need to have better hydrodynamics and more power-efficient operational and science systems as well as increased power, overall. These improvements are essential in order for the new submersible to be more efficient in reaching and traversing the seafloor and conducting sampling/manipulative operations. This option would require a major engineering effort. The consequences of having a bigger and heavier HOV than ALVIN need to be considered in terms of science capabilities.

Dudley concluded by outlining WHOI's plan of action. They will work with Portsmouth Naval Shipyard (PNS) on information transfer regarding ALVIN and SEACLIFF systems. WHOI will draft a preliminary response on the findings of their engineering discussions with PNS and present this to the DESSC at their July meeting. At this point WHOI and DESSC will deliberate on which option(s) are the most likely to produce the greatest improvements in science capability which are sustainable and realistic from an engineering point of view, and which are feasible from a cost/funding perspective. Those options will be finalized and transmitted in a letter from WHOI to ONR which has the Working Group's and DESSC approval. An update on the status will be provided at the next general DESSC meeting.

CONCLUSIONS OF WORKING GROUP DISCUSSION AND RESPONE TO ONR OPTIONS

ONR OPTION	RESPONSE
1. Deactivate SEACLIFF	Unwise use of facility
2. Transfer to other than WHOI.	No
3. Decline SEACLIFF.	No
4. Accept SEACLIFF, retire ALVIN.	No
5. Accept SEACLIFF, retain ALVIN.	No-cannot support additional platform /crew.
6. Accept SEACLIFF, operate ALVIN.	No-Waste of efforts and interim basis. Impractical use of funds.
7. Modify SEACLIFF using ALVIN equipment.	Serious reservations, probably no. Major modifications to ATLANTIS required. Lose ALVIN capabilities. Substantial costs involved with little benefit.
8. Modify ALVIN using SEACLIFF sphere and equipment.	Possibly, but requires further investigation of technical feasibility and impact on current ALVIN capabilities. Heavier sphere, batteries, major structural upgrade required.

WHOI OPTION	RESPONSE
8A. Improve ALVIN with SEACLIFF components, excluding sphere. Keep shpere for future upgrade.	Yes-enhances sensors and operational equipment available for ALVIN and preserves ONR option 8.
9. Redesignof a new submersible using ALVIN and SEACLIFF equipment.	Possibly, requires further design study and identification of funding sources.

Other important points that were brought up during the discussion included:

- Concerns about losing existing maneuverability and science capabilities on ALVIN as a result of a conversion.
- Impact on ongoing science programs, especially time-series experiments and observatory experiments during conversion.
- Identification of funding sources for conversion and maintenance.
- Extent of engineering effort required.
- Trade-off between 6000m capability and bottom-time for HOV versus developing a 9000m ROV dedicated for science that could carry out sampling, mapping and other work efficiently at deep depths.

Conclusions of Working Group included:

- Options 8 and 8A are the most appealing.
- WHOI technical evaluation of options is needed and requires ONR funding.
- Deep submergence community has identified numerous scientific objectives to be met in the deep ocean and on the seafloor that require HOVs, ROVs and AUVs.
- A new science ROV must be designed and built.
- Deep submergence science should be highlighted as a key initiative for 21st century exploration and discovery of Inner Space.

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APPENDIX I

Working Group Membership
M. Perfit (Chair)- U. Florida
K. Becker -U. Miami
J. Bellingham-MIT
R.W. Embley-NOAA-Hatfield
P. Fryer-U. Hawaii
D. Fornari-WHOI
P. Jeff Fox- Texas A&M
J. Paul Johnson-U. Washington
M. Lilley-U. Washington
P. Lonsdale-SIO
K. Von Damm-U. New Hampshire
Also Attending
A. DeSilva-UNOLS (ex officio)
D. Elthon-NSF (ex officio)
D. Foster-WHOI (ex officio)

APPENDIX II

Date: February 14, 1997
To: Deep Submergence Research Community
From: Mike Perfit, DESSC Chair
Subject: DESSC Questionnaire to the Deep Submergence Research Community

Future Requirements for Deep Submergence Vehicles and Research Directions into the 21st Century

The following short questionnaire is designed to compile some specific responses on key issues related to deep submergence vehicle access to the sea floor for academic research. The results of this compilation will be utilized by the Deep Submergence Science Committee (DESSC) and a DESSC Working Group that will meet on March 20, 1997. DESSC will provide the Federal Agencies (NSF, ONR, NOAA) with guidance from the scientific community regarding the possible inclusion of the capabilities of DSV SEA CLIFF in the 1998-99 time frame and future research directions that would utilize these capabilities, especially the increased operational depth capability (6000 m). The Working Group will provide a short report to the funding agencies and oceanographic community by April 1997. Although the Working Group is comprised of a wide spectrum of marine scientists with deep submergence experience, we hope to elicit responses from most of the deep submergence community through this questionnaire.

We have tried to keep the questions short and specific in order to not take up too much of your time. However, we have left room for you to make specific comments on most questions if you care to do so. Because of the short lead time before the Working Group meeting, we ask that you respond as soon as possible and no later than March 3. The questionnaire should be sent directly to the UNOLS Office or you can fill out the questionnaire on-line via the UNOLS/DESSC web site (http://archive.unols.org/committees/dessc/index.html). If you have more specific issues related to the general topic of deep submergence vehicle needs and future directions please enclose those on a separate sheet or send them in a separate e-mail or fax message to me (perfit@geology.ufl.edu; (352) 392-9294) or to the UNOLS Office (office@unols.org, fax: (401) 874-6167). The results of the questionnaire will be made available to ONR, NSF and NOAA and will be posted on the UNOLS and DESSC web sites.

The questions fall into two broad categories: A - Future directions in deep submergence science, and B - Disposition of the US Navy submersible SEA CLIFF.

We appreciate your taking the time to complete this questionnaire. The future makeup of deep submergence vehicle assets in the US will, in part, be guided by the community's response to this message.

Thank you.

QUESTIONNAIRE

Category A - Future Directions in Deep Submergence Science (indicate all that apply)

1. What is your primary field of research?

- biology (physiology, ecology, microbiology)
- chemistry
- physical oceanography
- sedimentology
- marine geology
- petrology
- geophysics
- tectonics/structure
- engineering
- ___________ (other)

2. Which area(s) is your research work principally focused on NOW?

- continental shelf/slope
- abyssal plains
- mid-ocean ridges
- transforms
- trenches
- seamounts
- mid-water
- ___________ (other)

3. Which area(s) do you expect your research work will be concentrated in the next 10 years?

- continental shelf/slope
- abyssal plains
- mid-ocean ridges
- transforms
- trenches
- seamounts
- mid-water
- ___________ (other)

4. How many times (cruises) in the past 5 years have you used deep submergence vehicles for your research?

ROV/tethered vehicles? Name of vehicles _______________

Manned submersibles? Name of vehicles _______________

5. What is the maximum depth range that deep submergence vehicles (all types) available to US scientists should have in terms of your future science requirements for the next 20 years?

- 3000m
- 4500m
- 6000m
- 7500m
- 9000m

6. Do you foresee that there is and will be a need for human-occupied submersibles to accomplish scientific missions in the depth ranges given below?

	CRITICAL			NOT IMPORTANT	
1500-3000	1	2	3	4	5
3000-4500	1	2	3	4	5
4500-6000	1	2	3	4	5
6000-7500	1	2	3	4	5
7500-9000	1	2	3	4	5

Comments:

7. On a scale of 1 (critical) to 5 (not important), how important is it to your present or future research to have a human-occupied submersible capable of working between the depths of 4500 and 6000(+) m?

CRITICAL			NOT IMPORTANT	
1	2	3	4	5

Comments:

8. To what extent could your current and future science objectives at depths greater than 4500 meters be accomplished by human operated vehicles (HOVs), remotely operated vehicles (ROVs) or autonomous vehicles (AUVs)?

HOV-	100%	75%	50%	25%	less than 10%
ROV-	100%	75%	50%	25%	less than 10%
AUV-	100%	75%	50%	25%	less than 10%

Comments:

Category B - Disposition of the US Navy Submersible SEA CLIFF

The cost of carrying out the work required to implement solutions associated with the questions below is unknown at this time. Navy moneys traditionally budgeted to support their submersible program are not likely to be provided to operate SEA CLIFF. Fiscal aspects of the problem (i.e. conversion costs) are currently being evaluated by WHOI and the Navy. It is still uncertain at what level funds will be provided by the Navy and other Federal agencies to pay for the possible scenarios of a SEA CLIFF/ALVIN conversion. Consequently, in answering the following questions, please ignore the potential funding constraints. The working group will be addressing the financial issues after the data is made available and the potential impact these may have on the ongoing operations of the National Deep Submergence Facility.

1. Should the capabilities of both ALVIN and SEA CLIFF be merged so that the result is a 6000 m depth capable submersible?

Yes No Unsure

Comments:

2. Should SEA CLIFF replace ALVIN as the primary research submersible for US scientists?

Yes No Unsure

Comments:

3. Should SEA CLIFF be given to another institution or facility with the desire to operate a manned submersible although federal funding levels for deep submergence science will likely stay level for the foreseeable future?

Yes No Unsure

Comments:

4. Should SEA CLIFF equipment (e.g. manipulators, electronics, sonars, vehicle systems) be transferred to the National Deep Submergence Facility at Woods Hole to enhance ALVIN while the 6000 m SEA CLIFF titanium sphere is preserved for possible future replacement for the existing 4500 m depth rated ALVIN sphere?

Yes No Unsure

Comments:

APPENDIX III

SURVEY RESPONSES
106 QUESTIONNAIRES SUBMITTED
April 1997

Category A - Future Directions in Deep Submergence Science (indicate all that apply)

Note: The survey response totals and comments are indicated in parentheses

1. What is your primary field of research? See Figure 1.

- (33) biology ((2)physiology (9)ecology (4)microbiology)
- (19) chemistry
- (7) physical oceanography
- (6) sedimentology
- (30) marine geology
- (8) petrology
- (18) geophysics
- (13) tectonics/structure
- (6) engineering
- (8) other:
  - Marine Archeology
  - Physics
  - Bathymetry
  - Biogeochemistry CNS Cycling
  - Economic Geology
  - In Situ Chemical Sensing Instrumentation
  - Science Education
  - Evolutionary Genetics

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2. Which area(s) is your research work principally focused on NOW?

- continental shelf/slope - 47
- abyssal plains - 17
- mid-ocean ridges - 59
- transforms - 9
- trenches - 13
- seamounts - 15
- mid-water - 3
- Other - 14:
  - Deep Basins
  - Hydrothermal areas of sedimented ridges
  - Hot Spots - Oceanic Islands
  - Cold Seeps
  - California Borderland Basins
  - Coastal and Open Ocean
  - Arcs/Back Arc Basins
  - Island Flanks
  - ROV/AUV Technology/Capabilities
  - Ridge Flanks

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3. Which area(s) do you expect your research work will be concentrated in the next 10 years? Figure 2 summarizes the results of questions 2 and 3.

- continental shelf/slope - 53
- abyssal plains -15
- mid-ocean ridges - 55
- transforms - 12
- trenches - 18
- seamounts - 23
- mid-water - 17
- Other - 15:
  - Deep Basins
  - Neritic Zones
  - Cold Seeps

- California Borderland Basins
- Coastal and Open Ocean
- Arcs/Back Arc Basins
- Hot Spots/Oceanic Islands
- Continental Slope/Rise/Abyssal Plains of Passive Margins
- Island Flanks
- ROV/AUV Technology/Capabilities
- Ridge Flanks

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4. How many times (cruises) in the past 5 years have you used deep submergence vehicles for your research? See Figure 3 and Figure 4.

ROV/tethered vehicles?

- Jason - 19
- ARGO II - 6
- ARGO - 1
- DSL120 - 7
- ATV - 12
- ROPOS - 20
- VENTANA - 6
- MPL Deep Tow - 3
- MPL Control Vehicle - 5
- HBOI ROVs - 5
- Minirover - 1
- Scorpio - 2
- Voyager - 1
- Phantom HVS4 - 14
- TOSS (NAVO) - 1
- NURP ROV - 1
- Heat Flow Probe - 1
- Scampi - 1
- Name of Vehicle not indicated - 6
- None Used - 54

Manned submersibles?

- ALVIN - 115
- SEA CLIFF - 11
- TURTLE -14
- NAUTILE - 12
- SHINKAI 6500 - 10
- PISCES V - 13
- PISCES - 3
- MIR - 1
- DELTA - 1
- SDL-1 (Canadian Navy) - 7
- NR-1 - 7
- Johnson SEA LINK - 38
- Name of Vehicle not indicated - 8
- None Used - 23

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5. What is the maximum depth range that deep submergence vehicles (all types) available to US

scientists should have in terms of your future science requirements for the next 20 years? See Figure 5.

- 3000m - 11
- 4500m - 26
- 6000m - 36
- 7500m - 12
- 9000m - 13
- 6500m - 1
- 11,000m - 1

Summary of Comments:

It was commented that this is a difficult question to answer since there is a big trade off of depth versus weight, power, etc.

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6. Do you foresee that there is and will be a need for human-occupied submersibles to accomplish scientific missions in the depth ranges given below? See Figure 6.

	CRITICAL			NOT IMPORTANT	
1500-3000	1(76)	2(20)	3(7)	4(3)	5(2)
3000-4500	1(52)	2(31)	3(10)	4(3)	5(2)
4500-6000	1(27)	2(13)	3(24)	4(5)	5(2)
6000-7500	1(10)	2(10)	3(22)	4(18)	5(21)
7500-9000	1(4)	2(8)	3(20)	4(18)	5(30)

Summary of Comments:

Comments were mixed and samples are summarized below:

HOVs are critical: There is no adequate substitution for human presence. Given an almost equal cost, experimental work has better chances with HOV. Some instrumentation still requires manned operations and a scientist on site for real time assessments. The need for manned submersible is a "key" component to any deep sea research program. Work in the Western Pacific needs the greater depth capability. With emphasis on "observatories" studies (coastal or mid-ocean ridges) human-occupied subs are still needed down to 4500m until ROVs are capable of comparable manipulation of experiments. HOV combinations with ROV are envisioned.

HOVs are not Important: Human endurance in small cramped space is limited to about eight hours; this makes human presence at depths greater than 4000m difficult given transit times in today's vehicles. Tele-presence needs improvement especially with regard to video, but is clearly the way to go for the deepest deep-sea exploration and experimentation. ROV capabilities are more important at the depths greater than 4,500m. A combination of manned submersibles with depth capability to 6000m and unmanned vehicles to ~7500m should meet almost all of our research needs and still be financially reasonable. It was suggested that the deepest diving submersibles (manned and unmanned) should be a shared international resource. Available Japanese, Russian, and French manned vehicles should be used for 4500-6000 work.

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7. On a scale of 1 (critical) to 5 (not important), how important is it to your present or future research to have a human-occupied submersible capable of working between the depths of 4500 and 6000(+) m? See Figure 7.

CRITICAL				NOT IMPORTANT
1(18)	2(20)	3(25)	4(17)	5(20)

Summary of Comments:

HOV is critical: A US platform with a proven performance record is needed. It is essential as a nation that we not lose the 6km capability. Because much of scientifically interesting seafloor falls between 4500 and 6000 m, this direct observation function is critical. While ROVs and AUVs can replace many of the functions of manned submersibles, direct observation of the seafloor is critical for many biological and chemical studies of soft-sediment habitats. Work in the Western Pacific is >4500m deep and work on mid ocean ridges has axial depths in the 4000-5000m range. Tectonics/petrology studies of transforms and ridge-transform intersections will also require submersible depth capabilities in this range. Extensive fine-scale manipulations, to date, can best be carried out only by manned submersible; without this capability, work at 4500-6000m depths is limited.

HOV is not important: A 4500m HOV depth capability is sufficient. Most deep tasks can be handled by ROVs. Many aspects of this research support are already covered by ROVs.

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8. To what extent could your current and future science objectives at depths greater than 4500 meters be accomplished by human operated vehicles (HOVs), remotely operated vehicles (ROVs) or autonomous vehicles (AUVs)? See Figure 8.

	100%	75%	50%	25%	less than 10%
HOV-	25	18	20	12	9
ROV-	20	22	30	12	6
AUV-	6	7	6	18	34

Summary of Comments:

The HOV offers sampling capability and an in situ observation (3D visualization) that is not yet possible with other vehicles. Bottom time of HOVs, however, were noted as a limitation. Both HOVs and ROVs are needed to do the job adequately. High resolution detailed sonar mapping benefits from the unlimited power on an ROV tether, but detailed sampling and seafloor instrument set-up is better done from an HOV. Most ROVs are too light to do good coring. ROVs and AUVs are adequate for camera and bathymetry surveys.

Many surveys indicated that not enough is known about AUVs to rate them. AUVs are not yet proven. However, there was one comment that an AUV such as ABE should be incorporated in the National Deep Submergence Facility. It provides an electromagnetically quiet platform for near-bottom magnetics studies, as well as survey flexibility, duration, and efficiency that currently are not available with HOVs and ROVs.

Category B - Disposition of the US Navy Submersible SEA CLIFF (see Figure 9)

The cost of carrying out the work required to implement solutions associated with the questions below is unknown at this time. Navy moneys traditionally budgeted to support their submersible program are not likely to be provided to operate SEA CLIFF. Fiscal aspects of the problem (i.e. conversion costs) are currently being evaluated by WHOI and the Navy. It is still uncertain at what level funds will be provided by the Navy and other Federal agencies to pay for the possible scenarios of a SEA CLIFF/ALVIN conversion. Consequently, in answering the following questions, please ignore the potential funding constraints. The working group will be addressing the financial issues after the data is made available and the potential impact these may have on the ongoing operations of the National Deep

Submergence Facility.

General comments from surveys regarding Category B questions:

· It is impossible to ignore funding constraints! The cost-benefit assessment is essential in discussing options.

· SEA CLIFF's capabilities and characteristics were unknown to many surveyed and as a result there were many "unsure" responses.

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1. Should the capabilities of both ALVIN and SEA CLIFF be merged so that the result is a 6000 m depth capable submersible?

Yes	No	Unsure
47	17	38

Summary of Comments:

Although many surveys indicated "yes" to merging ALVIN and SEA CLIFF, there was a great deal of uncertainty.

<u>Yes, Merge SEA CLIFF and ALVIN:</u> Efforts should be made to obtain an HOV 6000m depth capability for the National Deep Submergence Facility. A 6000m depth capability is needed for work in the W. Pacific.

<u>Unsure about Merging SEACLIFF and ALVIN:</u>
· The approach should be to preserve ALVIN by cannibalizing SEA CLIFF, since ALVIN is the more mature, effective system. None of the capabilities (operational or scientific) of ALVIN should be compromised. SEA CLIFF is much less valuable and capable as a sea floor research tool than ALVIN. Thus if the process of merging the two vehicles produced a hybrid which has fewer capabilities than ALVIN, that would not be good. If the hybrid had all of ALVIN's capabilities plus greater depth capability, that would clearly be an improvement. If the best equipment is selected in the merge and if the resulting vehicle would be operated as ALVIN is, then "yes." Power issues are critical; time on bottom must be maximized.
· Certain capabilities are based on cost and this information is needed to make a recommendation. A hull change may take the sub out of service for too long a time with respect to ongoing science programs.
<u>Do not merge SEA CLIFF and ALVIN:</u>
· The 4500m capability should be kept intact. It will be needed more than the 6000m capability in the near future (~10 years).
· This approach is recommended only if SEA CLIFF cannot be operated reliably by another institution (e.g., HURL). Two vehicles are more versatile. Both submersibles should be maintained. Modernize SEA CLIFF, make it a science platform, and operate it separately.
· If funding allowed, it would be ideal to upgrade ALVIN to the same depth capability or build a new vehicle -- if for no other reason than to have a viable US rescue capability. What is needed is a new generation of HOV submersibles; smaller, lighter and less logistically challenging.
· ROVs and AUVs hold more promise than increased capability to put a human at 6000m. Use money to replace Jason with an ROV designed for science research.
· This effort is beyond the capabilities of the DSOG at WHOI. If it is going to be undertaken it should be elsewhere, or under a new and revitalized DSOG management, and with a revitalized team and a long term commitment from the sponsors. Since a DSOG restructuring is unlikely, or that a revitalized funding commitment is in the cards, this level of effort is impractical.

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2. Should SEA CLIFF replace ALVIN as the primary research submersible for US scientists?

Yes	No	Unsure
7	53	40

Summary of Comments:

Surveys overwhelmingly indicated that SEA CLIFF SHOULD NOT replace ALVIN.

SEA CLIFF should NOT replace ALVIN:

· ALVIN is a much more supportable, effective, mature vehicle than SEA CLIFF. If ALVIN can be readily modified for 6000 meter operation by cannibalizing SEA CLIFF, great, but replacing ALVIN with SEA CLIFF would be a disaster for the community! ALVIN has a much higher productivity (dives/year) and has been outfitted specifically for science research.

· SEA CLIFF has suffered extensively from reliability problems (poor track record), while ALVIN continues to be an incredibly productive workhorse. SEA CLIFF is much less capable than ALVIN for seafloor sampling and observing. SEA CLIFF (aside from depth advantage) would require major modification to be as capable as ALVIN. It is too expensive to operate. The sphere is the only useful thing on SEA CLIFF.

· Although there is certain value in diving beyond ALVIN's limits, the problem is one of ALVIN availability not diving capability or depth limits. Simple replacement of ALVIN with SEA CLIFF is very risky, and does not solve the growing problem if insufficient submersible access to US scientists. Two vehicles would add versatility.

Conditional Yes: SEA CLIFF should replace ALVIN if all ALVIN's capabilities and operational procedures/crew are transferred. The reliability and performance record of ALVIN must be continued with a 6000m vessel. Capabilities should be merged so that the net result is just one HOV that can dive to 6km.

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3. Should SEA CLIFF be given to another institution or facility with the desire to operate a manned submersible although federal funding levels for deep submergence science will likely stay level for the foreseeable future?

Yes	No	Unsure
24	43	31

Summary of Comments:

SEA CLIFF should be given to another institution or facility:

· U.S. scientists continue to be limited, relative to scientific needs and submersible access. ALVIN is often not available due to logistics of cruise planning. Another DSV for U.S. shelf/slope (east & Gulf) is needed, especially if new funding sources including federal/industrial/commercial are sought. A deeper submergence presence is needed on a more regular basis for Pacific area projects.

· The scientific community as a whole is best served by keeping SEA CLIFF running, especially on a resource base other than UNOLS (e.g., NURP).

· Keep SEA CLIFF alive (without diverting funds from ALVIN), and use its presence as a rationale for ratcheting up submersible funding in the U.S.

· One idea would be to upgrade HURL with SEA CLIFF since they already have funding for Pisces V.

· Competition might be good for WHOI's operation, and it helps relieve the costs of forcing the schedule to be in specific oceans/locals.

SEA CLIFF should NOT be given to another institution or facility:

· Giving SEA CLIFF to a facility that could not support it well would be a huge and perhaps tragic mistake. This is guaranteed to risk the viability of both facilities.

· Unless the institution has the funds in-house for operation and upgrades this option should not be pursued.

· For the time being, we should focus the resources on the WHOI group. Support for ALVIN appears minimal already.
· If we could find more support, this would be a good idea.
· Given infrastructure costs, it makes no sense to split things up. Duplication of engineering and expertise would be wasteful.
· Centralized operation for deep sea research is more realistic.
· One institution should operate both; however, the Navy may wish to receive bids from Hawaii, for example, if resources of deep-diving should logically be moved from N. Atlantic to N Pacific.

4. Should SEA CLIFF equipment (e.g. manipulators, electronics, sonars, vehicle systems) be transferred to the National Deep Submergence Facility at Woods Hole to enhance ALVIN while the 6000 m SEA CLIFF titanium sphere is preserved for possible future replacement for the existing 4500 m depth rated ALVIN sphere?

Yes	No	Unsure
58	14	26

Summary of Comments:

Transfer SEA CLIFF equipment to the National Deep Submergence Facility:
Many of the surveys indicated that this would be the most attractive option for a variety of reasons
· This sounds like the best compromise with shrinking support. It leaves the 6000m option open, but doesn't throw away a high productivity resource. Combining the best attributes of ALVIN and SEA CLIFF has many attractions.
· This option makes the best use of Navy facilities and equipment for academic science and is the most cost-effective.
· This seems to be the best alternative even though loss of any submersible capability is bad for the entire community.
· This seems like the do nothing default approach and probably the right approach unless DSOG and the funding base can be revitalized sufficiently to undertake a major revision of ALVIN, including a 6000m capability.
· ALVIN plus present ROVs can address a larger range of relevant problems than can presently be funded. Therefore, competitive funding of another deep-sea asset is unwise at this time.
· This seems like a good way to go for the near future and if funding and a good scientific rationale were generated a couple of years hence, it would be appropriate to make the conversion when ALVIN comes due for the next major overhaul.
· For reference, see the article: Deep Sea Research by Manned Submersible, J.R.Heirtzler and F. Grassle, Science, v. 194, 294-299, 1976

Do NOT transfer SEA CLIFF equipment to the National Deep Submergence Facility:
· This may be a practical short-term solution but is does not address the basic issue that the ALVIN-class vehicles are obsolete... they are very costly to operate ... and should be replaced by HOVs utilizing modern materials and technologies. We need to build a sub that can go to 6000m.
· Both SEA CLIFF and ALVIN should be maintained separately while pushing for additional funding or inventive ways for this to occur, such as porting SEA CLIFF to an already established submergence facility. This options should be pursued only if SEA CLIFF conversion/update is deemed unfeasible. Keeping SEA CLIFF operational separately sounds preferable as long as it does not endanger ALVIN.
· This should be done only after moneys from other agencies are provided to support the vehicle.
· Proceed with merging ALVIN and SEA CLIFF before the opportunity is lost. There will probably not be another such opportunity to bring such a facility on line for many years.

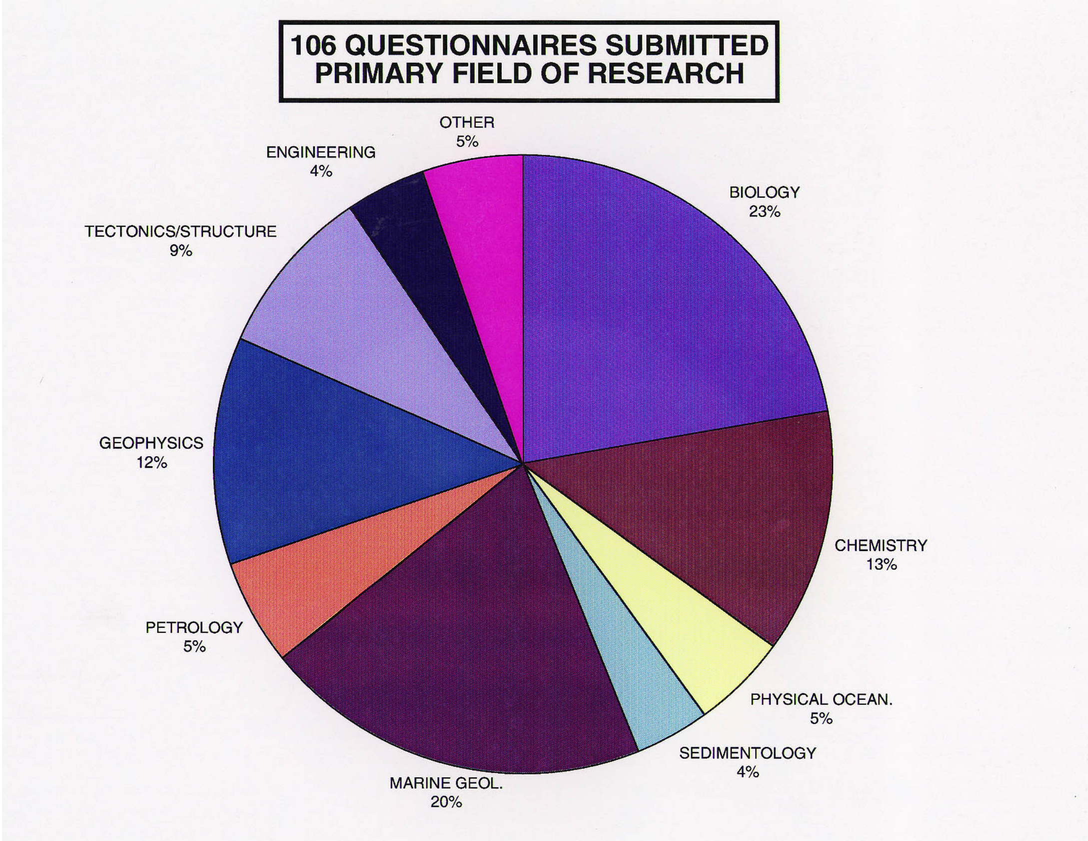

FIGURE 1

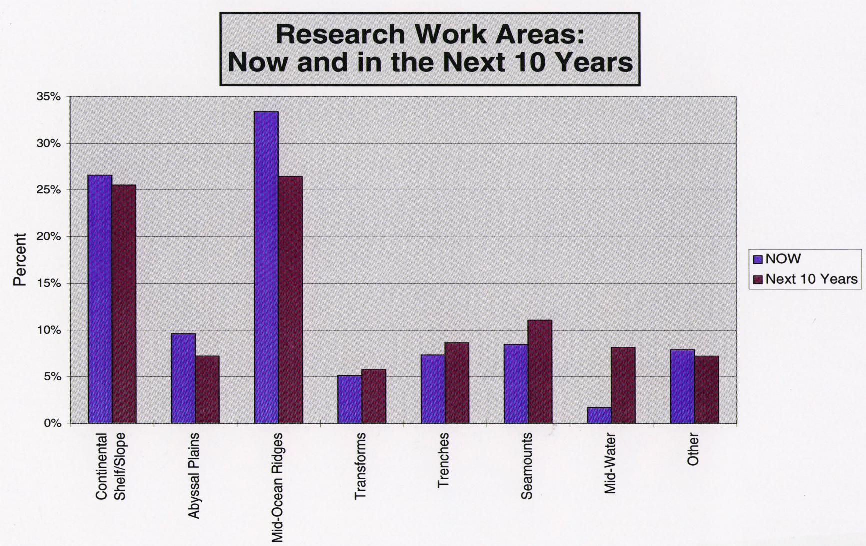

FIGURE 2

ROV/TETHERED VEHICLE USE

VEHICLE	CRUISES
ROPOS	20
JASON	19
PHANTOM	14
ATV	12
DSL-120	7
ARGO II	6
VENTANA	6
OTHER*	28
TOTAL	**112**

* Twelve other vehicles were listed as being used.

51% of those responding to the survey had not used an ROV

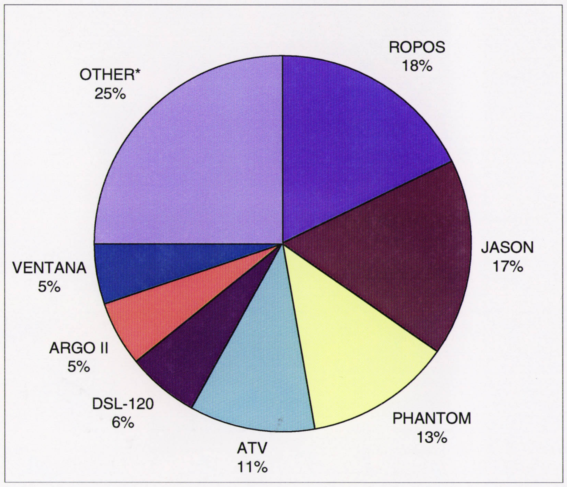

FIGURE 3

HUMAN OCCUPIED VEHICLE USE

VEHICLE	CRUISES
ALVIN	115
SEA LINK	38
TURTLE	14
PISCES V	13
NAUTILE	12
SEACLIFF	11
SHINKAI 650	10
OTHER*	27
TOTAL	240

* Six other HOVs were listed as being used.

22% of those responding to the survey had not used an HOV.

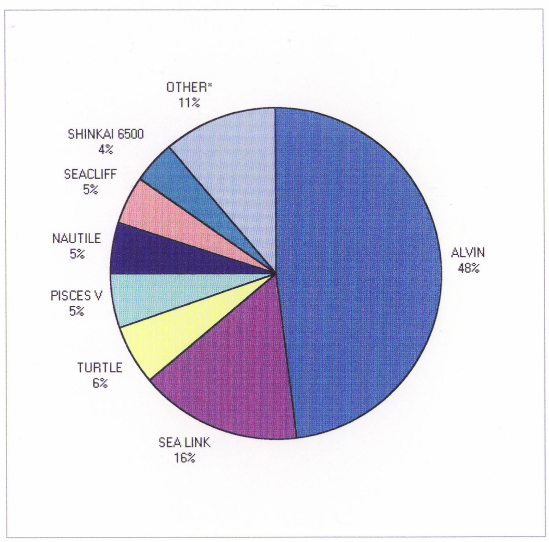

FIGURE 4

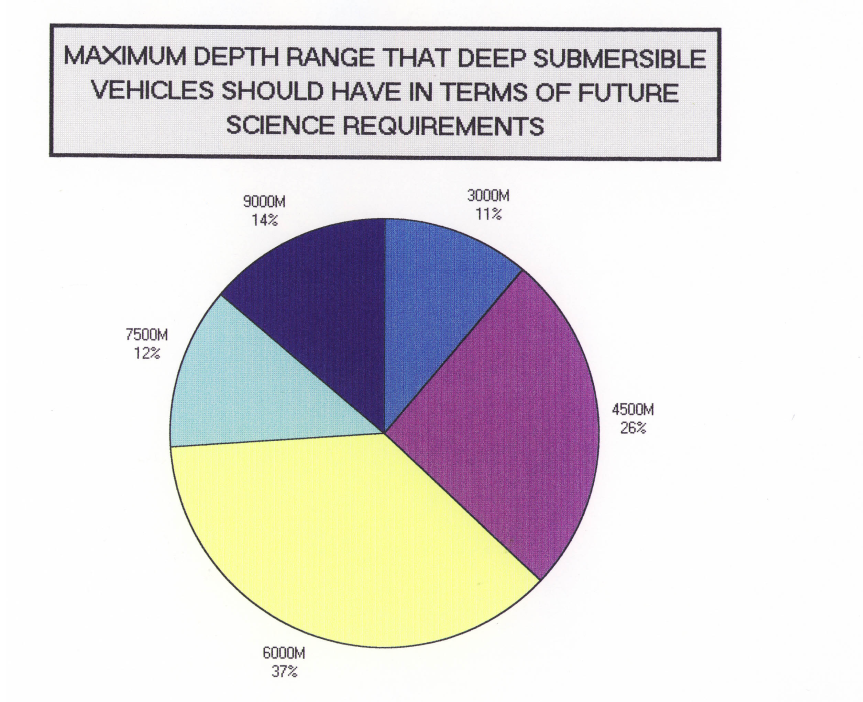

FIGURE 5

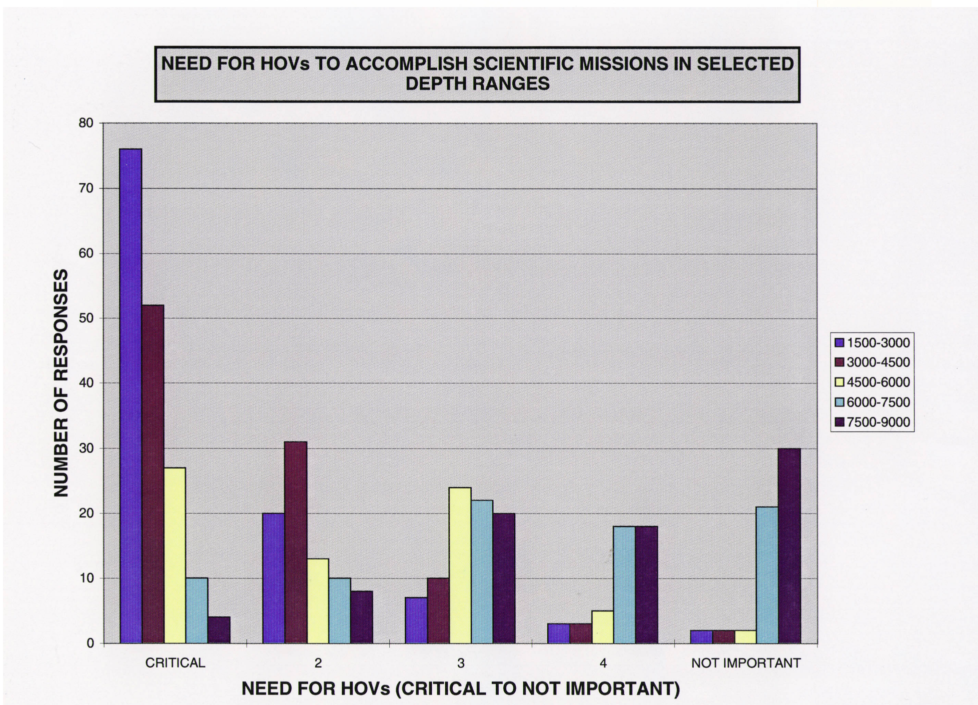

FIGURE 6

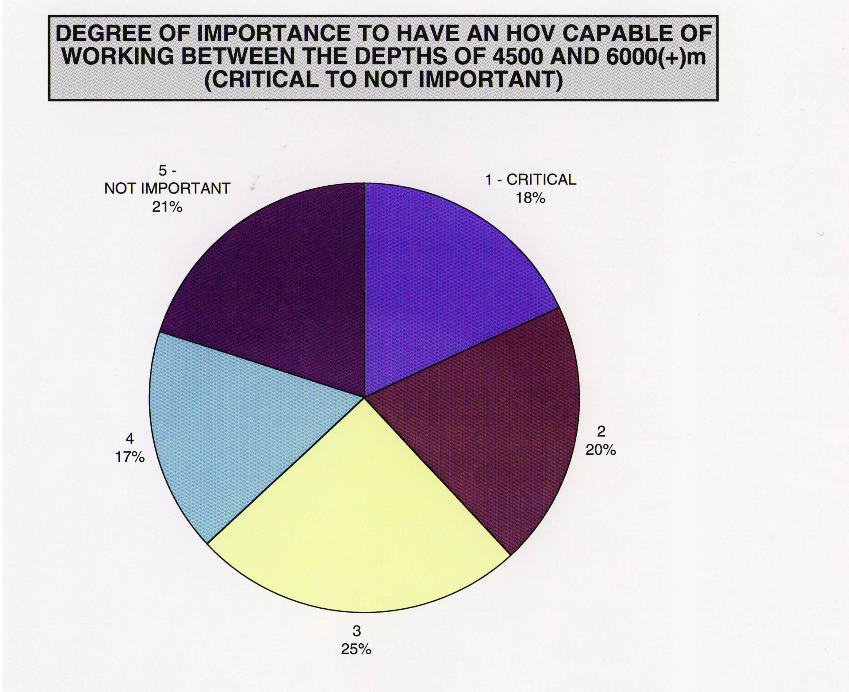

FIGURE 7

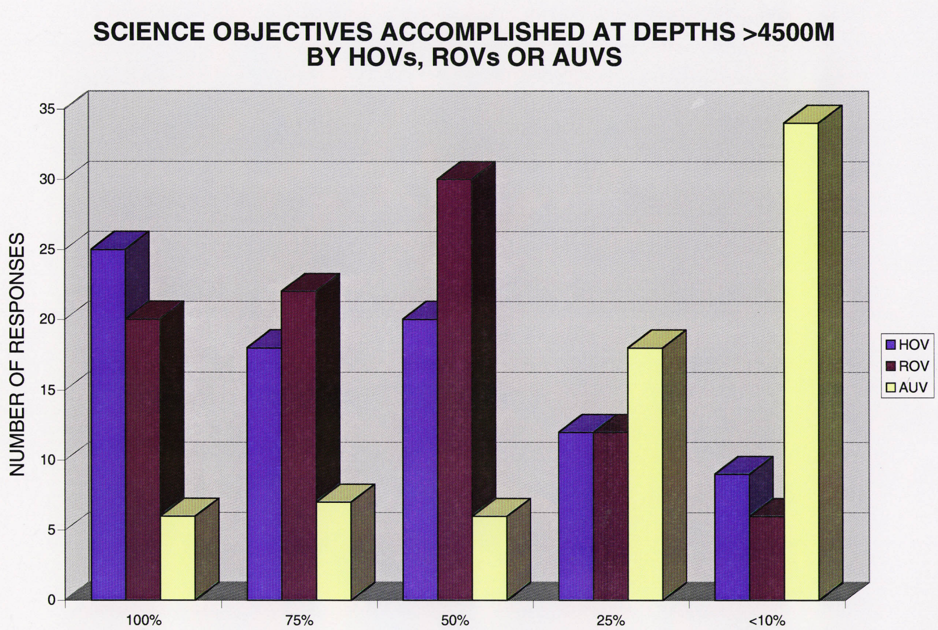

FIGURE 8

SURVEY RESULTS OF CATEGORY B

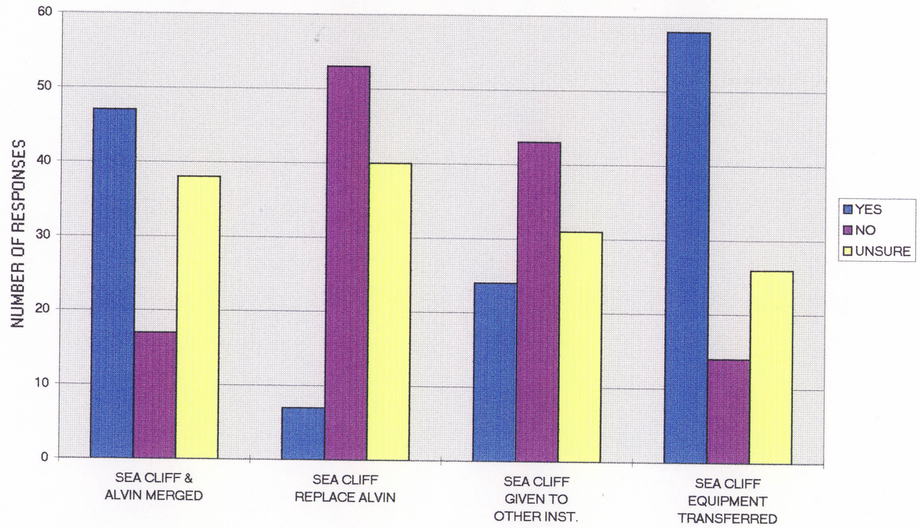

FIGURE 9