# Discovering the Oceans

## DEveloping Submergence SCiencE for the Next Decade

# "DESCEND"

### Workshop Proceedings

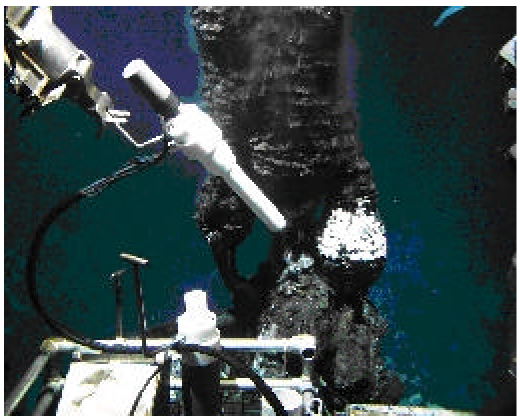

***Photo by Craig Cary***

## October 25-27, 1999
## National Science Foundation
## Arlington, VA

# DESCEND '99

# Proceedings

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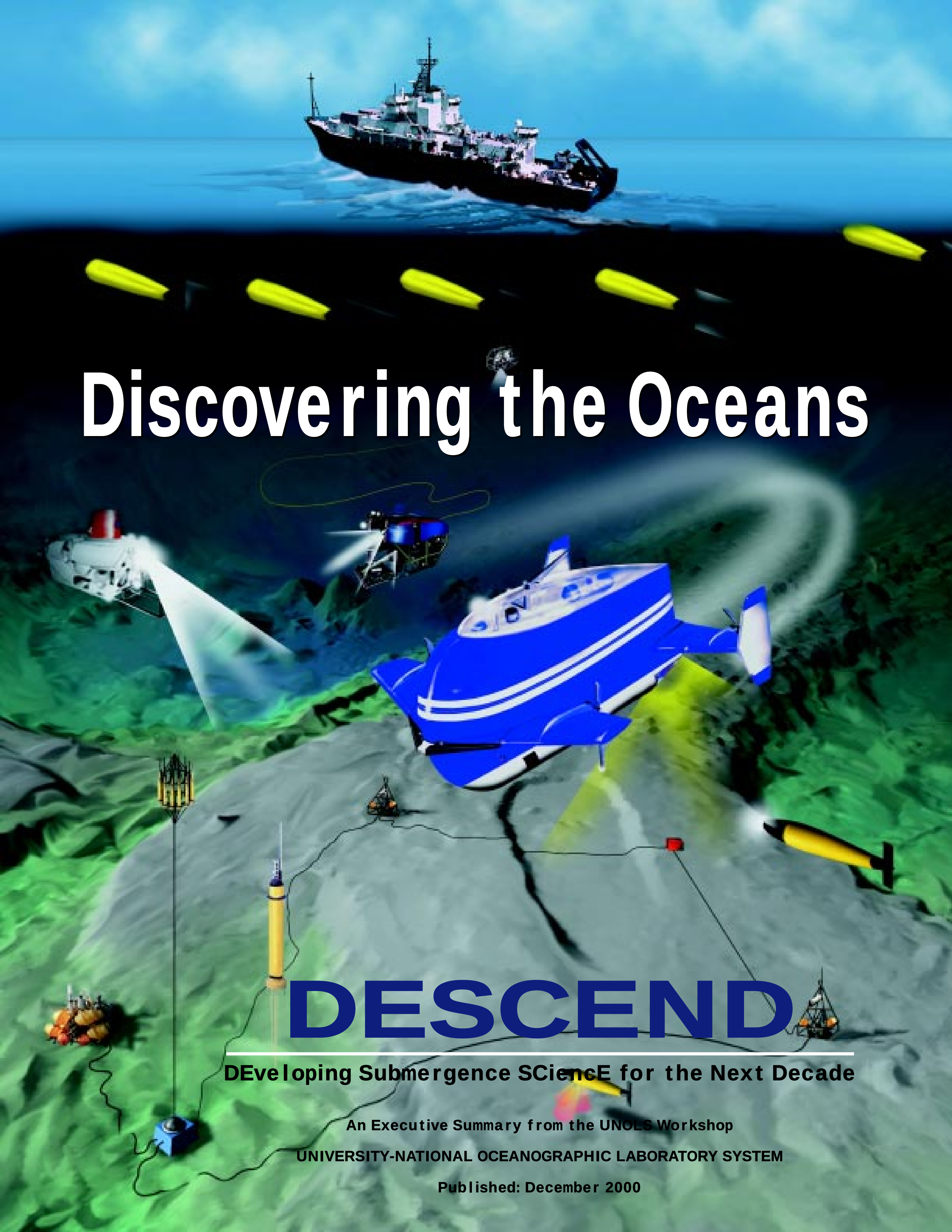
The Executive Summary of the DESCEND Workshop has been published into an 8-page brochure. Copies of the brochure can be obtained from the UNOLS Office, office@unols.org.

It is also included here in its entirety.



# Discovering the Oceans

# DESCEND

## DEveloping Submergence SCiencE for the Next Decade

**An Executive Summary from the UNOLS Workshop**

**UNIVERSITY-NATIONAL OCEANOGRAPHIC LABORATORY SYSTEM**

**Published: December 2000**

# Discovering The Oceans

## DEveloping Submergence SCiencE for the Next Decade: DESCEND

### Scientific Challenges, Technology Developments, and Investigative Strategies

Oceanographic research has led to discoveries that are critical to our understanding of Earth processes. Since the voyage of *H.M.S. Challenger* over 125 years ago, our understanding of global tectonic processes, coastal hazard assessment, marine resource management, geochemical cycling, global climate change, and even the origins and processes of life have been advanced though ocean research.


Courtesy of Challenger Society

*HMS* Challenger

During the last 30 years, systematic observation and sampling of the world's oceans have led to significant discoveries that have influenced many scientific disciplines. For instance, in the late 1970s, biological science was revolutionized when hydrothermal vents and complex, chemosynthetically-based animal communities were discovered on the mid-ocean ridge crest using deep submergence vehicles. Over the past few decades, nearly every venture into the vast realm beneath the sea surface has produced startling discoveries in all branches of oceanographic sciences, often with important implications for cross-disciplinary studies, from tsunami prediction to pharmaceutical research. In addition, the application of new technologies enhances our abilities to sense, sample, and record phenomena throughout the world's oceans and at the seafloor. The U.S. oceanographic community is poised on the threshold of innovative technologies and a new class of experiments that will provide the foundation for oceanographic science in the 21st Century.

The DESCEND (DEveloping Submergence SCiencE for the Next Decade) Workshop, held in October 1999, was prompted by the need to bring together oceanographic scientists and engineers to specify the important scientific goals of submergence research, and to define the vehicle and sensor technologies that will be required in the coming decades. In order to accomplish this objective, the three-day DESCEND Workshop provided 119 scientists, engineers and federal agency personnel the venue to discuss submergence science and technology. The first day was devoted to scientific discussion, followed on the second day with an exploration of technological needs and possibilities. The final morning was devoted to a plenary discussion to review results and formulate recommendations. The summary that follows also incorporates follow-up and feedback discussions among participants after the meeting. The full Proceedings of the DESCEND workshop can be found at the following web site: < www.unols.org/dessc/descend/descend.htm >.

In addition, during the course of the past year, several parallel efforts have been made to further identify the scientific and technical requirements for an occupied submersible and deep-diving remotely operated vehicle (ROV) to conduct deep submergence science at depths greater than 4500 meters, the current limit for *Alvin*. Because of the closely-linked nature of these deliberations with the objectives and results of the DESCEND meeting, it was considered appropriate to include key recommendations pertaining to construction of a new occupied submersible with a depth capability of at least 6000 m and equipped with state-of-the-art technology, as well as future construction of a deep-diving ( > 7000 m) ROV.

## Key Findings

**1** The oceans remain a scientific frontier for the 21st century, with broad societal and academic relevance to issues such as the role of the oceans in moderating global climate change, and the limits of life-processes in extreme environments on Earth and other planets.

**2** Dramatic advances in submergence vehicle technologies and instruments, including autonomous underwater vehicles (AUVs), occupied submersibles, remotely operated vehicles (ROVs), specialized sensors, and *in situ* samplers, now provide the potential for unprecedented access to the oceans and seafloor. These new technologies and vehicles will foster a revolution in our ability to synoptically measure the chemical, biological and physical processes that occur in the oceans.

**3** New mechanisms are required to improve access to all types of submergence vehicles and tools by the scientific community. These should be developed in order to address issues relating to scheduling existing assets, conducting field work outside traditional operating areas, and the need to respond to time-sensitive processes at the seafloor or in the water column (e.g. submarine eruptions). The broadest range of vehicle capabilities needs to be provided to investigators throughout the U.S. while preserving the existing capabilities achieved by our National Deep Submergence Facility.

**4** Long-standing U.S. leadership in submergence science and technology is being challenged by other countries, principally France, Germany and Japan. These countries have greater funding levels for submergence science and vehicle facilities and long-standing support for the advancement of submergence technologies.

# Recommendations

The recommendations listed below are each vitally important to the overall goal of fostering strong U.S. programs of submergence vehicles and technology that will provide the facilities and instruments required to support critical scientific research in the oceans for decades to come.

## Key Recommendations

- Develop new sensors and tools
- Accelerate development of autonomous underwater vehicles (AUVs)
- Construct a new, state-of-the-art, deep diving (>6000 meter) occupied submersible
- Plan for a new, robust deep-diving (>7000 meter) ROV for science
- Increase access to submergence vehicles and tools
- Convene a submergence technology meeting

### Develop new sensors and tools

New sensors and samplers, including instruments that operate at the micro-scale, are needed for a wide variety of *in situ* operations and time-series studies of seafloor and oceanographic processes. These suites of instruments should incorporate the latest technology, be multidisciplinary where possible, available to a broad range of investigators, and be capable of making measurements that provide high-frequency, temporal links between geological, chemical, biological, and physical processes. Improved manipulator capabilities and imaging systems on the vehicles are necessary to utilize these sensors and tools to greatest advantage.

Photo by Rod Catanach, WHOI

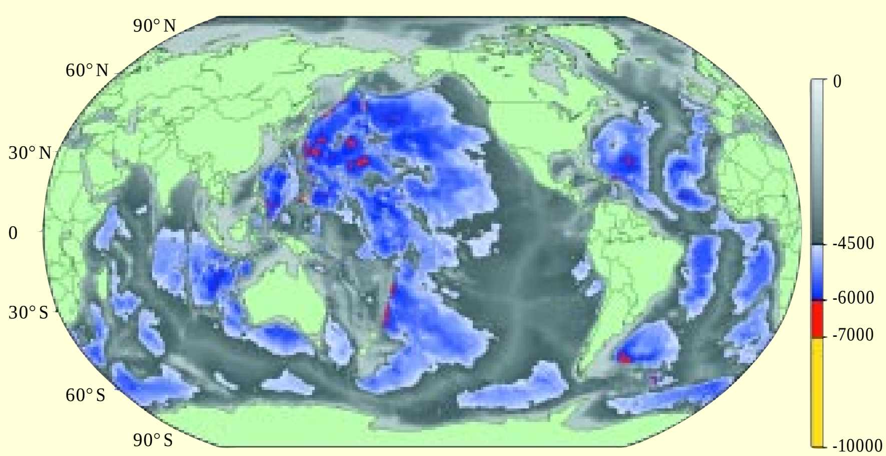
*The Autonomous Benthic Explorer* (ABE), *is an AUV developed by the Deep Submergence Lab of the Woods Hole Oceanographic Institution (WHOI).* ABE *has been used to create some of the most detailed maps and images of seafloor terrain on the Juan de Fuca Ridge and southern East Pacific Rise during field experiments over the past few years.*

### Accelerate development of autonomous underwater vehicles (AUVs)

AUVs will revolutionize how multidisciplinary data are collected at all levels in the ocean and on the seafloor in the coming years. Development of AUVs of all types should be accelerated so that within 3-5 years all oceanographic research vessels can carry basic AUVs capable of routine oceanographic or seafloor surveying that can be supported by shipboard technicians. In addition, specialized AUVs capable of detailed surveys, sampling and mapping, and long-term operations should be developed to complement seafloor observatory experiments.

### Construct a new, state-of-the-art, deep diving (>6000 meter) occupied submersible

Questions of biodiversity, biomass of the oceans, and of processes at work in the world's abyssal plains and deep-sea trenches, the last untouched frontier of ocean discovery, require access to depths greater than we can currently reach with *Alvin*. Operations will continue to exist that require the power and lift capabilities, tether-free maneuverability, and human presence that can only be achieved with an occupied submersible. A new, deep-diving occupied submersible capable of operations to at least 6000 meters should be built to replace *Alvin*. This depth capability will permit scientists to access ~30% more of the worlds ocean floor than they presently can with *Alvin*'s 4500 m depth rating. It will provide access to greater than 98% of the global seafloor. A new submersible would build on 35 years of experience and improvements that have made *Alvin* the most successful research submersible in the world. The new submersible would be better able to handle the burgeoning scientific




*Global ocean depth showing areas which can currently be accessed by* Alvin *down to 4500 meters depth (shown in gray). Blue regions show depths between 4500 and 6000 meters which can be accessed by ROV* Jason, Argo II, DSL-120 *sonar, and the* Control Vehicle. *Red areas show depths between 6000 and 7000 meters in areas of oceanic trenches which are currently inaccessible to US submergence capabilities. Depths greater than 7000 meters in the trenches of the western Pacific are shown in yellow.*

Figure by Roger Goldsmith, WHOI

# Recommendations (continued)

equipment and technology requirements of future research needs. Engineering and budgeting for construction of the new submersible should begin immediately so that it can be ready within 5 years.

### Planfor a new, robust deep-diving (>7000 meter) ROV for science

The deepest parts of the oceans, the oceanic trenches at plate margins, provide some of the most dynamic environments on this planet. These are regions where natural hazards to human habitations from plate tectonic forces are greatest. Scientific programs that seek to unravel the complex processes operating in these environments will require deep diving ROVs with specialized capabilities for science. The planning process to construct a deep (> 7000 meter) ROV should begin now so that in the next 5-10 years the U.S. academic community has access to a vehicle system that can reach the deeper portions of oceanic trenches.

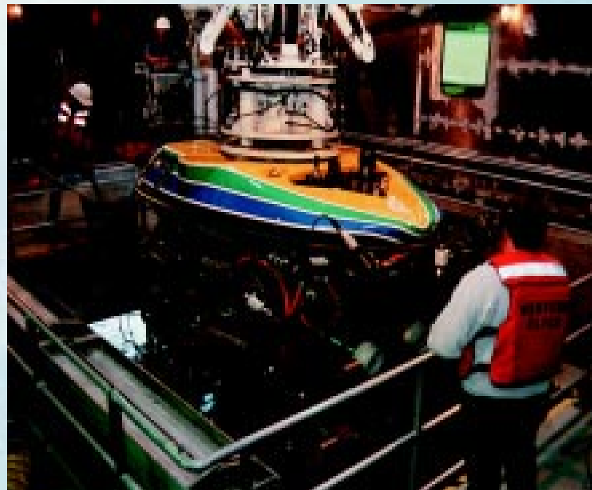


Photo by Greg Pio for MBARI ©1997

*The ROV* Tiburon *is operated by the Monterey Bay Aquarium Research Institute (MBARI). It can operate to depths of 4000 meters and is shown here above the moon pool on board the R/V* Western Flyer, *its support ship.* Tiburon *is a fiber optic based ROV and has sophisticated sampling and imaging systems and modular, mission-specific tool-sled packages for different science operations.*

### Increase access to submergence vehicles and tools

A thread that connects all of these recommendations and an issue of great concern to the Workshop participants is access to submergence systems in its various forms as noted in the findings above. The science community, science advisory committees, facility operators, and federal funding agencies should develop new mechanisms to facilitate and improve scheduling and support of vehicle systems. An infrastructure should be developed to provide adequate and long-term support for U.S. submergence science at least on a par with similar efforts by other developed countries.

Photo by Maurice Keehan, SIO

*The* Control Vehicle *(CV) of the Marine Physical Laboratory - Scripps Institution of Oceanography (SIO) on the after deck of R/V* New Horizon. *The CV has a working depth of 6000 meters and operates over coaxial or fiber optic cable. It is equipped with TV cameras, lights, scanning and down-looking sonars, attitude sensors and remotely operated payload releases. It has been used to place geodetic instruments on the sea floor, to install, monitor and retrieve seismometers from deep ocean drill holes, to log drill holes, and to recover instruments from the sea floor.*

### Convene a Submergence Technology Meeting

The need for new submergence vehicles, sensors and tools underscores the diversity in technology required to conduct multidisciplinary submergence science. The potential exists for application of existing technologies (e.g. biomedical, materials and space technology) to submergence research, but there is a need for a focused national meeting on future directions in submergence technology. Attendees to such a meeting should include prominent engineers, chemists, biologists, space scientists, oceanographers and geologists who are working on technologies that have applications for *in situ* measurements and sampling of seafloor processes. Mechanisms for fostering technology development and ensuring broad access to new instrumentation should be addressed at the meeting.

*View through* Alvin*'s forward view port of the manipulator as it prepares to sample an active hydrothermal chimney on the axis of the southern East Pacific Rise near 18.5° S. Photo by* Alvin *Pilots, WHOI. Courtesy of Karen Von Damm, Univ. of New Hampshire and Marvin Lilley, Univ. of Washington.*

# Research Priorities

There is general consensus among the DESCEND Workshop participants that both deep and shallow submergence science will play important roles in oceanographic research in the coming decades. The research opportunities are global, varied in scope, and multidisciplinary in nature.


Photo by Dan Fornari, WHOI

Alvin *is a deep-diving submersible that can dive to 4500 meters with one pilot and two observers. It is equipped with two manipulators and sophisticated imaging, attitude sensors and sonar systems and has conducted >3600 dives during its >30 year history. It is one of the systems in the National Deep Submergence Facility operated by WHOI for UNOLS.*

In the mid-ocean ridge environments, we seek to understand the complex interactions between the development of lithosphere, the biological processes in these regions, and the geochemical cycling phenomena that affect the composition of the world's oceans. In addition, scientists are actively working on models that describe the linkages among and between all of these complex processes and to the mantle source of heat, volatiles, and silicate melts that drives these dynamic systems. The research conducted at individual ridge crests must be compared and integrated so that global variability in these processes can be better understood.

Research in the global abyss and open oceans faces the greatest challenges because of the need for comprehensive mapping of spatial and temporal variations of a wide array of phenomena. Quantifying the dynamics of abyssal and open ocean systems must include resolving the fluxes, changes in the storage of energy and mass, reactions and interactions between components of abyssal and open ocean systems (chemical, physical, biological, geological), and the importance of variations over many time scales. We seek to answer fundamental questions concerning abyssal and open ocean biological communities and their abundance and spatial distribution patterns, and we must understand the influences of physical, chemical and geological processes that govern them.

The margins of the oceans, where the impact of geologic and ocean processes on human populations is of critical interest. They are also the locations where some of the most spectacular natural phenomena are to be observed. We wish to better understand the seismicity and volcanism that accompany plate subduction, the slope stability factors that affect hazard assessment in coastal regions (including land slides and tsunami generation), and the factors that adversely affect ecosystems in coastal environments. The geological, biological, and geochemical dynamics that accompany subduction, the evolution of continental crust, global biogeochemical element cycling, the tectonic forcing of hydrologic systems in margin settings, gas hydrate systematics, and anthropogenic impacts on coastal environments are all research areas critical to the study of the margins of the oceans.

Polar regions present particular difficulties for submergence science but, offer some of the most exciting scientific challenges and potential for discovery in the next century. The dynamics of the polar oceans, glaciation, and the role these oceans play in global biological cycles and ecosystems are fundamental problems that require field and laboratory studies. Similarly, the record of global climate change that is preserved in the polar regions and the study of the slowest-spreading mid-ocean ridges that are present in the polar basins offer important opportunities to provide fundamental advances in our understanding of global processes.

Photos by Shirley A. Pomponi, HBOI

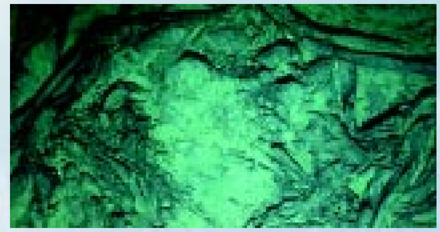
*The* Johnson-Sea-Link I *and* II *submersibles (left and center) of the Harbor Branch Oceanographic Institution, operate to a depth of 914 meters. Each sub can accommodate one observer and a pilot in the forward acrylic sphere, and a sub crew and observer in the aft observation chamber. The* Clelia *sub (right) operates to a depth of 300 meters, and carries two observers and a pilot. Each sub can be equipped for a variety of benthic or mid-water sampling applications. Inset: The* Johnson-Sea-Link I *being deployed with a basket of push corers as scientists prepare to sample cold seep sediments in the Gulf of Mexico.*

# Technology and Development

Participants of the workshop strongly support the continued development of AUVs for a variety of applications and the rapid integration of different types of AUVs into the U.S. oceanographic fleet facilities. AUVs have the potential to enable the oceanographic community to respond rapidly to ephemeral events, to revolutionize certain types of global and regional oceanographic research, to make operations possible in remote geographic areas, and to facilitate measurements and operations of seafloor observatories. Recent advances and utilization of AUVs for science have demonstrated how this technology can revolutionize data collection, and can increase its precision and repeatability, thereby providing new and unprecedented perspectives on the geology, chemistry, physical oceanography, and biology of the oceans.

Occupied submersibles will continue to be the most effective way to provide human cognitive presence at sites of experimentation, observation, and seafloor sampling. The U.S. research community requires an occupied submersible with depth capability down to 6000-6500 meters. Submersibles and ROVs will require better manipulative capabilities, chemical, biological and physical properties' sensors, and the capability to maintain *in situ* conditions during experiments and sample recovery. Continued development of remotely operated vehicle capabilities should be encouraged, and access to more ROV facilities at both private institutions and universities will help scientists gain access to seafloor experiment sites.

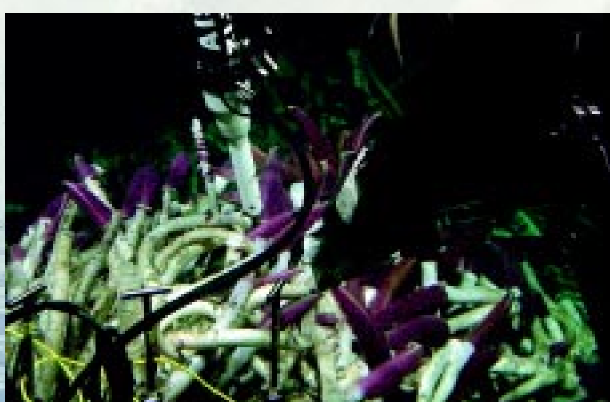
Photo by Dan Fornari, WHOI



*The Argo II optical and acoustic mapping system (left) permits scientists to view the seafloor via video and electronic still cameras, at centimeter-scale resolution, in real time from altitudes of ~5-15 meters while traversing at speeds of ~1/4 to 1 knot. It also has a sophisticated array of single- and multi-beam sonars and oceanographic sensors which transmit data via the fiber optic cable to the support ship. It is one of the systems in the National Deep Submergence Facility operated by WHOI for UNOLS. Photo at right, taken by Argo II, shows curtain folded lava flow dusted with sediment at the summit of Lucky Strike Seamount, Mid-Atlantic Ridge near 37°18'N.*

Future submergence research will require improvements in imaging, particularly high-resolution digital video and still imagery. In addition, new protocols and equipment to facilitate data telemetry to the surface, and the transfer of data to and from seafloor sensors will be required, especially with the development of seafloor observatories. Sea floor mapping at various scales using ROV and tethered systems will continue to be important, especially for nested surveys that seek to resolve process-oriented problems at a range of spatial and temporal scales.

In the past, scientists have been largely restricted to collecting samples from the ocean floor for experiments onboard ship or in shore-based laboratories. While this standard approach has been successful in identifying first-order processes and laying the groundwork for oceanographic studies in many disciplines, we now recognize that *in situ*, integrated experiments are required to fully characterize the oceanic chemical, physical and biological processes. With the vast improvements in technology and miniaturization that have taken place in the past decade, designing and carrying out complex experiments in the hostile oceanic environment are now realizable. A key to facilitating this important leap in submergence science technology will be the transfer of knowledge and instrument design from public and private engineering groups to the broad oceanographic community. Improved sensor capabilities will be required for occupied submersibles, remotely operated vehicles, and autonomous underwater vehicles. The recommendations for sensors include: *in situ* optical, chemical, high temperature, and heat flow sensors, long-term nondegradable, gas-type manifold for water sampling, pressure sensors, gravimeters, magnetometers, multi-spectral sensors, current flow meters, *in situ* X-ray and mass spectrometers, molecular and biochemical probes and sensors, and computer-controlled sediment samplers. Occupied submersibles and ROVs will need to be upgraded to perform precision experiments and analyses *in situ*, to use small-volume samplers, to sample and preserve delicate biological specimens, and to recover samples without cross-contaminating them. Improved sediment coring, and the ability to drill various seafloor lithologies to collect samples and deploy instruments down hole, will be required in the future.



Alvin's *manipulator deploying a sensor wand in a clump of tubeworms in the Guaymas Basin, Gulf of California at 2005 meters. The sensor wand contains a thermocouple, sipper tubing to collect discrete water samples and in situ solid state voltammetric microelectrodes to measure $O_2$, $H_2S$, Fe(II), FeS and polysulfides in real time. Photo by* Alvin *pilots,WHOI, courtesy of George Luther and Craig Cary, Univ. of Delaware and Donald Nuzzio, Analytical Instrument Systems Inc., developers of this new sensor.*

# Infrastructure and Funding

US leadership in submergence technology and scientific productivity is unmatched anywhere in the world. This leadership position has been attained through dedicated efforts by facility providers, individual scientists and engineers, and federal agency program managers. The infrastructure that supports the U.S. academic research needs for deep ocean science consists principally of the U.S. National Deep Submergence Facility operated by the Woods Hole Oceanographic Institution[1]. This facility is part of the University-National Oceanographic Laboratory System (UNOLS). It includes the submersible Alvin, which can dive to 4500 meters depth, and several 6000 meter-rated remotely operated vehicles and tethered mapping and imaging systems (ROV Jason, Argo II mapping and imaging system, and DSL-120 sonar system). Several other universities and research organizations in the United States have technical capabilities that provide access to the water column and seafloor. These include Harbor Branch Oceanographic Institution (HBOI)[2], the Marine Physical Laboratory (MPL)[3] of the Scripps Institution of Oceanography, the Monterey Bay Aquarium Research Institute (MBARI)[4], and the Hawaii Undersea Research Laboratory (HURL)[5]. The vehicles operated by all of these facilities provide the primary U.S. submergence capabilities.

A key component of many of the research initiatives to be carried out in the coming years will be the investigation of temporal processes on the seafloor and in the water column over both short and long (decadal) periods. The observational and sampling requirements implied by time-dependent research demands that new enabling technologies be developed and made available. The existing suite of deep submergence vehicles and capabilities at the U.S. National Deep Submergence Facility and elsewhere in the U.S. must be maintained and adequately supported, and the research community must be assured of access to the facilities necessary to carry out time-series experiments as well as other submergence research.

A stable funding base for oceanographic facilities, for time-dependent studies, as well as for basic research is critical to the success of future submergence research. The workshop participants expressed concern that even field programs that are fully funded sometimes lack sufficient access to needed submergence assets on a timely basis. Scheduling of seagoing programs has, at times, been delayed for several years because of insufficient vehicle availability, either because of logistics or shortfalls in oceanographic facility funding. Providing a stable funding base and greater access to appropriate submergence assets will result in the timely achievement of our federally supported research goals and enhance future research efforts.

Despite the acknowledged dedication to submergence science in this country, annual U.S. federal spending on submergence science and facilities is far less than that of our foreign competitors, principally Japan (which spends about 15 times as much as the U.S.) and France (which spends about five times more than the U.S). The DESCEND Workshop participants stressed the importance of maintaining and expanding our submergence science capabilities and assets. A key recommendation of the workshop is for increased access to submergence vehicles and tools. This implies that the U.S. federal agencies increase spending for submergence facilities support and technology to ensure the access, facilities infrastructure, and technology required to meet the challenges and needs of submergence research in the coming decades. Given the five- to ten-year time frame for design and development of submergence vehicles and facilities, planning and budgeting should begin immediately to ensure U.S. leadership in submergence research in the next century.

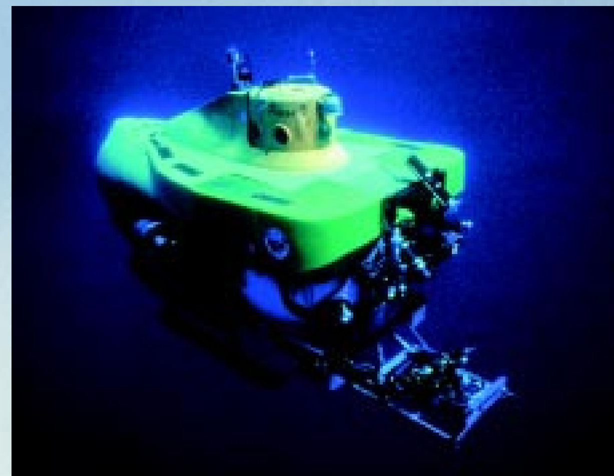
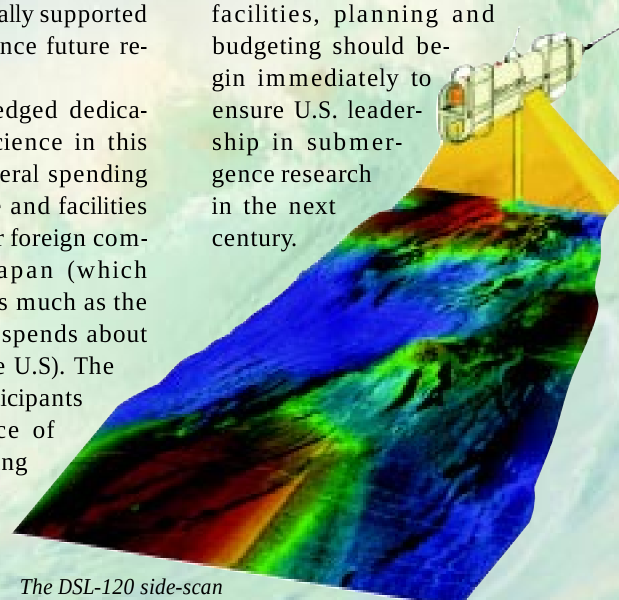


Photo by Terry Kirby, Pisces V chief pilot

*The Hawaii Undersea Research Laboratory (HURL) 3-person submersible,* Pisces V *(depth capability 2000 m) descending in Hawaiian waters. The* Pisces V *submersible cruises at speeds of up to 2 knots, dives with one pilot and two scientists, and generally remains submerged for 7 to 10 hours per dive.*



*The DSL-120 side-scan sonar system produces back-scatter and phase-bathymetric images of seafloor in 1 kilometer wide swaths with resolution of ~2 meters down to depths of 6000 meters. Sonar image shows seafloor structures and bathymetry of the crest of Lucky Strike Seamount, Mid-Atlantic Ridge near 37° 18'N. This sonar system is towed ~100 meters above the seafloor at a speed of ~1-1.5 knots and uses a fiber optic cable to transmit data back to the support ship. It is one of the systems in the National Deep Submergence Facility operated by WHOI for UNOLS. Data courtesy of Dan Fornari and Susan Humphris, WHOI. Sonar image processed by Steve Lerner, WHOI DSL.*

Photo by Dan Fornari, WHOI

*ROV* Jason *can operate to depths of 6000 meters while performing a wide array of imaging, mapping and sampling tasks. Since 1988* Jason *has made 223 dives and spent over 3000 hours surveying the seafloor.* Jason *uses a fiber optic cable to transmit data back to the support ship. During CY2001-2002* Jason *will be upgraded to the* Jason II *system which will have significantly increased power and manipulative capabilities among other improvements. It is one of the systems in the National Deep Submergence Facility operated by WHOI for UNOLS.*

Photo by Dana Yoerger, WHOI

*The* Odyssey IIB *AUV being recovered on the deck of R/V* Knorr *from the Labrador Sea in 1998. The* Odyssey *AUV was developed by the Massachusetts Institute of Technology's Sea Grant Program. It is 1.5 meters long and travels through the water at speeds up to 3 knots. The vehicle carries an array of oceanographic sensors and has been used for a wide range of applied and physical oceanographic surveys.*

*Active hydrothermal chimneys on the southern East Pacific Rise crest near 21.5° S. Left photo shows titanium fluid sampling bottles on the front of* Alvin's *basket prior to sampling the vents. Right image shows* Alvin's *temperature probe inserted into one of the >400°C chimney orifices prior to fluid sampling. Photos by* Alvin *Pilots, WHOI. Courtesy of Karen Von Damm, Univ. of New Hampshire and Marvin Lilley, Univ. of Washington.*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**To view the entire DESCEND Workshop Proceedings Report, please visit the website:**

www.unols.org/dessc/descend/descend.htm

1) National Deep Submergence Facility, WHOI: <www.marine.whoi.edu/ships/ships_vehicles.htm>
2) Harbor Branch Oceanographic Institution: <www.hboi.edu>
3) Marine Physical Laboratory, Scripps Institution of Oceanography: <www.mpl.ucsd.edu>
4) Monterey Bay Aquarium Research Institute: <www.mbari.org>
5) Hawaii Undersea Research Laboratory: <www.soest.hawaii.edu/HURL/hurl.html>

## The DESCEND Workshop Steering Committee:

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University of Hawaii, SOEST

Dr. Keir Becker
University of Miami, RSMAS

Dr. Marv Lilley
University of Washington

Dr. Craig Cary
University of Delaware

Dr. Lisa Levin
Scripps Institution of Oceanography

Dr. James Bellingham
Monterey Bay Aquarium Research Institute

**Ad hoc Steering Committee Member**

Dr. Daniel Fornari
Woods Hole Oceanographic Institution


**UNOLS Office**
**8272 Moss Landing Road,**
**Moss Landing, CA 95039**
**831-632-4410**
**www.unols.org**



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# Meeting Proceedings

## DEveloping Submergence SCiencE for the Next Decade DESCEND

**Steering Committee:**
Keir Becker, University of Miami
Jim Bellingham, MBARI
Craig Cary, Univ. Delaware
Patty Fryer, Chair, Univ. Hawaii
Lisa Levin, SIO
Marv Lilley, PMEL

# I. Background

The DESCEND workshop, held on October 25-27, 1999 in Arlington, VA, was prompted by the need to define both the critical scientific goals for the submergence community and the technological directions that will be required to take submergence research into new realms of discovery in the coming decades.

In order to accomplish its goals the DESCEND Workshop involved both scientists and technology experts. The scientists utilized creatively the face-to-face interaction with the engineers and technicians to articulate the types of research that will need new tools and innovative technological approaches in submergence science. The attendees were charged to think in terms of (1) multidisciplinary and multi-institutional use of multi-purpose platforms distributed globally and (2) in terms of developing infrastructure and specialized tools as appropriate for particular initiatives.

The spectrum of scientific problems and environments that must be investigated require access to a broad scope of ocean environments with a range of safe, reliable, multi-faceted, high-resolution vehicles, sensors and samplers operated from support ships with global reach and station-keeping capabilities in all weather. The marine science community requires the right complement of deep submergence vehicles and versatile support ships from which they can operate. The attendees agree that submersibles, which provide the cognitive presence of humans and heavy payload capabilities, will be critical to future observational, time-series, and observatory-based research in the coming decades. Fiber-optic-based remotely-operated vehicles (ROVs) and tethered systems, especially when used in closely-timed, nested investigations offer unparalleled maneuverability, mapping and sampling capabilities with long bottom times and without the limitation of human/vehicle endurance. The community strongly encourages development of autonomous underwater vehicles (AUVs) of various designs to provide unprecedented access to the global ocean, deep ocean and sea floor without dedicated support from a surface ship.

There are serious impediments to funding for multi-disciplinary science and for global, time-series, or long-term observatory work. Education of the public, our fellow scientists and assisting the funding agencies in education of the appropriate science advisory groups with regard to the advances in and potential from submergence research will be critical to implementing the recommendations from this workshop.

Follow-up to this workshop, by both the deep submergence community and federal agencies is also a critical component to the future success and health of deep submergence facilities and science in the US. The funding agencies have discussed the possibility for a follow-up engineering and technology workshop to discuss details of the priorities of technology research and development that have been recommended at this meeting.

# II. Science Sessions

The workshop science sessions were based on the types of environments in which submergence science is pursued, i.e., mid-ocean ridge environments, the abyss and open ocean, plate margin environments, polar and coastal regions. The objectives were to 1) define the critical scientific research themes to be emphasized in the next decade, 2) to specify the scientific questions to be addressed and to define strategies needed to approach answers to these questions, and 3) to define what technological approaches are needed to carry out these objectives. The objective is to help to direct future strategies for upgrades to vehicles, science sensors, sampling techniques, and imaging capabilities of submersible vehicle systems funded by the federal agencies.

## A. Mid-Ocean Ridge Processes.

There are a host of fundamental, interdisciplinary questions requiring deep submergence technology that need to be answered in order to understand the Earth's complex geochemical, biological and geological processes at mid-ocean ridges.

**The Biosphere.** The biological, chemical and physical processes that have controlled the origin and development of life on Earth can be studied in situ in the ocean crust and upper mantle beneath the global mid-ocean ridge system.

- What are the spatial extent and diversity of the ridge system biosphere?
- What are the relationships between vent communities/volcanism/hydrothermal activity at all scales.
- What controls the subsurface biosphere and how can it be investigated "non-invasively"?
- What is the physical and chemical character of the subsurface biosphere and its circulating fluids?

**Crustal Architecture.** Mid-ocean ridges are the locus of the Earth's greatest mass, chemical, and energy fluxes from the deep interior to the surface; as such, they provide the best windows into their associated processes. The magmatism and tectonism that create oceanic crust are neither steady state nor periodic nor well understood.

- What is the composition and 4-D structure of the oceanic crust and how do they relate to mantle dynamics, magmatic, tectonic, hydrothermal, and biological processes?
- How do hydrothermal circulation and alteration affect crustal structure and composition?
- What controls the permeability structure of oceanic crust and its evolution?
- How is off-axis volcanism related to mantle dynamics and magmatic plumbing systems? How is tectonic extension accommodated in ridge environments?
- How do faults initiate and evolve?

**Active Cyclic Processes.** The entire volume of the world oceans is cycled through hydrothermal vents at mid-ocean ridges every few thousands years. The oceanic crust represents the fundamental reaction zone between the ocean and the deep mantle, yet we still do not understand how it interacts with chemical and biologic processes along ridges.

- What processes occur during an accretion episode during the first few days after the intrusion/eruption, and over what scale in x, y, and z are their effects felt?
- How are lavas emplaced on the seafloor?
- How wide and long are the zones of dike injection?
- What are the consequences of hydrothermal plume discharge at the seafloor and in the overlying water column and how do they vary over time (rates of change, etc.)?
- What can plume biological, chemical, and physical characteristics reveal about crustal and magmatic processes?
- How do plumes influence larval dispersal and global biogeography?

**Global Variability.**

- How do magmatism and tectonism control the distribution and character of hydrothermal systems along the global mid-ocean ridge?
- How have vent fauna evolved throughout the global ocean?
- What are the characteristics of communities that exist beneath Arctic (ice bound) ridges?
- What are the geologic, biotic, and geochemical linkages that determine the structure of hydrothermal vents and vent communities in differing spreading regimes?

**The Mantle Connection.** Ultimately it is the heat, volatiles and silicate melts derived from the mantle that drive the magmatic, hydrothermal and biologic processes at ridge crests. Understanding the way in which magma melts and flows beneath ridges to form basaltic magmas is a main goal that can be addressed indirectly through submergence research.

- How are magma and volatiles transported and distributed to make the oceanic crust?
- Is ridge segmentation a fundamental manifestation of the underlying pattern of mantle flow beneath ocean ridges or the mechanical reaction of ridge geometry to variations in far field forces?

## INVESTIGATIVE APPROACHES

We must be able to map and sample, from the seafloor and at depths, at all appropriate scales, to document the extent and diversity of biological communities and to define crustal architecture and maturation. Delicate biological samples must be obtained with precision-controlled manipulators and the samples must be protected from contamination. In situ monitoring of biological communities both at the seafloor and down-hole will be required. Near-bottom magnetic, gravity electromagnetic surveys, and active and passive seismic studies will help to define interrelations between tectonic forcing functions and biological and chemical processes.

The study of cyclic processes will require event response sampling of lava, biota and vent/plume fluids, as well as sustained time-series observations. We must anticipate events and map and instrument likely sites. Such activities could be accomplished in the future with a fleet of AUVs that can be airdropped in a region that has a navigation net in place. Development of sensors will be a critical component of this effort. Optimally, we will deploy extensiometers, tiltmeters, heatflow and geodetic devices, chemical monitors, and seismometers at likely sites of activity in order to monitor cyclicity of various processes.

To address questions regarding global variability we must be able to optimize locating vents therefore we must improve spatial coverage. One way to do this would be to develop smart AUV (e.g., instruments that can detect various water properties). To gain wider spatial coverage we could look toward piggybacking AUVs on other cruises. The critical need is to map the ridge and near-ridge geology and obtain representative surface and subsurface sampling over segment-scale and larger regions.

To address questions regarding the mantle connection to ridge processes we must establish long-term seafloor observatories that are capable of monitoring a variety of chemical and physical processes. We must accomplish surface and subsurface sampling on a segment scale and engage in sampling for comparison along several segments. This will require detailed sampling by submersible or ROV and the capability to drill multiple holes in ridge environments.

## B. The Abyss and Open Ocean

The abyss and open ocean host a complex network of interrelated physical, biological, chemical, and geological systems, often difficult to identify and understand because they are spread out over large volumes and are dynamic over time scales of minutes to millennia.

**Mapping the Abyss and Open Ocean.** The open ocean hosts one of the largest ecosystems on Earth, but the life cycles, spatial and temporal distribution of organisms remains largely unknown.

- What is the three-dimensional distribution of water column particulate matter, chemical properties, and organisms?
- How do these distributions vary on different spatial scales?
- Are there interdependencies between physical, chemical and biological distributions that can be quantified either in space or in time?
- What types of perturbations to physical or chemical conditions most affect various populations? How time dependent are the resultant changes?

- What is the magnitude of the change effected and over what spatial parameters do changes take affect?
- How can populations be sustained as demands on ocean resources increase?

**Quantifying the Dynamics of Abyssal and Open Ocean Systems.** This field includes studying fluxes (in and out), changes in storage of energy and mass, reactions and interactions between components of abyssal and open ocean systems (chemical, physical, biological, geological), and studying the importance of variations over many time scales.

- What are the specifics of the primary production in the upper ocean, particle transport (in both horizontal and vertical senses), particle transformations, sedimentation, sediment processing, and abyssal hydrothermal and hydrological processes?
- How do both biologically mediated and strictly geochemical reactions influence these processes?
- How do these processes, their rates, their temporal and spatial dynamics influence element cycling, and how they interact?
- What are the essential reactions, fluxes and reservoirs involved in these processes throughout the water column and within the seafloor?
- What is the impact of disturbance on organisms and communities in time and space?
- What models best resolve biological and geochemical variability, models that include non-steady state, non-equilibrium and non-uniform phenomena?
- What models best suggest a reasonable and appropriate sampling methodology?

**Understanding the Natural History, Behavior, Ecology, and Evolution of Abyssal and Open Ocean Communities.** Fundamental questions concerning abyssal and open ocean biological communities revolve around their composition and variability, and the linkages, which govern their abundance. Spatial and temporal variability of biological systems appears to be higher than for physical parameters of the ocean.

- What are the causes of this phenomenon?
- Why are many types of water column communities patchy or confined to narrow depth ranges?
- Why do mesoscale scale ocean processes such as gyres cause large variability in some water column organisms?
- What exactly are the abundance and spatial distribution patterns of biological communities from small to large spatial scales?
- What are the affects, at high resolutions, of the many important inputs to the biological system that are pulsed?
- What is the full picture of seasonal and inter-annual variations? Long time-series observations covering decades are needed to begin to build up a full picture of these variations and their importance.
- What are the influences of physical, chemical and geological environment on biological communities in the oceans?

- What are the consequences of episodic events such as resuspension, upwelling, volcanic activity, and turbidity currents?
- Physical processes in the ocean such as temperature changes or currents may have direct effects on a given community or on its reproductive cycle (i.e. larval transport), or may indirectly affect it through its food supply. What is the nature of biological couplings, including trophic effects such as bloom die-offs?
- What is the relative importance of episodic events as compared to seasonal and inter-annual variability (e.g. El Niño)?

## INVESTIGATIVE APPROACHES

Mapping the abyss and open ocean regions will require both existing and yet-to-be-developed sensors on submersibles, ROVs and AUV platforms that give not only a three-dimensional view of sea floor topography, water column particulate matter and chemical properties, and the distribution of organisms but provide the ability to document the 4-D changes over time. Temporal variations in these processes are key to understanding them and their importance. Acoustic, photographic and laser line-scan imaging of water column and seabed features can be done in a nested mapping approach as has been done in ridge crest research. A similar nested scheme will need to be developed for mapping of organisms within the water column. Repeat surveys will provide the necessary temporal dimension. Permanent ocean bottom observatories such as those proposed under several initiatives are planned to be general-purpose observatories available to the community for installation of diverse experiments. Such stations will supply fixed sites for long time-series observations of geophysical, biological, chemical and physical oceanographic parameters over decadal time frames.

Quantifying the dynamics of abyssal and water column processes could take advantage of existing and new chemical sensors that can be deployed on ROVs and AUVs. Since chemical, biochemical and genome-based sensors are becoming smaller and are requiring less power; there will be an increasing demand to place them on AUVs and ROVs. These instrumented submergence platforms in conjunction with acoustic, photographic and laser line-scan imaging will result in a capability for an unprecedented dynamic view of physical, chemical and biological events and processes in the sea. This in turn will lead to obligatory changes in the need for modeling, data management and infrastructure support.

Detailed chemical sampling at particle layers and physical discontinuities will be needed. The mid-water column and seafloor organisms must be sampled and their behavior observed. Manipulative ecological experiments will be required. We must quantify biota in the water column and on the seafloor. The ranges and rates of activity of these organisms and the interactions among them will have to be defined. We must measure or infer rates of fluid flow over broad areas and with depth within the seafloor. We must quantify the mid-water processing of surface ocean biomass during its descent to the seafloor, including the role of anoxic/suboxic microzones within the oxic water column.

In-situ experiments and measurements are necessary to resolve time scales of forcing and responses. Sampling and monitoring rates will also need to be adjusted depending on interest in continuous or pulsed inputs, and will need to occur simultaneously over large areas in order to resolve regional-scale processes.

Although remote sensing can be used to resolve near-surface processes at most time and space scales of interest, we lack a similar capacity for the remainder of the water column and seafloor, and any new methods developed for this purpose will need to be extensively verified and calibrated for accuracy.

Addressing questions regarding the natural history, behavior, ecology, and evolution of abyssal and open ocean communities requires a broad new range of capabilities. Existing vehicle assets are not well suited to studying the mid-water environment in the oceans. Communities may be diffuse, consequently to obtain statistically significant population estimates, a key measurement for the studies outlined above, we must be able to search large volumes of water and large areas of seafloor. This observation capability must be backed up by an ability to detect and identify organisms, ideally autonomously. Sampling and collecting capability is also a requirement, especially the ability to acquire many samples per dive. To establish the context for more intensive experiments with mobile assets, work should be coordinated with deployment of equipment designed to obtain time-series data and samples. Access using both fixed and mobile platforms will be required.

The huge data sets will be not only of numerical character but will also consist of images. There is a need to establish a data management infrastructure that minimally catalogs the metadata and ideally compiles a distributed database. Meta-databases indicating the availability of such information will be useful.

## C. Margins

The active and passive margins of tectonic plates and continental masses present the full range of ocean depths from a few meters in estuaries and coasts to >10 km in deep-sea trenches. Margins also differ characteristically by latitude. At high latitudes there are shelf depressions, fords, and abyssal flood plains whereas low latitudes have carbonate platforms, reefs, and the world's steepest and tallest escarpments. Mid-latitudes have coastal deltas, slope gullies and canyons, and the deep-sea fans with their successions of meandering channels. Margins have extraordinarily high biological productivity and among the greatest human population densities. They are the Earth’s principle loci for production of hydrocarbon and metal resources, as well as earthquake, landslide, volcanic and climate hazards. Extreme environmental conditions are prevalent. Margins have the highest organic loading, lowest oxygen levels and the strongest currents. Escaping fluids can range from alkaline to hypersaline, from the lowest to the highest pH recorded on Earth. Margins are the regions where most major fisheries are centered, the areas where human impacts are greatest, and where known species diversity is highest. Major oceanographic features such as boundary currents and oxygen minimum zones often impinge on continental margins. Despite the scientific, societal, and economic importance of margins, many of the mechanical, fluid, chemical and biological processes that shape them, and the way that margins shape ocean life, are poorly known.

**Origins of the Continents, Oceans, and Life.** Subduction zones are the birthplaces of continents and are the recycling factories of the earth. Ore deposits, volcaniclastic sedimentation, and submarine calderas are among the principal continent-forming phenomena that are best studied on the seafloor at margins.

- How do the processes of tectonism, hydrogeology, geochemistry, volcanism and sedimentation act to create new crust and what is its subsequent evolution?
- How do magmas evolve and erupt at convergent margins?
- How do the products fragment, erode, and accumulate? How do fluids modify and interact with the volcanic products?
- The raw materials consumed and accreted at Subduction zones are ultimately recycled as part of a growing continent, or more deeply back into the mantle.
- We must determine the basic parameters of this recycling plant.
- How is recycling linked to dewatering, metamorphism, melting, earthquakes, and degassing of the crust?
- What are the flux rates of the input and output materials?

Rifting of continents creates new ocean basins. Oceans are formed, in part, by the outgassing of the planet at active plate margins. The geochemistry of fluids and mass balance of fluxes in submarine margin environments are least affected by the crust through which they pass and, therefore, most relevant to the origin of the oceans. These environments are unique to earth and processes unique to margin environments have been essential to life on Earth. How do substrate, depth distribution, and geochemistry of margins create variable life forms? Answers may be essential to understanding the origins of life, on Earth or elsewhere.

**Global Biogeochemical Element Cycling.** Plate margins cover about 30% of the oceans where most of the organic carbon and nutrient cycling occurs, hydrocarbon reservoirs are vast, and tectonically driven fluids are pervasive.

- What are the fluxes from these processes and what is their role in global cycles? What is the temporal control over diversity of the cycles?
- What is the spatial variability of these cycles?

Among the most important of these cyclic processes are gas hydrate systems. These dynamic systems, sensitive to subtle changes in pressure and temperature, represent an immense global carbon reservoir. They have the potential to drastically affect the global carbon budget and influence global geochemical change on a very large scale. Correlation between areas of gas hydrate and regions of massive slumps or slides suggests that these systems also are related to significant submarine hazard potential.

- What is the magnitude of gas hydrates as a carbon sink on Earth?

- How are the temporal and spatial distributions of gas hydrates controlled by tectonic processes on varied spatial scales?
- What role do gas hydrates play in the carbon cycle over a variety of temporal scales?
- Do tectonics directly force massive hydrate release via earthquakes and submarine slides?
- Over longer periods, does warming of the global ocean may trigger methane release through destabilization of hydrates? On what types of margins does this process take place?

**Biological Diversity and Productivity** Benthic communities in margins are extremely heterogeneous both spatially and temporally. This heterogeneity is driven by variations in currents, nutrient input, oxygen availability, sediment and pore water constituents, topography, sediment dynamics, and substratum type. This complexity results in a wide variety of unanswered questions regarding biological processes at margin environments.

- What drives variation in populations of species living in the spatially variable habitats at margins? We particularly need a greater understanding of recruitment and survival of harvestable species and the communities of organisms that provide their trophic base.
- How does coupling between the water column and benthos fuel biological productivity at margins?
- How are individual populations adapted to occupy specific zones of bathymetric and other gradients (e.g. oxygen, organic flux, pressure, temperature)?
- What generates and maintains patterns of zonation?
- Are there major physiological thresholds that control the distributions of species and biomass?
- Do reduced habitats such as methane seeps, oxygen minima and whale falls support specialized faunas that differ from the background fauna?
- What is the role of these communities in ecosystem function at a larger scale?
- How important are the linkages between chemosynthetic communities and the background fauna?
- Why is sediment biodiversity maximal at mid- to lower slope depths?
- Do high levels of habitat heterogeneity and steep environmental gradients lead to very high population differentiation and speciation rates on margins?
- How do margin cold seep communities differ from hydrothermal vent communities? Cold seep communities were originally assumed to be shallow-water analogs of hydrothermal vents, but preliminary work indicates that ecological, physiological and reproductive attributes of the species in seep communities are very different.

**Paleoceanographic Conditions.** Understanding of key taxa such as foraminifera, deep-sea corals, coccolithophores and fishes, as well as important processes such as bioturbation and microbial activity in present-day margin systems is necessary for reconstruction of paleoceanographic and climatic conditions. Certain margin environments such as near shore anoxic basins and deep-water coral reefs are likely to contribute valuable historical information. The original invasion of the deep sea from shallow water faunas presumably took place by movement down continental slope. Therefore, investigations of the physiological and reproductive adaptations of slope species can provide insights into how these invasion and speciation processes have occurred and are presently occurring.

**Anthropogenic Impacts.** Over the coming decades, humans will affect margin environments more significantly than other oceanic environments. Margins will experience greater pressure from deep-sea fisheries as shallow stocks are depleted and the demand for seafood increases with increasing human population. How does fishing modify margin habitats, ecosystems and trophic linkages on the seabed and in the water column, and what fishing practices maximize sustainable harvest and conserve ecosystems? Margins, because of their proximity to human population centers, will be impacted with higher nutrient input from agricultural drainage, sewage, land use/abuse, deforestation, as well as various chemical pollutants. Organic loading can alter the structure of margin ecosystems through eutrophication and associated hypoxia while non-living resource exploitation has other effects.

- What human activities cause the greatest alteration and what are the consequences for margin ecosystem function?
- What are the effects of mineral, oil and gas mining on margin biology and geology?
- What changes can be put in place to remedy existing problems?
- What practices are least harmful?

**Sediment Dynamics (erosion, transport, and deposition).** Process-based models of marginal marine deposition and basin-filling remain poorly tested and constrained. The distribution of marine sediments is a primary control on the distribution of marine biological communities. Coarse-grained sediments host significant hydrocarbon accumulation and currently are the most important target reservoirs for the petroleum industry. High energy mass wasting events (debris flows, slumps, turbidity currents) pose considerable hazards to society, to marine engineering facilities, and pose a strategic challenge.

- What are the magnitude/frequency relationships for sediment-gravity flow events for a given submarine drainage?
- How are sedimentation events linked to seismicity, storms, floods, etc.?
- How are materials (nutrients, elements, etc.) delivered to, sequestered in, and cycled within marine sediments?
- How is biological diversity and productivity affected by sedimentation?
- How is event magnitude related to deposit thickness and, therefore, the architecture of ancient deep-water depositional systems?
- How does topography at a range of scales control the distribution of coarse clastic detritus?

- How do natural flows that distribute sediment on the ocean margins differ from laboratory and theoretical flows in terms of thickness, velocity profiles, and concentration profiles?
- How does early diagenesis and bioturbation affect the macroscopic character of marine sediments?
- What are the fluxes of sediment delivered to the marine margin by various dynamic processes?
- What is the topographic and sedimentological 'signature' of a sedimentation event?
- How does topography at a range of scales control the distribution of clastic detritus?
- How do natural flows that distribute sediment on the ocean margins differ from laboratory and theoretical flows in terms of thickness, velocity profiles, and concentration profiles?
- What are the fluxes of sediment delivered to a sedimentary basin by various dynamic processes?

**Influences of Deformation Processes.** Deformation processes at margins control the largest scale topography, sediment transport and dynamics, and chemical fluxes, which in turn force links between biologic, chemical, and geologic processes, and hence the location and magnitude of resources and geologic hazards. Water/rock/organic-matter interactions during deformation change fluid compositions and, by altering rock porosity and permeability, create a feedback mechanism affecting fluid pathways and flow rates. These must be monitored *in situ.* These fluid flow and diagenetic processes represent important contributions to the global geochemical inventory. Many of these mechanisms, their rates, and the fluid pathways are still largely unknown.

- What controls the partitioning of strain and the distribution of magma?
- What fraction of subducted volatiles ($H_2O$, $CO_2$) is returned to the oceans and atmosphere, stored in crustal rocks, and subducted to the deep mantle?
- Does subduction of carbonate lead to enhanced volcanic $CO_2$ fluxes to the atmosphere?
- How do forcing functions such as convergence rate, volatile input and upper plate structure control magma production rates and composition?
- What are the nature and fluxes of the fluids and solids through forearcs?
- What is the relationship between earthquakes and the geometry/mechanical state of faults?
- What are the interrelations between the fault material properties and thermal structure, lithification, and intrinsic rock strength?

**Geologic Hazards.** Subduction earthquakes are the largest energy releases on Earth. Because most of the Earth's population lives within tens of kilometers of the coast understanding and monitoring forcing functions related to this seismicity is critical. We still do not understand the nature of strain accumulation related to great earthquakes.

- How do the physical properties of convergent and transform margins affect the dynamics of strain accumulation and rupture?
- What are the periodicity, segmentation, and rupture dynamics associated with great earthquakes?
- How do seismic waves propagate through a margin?

Mass wasting events accompany most large earthquakes in margin environments and cause far more damage close to the source region of earthquakes than does ground motion. Mass wasting can also be associated with sector collapse during volcanic eruptions and with large storms.

- What are the styles and extent of landslides associated with margin seismicity and volcanism?
- What are the structural features related to flank collapse of margin volcanoes?
- How would we distinguish volcanically vs. tectonically triggered events?
- How interrelated are seismicity and volcanism in convergent margins?

The massive landslides in margin environments have generated devastating tsunamis. In order to understand and ultimately predict adverse affects accurately, what is needed are accurate models based on observations of phenomena both before and during events. Detailed bathymetry and imagery surveys and studies of physical responses to mass wasting must be carried out.

- What are the triggering mechanisms and processes involved in scale large mass-wasting?
- What are the dynamics of tsunami generation in response to different types of events?
- How does submarine mass wasting influence mass fluxes of nutrients, sediments, and chemical species?
- Do mass wasting events link to global change through the release of dissociated methane hydrates?

Volcanic activity on convergent margins itself poses potential hazards for human populations and can have devastating effects on both subaerial and submarine ecosystems. Other hazards of importance on margins include hurricanes, storm surge, and flooding, yet we know very little of how storms and floods affect the biology and geology of margins.

**Tectonic Forcing of Hydrologic Systems in Margin Settings.** Episodic events, possibly associated with major earthquake rupture and accompanying ground motion, may dominate the flux of fluids at convergent margins. Variability of fluid fluxes within different portions of a given margin region may be related to both shallow and deep margin processes. These could include partitioning of fluid flux within the shallow outer forearc regions (prism or hard rock) and depths where fluids contribute to forearc mantle metamorphism or melt production the relative importance of transient vs. steady state hydrological processes. The presence of fluids in a margin setting does in itself alter the physical properties of the sediments and basement of which the margin is composed, therefore there is a potential feed-back loop between tectonic processes and hydrologic systems in these settings about which we know very little.

- We need to understand the role of tectonic processes such as seismicity in fluid flow through both convergent and passive margins. How do tectonically induced forces drive flow, and create the local barriers and pathways to fluid flow?
- What is the role of water in controlling deformational style in convergent margins? How does uptake of volatiles through alteration and metamorphism in the overriding plate at convergent margins influence the properties of the overriding plate?
- What is the role of fluids in rupture along the decollement in convergent margins, and how do earthquakes, in turn, influence fluid flow through the generation or release of pore-fluid pressures within the rupture zone?
- What is the relative importance of transient vs. steady state hydrological processes in margins of all types?
- Do episodic events, possibly associated with major earthquake rupture and accompanying ground motion; dominate the flux of fluids at convergent margins?

## INVESTIGATIVE APPROACHES

A variety of techniques and field/laboratory efforts are needed for studies of margins because the questions to be addressed are diverse and the areas encompass large and globally distributed regions at all latitudes. A global approach is required because the best examples of given margin processes do not all occur in a single region. Submersible vehicles capable of reaching a wide range of depths from shelf to trenches will be needed. Studies will require monitoring capabilities for both short- and long-term phenomena, *in situ* observation, sampling, and experiments for study of processes such as formation and/or dissociation of methane hydrates, fluid venting, and various responses of biological activity. ROVs and AUVs equipped with standard imaging packages and new coring devices can respond to individual events. Tethered, hard-wired observatories can provide time-series data on the magnitude and frequency of a variety of events.

Additional vehicle assets, which complement submersible, ROV and AUV systems and a new suite of chemical, biological, and geotechnical sensors will be needed to examine and respond to episodic events. Some experiments and observations will require a seafloor observatory approach. Analogous to the Ocean Drilling Program, we must consider the possibility of multi-platform options. For example, there is a need for alternate-type vehicles such as bottom crawlers, with tools optimized for imaging benthic organisms and measuring such phenomena as respiration rates and microbial activities. Portable rock drills for use in both shallow and deep seafloor environments will also be needed to drill shallow holes into the upper ocean crust. Vehicles must be able to work in regions of strong currents, poor visibility, corrosive water, and near vertical slopes. There will be demand for heavy payloads to accommodate sampling in biogenic substrates such as reefs, crusts, and carbonate sands, and amongst biogenic structures (shells, tubes, coral debris). Finally, some critical questions can best be addressed with efficient response to unpredictable events.

Improving our understanding of deformation at margins will require a better understanding of seafloor tectonics at a variety of spatial and temporal scales. Deep submergence assets are critical to address tectonics at smaller temporal and spatial scales, in much the same way as outcrop-scale geology and geophysics requires different tools than global studies.

Some of the technologies are available and rely on deep submergence assets primarily for installation and maintenance of geodetic reference markers and specialized seismometric, geodetic and strain measurement systems, fluid flow experiments and direct sampling and observations. New technologies under development such as ship-deployable drilling and coring rigs, ROV mapping systems, and others not yet devised will be required to advance our knowledge of margin environments.

All of the aspects of natural hazards that are outlined above are addressable with submersible technology, particularly geodetic and seismic monitoring, subduction zone physical properties, and tsunami warning systems. We will need medium to high-resolution surveys of targeted margins as the backbone of any comprehensive and multidisciplinary investigation. Submersible investigation of the 1998 New Guinea slide area proved the link between fluid venting and mass wasting. Monitoring microseismicity in areas prone to mass wasting events will facilitate forecasting. We also need detailed maps of venting regions in potential mass-wasting localities and monitoring of venting flux and composition. The study of hydrologic systems will require submergence assets to reveal tectonic processes occurring on smaller spatial scales than possible with surface assets and surface geophysics. The only way to study these sensitive systems in detail is by creating *-in situ* observatories and providing for submersible vehicles of various types to down-load data, collect samples, and service the observatories.

## D. Polar Regions

For many polar environments, little or no exploration has occurred using submersibles, let alone time-series measurements of key parameters over multiple spatial scales.

**Polar Oceans.** A great diversity of ocean environments exist in polar seas. They include ice-covered seas over shallow continental shelf and slope environments, abyssal plains, mid-ocean ridge systems, seamount chains, and many others. For polar oceans and most ocean systems, the priorities for investigations generally progress from: (1) exploration and discovery, in which the basic elements of the system are identified, 2) characterization of the system, quantifying spatial and temporal variability of physical, chemical, and biological elements of the system over multiple scales, and 3) experimental and theoretical examination of processes expected to influence system dynamics. These studies must be followed by predictive modeling and synthesis of relevant elements of earlier studies, in order to characterize the dominant sources and patterns of variation in the system.

- What is the hydrographic structure of the Arctic Ocean and adjacent seas?
- What are the physical and biological interactions between the polar oceans and the global hydrosphere?
- What controls the formation and maintenance of the Arctic sea-ice cover?
- What are the characteristics of the formation, movement, and mixing of arctic water masses? How does sea ice grow and decay?
- What are the controls over the exchange of salt and heat with the Atlantic Ocean and the Bering Sea
- What are the interdependencies of chemical and physical processes and marine organisms and productivity in the Arctic Ocean?
- What is character of the Arctic Ocean ridge system and what are the distributions of magnetic anomaly patterns, heat flow and gravity variations in the Arctic Ocean?

**Global Climate Change.** Polar amplification of climate warming (especially in the Arctic), coupled with accelerated climate warming expected in the next century, underscores the need for climate-related research in polar oceans. For example, there is temporal correlation between a fundamental change in the atmospheric circulation of the Northern Hemisphere and (1) the temperature increase of the Arctic Ocean Atlantic water, (2) the increase in the surface air temperature over the Russian Arctic, (3) the Arctic Ocean circulation changes, and (4) the freshening of the upper Beaufort Sea. These observations suggest the recent change in the Arctic is at least a decadal scale phenomenon and has broad implications for changes at lower latitudes. What are needed are long time-series measurements of physical variables, process studies, and modeling to track and understand the changes. We need to understand how changes in sea ice thickness and extent occur, and the consequences of such changes to upper-ocean hydrographic structure (density structure, formation, position, and intensity of oceanic frontal zones and other hydrographic interfaces), and how they affect climate change.

- What are the characteristics of ocean basin circulation in the Arctic Basin and Antarctic Circumpolar Current?
- How do various aspects of biogeochemical cycling, (especially carbon cycling) in various polar environments affect climate change?
- How do shelf/basin interactions, (in the Arctic these are the focus of a multidisciplinary Arctic System Science (ARCSS) Program) influence climate variability?

Research priorities include studies of shelf and basin patterns (physical and biological structure) and processes (biogeochemical cycling, physical oceanography, population dynamics), and interactions between the Arctic shelf and basin environments (e.g. carbon export from shelf to basin).

- How do polar ecosystems respond to climate variability?

- Polar ecosystem dynamics, remain unknown or understood poorly for many habitats, and in some cases, remain in the discovery phase of science progress. How are regime shifts related to natural variability in physical and biological parameters of polar systems?
- Rapid climate change is characterized by extreme climate variability, detected recently in ice core proxies. Is recent extreme climate variability related to global warming? Can we even detect environmental regime shifts?

**Arctic and Antarctic Ecosystems.** Biological diversity can be considered at three levels, genetic, species and ecosystem diversity. The first involves the variety of genetic information contained in individual plants, animals and microorganisms that inhabit the system. It occurs within and between populations of organisms that comprise individual species as well as among species. Understanding the natural variability of marine ecosystems is the goal. However, there are some fundamental questions for which we do not yet have answers. These must form the basis of our approach to understanding ecosystems in polar regions.

- What is the distribution of life in polar oceans?
- What are the specifics of low-temperature life processes?
- What is the correlation between the structure and function of the marginal ice-zone ecosystem with oceanic and atmospheric processes?
- What is the influence of nutrient limitations on primary production and the role of marine phytoplankton in carbon dioxide cycling?
- What are the dynamics of populations in the polar regions, especially metabolic, physiological, and behavioral adaptations of krill and other zooplankton and fish species?
- How do marine mammals and birds populations respond to changes in polar ecosystems?

**Glaciation.** Glaciological research is concerned with the study of the history and dynamics of all naturally occurring forms of snow and ice, including seasonal snow, glaciers, and the ice sheets. Studies of interest to submergence science communities include history of glaciation in the polar regions, ice dynamics, and remote sensing of ice sheets.

- What is the extent, timing, and regional differences of the last glacial maximum in the polar regions?
- What rapid or episodic events occurred during the Late Quaternary in both polar regions?
- What are the key forcings and feedbacks that influence the retreat and re-advance of the ice sheets?
- What changes have occurred to ice shelves and outlet glaciers during the Holocene?
- What is the correlation between Late Quaternary polar environmental history and deep-ocean sedimentary records?

- When was widespread continental glaciation initiated in the various sectors of the Antarctic margin?
- What is the stability of the East Antarctic Ice Sheet?
- Are the East Antarctic Ice Sheet and the West Antarctic Ice Sheet fluctuations in or out of phase?
- What is the relationship between Northern and Southern hemisphere glaciations?
- What is the nature of climate variability during the Holocene along the coastal setting of East Antarctica and the circum-arctic region and what was the response of the marine ecosystem to these changes?
- What is the Mesozoic and Cenozoic tectonic history of the East Antarctic margin?
- What is the relative role of shallow banks and cross shelf troughs on sediment supply and benthic ecosystems in polar regions?
- What is the evolutionary history of polar oceans and their flora and fauna?

- What are the characteristics of sea ice dynamics, including material characteristics of sea ice down to the individual crystal level and the large-scale patterns of freezing, deformation, and melting? These processes have implications for both atmospheric and oceanic 'climates.'

- What are the dynamics of Antarctic ice shelves?

## INVESTIGATIVE APPROACHES

Certain types of polar research will require new vehicle designs. For example, sampling of under-ice habitats is presently limited or impossible using existing submersible vehicles. The study of ecosystems, such as the mechanisms necessary for maintenance of cell function in fishes and their feeding behavior, require long-term observations. Such studies are needed to improve understanding of man-made or natural changes. Advances in instrumentation, including remote sensing or telemetering of ice type, thickness, motion, and growth, should enable large scale dynamics of sea ice to be monitored over long periods. Recent studies indicate that melting of Antarctic ice shelves progresses largely by melting from below, rather than ablation or melting on the surface. Monitoring such processes is critical to understanding the controls over this process. Increased access to sub-shelf cavities using submergence technology for studies of hydrography and glaciology is a desirable. Studies of the polar oceans will by necessity require a wide range of vehicles or systems. OSVs, ROVs, and especially AUVs. AUVs may be required for synoptic characterization of the Arctic Basin (requiring long range and long duration AUVs or other unattended vehicles (e.g. rovers). Long-term installation of sea floor observatories, either cabled to shore stations, or moored, equipped with sensor packages for water column and sea floor sampling will also be required. Submersibles will also be needed to support geophysical, geological, chemical, biological and other studies of polar rift zones. In addition, capabilities for drilling (core collection), high-resolution mapping, and imaging, and sample collection devices will be needed. A key requirement for polar science where access is often logistically difficult will be the deployment of fleets of AUVs for time-series measurements of various types and establishment of ocean floor observatories and programmable monitoring arrays served by AUVs.

# E. Coastal Environment

Coastal zones present challenges to exploration that are different from those of the open ocean and the deep sea. Physical conditions are often harsh, making it difficult to mount ship-based expeditions, yet most of the US population lives within 50 miles of the coast. Thus, there is high interest in coastal oceanographic processes, especially when these have an impact on human activities or welfare.

**Coastal Impacts**. Events such as harmful algal blooms, storms, introduction of exotic species, upwelling, bottom-water anoxia, oil spills, and other pollutant plumes can result in long-term impacts on coastal processes. The effects of various pollution phenomena have attracted a great deal of attention, but the details of the effects of these on the complex physical, chemical and biological systems in coastal environments are still poorly known.

- What are the temporal impacts of naturally short-term phenomena such as storms and floods on the geological, chemical and biological systems in coastal regions?
- What is the spatial distribution of the impacts from such events?
- How do climactic, geologic and chemical phenomena and biological systems all interact at these various spatial and temporal scales?
- What are the short and long-term effects of anthropogenic phenomena on coastal environments?

**Physical Oceanographic Interfaces**. Fronts and thin layers are common features of the coastal ocean. For instance patterns of turbulence on the shelf during up-welling and down-welling events are influenced by fronts and jets, and the levels of turbulence can reach sufficient intensity to influence the mesoscale circulation. The effects of the dynamics of mid-water circulation patterns on the water sediment interface are poorly known. Interfaces are intrinsically ephemeral and sensitive to physical, chemical, and biological variations on several time scales.

- How do boundary conditions at these interfaces fluctuate and what controls them?
- What are the forcing functions that control their distribution?
- How do the physical, chemical, and biological processes interact at the interfaces?

**Seafloor Topography and Sediment Properties.** Physical forcing from waves, tides, and storms, coupled with the activity of benthic animals, leads to a dynamic seafloor over most of the continental shelf. Seafloor topography (e.g., sand waves, ripples) and sediment geotechnical properties (e.g., shear strength, porosity) are affected. Along-shore topographic variations dictate the relative importance of two-dimensional versus three-dimensional cross-shelf transport processes with respect to wind-driven dynamics. Coastal morphology is affected by these functions and thus societal concerns are important aspects of the study of physical forcing functions in coastal regions. These effects impact biogeochemical processes. For example, most of the organic matter produced in shelf waters appears to be recycled on the shelf, not exported to the slope or deeper water. A significant portion of this organic matter appears to reach the bottom, where it is rapidly removed as water flows through the permeable, sandy sediments found on much of the shelf. The interactions of waves and currents with an uneven, permeable seafloor are responsible for driving this "subtidal pump."

- What are the physical and temporal affects on geotechnical properties of shelf sediments of tides and wave action?
- How do physical forcing phenomena control biogeochemical cycling on the shelf?
- What are the critical interactions among forcing phenomena that influence morphological changes in coastal environments?

Submerged reefs record the history of eustatic sea level change and the regional dynamics of tectonic uplift or subsidence. Correlations among globally distributed reef deposits will enhance our understanding of global climatic variability. The variability of coastal morphology both near-shore and on the shelf as a function of various forcing phenomena has important implications for military applications (such as object detection).

**Lake Phenomena**. Many of the processes operating in the coastal ocean are also important in lakes. One of the most critical aspects of lake studies is the record of climatic change that is preserved in remote locations in lakes throughout the world, including polar regions. Studies of individual lakes and global comparisons of the sediment records preserved in them are both essential components of the history of climate change.

- How does the variability in climate records compare globally among lake sediments?
- What are the relative effects of local vs. global climate change as recorded in lake sediments and how are they interrelated?

**Essential Habitat.** Anthropogenic perturbations and natural variation can adversely affect habitats of ecologically, commercially, and recreationally important species. Midwater and benthic fish communities, shellfish, and coral reefs are examples. The diversity of habitats is poorly known even in the shelf and coastal environments. In the 50-300 m depth range globally there are many communities that are poorly understood, particularly those other than sediment hosted communities. These communities have complex interdependencies on the geological framework for ecological niches. Effects of physical and chemical forcing functions on these communities are virtually unknown. These communities are sensitive to disturbance and a silent approach is needed in order to observe normal community behaviors (sole diver with re-breather). A more effective and less hazardous approach would be to employ ROVs or AUVs. We need to understand better the overall effects of anthropogenic perturbations to the natural system. What is required is a quantitative comparison among the responses of various ecosystems to a given perturbation. This necessitates an approach that includes both short-term and long-term monitoring

## INVESTIGATIVE APPROACHES

The need to survey and map the extent of various coastal events would be best met by rapid-response submersible vehicles, such as AUVs. Because these events are often widespread and evolve rapidly, synoptic sampling is required to prevent space/time confounding. Thus, numerous, inexpensive vehicles that can be deployed as a fleet to track these features would be ideal. Sensors capable of measuring basic chemical and physical properties of the water are widely available and should be standard equipment. Additional sensors, which could be used for identification of specific compounds in the water and even specific organisms (e.g., toxic dinoflagellates), should be employed as well. It is likely that such sensors have already been developed for other applications (for example, molecular and genetic probes), and could be used either as-is or adapted for oceanographic use. Navigation networks capable of tracking and controlling such fleets of submersible vehicles will need to be developed.

Interface areas of physical, biological, and chemical discontinuities can be widespread and rapidly changing. Ship-based sampling is usually impractical. Submersible vehicles, either remotely controlled or autonomous and capable of following gradients in water properties, probably represent the best method of studying interfaces.

The problems of addressing physical forcing functions in coastal environments could be addressed with submersibles equipped with sensors for measuring porewater chemistry and sediment physical and acoustic properties. These could be used to survey spatial patterns of seafloor topography and sediment properties, their linkage with water column processes, and how these interactions change over time. The availability of easily mobilized and demobilized AUVs would pay large dividends in lacustrine research. AUVs, ROVs, and submersibles, equipped with high resolution visual systems (e.g., laser line scanners) and more sophisticated, articulate samplers are needed to document spatial and temporal changes in essential habitat and understand the factors driving such changes. In order to obtain samples for studies of sediment properties it will be essential obtain drill samples. These samples must come from below the zone of bioturbation and below wave base. The optimum types of drills envisioned are relatively inexpensive portable drill systems that can be used with an ROV (for use in drilling into submerged coral reefs, for example). Also needed is a relatively inexpensive coring system that is tethered, but mobile, and equipped with a real-time video for obtaining precisely located cores on the order of 3 to 20 m deep in the shallow water environment. The study of the geological framework for ecologies of various types of sensitive biological communities would require as unobtrusive an approach as possible. Such work is more suitable for ROVs or possibly AUVs. Both short and long-term monitoring of such communities might best benefit from arrays of fairly simple sensors serviced by AUVs.

# III. Technical Sessions

This portion of the workshop defines strategies to ensure that the facilities and technologies needed to address the scientific themes defined in the Science Sessions are available. Critical issues, needs, and problems, both technical and infrastructural, were defined. The objective is to help to direct future upgrades of science sensors, sampling techniques, and imaging capabilities of vehicle systems funded by the federal agencies.

## A. Event Response

Occasional or periodic perturbations of ocean systems may have a profound impact on both local and distant integrated physical, geological, geochemical, and biological processes. The time scales from initiation to system recovery vary considerably. Most are unpredictable. Studies of such events pose tremendous scientific opportunities and major technical and logistical challenges. These events evolve rapidly, requiring swift deployment of required observational and sampling systems. Effective event responses are constrained by the availability of personnel and equipment at extremely short notice, funding availability, and weather constraints on over-the-side operations. Because most event response studies can best, or only, be accomplished using a submergence vehicle or tool, the availability and capabilities of submergence assets and their support systems are particularly critical.

The types of phenomena that cause sudden perturbations are diverse, and affect coastal, deep ocean, and lacustrine processes. They can include erosional events, dewatering or hydrocarbon release, volcanic or hypabyssal magmatic events, seasonal biological phenomena, storms, tsunami generation, anthropogenic events, etc. The various types of events commonly require both water column and seafloor response components. The potential for very rapid deployment, transportability, and for truly autonomous operation when weather conditions may preclude over-the-side operations makes AUVs the optimal tool for response efforts. Two separate, task-dedicated vehicles are highly recommended for responses to compound events.

> ***Water Column:** A water column response might generally require an AUV capable of performing 2 or 3-dimensional surveys using a CTD and variable arrays of optical, chemical and bio-sensors. Survey dimensions could require tens of square kilometers of spatial coverage and depth ranges of over 1000 m. "Smart" AUVs would be required to locate and survey "event," plumes, etc., by virtue of optical (e.g., threshold optical backscatter) or chemical tracers. AUVs equipped with high turbidity sensors would be required for many coastal events (e.g., storm sediment transport, mass-wasting events). Seeding of event plumes or other subject water mass (e.g., plankton bloom, oil spill) with Lagrangian drifters for tracking and relocation would extend the rapid response observations to

time-series studies. The scientific community interested in event response strongly encourages the submergence engineering community to examine the practicality of designing a hybrid vehicle (i.e., 3-D Lagrangian float and AUV) for some of these water column operations.

***Seafloor:** A robust AUV would be required for seafloor mapping and sampling. AUVs equipped with an array of mapping sensors can be used during an event-response expedition to efficiently detect and map the extent of anomalous regions on the seafloor. Mapping the environment also could be used as a navigational aide in comparison with previous maps where possible. Responses to dynamic sediment processes also require the capability to measure concentration, turbidity, and velocity through active sediment-gravity flows over the duration of the event using laser, acoustic backscatter, and sub-bottom profiler systems. This technology could be used to map concentration, velocity, and turbidity variations along AUV transects during a storm event on the shelf. High-resolution imaging is a high priority for documenting physical (e.g., vent sources, boulder size) and biological (e.g., vent fauna, microbial mats and "blooms") phenomena.

Optimally, the seafloor response AUV would be capable of limited fluid sampling for chemical and microbiological studies. Fluid sampling should include the use of physical, chemical and bio- (DNA-chip) sensors, and possibly the physical collection of small fluid volumes and their preliminary preservation (e.g., poison, filtration). Shallow sediment and sand cores (up to 1-2 m) collected shortly after a sedimentation event (hours to days) can provide important information on sediment thickness, texture, and structuring. Rock coring capability is also highly desired for both the core sample and the consequent access provided to subsurface fluids and biosphere.

Manipulative capability would allow the relocation or recovery of pre-event staged equipment. This could be manifested in little more than a "releasable hook". A suspected sedimentologically active area site (e.g., near the head of an active submarine canyon or within an active channel) could be ‘seeded’ prior to an event with small, negatively-buoyant transponder packages (so-called "smart rocks"), that behave as clasts in a bottom current. If relocated and recovered shortly after a sedimentation event they would provide unique data on the distances of transport and, therefore, estimates of boundary shear stress and velocity.

**Critical Issues Related to Event Response.** These include appropriate detection capability, adequate submergence vehicle and surface ship assets, and a stable long-term infrastructure support system. Submergence vehicle operations depend in turn on precise navigation, science task-specific capabilities, and pre-event staging.

*** Event detection capabilities:** Event response obviously depends on reliable event detection. Detection systems of coastal seismic or storm-related events are based on well-established and stable facilities (shore-based seismographic networks, satellites). The MOR event detection and response community has been able to productively exploit the Northeast Pacific SOSUS system since 1993. US Navy commitment to maintenance of SOSUS is declining and additional funding will be required from non-military sources. There are other exciting new possibilities on the horizon, including remote telemetered hydrophone mooring systems (after PMEL's Haruphones). Additionally, if and when a cabled system such as NEPTUNE comes on line, it is highly likely that it will be well equipped with its own hydrophone array, removing dependency on the aging SOSUS system.

*** Availability of vehicles:** The current availability of submergence vehicles is inadequate for planning and staging effective rapid response efforts. The time-sensitive nature of event response precludes reliance on assets that may need to be packaged up and shipped to the staging area from some remote location. For example, on the west coast the only US National Submergence Facility vehicle that it is currently possible to pre-stage in geographic proximity to a potential northeast Pacific event is a camera sled. It provides valuable seafloor imaging, but of only limited spatial coverage, using limited and precious response time and it is very weather constrained.

The Event Response Session participants strongly urge the funding agencies and submergence technical community to provide additional submergence vehicles. Event response oriented recommendations emphasize AUVs and modified ROVs. These recommendations are based in part on a vision of optimized event response efforts and in part on the realization that certain assets (i.e., full service ROV or occupied submersibles) are unlikely to be available within the short time frame of effective response efforts. The group proposed several scenarios that include the following:

> **- Dedicated event response AUVs** prepositioned in close geographical proximity to a region of expected event site(s). Ideally, an AUV or group of AUVs could be pre-deployed in situ as part of a cable (e.g., HUGO, NEPTUNE) or mooring system. AUVs could be docked in sleep-mode until activated for response or could also be used for observatory-related or other interim work. Alternatively, the vehicle could be staged on shore, ready for rapid transportation to a response-ship of opportunity. Because certain coastal storm-related events are inherently more (quasi-) predictable than other types of events, there

may be a warning of up to several days for final staging of response efforts for some coastal and lake events.

**- AUVs as standard UNOLS ship equipment:** The cross-disciplinary and global usefulness of AUVs as an oceanographic and geophysical support tool should encourage the UNOLS and funding community to elevate its status from that of novelty to accepted workhorse. This working group urges consideration of the proposal to equip every or many UNOLS ships with a standardized AUV. A mass order of similar AUVs would drastically drop the per-unit production costs; the costs of even a well-instrumented (e.g., geophysical and imaging mapping tools and water column sensors) AUV would likely be on par with that of a CTD/winch/wire system.

**- Response Support Ship:** Regardless of the nature of AUV asset deployments, a surface response ship will likely be required for all thorough response efforts. In all cases except that of a sophisticated cable system, the ship will be necessary for data recovery and for recovery and servicing of the AUV. Even a moored docking system would likely require servicing in terms of power. In all cases any actual water, fluid, biological or geological samples would need to be recovered for analyses. Consequently, the issues of ship availability and priority rescheduling at short-notice need to be explored for possible solutions. One possibility might involve an attempt at scheduling rotating "open" spots in ship schedules for ships within specific regions so as to maximize the time for which at least one UNOLS ship might be available for response efforts. If UNOLS ships were generally equipped with AUVs, a ship in the vicinity of an event could steam to site and, at minimum, drop an AUV and return to their original project work. Mechanisms for rapid funding of pre-approved commercial vessels need to be designed and implemented.

*** Optimum response vehicles:** As noted above, the sampling requirements and logistical realities of most event response efforts suggest that the primary submergence assets for event response should be the AUVs. However, AUV design needs to be optimized for the specific operations required. As described in earlier sections, the event response group strongly advocates development and pre-event staging of two AUVs with different capabilities. The requirements of the optimized ‘seafloor’ AUV are more demanding and require an overall more robust vehicle than the ‘water column’ AUV in terms of mass, power, instrumentation, and manipulative capabilities. The event response group also recognizes the potential counter-productivity of over building an AUV. The group discussed some alternative vehicles.

**- Portable/limited task ROV or telemetry capable AUV:** Such a minimal ROV could be maintained on "rapid access" status. Considering the depths at which we expect many of the events to occur, the winch and wire handling equipment that full ROVs require is heavy and bulky, requiring a large ship. It is unlikely that a full-scale deep ROV and support ship would be available within an extremely short response period.

One compromise is to operate an AUV as a "tetherless ROV" with an acoustic link. This would make a much smaller and portable kit that could be operated from a wider range of ships. In the vertical acoustic path, one video frame in 3 to 30 seconds (depending on quality) has been realized. This would require the hybrid AUV/ROV to be operated in a "chess game" mode, where as each image is received, the next target is selected. The vehicle would then make its surface-directed move (e.g., collect vent fluids) and then hover while reporting to the surface and receiving its next instruction.

Such an AUV would be somewhat power demanding, as it needs to compress and transmit a video image and also operate a Doppler bottom lock log to hold position while waiting for the next word from on high. This would limit it to perhaps eight hours on the bottom, during which the ship could perform other over the side operations. Such an AUV could of course also be used for unsupervised surveys such as area mapping or plume tracking. The vehicle would return samples to the ship and receive a battery recharge and other service.

**- Hybrid AUV/Lagrangian float:** Tracking and relocation of event related water masses is an invaluable component of responses to many different types of events including magmatic event associated plumes and seasonal plankton blooms. It is the primary means by which subsurface plumes can be monitored and sampled over time without a constant ship presence. Simple Lagrangian drifter floats have been shown to track such water masses for months. However, such floats record little other than temperature and position, and nothing about the 2- or 3-D structure of the water mass. Navigation requires sound sources to be in place. Alternatively, some floats (e.g., ALACE) are capable of operating without a local navigation support system by recycling to the surface to both receive navigational information and download data via satellite. However, the combined total vertical transit time from deep plumes to the surface plus surface data transfer time would likely cause a disconnect from the original target water mass. Some kind of "smart" float, or hybrid between a Lagrangian float and AUV, could both track the target water mass using either in-place navigational network or a self-contained system (coupled INS/DVL/GPS navigation systems) and periodically make at least a limited 3-D sensor survey of the water mass. Not only would this provide time series information of the structure of the water mass, but could cue the hybrid float/AUV as to its approximate center, thus helping to insure that the vehicle remains with the target.

**- Shallow water, high-energy vehicle:** For the coastal zone, an AUV is needed that has the capability of operating in shallow water, high energy (currents to >1m/sec) environments. The vehicle would require high power and be survey capable with a versatile payload arrangement

*** Navigation problems:** Navigation, already a major element of the cost of operating underwater vehicles, is particularly demanding for rapid event response. The difficulty stems from the requirement that platforms operate off of ships of opportunity, with a minimum of setup time, and probably a minimal crew. Under less constrained circumstances, key navigation elements, such as ultra-short baseline acoustic tracking systems, are either provided from an already well-equipped ship, or are carefully installed on a ship of opportunity. Note that not all ships are friendly platforms for acoustic systems, so the need to operate acoustic tracking, navigation, and acoustic systems may preclude use of some ships, and implies some level of pre-screening of possible vessels. If long-baseline navigation is used, then the transponders commonly used by the scientific community today must be deployed and calibrated at significant cost of ship time. For a rapid deployment effort, these impose delays on the order of a day. This loss of time might be compounded if subsequent measurements determine that the array is deployed in the wrong location, and must be redeployed.

Clearly the most attractive navigation capability for rapid event would provide the platform with a self-contained navigation system. The only systems that currently satisfy this requirement are coupled INS/DVL/GPS navigation systems. These are used in military underwater vehicles today, and could be obtained by the scientific community. While expensive, such an approach may be the most cost-effective for this application. Ongoing development will likely bring costs down and performances up in the future. The development of sophisticated cable network systems as proposed for NEPTUNE would likely provide a stable, widespread, well-maintained transponder net for acoustic navigation in select areas.

**Technological Needs for Event Response:** A detailed list of the identified technological needs is given in Appendix 1 and shown in Table 1.

# B. Time-series Short

Events in the oceans take place on a variety of time scales. The short time-series events are defined here as those events or processes that take place over periods of less than one year. The investigation of many of these phenomena requires access to shallow water submergence vehicles and tools. At the short end these merge with event response. They can also span periods of weeks to months and can cover a range of annual phenomena

**CRITICAL ISSUES RELATED TO SHORT TIME-SERIES STUDIES.** Comprehensive event response depends on the satisfactory solution of a number of critical problems. These include appropriate detection capability, adequate submergence vehicle and surface ship assets, and a stable long-term infrastructure support system. Submergence vehicle operations depend in turn on precise navigation, science task-specific capabilities, and pre-event staging.

*** Gaining access to vehicles and tools** is a critical problem for investigation of these phenomena. Many take place in shelf environments and access to vehicles to use in shallow-water is difficult to obtain. Access to deep seafloor, depths in excess of 6500 m (submersible or ROV), is needed by the deep-sea community. Currently there is none available except by cooperation with foreign investigators.

*** Standardization of basic operating tools among submersibles.** This is a general recommendation, but is particularly relevant if there is a high demand for study of short-term phenomena in many localities simultaneously.

*** Development of chemical and other sensors** is needed to affect a variety of in situ biological and geochemical measurements. Examples of these include: Redox-sensitive chemical species, particularly those influenced by hydrothermal reactions: pH, $O_2$, $H_2$, $Mn^{2+}$, $Fe^{2+}$; Chemosynthetic substrates and products: $H_2S$, $CH_4$, $H_2$, $Mn^{2+}$, $Fe^{2+}$, $CO_2$, $NH_4$, $NO_3^-/NO_2^-$, $N_2O$. Also sensors for measurement of metabolism, e.g., respiration and excretion, salinity (not CTD) are needed. There are constraints associated with such sensors. Development of sensors may require time periods much longer than the typical 2-3 year single PI

NSF grants. They must be designed so as to operate on a variety of submersible platforms. A common pool of general-purpose sensors (e.g., temperature, conductivity, pressure, transmissometer, oxygen, pH, $H_2S$) is also required. There will be a need to support operation, calibration and maintenance of the sensors in the field.

*** Flow Sensors and Pore-water Flow Measurement**: Robust and portable devices to measure water velocities over a large range of values (< 1 mm/min to 10s of cm/sec) on the seafloor are needed. These sensors must be capable of measuring flow rates of particle-rich, high temperature vent fluids, and should have low power requirements and the ability to send processed data in real time to the pilot and observers. Submersible acoustic Doppler velocimeters that meet most of these requirements are currently available for depths <2000m, but are not available for full ocean depths. Very low velocity flowmeters are required in order to determine pore-water flow rate variability over short (minute – hour) time scales. Many areas of the seafloor are sites of pore-water advection from the sediment to the overlying water, and these fluxes may be significant contributors to local and/or regional biogeochemical cycles. Several devices are available for collecting these fluids and measuring their flow rate integrated over extended periods of time.

*** Observatories:** For short-term studies, "temporary" observatories offer advantages over cabled observatories. Because of their stand-alone status, such observatories will require adaptive sampling algorithms that can alter sampling frequencies of connected instruments and sensors in response to events of interest. In coastal waters we can predict events such as hurricanes and blooms.

*** Optics:**

- Video needs for all vehicles include:

    - High definition digital video cameras with telemetry systems and high quality lenses that are good for media purposes.
    - Support equipment for high definition cameras/ IE recorders/ monitors, including conversion equipment from high definition to more user-friendly format.
    - Simple camera controllers for operation by scientific observers.
    - Smooth, variable speed pan & tilt camera with simple controller

- Electronic/digital still cameras with large storage capacity

*** Lighting**: Red light operation for biological purposes will be required. HMI (400 watt/1200 watt) will be needed.

*** Manipulators**: Multiple-jaw designs will be required for various sampling tasks.

Resolution to mm scale with very smooth articulation is needed. Programmable manipulators in XYZ for accurate placement of devices and for repetitive operations need to be developed. Forced feedback is needed for care in sampling. Computer-controlled sediment profilers for microelectrodes are needed.

* **Sampling Devices:** Gas-type manifold for chemical sampling in the water column. Improved corers for coarse and hard sediments are needed. Very soft sediments can be sampled with punch cores and box cores from ROVs and occupied submersibles. However, sandy sediments, sediments with large particle inclusions and sediments with tubes or other subsurface structures generally cannot be sampled by traditional coring methods. This is a major limiting factor in biological sampling over much of the sea floor, particularly in shallower coastal and margin habitats. New technologies are needed for sampling such sediments. Vibrating corers may be a solution for sandy sediments.

* **Drilling technology**: We need to resolve deficiencies in existing technology regarding drilling on the seafloor.

* **Appropriate sampling of biological specimens**: The biological community, particularly, needs to be able to amass collections that are made gently, maintained in discrete and separate containers on the way to the surface, and arrive at the surface at ambient temperatures and pressures. Where sophisticated suction samplers have been developed, they have proven to be almost universally better for gentle collection of biological samples than traditional manipulator arms. The JSL technology in which suction hoses lead to large, lazy-susan, indexed collection containers should be examined for possible application to submergence vehicles.

**Technological Needs for Short Time-Series Science**: A detailed list of the identified technological needs is given in Appendix 1 and shown in Table 1.

## C. Time-series Long

Processes that take place over extended time spans may be at equilibrium or may be continually changing in response to fluctuations in the environment on shorter time scales. Long time-series measurements require decadal and longer commitments of investigators, assets and funding. Two types of long time-series studies must be considered, periodic and continuous. Periodic measurements involve repeat measurements of slowly varying parameters on a regular basis. These may include geodetic studies, water column measurement, and growth rate of ecosystems (though optimally this would also be continuously monitored). Periodic observations usually have low data rates, do not require continuous presence, require less infrastructure, and are less complex than continuous measurements. Continuous measurements often require installation of monitoring devices on the ocean floor that necessitate considerable dexterity with an occupied vehicle and interdisciplinary experiments that commonly share extensive infrastructure. These might include seismic monitoring, studies of flux rates of pore fluids in hydrologically active areas, monitoring the life cycle of a particular ecosystem. In most cases, where continuous studies are envisioned, the time series should be monitored indefinitely, meaning decades to potentially hundreds of years for detailed understanding of the phenomena,

**Critical Issues Related to Long Time-series Studies.**

> *** Manipulators and tools:** Since manipulator and tool technology are not standardized, hardware should be designed for servicing by "generic" manipulators and vehicles. Future design of manipulators and tool sets would benefit from standardization of interfaces for ease of use.
>
> *** Connectors:** Similarly, standardization of electrical and optical connectors and power interfaces for ease in moving scientific hardware from one system to another would be cost effective.
>
> *** Benchmarks:** Long time series often require exact positioning on the ocean floor, possibly obtained by occupation of or reference to benchmarks. Benchmark technology needs to be improved to provide mm accuracy for extended periods. Precise location of transponders will require short tethers or mounting on tripods and possibly battery packs that can be replaced on the ocean floor. Transponders can be connected to cabled observatories for power and continuous processing of data on shore.
>
> *** Observatories:** Observatories are a fundamental requirement of long time-series research. Observatory research has a number of technologic requirements.
>
> > **- Required assets:** Installation of multi-use observatories for measurement of continuous time series will require substantial capabilities for installation. Cabled observatories for example, will require the use of cable laying ships, multiple ships for laying multi-leg moorings, heavy-lift ROVs for installation of junction boxes and other equipment, and substantial ROV time for ongoing installation, maintenance, and removal of experiments.
> >
> > **- Need for new assets:** Increasing demand for long-term experiments will require the operation of a new ROV system comparable to the JASON/MEDEA or ROPOS systems within the next few years. Important characteristics of this system include heavy lift capability, long bottom time, and dexterity in manipulation.

**- Observatory maintenance:** Submersible assets will be required for maintenance of observatories, addition and removal of sensors, and extensions of the infrastructure. Periodic visits will be required for maintenance of transponder networks, replacing expendables, and for calibration of some sensor systems. The high cost of such visits requires that substantial front-end effort and funds be made available to make the systems as robust and reliable and as possible. Use of redundant systems, modular components that can be easily removed and replaced, and use of generic submersible interfaces that allow use of a number of assets for the same task.

**- Flexibility:** The high cost of such systems can be mitigated by making them very flexible for use by many different instrument systems. Flexibility includes availability of a variety of data rates, power, and control systems such that both low demand systems, such as thermister arrays, and high demand systems, such as video systems, could be accommodated. The design of these systems should assume high power consumption, large data rates, and requirements for command capability. Any functionality offered is likely to be used.

**- AUVs, etc.:** Some systems will require docked AUVs for collection of data beyond the spatial extent of the observatory and for rapid response to transient events. Similarly, some sites will require fixed manipulators that can sample, image, and take measurements of a feature such as an active vent for an indefinite period. Bottom rovers could perform similar functions, much like the mars Pathfinder rover. Such active research components will be particularly interesting and appealing for outreach programs. With sufficient electrical power, it is also be practical to provide a freezer to store biological samples until they can be collected.

**- Shared infrastructure:** At sites where water column measurement systems (GOOS and others) are planned, the feasibility of including bottom sensor systems on such buoyed arrays should be pursued. Similarly, the inclusion of vertical arrays and other water column measurement systems would not substantially increase the infrastructure effort of a bottom observatory. At the very least, placing water column and bottom observatories at nearby locations whenever practical would considerably reduce the ship-time component of maintenance costs. We encourage interaction between the concerned communities to evaluate the possibilities of shared sites and infrastructure. It may be desirable to have recommended minimum suites of sensors for observatories to maximize cost effectiveness.

* **Networking among technical groups:** Continuous long time-series experiments will require systems that will be designed to last for decades and longer. Thus, dissemination of information concerning new developments with regard to batteries, corrosion, connectors, reliability and other engineering issues would benefit greatly from regular meetings between technical groups and the establishment of WEB sites.

**Technological Needs for Long Time-Series Science:** A detailed list of the identified technological needs is given in Appendix 1 and shown in Table 1.

# D. Global

Global submergence science research encompasses three possible approaches. (1) Some global research requires simultaneous observations at many sites distributed worldwide. For example, the ocean seismic network (with as many as 20 permanent broadband seismometer installations globally distributed in fairly remote areas) will require submergence assets for installation and/or servicing and experiments to test linkages among oceanographic processes spanning large sections of the oceans will have to be done simultaneously. (2) Some global research requires detailed surveys, observations, sampling and experimentation at various sites distributed around the globe, but not done contemporaneously. For example, global mapping of distributions of hydrothermal activity and vent fauna will need to be done at several sites around the globe and studies of various margin processes will need to be performed where they are best exemplified. (3) Models developed by detailed studies at "representative" sites need to be tested in other (often remote) locations. For example, the connection between tsunamigenic events and submarine slumping must be explored in regions with a variety of tectonic, structural, sedimentological and hydrological characteristics.

**CRITICAL ISSUES RELATED TO GLOBAL STUDIES.**

* **Availability of current submergence assets**. For global studies, the situation is made especially acute by the strong draw of current assets to support long-term time-series observations at representative sites on the Mid-Atlantic Ridge, East Pacific Rise, and Juan de Fuca Ridge. While this emphasis has been solidly justified by strong peer-reviewed science, in the present system it has curtailed access to submergence assets for science at more globally-distributed sites.

* **Diversity of Assets:** If visions for seafloor observatory science by planning efforts such as DEOS reach full fruition, demands on submergence assets will be even stronger for regular servicing at a few select sites.

In the context of the Global group mandate, it was clear that almost the entire range of conceivable submergence functions would be required, in various combinations appropriate to the particular science requirements and the environmental conditions within which the research would be conducted. Matching vehicle types and instrument suites to the particular range of tasks at hand will be essential to the science- and cost-effective overall use of submergence assets present and future.

It is clear that scientific needs in the global context will call for the use of submergence vehicles from all three of the basic types: occupied submersibles, ROVs, and AUVs. These needs encompass vehicles that function effectively in the water column as well as those designed to operate on the seafloor. The latter case includes benthic crawlers as well as AUVs that fly above the seafloor. In each case, there are a variety of issues that must be considered. Operational depth requirements range to depths as great as 6000m or more, yet a significant need exists for vehicles that operate efficiently in the upper 2000 m. Economical use of assets suggests that vehicles designed for maximum depth are not necessarily the most appropriate platforms for work at shallower depths, and that alternative vehicles should be developed and/or made available.

Deployment characteristics vary with the type of platform and the mission at hand. Endurance needs range from hours to a day for occupied submersibles, from hours to days for ROVs, and from days to months for AUVs. Areas and volumes surveyed vary accordingly on scales from square meters to square kilometers and cubic meters to cubic kilometers, respectively. Linear surveys range from meters to kilometers for all vehicles and up to basin-scale for specialized AUVs.

*** Sensors and Sampling**: In general, global science applications of submersible technology have similar requirements for sensors and sampling capabilities, as do applications at other scales. There may, however, be a difference between the needs of exploratory work for a broad range of sensors to detect previously unknown physical, chemical, and biological signals, and the needs of fixed observations for highly specific sensors tuned and calibrated to specific, known processes.

Physical properties sensors may include pressure, temperature, magnetization, gravity, and in some cases, light distribution for down-welling and bioluminescent light. Multi-spectral sensors might eventually extend to low-frequency radiation at vent sites. Current and flow sensors are needed mainly for vent-related work. Chemical sensors may be used both to locate and identify geochemical or biological features at longer ranges, and then to quantify and characterize them at short range. Highly sensitive and specific chemical sensors recognizing particular chemicals and proteins, or nucleotides may be realistic in the near future. Acoustical and optical sensors provide the morphologic constraints on geologic features and organisms at varying ranges and resolutions both on the bottom and in the water column. High-definition video and photography extends the resolution progressively down to the near-microscopic. Multi-spectral imaging techniques may be valuable in some situations, and in-situ X-ray imaging can reveal internal structure of biological or geological features.

Submersible platforms need to be able to accommodate a variety of sampling devices for water, geological materials, sediment cores, and biological material. In any case, it is important to have the maximum capacity for multiple samples, especially for vehicles like ROVs and AUVs with long deployment times and/or distances. It is essential to avoid cross-contamination of samples, to index each with respect to collection and environmental data, and to preserve the chemical, geological, or biological integrity as much as possible. This may mean retaining ambient temperatures and pressures, preventing degassing, or providing in-situ fixation of some biological specimens.

Sampling modes for benthic environments include selection and manipulation of individual objects, coring and drilling for subsurface samples, and collection of water samples from specific locations. Deeper coring capabilities and better ways to maintain the physical and biological structure of cores are desirable. Water-column biological sampling requires suction collectors with multiple chambers, and enclosure-type samples ("detritus samplers") for especially fragile organisms and structures. Small-volume water samplers that can be positioned precisely are valuable for thin-layer features, detrital aggregates, etc.

These sampling and sensor issues require improved dexterity of manipulators, advancements in communication and data transfer mechanisms, and power, payload, propulsion, and structural materials of platforms.

* **Navigation**: Navigation systems are an essential element in carrying out all three essential categories of global submersible operations. Work in support of systems such as the Ocean Seismic Network can be supported with conventional long-baseline transponder systems. These can be used in other configurations scaled up or down to suit the area to be covered and the resolution required. In the global survey mode, short-baseline navigation of vehicles relative to their GPS-positioned tending ship may in some cases be an operationally preferable option. A special problem arises if assets are air-deployed into areas without extant transponder nets. In this case it may be necessary to provide means for generating tracks by use of dead reckoning (compass plus inertial and/or seafloor Doppler) from a GPS-determined initial water-entry datum.

* **Operating in Extreme Environments**: Specialization may be required to cope with unusual conditions such as strong currents (e.g., Gulf Stream, Kuroshio), highly sulfidic environments (e.g., Black sea, hydrothermal plumes), high temperatures (e.g., hydrothermal systems, volcanic environments), or high salinity (e.g., Red Sea brines).

Weather extremes pose problems relating to vehicle launch and recovery. Vehicle characteristics themselves can help mitigate these difficulties, but primarily they concern support ships and handling equipment. These could dictate use of interior wells or deep draft stable platforms (e.g., swath ships) to carry out winter operations at high latitudes.

Pre-deployed AUVs also could be the systems of choice in remote regions, ice-covered areas, and regions of heavy weather.

*** Data management, educational outreach, and training in support of global science endeavors.** The prospect of embarking on global studies brings with it the obvious need for mechanisms by which we can manage previously unimagined volumes of data. The opportunities to link data collection with educational efforts are easily envisioned for global studies. Infrastructure to facilitate such efforts exists in part through various agencies programs to promote education at the K-12 level and as research opportunities for undergraduates and graduate students. In addition to those foreseeable today, we realize that there will be a continual need for "technological refreshment" to accommodate future scientific needs over the next decades. This will enable us to maintain and upgrade systems and to provide mechanisms for training technicians to run the systems in the future.

**Technology Needs for Global Science**: A detailed list of the identified technological needs is given in Appendix 1 and shown in Table 1.

# E. Expeditionary

Expeditionary research, as meant here, refers to that which requires the deployment of any submergence assets to "geographically remote" parts of the globe. It can be defined in terms of two approaches, (1) mature and fundable but logistically difficult research and (2) high-risk research or field programs in previously unexplored regions.

The first of these involves field programs that are proposed for what would be considered geographically remote regions under the currently existing scheduling and funding paradigm (e.g., other than the East Pacific Rise and the Juan De Fuca). This has become particularly problematic as a consequence of the burgeoning success in time-series research. In practice, under the current situation, research that is based on mature field work (sufficient background information to justify the use of submergence assets and is highly recommended by reviewers based on its scientific merit) has little chance of being granted support from funding agencies unless a critical mass of proposals for that region is also highly ranked. Even those so highly ranked that they are granted funding are not being scheduled because of pressure to keep the assets in what has come to be termed the time-series "Yo-Yo." This situation underscores the insufficient access to submersible assets for accomplishing highly-ranked and even some funded submersible science.

Research that focuses on new territories or processes or that contains an element of discovery and is potentially scientifically high-yield may require new technology, tends to be interdisciplinary, is sometimes supported by circumstantial *a priori* data (i.e. multibeam, altimetry, SOSUS, cable breaks, etc.), but sometimes has little or no pre-existing data. The approach that is most useful in such areas is a nested mapping and sampling approach employing a full suite of multi-scale mapping/imaging tools combined with sophisticated sampling and in-situ sensing. New mapping systems on ROV platforms may be needed to fill in the gap between regional mapping tools and high-resolution mapping for small areas. The nested approach would be important in bringing previously unexplored areas up to the level of the mature field program. If such an approach is not possible, the alternative is to use portable, flyaway, lower-cost tools on ships of opportunity to produce a less comprehensive, but sufficient data set.

**Critical Issues Related to Expeditionary Science.**

*** Access to appropriate vehicles:** The principle factor impacting the ability to engage in submergence research in remote areas is the lack of access to the needed technologies (vessels, vehicles, etc). Such work is logistically expensive unless other work is scheduled in the same region. Within the existing constrained resources and scheduling process, time-series and observatory work fundamentally conflict with expeditionary science. Duplicating or complementing the existing submergence capabilities (i.e. Atlantis/Alvin, Argo/Jason, etc) would permit more expeditionary work. Such a solution is very unlikely without new influx of funding for submergence vehicles and tools. Gaining access to foreign assets, either for the expeditionary work or to fulfill the commitment to the time-series work would ease the pressure on existing vehicles and vessels. International and interagency involvements that mitigate the logistic and scheduling issues and enhance collaboration would extend the geographic range of scientific expeditions, but these historically have proven to be logistically difficult, require long-range planning, and involve the establishment of collaborative agreements. Developing partnerships with industry could provide access to additional assets.

*** Implications regarding observatories:** A conscious decision on the part of funding agencies to plan and budget support for observatories, as they are established, could be made so that they do not impose additional constraints on the ability to do expeditionary research. Linked proposals can be encouraged, both within and external to the submergence science community, that support efforts in remote areas. The development of submergence assets that are to be dedicated to observatories (AUV systems, for example), would both serve the specific needs of the observatory and free up traditional assets for use in other areas. The development of lightweight, portable tools (ROVs and/or AUVs) that can be transported inexpensively and can perform surveying and sampling for preliminary efforts in a high-risk area would provide a means to initiate the nested approach to expeditionary research. These tools could both stand on their own and could provide scientific justification for later commitment of the traditional submergence vehicles and tools.

*** Coping strategies:** Assuming the current funding and scheduling paradigm is not going to change, there are really only two alternative approaches. An investigation in a remote part of the world should employ all of the most sophisticated tools, thus ensuring maximum return, as it may not be possible to return for a long time, if ever. One of the most successful approaches used to-date in submersible exploration of any site is the application of a full suite of tools consisting of nested complementary systems that let the investigating team go from broad-area reconnaissance to site-specific measurement and sampling in a single expedition. This approach permits science objectives that are risky and have a significant component of discovery to be accommodated within the scope of hypothesis-driven inquiry. Multidisciplinary coordination of efforts that capitalizes on all capabilities of the assets and maximizes the knowledge returned would yield the greatest return. In order to accomplish this type of approach the community could be encouraged to design linked proposals that make it cost effective to take a ship to distant or logistically difficult regions. This may require a degree of direction from the agencies that is not customarily followed under the existing "science-driven" funding paradigm.

If additional vehicles were made available to the science community an entirely different set of constraints would apply. The community would have more chances to go to logistically remote locations for reconnaissance studies if there existed a less expensive, portable capability that could provide preliminary survey and sampling capability from vessels that did not have to transit long distances from US ports.

If it were possible to alter the existing funding/scheduling paradigm, then funding agencies and appropriate science advisory groups (e.g., various UNOLS advisory panels, proposal review panels, etc.) could encourage regional efforts (through the funding of planning workshops, for instance), review highly-ranked proposals for appropriateness of applicability of the requested submersible vehicle(s), and require the PIs to use alternatives if deemed advisable.

*** New technologies:** We can infuse new technologies into our existing funding and scheduling environment to increase the effectiveness of available ship time. AUVs, deployed in parallel with occupied submersibles or ROVs can fulfill this role. Improved sampling, imaging, and mapping capabilities for our existing vehicles, particularly ROVs would also be helpful. A seafloor mapping capability intermediate in resolution between the existing regional systems (hull-mounted or towed) and the high-resolution, site specific deep-towed ROV mapping. The development of additional portable, flyaway vehicle systems that allow reconnaissance work using ships with minimal positioning and cable-handling abilities would enhance the ability of investigators to develop programs for remote areas. The, development of such systems would permit the researcher to amass sufficient background data when needed to justify deployment of a full suite of traditional nested vehicles and tools. In some cases, sufficient data sets could be acquired to test basic models and hypotheses. New systems can offer cost-efficiency and remove the pressure from vehicles needed for seafloor observatories and time-series measurements. Using ships of opportunity, possibly including foreign vessels, sometimes in collaborative mode with submergence vehicles of foreign institutions sparks the international collaboration that could strengthen a given scientific program and enable proponents to improve the success rate of proposals to use a more comprehensive approach with nested systems. Taking this approach would permit spin-off components of the nested system to be engaged in more versatile and lower-cost methods of utilization. Portable, less expensive tools could consist of the following:

- AUVs, possibly supplemented by acoustic or fiber-optic links. These AUVs would have mapping, imaging, and sampling capabilities
- Lightweight TV-guided rock drill (CTD wire, can take a 1 meter oriented core)
- TV guided grab
- Lightweight, more portable ROVs and towsleds
- Small submersibles for shallow-water work

**Needs for Expeditionary Science**: A detailed list of the identified technological needs is given in Appendix 1 and shown in Table 1.

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# IV. INFRASTRUCTURE AND FUNDING

The workshop participants were asked to grapple with problems of infrastructure, funding, and education during both the science and technical sessions of the workshop. The final half-day included a plenary discussion of these complicated issues. The attendees agreed that in order to accomplish the scientific goals defined during the initial workshop sessions, the submergence science community requires greater access to a broad scope of ocean environments with a range of safe, reliable, multi-faceted, high-resolution vehicles, sensors, and samplers operated from support ships with global reach and station-keeping capabilities in all weather. It was recognized that there are serious impediments to funding for multi-disciplinary science and for global, time-series, or long-term observatory work. Education of the public, our fellow scientists, and the appropriate science advisory groups with regard to the advances in and potential from submergence research will be critical to the success of the recommendations from this workshop.

The attendees agreed that the fundamental requirement for advancing submergence science is the need to provide a dedicated national initiative to increase spending for submergence facilities support and technology. This is the only way to ensure the needed access, facilities infrastructure, and technology required to meet the challenges and requirements of submergence research in the coming decades. Generally the development of these types of infrastructure and technology takes 5 to 10 years thus planning and budgets for this must begin immediately.

**Increasing Availability of Assets:** The clear and resounding message from the workshop participants is that there is a severe problem with availability of submergence assets to the research community. Vehicles required to service far-flung observation sites and those needed in global surveys are difficult to integrate with other research operations. These factors dictate that the community should use existing assets more effectively as well as take measures to increase the number of available vehicles. In particular, any new programs (e.g., OSN, Observatory MRE) that would require additional vehicle services should include this factor in their funding plans so that assets are not removed from other needs.

An example of the manner in which assets could be more effectively used is that manned submersible operations in the upper oceans (<1500 m) could be carried out in a more economical manner via vehicles designed for such operation, rather than by their more expensive deep-diving counterparts. Similarly, less costly special purpose vehicles should be used when possible. This not only applies to planning efficient operations, but also to encourage the use of specialized, less expensive equipment to perform tasks in traditional work areas (e.g., Juan De Fuca Ridge) in order to liberate general purpose platforms for use elsewhere.

Finally, it should be recognized that the community needs a variety of unmanned work and survey vehicles. These should be available in ways that are flexible to schedule and economical to operate. A variety of institutions should operate these vehicles in order that the development of new capabilities be stimulated and driven by close coupling to specific science needs.

These circumstances lead to a requirement to use all of our submergence assets effectively in a coordinated mode that is well matched to the wide range of science needs. The "Global" discussion group, in considering this matter, recommends a UNOLS-type coordination model and corresponding funding mechanism be adopted in relation to operation of major submergence facilities. A similar recommendation was a major thrust of the 1992 Deep Submergence workshop as stated in the Executive Summary of the 1994 report "The Global Abyss."

**Strategies for Enhancing Diversity of Assets:** Many of the desired submergence capabilities do not now exist, or are available only in developmental form. The necessary innovation to bring these capabilities into operational status for the academic community are at present only supported through the limited funding available in the NSF Oceanographic Instrumentation Development program or in connection with special focus ONR programs. Greater innovation can be enhanced by new funding initiatives. The outputs from this workshop could well be the basis for generating a Submergence Assets Major Research Equipment initiative in NSF. Some elements (e.g., AUVs plus their docking facilities for deployment in areas of interest) might wisely be included in the projected Observatory MRE as well. Planning for such long-term programs such as the Ocean Seismic Network or seafloor observatories, could also include provision for submergence assets such as new ROVs or occupied submersibles required for system installation and servicing

Supporting the submergence needs for global science in addition to demands for time-series science, observatory science, and exploratory science, will require major investments in the infrastructure for submergence science -- probably at the level of many millions of dollars. They will be required to address two key aspects to increase investigator access to submergence assets 1) enhanced diversity and enhanced availability of these assets, and 2) they will probably require a reorganization of the current management structure for U.S. submergence science.

**Specific Session Suggestions:**

The individual science and technical sessions defined additional requirements and made suggestions as to how to achieve solutions to the principle requirements.

*** The Abyss and Open Ocean** group noted that, as technology becomes more sophisticated, there will be an increasing need to provide ships using submergence vehicles with engineering and technical support. The ideal model is that afforded by the use of SeaBeam technology whereby the technical support and the instrumentation is provided to scientists rather than each being required to bring his or her own.

*** The Event Response** group suggested that if UNOLS ships were generally equipped with AUVs, it would be helpful if such ships were encouraged to participate in response efforts, even if only to steam to site, drop an AUV, and return to their original project work. Mechanisms for rapid funding of pre-approved commercial vessels need to be designed and implemented.

*** The Short Time-series** group recognized a serious shortcoming in the availability of submergence assets through normal NSF channels. In the case of assets for work at less than 1500 meters, the shortcoming is especially severe. There are several alternative scientific US occupied submersibles, and a large number of ROVs that are available and appropriate for use for much of this work. In some cases these alternative assets are more appropriate than any of the assets of the National Deep Submergence Facility. However, the mechanisms for funding these assets as part of an NSF research proposal are perceived to discriminate heavily against the use of these alternative assets. This group recommends a serious effort be made to investigate a mechanism where by other occupied vehicles and ROVs can be funded (e.g., by facility and not core funds) so neither reviewers nor program managers will weigh the cost of the facility against the proposal (as is perceived to be the case currently). The group suggests that the HBOI Johnson Sea Links, HURL PISCES V, and ROPOS would be excellent test cases to establish an appropriate mechanism for funding the most appropriate submergence asset for the particular science project.

*** The Long Time-series** group emphasizes that time-series science requires commitment, protection, standardization, and benchmarks. Measurement of long time-series phenomena requires decadal and longer commitments of investigators, assets and funding, possibly placing severe constraints on scheduling of ships and submersible assets. Such a commitment is difficult to institutionalize, given current methods of funding and scheduling and competition for resources. Measurement of long time-series phenomena require that the environment being measured be protected for the duration of the study. For example, a long-term study of a particular hydrothermal vent would be severely compromised if the vent were to be destroyed by a mining operation.

A key concern of the Long Time-series group is the response to failures of observatories. The current scheduling of submersible assets with the high demand for their use normally results in a substantial delay from the time of an identified need for an asset to its actual use. When responding to failure in an observatory, a long delay could be devastating to a time-series measurement, potentially degrading the data from many experiments. The numbers of assets, particularly high-capability ROVs, will need to grow during the next five years, and the methods of scheduling will need to be modified to include the possibility of rapid response to both emergencies and to science opportunities. It may be possible to prioritize scheduling to accommodate these types of events in similar ways.

As the number of experiments at an observatory grows, the complexity of management and safety considerations on the ocean floor will increase. Any initial design should include planning to ensure the safety of experiments and the assets that service the system. For example, at cabled observatories, cables should be laid on predetermined paths to minimize cross-overs and can be labeled with bar codes or other identifying marks.

Obtaining long time-series data from remote sites will place even stronger demands on the existing assets. To minimize the impact, observatories in environmentally difficult and remote areas must be as self-sufficient as possible and servicing should be required no more than once per year. It is not obvious that the buoy technology required for reliable installation and operation of such observatories is available, particularly for ocean bottom observatories in the Southern Ocean.

*** The Coastal and Polar** group expressed concern that this workshop was underrepresented by many ocean scientists who work in shallow or remote seas or lakes, owing to the erroneous perception by members of the shallow submergence science community that the shallow water aspect of the DESCEND workshop was to focus on DESSC (DEep Submergence Science Committee - the UNOLS subcommittee that provides oversight for the National Deep Submergence Facility) issues. Coastal and Polar group recommended that the scope of facilities supported as such be broadened and that UNOLS revise DESSC priorities to more closely represent the wider breadth of submersible priorities for ocean science. Specifically, they recommend the following:

- Acquire additional assets to support a broader spectrum of submersible science,
- Reconfigure of DESSC to SSC (Submersible Science Committee) to broaden the scope of representation and advisory activities,
- Encourage deployment of submergence resources more equitably across world ocean environments,
- Foster partnerships with industry to encourage technology development,
- Endorse inter-/intra-agency technology transfer to accelerate development and distribution of submersible science technology,
- Promote education and training of personnel in submersible science technology

The UNOLS DEep Submergence Science Committee has initiated action that will incorporate a representative of the shallow water community on DESSC with the goal of providing liaison between the deep and the shallow water submergence communities. The community of investigators involved in shallow oceanography, however, merit a focused committee that can serve as an advocate for facility needs within the UNOLS system and provide guidance to the federal agencies.

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# V. Key Recommendations

**1) The oceans remain a frontier of science; this frontier has broad and rich societal and academic relevance, from understanding the role of the oceans in moderating global change to understanding the very limits of life on this and other planets.**

**2) Recent escalating advancements in submergence technologies (submersibles, ROVs, AUVs sensors, samples, etc.) provide unprecedented access to the oceans, with astounding promise for further advancement hampered not by imagination or need but by funds.**

**3) US leadership in submersible science and technology is in jeopardy in the absence of a dedicated national initiative to support increased access to existing submergence assets and to support technological developments.**

# Table 1

## <u>Matrix of Technical Needs</u>

| | EVENT | TS SHORT | TS LONG | GLOBAL | EXPEDITIONARY |
|---|---|---|---|---|---|
| **VEHICLES** | Existing 4500m sub<br><br>AUVs with limited manipulation (maybe simple releasable tools)<br><br>ROVs: dexterity (fine-scale and delicate samples)<br><br>"smart" rocks | Existing 4500m sub<br><br>Deep 6500+ sub | Existing 4500m sub<br><br>Generic vehicles<br><br>Observatories<br>Robust ROV<br>(heavy lift,<br>long bottom time)<br><br>Generic interfaces<br>(so can use various vehicles for same task.)<br><br>Dedicated AUVs (docked)<br>Flexibility (can download at various data rates)<br><br>Take up power and interact with control system/vehicles. | Existing 4500m sub<br><br>Vehicles that match to tasks<br><br>Both water column and seafloor vehicles<br>- benthic crawlers<br>- AUVs in water column<br>- 6000+m capability<br>- 2000m efficiency<br>- wide range time and distance<br>- exploratory (cheap, small, simple)<br>- specialized<br>- | Existing 4500m sub<br><br>ROVs with inter-mediate resolution mapping capability<br><br>More portable ROVs and tow sleds<br><br>AUVs:<br>- long range (gliders, solar power)<br>- Air dropped (new nav)<br>- Multiple<br>- AUVs with sampling<br>- With fiber or acoustic tether<br>- More intelligent<br>- Expendable<br><br>Portable observatories |
| **IMAGING** | High res | - High definition digital video and telemetry<br>- Elect. Digital still cams<br>- red light ops | | High definition video and photog | |
| **MANIPULATORS** | - Delicate sampling insitu experiments<br>- Programmable | - More precise control for delicate work<br>- Programmable | Generic manipulators<br>Dexterity | Improved | |

| | EVENT | TS SHORT | TS LONG | GLOBAL | EXPEDITIONARY |
|---|---|---|---|---|---|
| **PAYLOAD** | Versatility | | | | |
| **SENSORS** | - Insitu: optical, chem, gradients, hi temp, heat flow, long term non degradable (H2, pH,EH metals, sulfides, DNA)<br>- survey compatibilities<br>- bathy, grav mag, backscatter, subbottom, CTD-optical, photomasaics | - chemical and physical (may need 2+ yr grants)<br>- porewater flow<br>- smooth var spd pan and tilt<br>- computer controlled sed profilers<br>- gas-type manifold for water column sampling | -minimum suites of sensors (so all are similar?) | - presure,temp, grav mag, lights, multi spectral (low freq radiation)<br>- current and flow<br>- chem (both long range and detailed site specific)<br>- acoustic and optical<br>- insitu xray | - molecular and biochem probes and sensors<br><br>- insitu mass spec |
| **SAMPLERS** | - Softside and sand/rock coring<br>- sample preservations<br>- fauna/larvae (slurp pump) fluid samplers(small to large volume) | - standardized tools (shareable)<br>- coring improvement (vibracorer?)<br>- drilling capability (subs and rigs)<br>- standardized shareable tools | generic tools | - cores, seds<br>- drills, rocks, etc<br>- water (sml vol/multiple)<br>- geol samples<br>- biology<br>- avoid cross-contain<br>- preserve insitu contam<br>- multiple chamber suction collectors<br>- “enclosure” for delicate | |

| | EVENT | TS SHORT | TS LONG | GLOBAL | EXPEDITIONARY |
|---|---|---|---|---|---|
| **NAVIGATION** | Meter or better<br>Simultaneous vehicles<br>Self-contained for AUVs | | | Short baseline for some may be better option | Improvement |
| **DATA** | Storage | | | Better communication or data transfer | More rigorous data sets |
| **POWER** | Advance battery technology | | | | |
| **OTHER** | | | Benchmarks needed | - environ extremes<br>- tech training and infrastructure | |

# Appendix I:

## Summary of Specific Technological Recommendations

The majority of participants agreed that there is a continuing need for human-occupied submersibles. The occupied submersible affords the researcher a currently unparalleled perspective on submarine environments, structures, and biological communities. The occupied submersible is a more robust vehicle, with greater power than most of the existing ROV systems and all of the AUV systems and is currently a more versatile tool than either. Until such time as the ROV and AUV technology can effectively mimic the human presence, there will continue to be a need for submersibles capable of taking the scientist into the submarine realm. The participants reviewed the current and potential requirements for improvement in technologies for submersible vehicles and tools. The participants in each technical session provided a list of identified needs in terms of technological improvements to these vehicles and systems. These lists follow:

**Summary of Technological Needs for Event Response:**

- In situ Sensors:
  - Optical and chemical
  - Probes for detailed chemical gradients
  - Hi-temp probes
- Heat flow probe
- Probes for measuring long-term non-degradable signals (new anti-fouling methods) e.g.: $H_2$, pH, Eh, metals, sulfide, POC, DOC, bio- (DNA-chip),
- Fluid Samplers: small (AUV) to large (ROV) volume, sample number/dive, manifold; profiling
- High Resolution Imaging
- Soft Sediment and sand/rock coring
- Payload: versatility, interchangeability
- "Smart" rocks (to follow sediment transport)
- Sample preservation capability (e.g., fixatives, freezing, maintaining in situ pressures)
- Fauna/larvae samplers (e.g., slurp, larval pumps)
- Manipulators with greater dexterity and capability
- AUVs: limited manipulation (maybe simple releasable hooks)

- ROVs: Dexterity (fine scale and delicate sampling/ manipulations of in situ experiments or sample preparation)
- Power: extend battery life/bottom time; advance battery technology;
- Data storage improvements
- Communication: cable (ROV, "HUGO" or "NEPTUNE" network docking stations); acoustic and/or radio telemetry
- Survey capabilities: bathymetry, magnetometer, acoustic backscatter, sub-bottom profiler, CTD-optical (water column)-rosette, photomosaics, and gravimetry
- Navigation: up to meter scale or better;
- Simultaneous multi-vehicle navigation (modification of present transponder net navigation systems); self-contained navigation for drop-in AUVs

**Summary of Technological Needs for Short Time-Series Science:**

- Deep (6500+m) submersible vehicles
- Standardized tools for use on various platforms or with various submergence vehicles/tools
- Sensors: chemical and physical (may require longer support periods than usual 2-yr grant to develop)
- Devices to measure pore-water flow
- High definition digital video cameras with telemetry system and high quality lens.
- Support equipment for high-definition cameras/ IE recorders/ monitors; includes conversion equipment from high definition to more user-friendly format.
- Simple camera controllers for scientific observer operation
- Smooth, variable speed pan & tilt with simple controller
- Electronic/digital still cameras with large storage capacity
- Red light operation for biological purposes
- More precise, programmable, manipulators with feed-back capability for gentle handling
- Computer controlled sediment profilers
- Gas-type manifold for water column sampling
- Improved corers for coarse and hard sediments (vibra-corers?)
- Better seafloor drilling capability (from submersible vehicles and with sea-floor rigs)

**Summary of Technological Needs for Long Time-Series Science:**

- Generic manipulators and vehicles
- Standardization of electrical and optical connectors and power interfaces
- Improved benchmark technology to provide mm accuracy for extended periods

**Observatory science:**

- Established of observatories on the seafloor
- New more robust ROV system with heavy lift capability, long bottom time, and dexterity in manipulation.
- Generic submersible interfaces that allow use of a number of assets for the same task.
- Flexibility in ability to down-load at various data rates, take up power, and interact with control systems
- Dedicated, docked AUVs for collection of data beyond the spatial extent of an observatory and for rapid response to transient events
- Recommended minimum suites of sensors for observatories

**Summary of Technology Needs for Global Science:**

- Matching vehicle types and instrument suites to the particular range of tasks at hand will be essential to the science- and cost- effective overall use of submergence assets present and future
- Both water-column and seafloor vehicles
- Benthic crawlers
- AUVs that fly above the seafloor.
- Vehicles that can go to depths of 6000m or more
- A significant need exists for vehicles that operate efficiently in the upper 2000 m
- Wide range of time and distance endurance for vehicles
- Exploratory vehicles (possibly cheap, simple, with minimal capabilities)
- Specialized vehicles for specific tasks
- Sensors for pressure, temperature, magnetization, gravity, and light
- Multi-spectral sensors (e.g., low-frequency radiation)
- Current and flow sensors.
- Chemical sensors both long range and for detailed site-specific work
- Acoustical and optical sensors with varying ranges and resolutions both on the bottom and in the water column.
- High-definition video and photography

- In-situ X-ray imaging.
- Better sampling devices for water, geological materials, sediment cores, and biological material. - - Maximum capacity for multiple samples
- Samplers that avoid cross-contamination
- Samplers that retain in situ conditions
- Sampling modes that enable coring and drilling for subsurface samples
- Suction collectors with multiple chambers,
- Enclosure-type samplers for especially fragile samples.
- Small volume water sampler
- These sampling and sensor issues require improved dexterity of manipulators,
- Advancements in communication and data transfer mechanisms, and power, payload, propulsion, and structural materials of platforms.
- Technology training and networking to maintain and upgrade systems
- Short baseline navigation of vehicles relative to their GPS-positioned tending ship may in some cases be an operationally preferable option.
- Systems that can withstand environmental extremes (strong currents, caustic environments, high temperatures, high salinity, etc.
- Weather constraints (e.g., polar environments) may require new support ship designs.

**Summary of Technology Needs for Expeditionary Science:**

- Very long range AUVs, expand on the ALTEX model to include other approaches such as gliders and solar-powered AUVS
- Air drop AUVs and navigational infrastructure
- Multiple AUVs
- AUVs with sampling capabilities
- Molecular and biochemical probes and sensors
- In-situ mass spectrometers
- AUVs with fiber or acoustic links
- More portable ROVs and towsleds, supported by improved, lightweight cables that can provide adequate power with smaller diameter cable.
- More intelligent AUVs
- Expendable AUVS

- Improved navigation
- Portable observatories
- Improve our abilities to produce rigorous data sets that allow others to explore after the expedition has ended.

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# APPENDIX II:
## *Meeting Agenda*

**DEveloping Submergence SCiencE for the Next Decade: "DESCEND"**
**Scientific Challenges, Technology Developments, and Management Strategy**

**National Science Foundation**
**4201 Wilson Boulevard**
**Arlington, VA**
**October 25-27, 1999**

***Monday, October 25th,***

**Day 1: Science Discussions**

**8:30 a.m. Open Meeting (Room 375)**

- UNOLS Welcome/Introduction - Dr. Thomas Royer, UNOLS Vice Chair
- Overview DESCEND – Dr. Patricia Fryer
- Overview of Submersible Science – Dr. Daniel Fornari
- Observatory Science Overview – Dr. Keir Becker & Dr. John Delaney
- Charge to Participants/Workshop Ground rules – Dr. Patricia Fryer

**10:15 a.m. Breakout Sessions: Science Breakout Sessions:**

- Ridge Processes I (Room 375) – Tim Shank/Karen Von Damm
- Ridge Processes II (Room 390) - Cindy Van Dover/ Mike Perfit
- The Abyss/Open Ocean (Room 375) – Art Yayanos/Andy Fisher
- Margins (passive & convergent) (Room 360) – Chuck Fisher/Brian Taylor
- Shelf, Coastal, and Polar (Room 370) – Gary Taghon/ Jim Barry

**12:00 Lunch**
**1:00 p.m. Reconvene Break-Out Sessions**

**3:45 p.m. Break**

**4:00 p.m. Plenary Session** (Room 375) – Each session leader will provide a brief (one bulleted overhead) summary of their respective session. At the conclusion of all summaries there will be an open discussion.

**6:00 p.m.** ***Adjourn Day One***

***Tuesday, October 26th***

**Day 2: Technology & Instrumentation**

**8:30 a.m. Commence Day 2 (Room 375)**

- Overview of untethered systems – AUVs: Dr. James Bellingham
- Manned and Unmanned Vehicles: Mapping: Dr. Dana Yoerger
- Data Systems – Case studies within and outside of MG&G: Dr. Dawn Wright

**10:15 a.m. Technological Breakout Sessions:**

- Event Response (Room 370) – Jim Cowen/Hugh Milburn
- Time Series – Long (Room 360) – Fred Duennebier/Ross Heath
- Time Series – Short (Room 390) – George Luther/ Marsh Youngbluth
- Expeditionary (Room 375) – Dana Yoerger/Bill Ryan
- Global (Room 375) – Fred Spiess/ Marty Kleinrock

**12:00 Lunch**

**1:00 p.m. Reconvene Break-Out Sessions**

**3:45 p.m. Break**

**4:00 p.m. Plenary Session** (Room 375) – Each session leader will provide a brief (one bulleted overhead) summary of their respective session. At the conclusion of all summaries there will be an open discussion.

**6:00 p.m.** ***Adjourn Day Two***

***Wednesday, October 27th***

**Day 3: Wrap-Up:**

**8:30 a.m. Commence Day 3 (Room 1235)**

**Morning: Future Technologies and Facilities: Developmental paradigms and tradeoffs –** Dr. James Bellingham

A final plenary discussion among all participants will follow. A summary of the morning's discussion by the steering committee will close the workshop.

**Afternoon:** The afternoon will be set aside to allow the Steering Committee to complete writing assignments.

# Appendix III:

## DESCEND Workshop Steering Committee


**CHAIR - Dr. Patricia Fryer, Professor**
**SOEST/Planetary Geosciences, University of Hawaii**
**pfryer@soest.hawaii.edu**

***

**Dr. Keir Becker – (Ocean Bottom Observatories) -**
**Marine Geology and Geophysics, RSMAS, University of Miami**
**kbecker@rsmas.miami.edu**

***

**Dr. Marv Lilley - Chemistry**
**University of Washington**
**lilley@ocean.washington.edu**

***

**Dr. Craig Cary – Biology**
**College of Marine Studies, University of Delaware**
**caryc@udel.edu**

***

**Dr. Lisa Levin - Biology**
**Marine Life Research Group, Scripps Institution of Oceanography**
**Llevin@ucsd.edu**

***

**Dr. James Bellingham - AUV**
**Underwater Vehicles Laboratory, MIT Sea Grant Program**
**belling@mit.edu**

# Appendix IV:
## DESCEND Participants

| Name of Participant | Date Application Submitted |
|---|---|
| Jess Adkins | August 4, 1999 |
| Jon Alberts | October 4, 1999 |
| Carole C. Baldwin | September 2, 1999 |
| Jim Barry | September 23, 1999 |
| Gregory S. Boland | September 16, 1999 |
| Andy Bowen | July 30, 1999 |
| Albert M. Bradley | August 19, 1999 |
| Robert Brown | August 19, 1999 |
| Craig Cary | September 13, 1999 |
| Lawrence William Carpenter | August 30, 1999 |
| Dale Chayes | October 8, 1999 |
| Edward Cooper | August 17, 1999 |
| Milene Cormier | August 24, 1999 |
| Nicole Crane | Setpember 9, 1999 |
| Alec Crawford | September 21, 1999 |
| John R. Delaney | August 21, 1999 |
| Henry Dick | July 30, 1999 |
| Tommy D. Dickey | August 19, 1999 |
| Fred Duennebier | August 2, 1999 |
| Eileen E. Dunn | August 23, 1999 |
| James E. Eckman | August 17, 1999 |
| Bob Embley | August 29, 1999 |
| Andrew Fisher | August 17, 1999 |
| Chuck Fisher | September 10, 1999 |
| Daniel J. Fornari | August 9, 1999 |
| Dudley Foster | August 23, 1999 |
| Patricia Fryer | August 24, 1999 |
| Chris German | August 16, 1999 |

| | |
|---|---|
| James Gill | August 5, 1999 |
| Chris Goldfinger | September 3, 1999 |
| G. Ross Heath | August 22, 1999 |
| Thomas A. Hickson | August 1, 1999 |
| Ray Highsmith | August 20, 1999 |
| Susan E. Humphris | August 20, 1999 |
| S. Kim Juniper | September 1, 1999 |
| Miriam Kastner | August 11, 1999 |
| William J. Kirkwood | August 13, 1999 |
| Martin Kleinrock | August 23, 1999 |
| Val Klump | August 24, 1999 |
| Lisa A. Levin | August 23, 1999 |
| Don Liberatore | August 23, 1999 |
| Dave Lovalvo | August 24, 1999 |
| John Lupton | July 30, 1999 |
| George W. Luther, III | August 17, 1999 |
| Richard A. Lutz | August 17, 1999 |
| Laurence P. Madin | August 24, 1999 |
| Alexander Malahoff | August 24, 1999 |
| Russell McDuff | August 25, 1999 |
| Jon D. McWhirter | September 8, 1999 |
| Hugh Milburn | August 5, 1999 |
| David Naar | August 19, 1999 |
| Dr. Donald Nuzzio | October 8, 1999 |
| Scott Olson | August 20, 1999 |
| Daniel Orange | August 30, 1999 |
| Michael Perfit | September 7, 1999 |
| Richard F. Pittenger | August 5, 1999 |
| Shirley A. Pomponi | August 23, 1999 |
| Frank R. Rack | August 24, 1999 |
| Anna-Louise Reysenbach | August 24, 1999 |
| Veronique Robigou | August 21, 1999 |
| Bruce H. Robison | August 24, 1999 |
| Peter A. Rona | August 17, 1999 |
| John D. Rummel | August 11, 1999 |

| | |
|---|---|
| William B. F. Ryan | August 27, 1999 |
| Frank Sansone | August 24, 1999 |
| Daniel Scheirer | August 19, 1999 |
| Daniel S. Schwartz | October 1, 1999 |
| Timothy M. Shank | August 26, 1999 |
| Andrew Shepard | August 6, 1999 |
| Craig R. Smith | August 24, 1999 |
| Deborah K. Smith | August 16, 1999 |
| Fred Spiess | August 18, 1999 |
| Gary Taghon | August 24, 1999 |
| Shozo Tashiro | August 24, 1999 |
| Brian Taylor | September 8, 1999 |
| Maurice A. Tivey | August 13, 1999 |
| Robert F. Tusting | August 10, 1999 |
| Cindy Lee Van Dover | August 11, 1999 |
| Karen L. Von Damm | July 30, 1999 |
| Barrie Walden | August 24, 1999 |
| C. Geoffrey Wheat | August 23, 1999 |
| Dawn Wright | August 2, 1999 |
| A. Aristides Yayanos | August 24, 1999 |
| Dana R. Yoerger | September 2, 1999 |
| Craig M. Young | August 23, 1999 |
| Marsh Youngbluth | September 21, 1999 |
| Jill Zande | September 8, 1999 |

# APPENDIX V:
## DESCEND Abstracts

Meeting participants provided information about their submergence science interests and abstracts in advance of the DESCEND workshop. This information has been compiled and is provided below.

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**Jess Adkins**


| | |
|---|---|
| Organization: | Lamont-Doherty Earth Observatory |
| Address: | Route 9W |
| City: | Palisades |
| State/Province: | New York |
| Country: | USA |
| ZIP Code: | 10964 |
| Email: | jess@ldeo.columbia.edu |


-------------------------------------------------------------------

1. Field of Expertise: Geochemistry
2. Submergence Platform(s) Used:
3. Workshop Questions: Collection and monitoring of deep-sea coral.
4. Region of Interest: All deep ocean basins
5. Types of submergence systems anticipated for work/technology development:
   - Alvin
   - ROVs
6. Abstract:


The use of deep-sea corals as monitors of deep ocean behavior is an exciting new area of research that requires deep submergence technology. This new archive can address problems in two key areas of abyssal research; the deep ocean's relation to climate on glacial/interglacial time scales and time series of modern deep water, and vent area, chemistry on decadal time scales. From a "paleo" point of view the corals not only represent an archive that records very high temporal resolution relative to deep-sea sediments but also contains a fundamental, and until recently, unmeasurable tracer in Paleoceanography. Coupled U-series and radiocarbon dates from the same coral free 14C from being a chronometer and allow us to calculate the initial radiocarbon content of past water masses. This measurement constrains the rate of paleo-circulation, adding transport to our understanding of past water mass volumes and distributions.

Modern samples provide both a calibration for our paleo studies and the potential for time series of chemical species. This archive is akin to an abyssal observatory of deep-sea-chemistry spanning at least the last several decades. In the same way that overlap

between the atmospheric and ice core measurements of carbon dioxide strengthened the findings from each data set, modern abyssal observatories and deep-sea corals could complement each other.

Deep-sea coral studies are in their infancy, and the types of studies to be conducted with current and future deep submergence are therefore varied. However, my recent work shows that there are some key gaps in the collections from dredges over the last 30-40 years. We need samples from the deep Pacific, down the sides of seamounts and from previously dredged "gold mines" of deep-sea corals. For all of these reasons, I would like to explore, with the deep submergence community, how to collect and monitor these animals in a more rigorous manner than as a side benefit to dredging.

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### Jon Alberts


| | |
|---|---|
| Title: | Marine Operations Coordinator |
| Organization: | Woods Hole Oceanographic Institution |
| Address: | Mail Stop #37 |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | jalberts@whoi.edu |


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1. Field of Expertise: Deep Submergence Vehicle Operator
2. Submergence Platform(s) Used: ALVIN
3. Workshop Questions: Future Trends in Deep Submergence Research
4. Region of Interest: All Oceans
5. Types of submergence systems anticipated for work/technology development: NA
6. Abstract: NA

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### Carole C. Baldwin


| | |
|---|---|
| Organization: | NMNH, Smithsonian Institution |
| Address: | Division of Fishes, MRC 159 |
| City: | Washington |
| State/Province: | D.C. |
| Country: | USA |
| ZIP Code: | 20560 |
| Email: | baldwin.carole@nmnh.si.edu |


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1. Field of Expertise: Deep Sea Biology
2. Submergence Platform(s) Used: Johnson Sea Link II
3. Workshop Questions: 1. What is the role of systematic biologists in the next decade of deep-sea investigations? What are the best sources of funding for purely biological (micro and macro) exploration?
4. Region of Interest: For now, tropical Atlantic, Pacific
5. Types of submergence systems anticipated for work/technology development:
Submergence systems: Manned submersibles, ROVs

Technology development: Efficient means of sampling organisms in the water column, not just on the bottom.

6. Abstract:

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**Jim Barry**


| | |
|---|---|
| Organization: | MBARI |
| Address: | P.O. Box 28 |
| City: | Moss Landing |
| State/Province: | CA |
| Country: | USA |
| ZIP Code: | 95039 |
| Email: | barry@mbari.org |


------------------------------------------------------------------

1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: ROVs (MBARI, JAMSTEC, Other)
Subs (Shinkai, Delta)

3. Workshop Questions: What are the priorities of the submergence science community for future development? More vehicles or greater capabilities for existing vehicles. What balance should exist between submergence vehicles and deep-sea observatories, since these may compete for funding?

4. Region of Interest: Eastern Pacific, Antarctic continental margin.

5. Types of submergence systems anticipated for work/technology development:
My research is generally concentrated along the US west coast (chemosynthetic community studies) and Antarctica (pelagic Benthic coupling). Submergence systems for

this work include ROVs, subsea camera systems, and in situ sensors.

6. Abstract:

a) Current technological limitations: Subsea navigation, sensors (sulfide, carbon (POC, DOC), fluid samplers, pore fluid profilers, high resolution imaging, image analysis systems, high dexterity manipulators to measure / tag organisms in situ, battery power for subs / AUVs. High resolution navigation would allow more repeatable video transects, in situ sensors & profiling system would increase resolution of chemical gradients, imaging systems would aid in characterization of fauna (distribution, size structure, growth, etc.).

b) Generally available capabilities: Greater access to vehicles for submersible science, with high-resolution navigation & imaging, dexterous manipulators, various sampling devices (fluids, animals, and sediments).

c) I expect an increase in the availability and capabilities (depth, functionality) of both ROVs and manned submersibles in the future. Ocean exploration will continue to be limited by submersible technology. An acceleration in ocean exploration and understanding will require greater accessibility to submersible technology by the scientific community. ROVs will likely increase in importance over manned submersibles. AUV developments in the next decade or two will broaden sampling capabilities for some disciplines.

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**Gregory S. Boland**

| | |
|---|---|
| Organization: | Minerals Management Service |
| Address: | 1201 Elmwood Park Blvd |
| City: | New Orleans |
| State/Province: | LA |
| Country: | USA |
| ZIP Code: | 70123 |
| Email: | Gregory_Boland@mms.gov |


------------------------------------------------------------------

1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: Johnson Sea Link I and II
TAMU Diaphus
Nekton Gamma
Various mini-ROVs

3. Workshop Questions: Sampling methodologies
Physical manipulation of experiment packages

Acoustic telemetry between platforms and experiment packages
Acoustic transmission of images
Deep >1000 m ROV scientific capabilities

4. Region of Interest: Gulf of Mexico

5. Types of submergence systems anticipated for work/technology development:
>1000 m manned submersibles and ROV for study of deep-sea biology, especially chemosynthetic communities.

Deep ROV capabilities and payload (experiments)

6. Abstract:

What are the current technological limitations on your research, and what science could you do if these problems did not exist?

One of the most critical limitations to Gulf of Mexico submergence science is the lack of platforms capable of greater than 1000 m operation. The Alvin is very difficult to obtain funding for as well as problems with long-term commitments and availability. Deep ROV capabilities are expanding but my personal knowledge is lacking (a primary reason for attending). Additional deep subs would benefit our nation's program but perhaps with the escalation of deep oil and gas development in the Gulf of Mexico, deep ROV technology will eventually substitute for much of the science thought only possible by a manned submersible.

In the Gulf of Mexico, there are potentially twice the number of known chemosynthetic communities that exist below the depth capability of the much-used JSL subs. Only one site has been investigated in the Alaminos canyon with Alvin. Numerous oil seeps exist in deep water (with probable associated communities of some sort) with no easily available platform to investigate them.

b) What capabilities should be generally available for submergence science?

Fine scale manipulation of sampling apparatus and external experiments should be a general capability on all submergence platforms. Little can be done with simple visual feed back alone. Even direct observation of chemosynthetic communities is commonplace now and complicated collections and experiments must be performed to move forward in our scientific understanding of these spectacular deepwater sites.

c) Where do you see submergence science going in the next decade?

Autonomous vehicles seem to be very promising. Real time acoustic transmission of visual data (video or digital stills) would be a major breakthrough for untethered systems. Perhaps this technology exists but is not well known.

**Andy Bowen**

Organization: WHOI
Address: MS #7
City: Woods Hole
State/Province: MA
Country:
ZIP Code: 02543
Email: abowen@whoi.edu

-------------------------------------------------------------------

1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used:

3. Workshop Questions: Facilities needs of the science community

4. Region of Interest: various

5. Types of submergence systems anticipated for work/technology development:

6. Abstract:

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**Albert M. Bradley**

Organization: WHOI
Address: MS #18
City: Woods Hole
State/Province: MA
Country: USA
ZIP Code: 02543
Email: abradley@whoi.edu

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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: ABE (Autonomous Benthic Explorer)

3. Workshop Questions: What vehicle and systems do we need?

4. Region of Interest: this solar system, preferably earth...

5. Types of submergence systems anticipated for work/technology development:
AUVs and ROVs and what they can do for science

6. Abstract:

Technological Limitations

My work with AUVs is severely constrained by current battery technology. There are promising improvements on the horizon, but this remains our biggest constraint. Perhaps the next most severe limitation is navigation. Current Acoustic systems in use seem to all have an accuracy of 0.1% of their working range. Communication is often a limitation, but I de-emphasize this since to be economical to operate an AUV should do its job without requiring an operator. Of course there are places where an AUV is used as a "tetherless ROV" (for deep trenches) and communication then becomes critical.

Available Capabilities

I'll be at this workshop to hear others address this topic!

Next Decade

I think the next decade will be the decade of the AUV in deep ocean science. The question is, what are the science problems and how can AUVs address them?

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**Robert Brown**

| | |
|---|---|
| Title: | Research Associate/ALVIN PROJECT ENGINEER |
| Organization: | Woods Hole Oceanographic Institution |
| Address: | MS # 17 |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | rbrown@whoi.edu |


-------------------------------------------------------------------

1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: ALVIN JASON

3. Workshop Questions: N/A

4. Region of Interest: N/A

5. Types of submergence systems anticipated for work/technology development:
Involved in development of manned and unmanned vehicles and instrumentation/sampling equipment for those vehicles.

6. Abstract:

These are specifically questions for science. My desire is to enhance the technical capabilities of our deep submergence vehicles to perform the science envisioned for the next decade.

---

**Craig Cary**

Organization: University of Delaware
Address: CMS, 700 Pilottown Rd
City: Lewes
State/Province: DE
Country: USA
ZIP Code: 19958

Email: caryc@udel.edu

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1. Field of Expertise: Microbiology
2. Submergence Platform(s) Used: Alvin
Nautile
Nekton
3. Workshop Questions:
4. Region of Interest: EPR

5. Types of submergence systems anticipated for work/technology development:
Both Submersible and ROV. I am interested in microscale sampling capabilities in particular small water sampling coupled with in situ geochemical analysis. I am also interested in rock coring at the same scale.

6. Abstract:

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**Lawrence William Carpenter**

Organization: School of Marine Science, Virginia Institute of Marine Science
Address: P.O. Box 1346
City: Gloucester Point
State/Province: Virginia
Country: USA
ZIP Code: 23062

Email: Pianoman@vims.edu

--------------------------------------------------------------------

1. Field of Expertise: Hydrothermal Vent Biology
2. Submergence Platform(s) Used: Alvin Jason
3. Workshop Questions: biogeography, astrobiology, ecology
4. Region of Interest: global

5. Types of submergence systems anticipated for work/technology development:
   Manned, ROVs, AUVs, observatories

6. Abstract:

Current Limitations:
Frequency of sampling and of deploying/recovering instruments. Ability to access remote sites with suite of deep submergence assets.

Capabilities available for deep submergence science:
24-h ROV ops at 6500 m or less with full suite of capabilities mapping at multiple scales, including imagery, sampling, instrument deployment and recovery) manned ops at 4500 m or less with full suite of capabilities

Future:
maintenance of current level of expeditionary and short time-scale observations and expansion of observatory capabilities. Both approaches are complementary.

---

## Dale Chayes

Organization: Lamont-Doherty Earth Observatory/CU
Address: Instrument Lab, 61 Route 9W
City: Palisades
State/Province: NY
Country: USA
ZIP Code: 10964

Phone Number: 914-365-8434
Email: dale@ldeo.columbia.edu

--------------------------------------------------------------------

1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used: Alvin
Sea Cliff
Turtle
NR1
USS Hawkbill
USS Cavalla
USS Pargo
USS Pogy
Deep Tow
SeaMARC I
SeaMARC II

3. Workshop Questions: Relative merits of "manned", unmanned, autonomous and tethered, permanent, temporary platforms.

4. Region of Interest: Global

5. Types of submergence systems anticipated for work/technology development:
Submarine-based AUV and ROV platforms.
Submarine-based "manned" surveys.

6. Abstract:
Mapping in the arctic is seriously limited by the ice cover and at high latitudes by distance and weather. The SCICEX program has proven that good science can be done using US Navy nuclear submarines. Better access to such platforms coupled with development of suitable techniques and technologies will finally allow access to these remote and hostile areas.

---

**Edward Cooper**

Title: Mr. / Acting Scientific Superintendent
Organization: Research Vessel Services
Address: Rm 341/01, Southampton Oceanography Centre, European Way
City: Southampton
State/Province: Hampshire
Country: United Kingdom
ZIP Code: SO14 3ZH
Email: ebc@soc.soton.ac.uk

-----------------------------------------------------------------

1. Field of Expertise: Ocean Engineering
2. Submergence Platform(s) Used: None
3. Workshop Questions: Facility needs for the science community
4. Region of Interest: As determined by UK scientific community.
5. Types of submergence systems anticipated for work/technology development: ROVs & AUVs
6. Abstract:

---

**Milene Cormier**


| | |
|---|---|
| Organization: | Lamont-Doherty Earth Observatory |
| Address: | Oceanography 208 |
| City: | Palisades |
| State/Province: | NY |
| Country: | USA |
| ZIP Code: | 10964-8000 |
| Email: | cormier@ldeo.columbia.edu |


-----------------------------------------------------------------

1. Field of Expertise: Marine Geophysics

2. Submergence Platform(s) Used: Alvin and Nautile submersible; ABE AUV.

3. Workshop Questions: - What are the styles, volumes, aerial extents, flow morphologies, melt pathways, and timing of individual eruptive events at mid-ocean ridges?
- What is the detailed distribution of faults and fissures in the axial region of mid-ocean ridges and what strain does it accommodate?

4. Region of Interest: all mid-ocean ridges

5. Types of submergence systems anticipated for work/technology development:
I am interested in the following technology developments:
- Very accurate navigation (with resolution of a few meters) routinely available for manned submersibles, AUVs, and ROVs would be wonderful. Precise navigation would allow to produce photomosaic of relatively large area, and co-located, very high resolution maps (better than available on land!) of the bathymetry, magnetics, gravity, temperatures, geology, etc.
- The capabilities to deploy AUVs simultaneously to other deep submergence systems would greatly optimize the use of ship time. It would require the conception of a new transponder systems that could be queried simultaneously by different platforms (?)

- The capabilities to recover many rock samples (several dozens? Small glass chips would be sufficient...) during a single deployment would allow very precise geological mapping.

6. Abstract:

During a recent cruise to the East Pacific Rise, we surveyed a 2.5 km2 area of the seafloor with the AUV "ABE". Because ABE's navigation was so accurate, we were able to produce maps of the bathymetry, magnetic field, CTD, and optical backscatter as well as to obtain photomosaics of the study area with an unprecedented resolution. The results unambiguously outline a system of en-echelon eruptive fissures, the lava pillars standing within the fissures, the individual lava lobes, networks of lava channels and collapse lava tubes emanating from these fissures, and even the locations of a few black smokers.

In view of these exciting results, I envision the following developments as important to future research:

- The capability to simultaneous use several platforms, such as Alvin plus a few AUVs, would provide an optimal use of ship-time. It would require a modification of the present transponder navigation system to allow several platforms to communicate simultaneously with the array of acoustic beacons.
- An accurate navigation for all the platforms (better than 5 m) would allow the precise co-location of the different data sets.
- The possibility to collect more samples during one deployment. For instance, the possibility to collect a few basaltic glass chips at several dozen locations during one dive would allow the systematic typing of lavas in the neovolcanic zone at mid-ocean ridges.
- An extended battery life for AUVs would allow more time on bottom and therefore increase the areas that could be surveyed during one cruise.

- The availability of gravimeters that makes continuous underway measurements on AUVs or ROVs. The feasibility of these measurements has been recently demonstrated on Alvin, and would potentially be done more effectively from AUVs.

Near-bottom surveys will become increasingly time- and cost-efficient with the use of several complementary platforms during one cruise. Unlike tethered ROVs, manned submersibles offer an immediate 3–D, peripheral view of the seafloor. As such, in the hand of experienced field scientists, they allow for a very efficient exploration of the seafloor. Manned submersible are also versatile and effective sampling platforms. ROVs and AUVs on the other hand are unsurpassed for providing the complete geological and biological context of an area.

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**Nicole Crane**

| | |
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| Organization: | Marine Adv. Tech. Ed./Monterey Penin. Coll. |
| Address: | 980 Fremont St |
| City: | Monterey |

State/Province: CA
Country:
ZIP Code: 95076
Email: ncrane@marinetech.org

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1. Field of Expertise: Fisheries

2. Submergence Platform(s) Used: Saturation (Aquarius)
Scuba
ROV

3. Workshop Questions: Our NSF funded center is involved with the development of educational programs to prepare people for careers in marine science and technology. The focus is on the technical and support side of commercial and research operations. We are actively developing partnerships and collaborations with industry and academic programs to shape the work we do, and provide opportunities for students.

4. Region of Interest: National

5. Types of submergence systems anticipated for work/technology development:
Scuba (research and applied diving)
ROVs: piloting, maintenance, operations
Subs: piloting, maintenance, operations
AUVs: piloting, maintenance, operations
Other: instrumentation, telemetry, remote sensing

6. Abstract:
Given the nature of our program, the above questions are not entirely relevant. I have included an abstract here, which describes our work, and the major technical areas in which we concentrate.

Marine Advanced Technology Education (MATE) Center:
Education and preparation for careers in ocean science and technology

www.marinetech.org

The National Science Foundation's Advanced Technological Education (ATE) program is showing their commitment to improving the education of people who work in and are interested in ocean-related careers through their award to the Marine Advanced Technology Education (MATE) Center. The MATE Center is located at Monterey Peninsula College in Monterey California. It was established in September 1997.

The MATE Center is a partnership of organizations and individuals concerned with the broad field of marine science and technology and the education of people to work in that field. Technological advances have created new opportunities for ocean exploration and

research, and will shape a growing need for people who understand and can work with the technology. The MATE Center is coordinating and facilitating the development of programs in marine science and technology involving high schools, technical schools, community and four-year colleges, and graduate schools, with an emphasis on community college program development, to meet that need. The MATE Center is developing collaborations between educational institutions and industry, military, government, research, and labor organizations. These collaborations facilitate the development of courses and programs based on industry-established guidelines, which provides students with both academic and technical skills and knowledge.

The Center has launched a national technical internship program in partnership with the University National Oceanographic Laboratory System (UNOLS) and the Ocean Drilling Program (ODP). This program emphasizes technical skill acquisition, and matches students with positions that best suit their interests and the needs of the ship operations. Hands-on, work-place experiences such as this are an integral part of the MATE educational pathways, and are key to establishing relationships between students and industry/research.

The MATE Center is conducting a series of on-going workshops with industry and research institutions to gather information on the skills, knowledge and abilities needed to perform in several marine technical occupational areas. These employer-based guidelines are then used to develop courses and programs, which are relevant and up-to-date. Workshops have been held for Marine Research (ship-board) Technician, ROV Technician, Hydrographic Survey Technician, Aquaculture Technician, and Oil Spill Response Technician. Using this information, Monterey Peninsula College launched a new Marine Science and Technology A.S degree and certificate program in the fall 1999.

A major goal of the Center is to heighten the awareness of marine-related careers and provide students, educators, workers, and employers with up-to-date information to assist them in making informed choices concerning their education and future. In addition to being available to educators and employers, the information gathered through the MATE Center is available to students and other interested parties through our office and our website. For more information, call our office at 831.645.1393, e-mail us at info@marinetech.org, or visit our website at www.marinetech.org

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**Alec Crawford**

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|---|---|
| Title: | Captain |
| Organization: | Deep Tek Ltd |
| Address: | Kilburns |
| City: | Newport on Tay |
| State/Province: | Fife |
| Country: | UK |
| ZIP Code: | dD6 8PL |
| Email: | deeptekltd@aol.com |

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1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used: Various:  have been developing remote electro-hydraulic systems using a vertical hoist member to take power, precision and lift to ever increasing depth.

3. Workshop Questions: n/a

4. Region of Interest: n/a

5. Types of submergence systems anticipated for work/technology development: Harnessing of man-made fibre, such as "Plasma", as part of a novel, patented winding mechanism.   Services, such as power and fibre optics are wound helically onto the strength member as the bottom equipment is deployed, and wound off as it is winched in, due to low specific gravity (<1.0) this opens up the potential of going to full ocean depth.

6. Abstract:
There are no technological limitations on the development work we wish to carry out, merely money.

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**John R. Delaney**


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|---|---|
| Organization: | University of Washington |
| Address: | School of Oceanography |
| City: | Seattle |
| State/Province: | WA |
| Country: | USA |
| ZIP Code: | 98195 |
| Email: | jdelaney@u.washington.edu |


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1. Field of Expertise: Marine Geology
2. Submergence Platform(s) Used:

3. Workshop Questions: How do entire plates and their overlying water masses evolve on time scales from minutes to decades?

4. Region of Interest: Global with focus on NE Pacific

5. Types of submergence systems anticipated for work/technology development: Fiber Optic Cable networks and all the associated technology necessary to provide plate scale observatories.

6. Abstract:

c) Where do you see submergence science going in the next decade?

The ocean and planetary sciences are not so gradually shifting from an exclusively expeditionary mode of operation toward one that also involves in situ experimental and interactive modes of conducting scientific inquiries and testing well-framed hypotheses. This new direction will require a host of innovations that require extensive and diverse sensor arrays in a broad range of remote and hostile environments with which scientists and educators can establish two-way interactive communication in real time. Systems of this type must also deliver power to the instruments and carry a commitment of decades to explore the temporal behavior of the many basic processes that form and modify the planetary surface and control its environment. To a first order, many such processes operate at or below the scale of tectonic plates. The coming decade will see selection of a small number of locations where comprehensive studies of individual plates can be conducted. These must be complemented by a number of well chosen, but less comprehensive, installations that illuminate the diversity and complexity of the basic solid earth, planetary, or oceanographic processes selected for study.

b) What capabilities should be generally available for submergence science?

All the obvious capabilities to work the seafloor – high precision mapping capabilities such as multibeam deep tow systems, low light level cameras, laser ranging and mapping systems, sampling devices of all sorts, positioning systems the cover the intermediate range between long-baseline nav systems in the 8 to 13 kHz range and the more precise high resolution systems using 300 kHz transponders. We need powerful and precise ROVs and highly flexible and sophisticated AUVs of different sorts to allow routine surveying, sampling, and mapping as well as ROVERS that can tractor around on the seafloor doing heavy jobs like drilling and sustained observations of specific bottom terrains. The single most important area for development is in the arena of chemical and biological sensors that can operate remotely for long periods of time. It is anathema to some but eventually we should move toward being independent of the need to sample.

a) What are the current technological limitations on your research, and what science could you do if these problems did not exist?

Many of the answers to b) are critical for entering the next generation of seafloor studies which I believe will entail an entire new era of exploration of the time domain within a wide range of remote systems on this planet and on others. We would be well served by entraining the space science communities and by focusing strongly on outreach and education.

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**Henry Dick**

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|---|---|
| Organization: | Woods Hole Oceanographic Institution |
| Address: | Rm 214, McLean Laboratory |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543-1539 |

Email: hdick@whoi.edu

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1. Field of Expertise: Petrology

2. Submergence Platform(s) Used: ANGUS
ALVIN
ROOPOS
SHINKAI 6500

3. Workshop Questions: Mapping lower crust and mantle in tectonic windows - determining the nature of the crust mantle boundary and the architecture of the lower crust and mantle at ocean spreading centers.

4. Region of Interest: SWIR, MAR,

5. Types of submergence systems anticipated for work/technology development:
Submersibles
ROVs
Seafloor video guided rock drills

6. Abstract:
The recent highly successful mapping of the lower crust and mantle outcrops at Atlantis Bank in the Indian Ocean using seafloor rock drills, ROVs and Submersibles has demonstrated the utility of using tectonic windows into the lower crust and mantle as a means of directly studying the architecture and composition of the lower crust and mantle at the ridge segment scale at slow spreading ridges. A significant problem, however, is a limited ability to take oriented rock samples and make structural measurements on the seafloor. Recent results drilling with an as yet somewhat primitive system at Atlantis Bank, however, shows that video guided drilling of oriented cores is well within our technological reach and should be an area in which resources should be focused over the next decade. With this ability in hand, we would be able to directly assess tectonic rotations on the seafloor related to both local tectonics, and larger scale plate rotations. An improved ability to take structural measurements, preferably using some form of laser system would make routine structural geology on the seafloor a reality. In particular, this should be developed for both ROVs and submersibles.

I continue to see ROVs and Submersibles as complementary to each other, but would also like to see a more robust ROV capability, similar to the large well powered commercial ROVs presently available in industry, made accessible to the academic community.

**Tommy D. Dickey**


Organization: Univ. of California, Santa Barbara
Address: 6487 Calle Real, Suite A
City: Goleta
State/Province: CA
Country: USA
ZIP Code: 93117
Email: tommy. Dickey@opl.ucsb.edu


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1. Field of Expertise: Physical Oceanography

2. Submergence Platform(s) Used: Moorings, AUVs, and Drifters

3. Workshop Questions:
During the past decade, there has been a major thrust forward in sensors, which are capable of providing important chemical, optical, biological, and acoustical as well as physical data. Interdisciplinary sensor suites are important for studying problems such as carbon dioxide cycling and variability, the role of biology in upper ocean heating, phytoplankton productivity, upper ocean ecology, population dynamics, and sediment resuspension. Many of the new sensors are relatively small and have modest power requirements. Thus, the deployment of an increasing number of these sensors from autonomous platforms is becoming practical (e.g., Dickey, 1991). The increased availability of platforms such as moorings and AUVs is critical for future advances.

4. Region of Interest: Open and coastal ocean

5. Types of submergence systems anticipated for work/technology development:
Moorings and AUVs. Interfacing new interdisciplinary sensor suites to these platforms.

6. Abstract:


During the past decade, there has been a major thrust forward in sensors, which are capable of providing important chemical, optical, biological, and acoustical as well as physical data. Interdisciplinary sensor suites are important for studying problems such as carbon dioxide cycling and variability, the role of biology in upper ocean heating, phytoplankton productivity, upper ocean ecology, population dynamics, and sediment resuspension. Many of the new sensors are relatively small and have modest power requirements. Thus, the deployment of an increasing number of these sensors from autonomous platforms is becoming practical (e.g., Dickey, 1991).

Moorings have been used to obtain chemical, optical, biological, and acoustical data in addition to the more common physical data (e.g., temperature, salinity, and currents) and have proven to be excellent platforms for testing and developing new sensors (Dickey et al., 1998). A few examples of variables which can now be sampled from moorings

include: nitrate concentration, dissolved oxygen, partial pressure of carbon dioxide, scalar irradiance, spectral inherent and apparent optical properties, chlorophyll fluorescence, and size distributions of particles and zooplankton. Most variables can be sampled every few minutes.

Already, new scientific insights into interdisciplinary processes have resulted from concurrent, multi-sensor measurements from moorings. Examples include: the roles of seasonal and episodic forcing and eddies in increasing upper ocean nitrate and levels of primary productivity at mid- and high-latitudes; monsoonal atmospheric and eddy forcing of productivity in the Arabian Sea; modulation of productivity in the equatorial Pacific through tropical instability waves, Kelvin waves, and El Nino/La Nina sequences; sediment resuspension via internal solitary waves and hurricanes; and variability in upper ocean heating caused by phytoplankton. Moorings are also being used to ground truth ocean color data collected from satellites. Durations of interdisciplinary moorings have typically been a few months to a year. The major constraint remains biofouling. However, new anti-biofouling methods are being developed and tested; encouraging results suggest that this impediment will be considerably less limiting in the future.

Autonomous underwater vehicles (AUVs) have also been used to collect limited interdisciplinary data sets. Size and power are more constraining parameters for drifters, AUVs, floats, and gliders than for moorings. Nonetheless, some optical and chemical sensors have been successfully deployed from drifters and plans are underway for float and glider applications. AUVs have already carried similar sensor suites as well as ADCPs and turbulence probes. Again, biofouling will be problematic for long-term measurements from these various platforms. In the future, it is likely that continued expansion will occur in the areas of small, energy efficient, interdisciplinary sensors. In particular, sensors will likely be capable of measuring a much wider range of chemical compounds and trace elements, higher spectral resolution inherent and apparent optical properties and spectral fluorescence, and multi-frequency acoustical systems for better resolution of zooplankton size classes. Cost per sensor is an important issue and may be a major limiting factor, especially for expendable platforms. Commercialization of key sensors will be essential for this reason. Telemetry of data from the various platforms is critical for many, if not most, new applications. The sensor and telemetry technologies mentioned here would be important for maximum utilization of the various platforms.

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## Fred Duennebier


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| Organization: | SOEST, Univ. of Hawaii |
| Address: | dept. of Geology & Geophysics, U. of Hawaii |
| City: | Honolulu |
| State/Province: | HI |
| Country: | USA |
| ZIP Code: | 96822 |

Email: fred@soest.hawaii.edu

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1. Field of Expertise: Marine Geophysics

2. Submergence Platform(s) Used: PSICES V
TRIUMPH ROV
JASON/MEDEA

3. Workshop Questions: I will probably do most of my work on hot spot volcanoes, which are not addressed in the list below.

4. Region of Interest: Pacific

5. Types of submergence systems anticipated for work/technology development: heavy lift ROVs, submersibles

6. Abstract:
A marked increase in numbers and capabilities of submergence assets will be necessary to support ocean bottom observatories installed during the next decade. The most effective observatories will be permanent installations that can support connection and removal of experiments on the ocean floor, requiring both routine maintenance and emergency support of these observatories.

It is likely that the most efficient vehicles for servicing observatories will be ROVs, with their capabilities of extended operations on the ocean floor, heavy lift, and lighter restrictions on working in hazardous situations, such as near cables, than manned vehicles. At this point we are involved with two observatories, HUGO, the Hawaii Undersea Geo-Observatory, and H2O, the Hawaii-2 Observatory, both of which require servicing. HUGO has been down for more than a year, and a heavy-lift ROV is needed to cut the cable and lift the Junction Box to the surface, although getting HUGO operational again will require a new cable.

H2O has problems with its Junction Box and seismic package, which require both of these packages to be brought to the surface. The H2O cruise (with JASON/MEDEA) will be completed by the time of this workshop, bringing the system back on line after about nine months of data loss.

Without sufficient assets to service ocean bottom observatories, and without procedures to provide rapid repairs when needed, they will suffer prolonged data losses, potentially for large numbers of experiments.

Necessary capabilities include prolonged bottom time, heavy-lift, high quality imagery, and considerable dexterity.

If NEPTUNE flies, it will likely require its own full-time support vessel and ROV on call and available for other science when not needed for observatory support. A few other similar ROVs will be needed to service other observatories, depending on the number and complexity of those funded.

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**Eileen E. Dunn**


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| Organization: | Arizona State University |
| Address: | Department of Geology 1404 |
| City: | Tempe |
| State/Province: | AZ |
| Country: | USA |
| ZIP Code: | 85287-1404 |
| Email: | EEDunn@aol.com |


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1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used: Alvin

3. Workshop Questions: How do we set up a database of available sensors, sampling devices, or technologies currently being utilized by the science community for deep-sea research? What limits do these devices or technologies have, and where can complete information about them be obtained so that research moneys are not spent on duplicated efforts? How do we make the community more aware of, and provide access to, the newest industrial technologies? Are there thermal or chemical energy sources that could be harnessed and utilized for a power source for sensors and/or sampling devices at an active vent site to lessen the power burden on submergence platforms in order to extend bottom time?

4. Region of Interest: Juan de Fuca, N EPR, S EPR

5. Types of submergence systems anticipated for work/technology development: Laboratory vent simulation systems capable of producing an active hot vent environment for extended periods of time large enough for sensor or sampling device development/testing prior to ocean activity in order to minimize failure/cost and/or downtime at sea. Fiber optic sensors utilizing an intelligent controller that will " learn " from information received to optimize its activities with minimal outside assistance, if any, other than initial set-up that will withstand a hot vent environment for extended periods of time.


6. Abstract:
My research is limited by the lack of materials and technologies that will withstand long-

term the chemical, pressure, and temperature environment at an active hydrothermal vent. My industrial background makes me aware of technologies being utilized by industry that are more advanced than those being applied to submergence science at this point and I am interested in exploring ways of making those technologies more accessible to this community. Submergence science will need both short and long term sensors with the capability to sense various spectral, chemical, or biological activities. These sensors need to be intelligent, reliable, and easy to install or retrieve. There could be a sensor dedicated to event detection that powers up the sensor array when an event occurs. The sensor array information could be stored for download via a robotic vehicle. In the next decade, we need sensor array networks installed in vent fields capable of real time communication or memory storage that is easily exchanged and expandable. Autonomous robotic vehicles designed for repairing, exchanging sensors, as well as downloading information collected by the sensor array network could service these networks. These robotic vehicles could be "parked" near vent fields, close to potential activity sites. The parking dock could have a cabled buoy to the surface containing a solar powered battery-charging unit to power communication equipment and recharge the vehicle. The information collected by the network could then be transmitted to a ship or shore station.

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**James E. Eckman**


Organization: Office of Naval Research
Address: 800 North Quincy St.
City: Arlington
State/Province: VA
Country: USA
ZIP Code: 22217

Email: eckmanj@onr.navy.mil


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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: Alvin
Sea Cliff

3. Workshop Questions:

a. What are the main limitations (technological, pilot experience, access) to EXPERIMENTAL study of the most important biological, physical, geological and geo-chemical issues in deep-sea science?

b. What is the best investment of limited resources available to correct identified deficiencies in our capabilities to study deep-sea science?

4. Region of Interest: Southern California continental borderlands

5. Types of submergence systems anticipated for work/technology development: short-term needs require a capable manned (pilot & scientist(s)) submersible.

6. Abstract:
With respect to manned submersibles my experience over the last decade indicates that in addition to technological advancement, pilot training and experience are critical to successful completion of scientific operations. This is especially important when fine-scale maneuvering and dexterous operations are demanded in situ. My colleagues and I have found that the rate of scientific productivity grows exponentially with the experience of the submersible operator, and I suspect this is equally true for ROV operations.

I feel it is critical that the existing fleet of manned submersibles be sustained and their technological capabilities constantly upgraded. However, there will no doubt be continued transitions to conducting science using technologically capable robotic vehicles, which allow for more continuous operations. Engineering improvements of ROVs are probably key to the future of deep-sea science.

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**Bob Embley**

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|---|---|
| Organization: | Pacific Marine Environmental Lab, NOAA |
| Address: | 2115 S.E. OSU Dr., Hatfield Marine Science Center |
| City: | Newport |
| State/Province: | OR |
| Country: | U.S.A. |
| ZIP Code: | 97365-5258 |
| Email: | embley@pmel.noaa.gov |

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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: HOVs--
(1) ALVIN
(2) SEA CLIFF
(3) Johnson Sea Link
(4) Nekton
(5) SHINKAI 6500
(6) PISCES IV

ROVS--
(1) ROPOS
(2) ATV
(3) JASON

Also have been to sea with ABE
and am long-term user of deep-towed sidescans and camera systems.
Co-developed a deep-towed camera system for ridge crest mapping.

3. Workshop Questions: Deep-sea eruption processes
Tectonic, magmatic, and hydrothermal processes along oceanic transform fault zones
Ridge Crest seafloor observatories

4. Region of Interest: Eastern Pacific

5. Types of submergence systems anticipated for work/technology development:
ROVs and AUVs
(1) Development of advanced acoustical and optical imaging systems
(2) Development of AUV and other technology for autonomous event response
to events on deep seafloor

6. Abstract:

Some present limitations are:
(1) lack of high resolution and easily useable (mosickable) optical imaging systems deep ocean floor. The scale of many features we want to look at is above size of single frame digital cameras now used. Laser line scan is one possibility, perhaps mounted on an ROV, which could provide the power and stability needed. I think we could understand a lot more about volcanic processes if we could provide better context for observations and sampling within the limited light pool of an ROV or HOV crawling along the seafloor.
(2) A simple, easily useable 3D viewing system for ROV pilots to make sampling more efficient.
(3) High resolution navigation systems that will allow users to use multiple vehicles in the same area, perhaps at the same time.
(4) More robust systems for deep-ocean station keeping and heave compensation for ROVs.

In the next decade, I see the deep-sea community will be going more to using ROVs and AUVs with less (percentage-wise at least) use of HOVs.

I think NSF should to look ahead to develop a system to better utilize the best technology available. The current block-funding system, which makes it easy to use the WHOI assets under the national facility umbrella has worked well with ALVIN because of its unique status. It has worked less well with JASON; there is clearly more competition in this arena, and I would see this continuing in both the ROV and the AUV areas. WHOI is still clearly a world leader in deep submergence technology, and I'm not advocating compromising their engineering R & D in this area. However, in those occasions where it clearly makes sense to use an alternate system (e.g., availability, some built-in option not available on the WHOI asset, etc.), the user shouldn't have to deal with the perceived "penalty" of adding the system's operational costs onto the bottom line of the proposal.

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**Andrew Fisher**


| | |
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| Organization: | UCSC, Earth Sciences Dept. |
| Address: | 1156 High Street |
| City: | Santa Cruz |
| State/Province: | CA |
| Country: | USA |
| ZIP Code: | 95064 |
| Email: | afisher@es.ucsc.edu |


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1. Field of Expertise: Marine Geophysics
2. Submergence Platform(s) Used: Alvin, Nautile, Jason

3. Workshop Questions: How do seafloor hydrologic processes influence geological and biological systems, and how do these systems feed back to influence hydrologic properties

4. Region of Interest: ridge crests, flanks, accretionary systems

5. Types of submergence systems anticipated for work/technology development: manned and unmanned systems capable of: observatory establishment and servicing, heat flow measurements, running pump systems, downloading from data loggers, seafloor mapping, high-resolution seismic


6. Abstract:
The greatest limitations on understanding the dynamics of seafloor hydrogeologic processes, and sorting out the coupling between hydrogeology and magmatic, tectonic, and biological processes are (1) a lack of high-resolution, time-series data collected at a range of temporal and spatial scales, and (2) the difficulties associated with making measurements of hydrogeologic properties in general within vigorous, transient, flow systems. Submergence sciences can help to overcome these limitations during the next decade by focusing on the establishment of a small number of observatories where in-situ experiments can be run, and interdisciplinary data can be collected and accessed, and by working to keep platforms and technology readily available to scientists studying these problems.

There are several limitations with methods and tools available at present. For example, heat flow measurements require vertical emplacement of a stable probe in the seafloor. ROVs such as Jason are too light and unable to hold position for the necessary time, and all subs and ROVs have difficulty pushing the probe in straight up and down using only a manipulator. A hydraulic insertion frame has been used in the past to assist with probe emplacement, but pilots are often reluctant to use this device, which is large and heavy. As another example, if we are to run long-term hydrogeologic tests in seafloor boreholes, we will need to develop and deploy robust flow pumps capable of moving considerable volumes of fluid from over pressured or under pressured boreholes at controlled rates for months or years, and to measure and record rates of fluid flow. Another issue of importance for a wide range of submergence science is the need for real-time plotting of data and instrument locations within a GIS-like system, including absolute, meter-scale positioning, capable of incorporating input from a range of tools. Some scientists have created their own systems to handle these functions, but for the rest of us, it is daunting to consider building such a system from scratch.

I can imagine submergence science moving towards more capable ROVs in the future, but I'd guess that subs with people in them would still be needed for many complex functions. I hope that we can develop observatory systems, both autonomous and linked (by cable or satellite), that can respond to events in a way that is more rapid and efficient than sending out ships days or weeks later. My involvement in submergence science has been modest thus far, but I'd like to be more active in this area.

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## Chuck Fisher


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| Organization: | Pennsylvania State University |
| Address: | 208 Mueller lab. |
| City: | University Park |
| State/Province: | PA |
| Country: | USA |
| ZIP Code: | 16802 |
| Email: | cfisher@psu.edu |


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1. Field of Expertise: Hydrothermal Vent Biology

2. Submergence Platform(s) Used: Alvin
Nautile
Turtle
JSL I & II
Pisces II
ROPOS
JASON

3. Workshop Questions: I would prefer to discuss technical questions at this workshop

4. Region of Interest: The E. Pacific Rise, The Gulf of Mexico, And The JdFR

5. Types of submergence systems anticipated for work/technology development:
Sub and ROV now, AUV in the Future.
Anti-fouling camera's
chemical sensors
better sample collectors

6. Abstract:
The ecological aspects of my research have always been limited by to our ability to get the quality and quantity of samples we need. For that reason we have developed a variety of special devices for use on subs or ROVs. However, my budget and ability are considerably less than what should be applied to some of these efforts and there are a variety of types of devices/improvements that would be used by many scientists in our community.

One type would be collection devices for biologically relevant water samples in sufficient numbers for good characterization of habitat parameters. These need to be small volume and "pickled" in-situ for volatile species like sulfide. The right chemical sensor packages could alleviate this problem for some analyses. Over the past 15 years a variety of people have worked on different systems for measuring important chemicals in situ, and numerous biologists have benefited when they sailed and collaborated with them. If the time has come, incorporation of a chemical sensor package into the stock options for a deep submergence vehicle would be a major advance and would be utilized by many scientists.

Another type is collection devices designed for quantitative samples of communities. The Alvin Box cores are good for soft sediment, the JSL scoop (and ROPOS "packman") are pretty good in some situations, but that is all that is available to the community at this time. These collection devices should be designed in conjunction with transportation devices ("bioboxes") that allow maximum flexibility and replicate collections. Perhaps even designs that include secure transportation and loading into elevators on missions requiring multiple collection during a single dive or deployment of an ROV.

Another is better images, which can be used for quantification of faunal abundance or coverage. Higher quality imaging capability and better methods for determining scale in images are needed. The technology is clearly available for this goal, only the commitment (and $) is needed.

It seems that each of these are areas where improvement in our current capabilities would benefit the majority of biologists working in either vent or seep environments and

the first and third would benefit most biologists that use the facilities and many geologists or geochemists as well.

Over the past 20 years biologists have made giant strides in understanding the biology of the organisms that inhabit hydrothermal vents and cold seeps. Recently molecular tools are also making significant contributions to our understanding of these animals.

However, with only a relatively few exceptions, ecological studies have been limited to non-quantitative descriptive work. With the knowledge base currently in hand we are ready to undertake studies that address first order questions concerning the forces that structure these communities and test some hypotheses generated from the study of more accessible shallow water communities. Better tools will be one of the keys to making significant advances in our understanding of the ecology of the deep sea.

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**Daniel J. Fornari**


| | |
|---|---|
| Organization: | Woods Hole Oceanographic Institution |
| Address: | MS22 Woods Hole Rd. |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | dfornari@whoi.edu |


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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: Alvin
Sea Cliff
Turtle
ROV Jason
DSL-120 sonar
Argo I

3. Workshop Questions:

4. Region of Interest: E. Pacific, Atlantic, Indian Ocean

5. Types of submergence systems anticipated for work/technology development:
Alvin, ROV Jason, DSL-120 sonar, Argo 1

6. Abstract:
We need to develop a consistent program of federal facilities improvements and enhancements for deep submergence science that matches our advances in scientific understanding of seafloor processes, especially the temporal component of many volcanic and hydrothermal processes occurring in the deep ocean. We also need to advocate strongly for increased funding to make deep submergence science a focus element of national research funding, akin to ODP, in the next decade and beyond. All of the same scientific imperatives, and arguments regarding technological sophistication apply to a broad range of multidisciplinary deep ocean science as they do for ODP.

The mix of submersibles, ROVs, AUVs and mapping systems should provide the capabilities for nested surveys using multiple vehicles in sequentially staged field programs on the same cruise. The depth range of the combined assets should be in the 6000 m range to permit access to portions of active subducting margins.

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**Dudley Foster**


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| Title: | Operations and Engineering Manager, DSV Alvin |
| Organization: | Woods Hole Oceanographic Institution |
| Address: | MS 17 |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | dfoster@whoi.edu |


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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: DSV Alvin
DSL-120
Jason/Media

3. Workshop Questions: In what research areas does the science community think the future scientific emphasis will be?
What tools, tasks and instruments do they expect to need to conduct the future science needs?

4. Region of Interest: Where ever science has a need.

5. Types of submergence systems anticipated for work/technology development:
I expect the National Facility will want to be an active participant in the development of vehicles and tools to meet the future needs for research in all ocean environments. The hope and expectation is that this workshop will provide some outline of what areas of technology need to be addresses to meet the scientific needs.

6. Abstract:

(A) For manned vehicles, I see the following limitations:

- Limited depth capability
- Limited power availability
- Limited bottom work time in deeper sites

for unmanned systems I see the following limitations:

- Limited visual perspective
- Limit visual resolution
- Limited payloads
- Limited manipulator capability due to low vehicle mass
- Limited maneuverability due to tether constraints

(B) Desirable capabilities include:

- Access to deepest desired sites
- Remote access and monitoring on long term sites
- Initial system designs that allow long term service and maintenance of sites by either manned or unmanned vehicles.
- Improved AUV capability for site monitoring and survey work.

(C) Future of deep submergence:

- Increased remote monitoring and sensing of long term bottom stations with an emphasis on more cost effect means to accomplish the long term experiments.
- A reduction of emphasis on "traditional" ridge studies. More focus on monitoring and long term observations.
- More emphasis on margin studies, methane environments, and studies with more definable "social relevance."
- More work in new areas of study including trenches, margins, and global ridge areas that have had little or no study.
- More international collaboration and joint funding in areas of common interest.
- Increased activity related to life on other planetary bodies, particularly related to life detection, development and in-situ testing of instruments and systems for potential spacecraft mission applications.

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**Patricia Fryer**

Organization: SOEST/HIGP
Address: 2525 Correa Rd.
City: Honolulu, HI
State/Province: HI
Country: USA
ZIP Code: 96822
Email: pfryer@soest.hawaii.edu

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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: Alvin, Shinkai 6500, Jason/Medea, and smaller commercial ROVs

3. Workshop Questions: How does subduction influence structural deformation, geochemical cycling, seismicity, volcanism and biological activity at convergent margins.

4. Region of Interest: Western Pacific

5. Types of submergence systems anticipated for work/technology development: submersibles, ROVs and possibly AUVs

6. Abstract:
There is little doubt that the capabilities of existing deep submergence systems are being pushed to greater depths. The research that I am engaged in, however, continues to require depth capabilities that exceed those available with most existing submersibles and ROVs. Because I want to study features that extend to great depths, I would prefer to use an ROV (or AUV) to perform this work. Fro the sort of work I do, ROVs must be robust tools, capable of a variety of sampling techniques and sufficiently powered to perform adequately as a substitute for a deep submersible. With greater depth capability it would be possible to survey features in detail with side-scan imagery and various geochemical sensors, obtain geological and biological samples from well-defined settings, and deploy a variety of instruments on the deep sea floor to monitor geologic, hydrologic, biologic and geochemical processes in situ for both short- and long-term time series experiments.

It has become increasingly apparent over the past decade that the amount of work for submersible systems exceeds the number of tools available. The lack of availability of tools for time-series efforts and for operations in remote regions has become a problem that needs our attention. These problems will continue to escalate, as more effort is made toward the establishment of ocean-floor observatory sites in the next few decades. Servicing these sites and downloading data will require greater access to deep submergence systems. Scientists interested in work in both the deep ocean and in the near shore environments that use submersible systems must have access to both human-

occupied devices and ROV/AUV tools as needed. It will be a challenge to devise methods to provide for the research needs of this community.

Deep ocean science approaches a new millennium that will be characterized by cooperation among scientists of many different disciplines to grapple with the complex linkages between physical, chemical, biological, and geological processes occurring at and beneath the ocean floor throughout the world. This multidisciplinary approach in a response to unprecedented advances in understanding the complexities and interdependence of various phenomena that have been made possible through research using deep submergence vehicles over the past two decades. Marine scientists from all disciplines are forecasting that the next decade will see even greater linkage between oceanographic disciplines. They foresee a need to understand the temporal dimension of the processes being studied. Thus they will continue to use deep ocean submersibles and newly developed remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) to conducting time-series and observatory-based research in the deep ocean and at the seafloor. These approaches will enable marine scientists to achieve a greater understanding of the factors which influence global processes of climate change and geochemical mass balance, and to grapple with the intriguing problems of interrelated processes of crustal generation, evolution and transport of geochemical fluids in the crust and into the oceans, and origins and proliferation of life both on Earth and beyond.

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**Chris German**

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|---|---|
| Organization: | Southampton Oceanography Centre |
| Address: | Empress Dock |
| City: | Southampton |
| State/Province: | |
| Country: | UK |
| ZIP Code: | SO14 3ZH |
| Email: | cge@mail.soc.soton.ac.uk |

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1. Field of Expertise: Geochemistry

2. Submergence Platform(s) Used: Alvin
Jason
Shinkai 6500
Nautile

3. Workshop Questions: 1) Most effective way of conducting hydrothermal research in remote areas in the future? 2) How to establish capabilities required for deep-sea

observatories?

4. Region of Interest: Global but remote areas important.

5. Types of submergence systems anticipated for work/technology development: Increasingly ROVs and/or AUVs (e.g. to sample new vent-sites on E.Scotia Ridge, future discoveries on Arctic Ridges).

So: improved capabilities of ROVs & AUVs an issue. Also, development of in situ geochemical sensors & sampling gear.

6. Abstract:

a) Technological limitations:

Two themes underpin my research - a) understanding how venting is distributed around the world's oceans and b) understanding the fate of chemical tracers which are enriched in vent-fluids, once they have been erupted into the overlying water column: For global distribution studies some of the most important work remaining involves the search for, and preliminary seafloor investigation of, hydrothermal vent sites in remote sections of the global ridge crest away from major research ports. Examples include the Southern Ocean in general (e.g. southern Indian Ocean) and the "Arctic" (all points north of Iceland). These are not areas which can be considered ideal for manned submersible operations and so what is dearly needed is a robust and capable ROV with "fly-away" potential to operate from ships of opportunity. Requirement for such a vehicle is the ability to at least perform basic "first-cut" vent-field sampling: imaging, vent-fluids, biology etc.

For studying near-field processes, a key limitation is the ability to examine the geochemical processes active within a buoyant hydrothermal plume. Good capabilities have been developed for collecting end-member vent-fluids whilst surface ship operations have become adept at sampling neutrally buoyant plumes 100-300m overhead. What is still missing, however, is to get where the real geochemical action is: "in-between" within the first few tens of minutes post-eruption. That is where much of the net geochemical flux is determined. I recently built a simple prototype "Buoyant Plume Sampler", since used with both "Jason" and "Alvin", to prove the concept and the geochemical interest. What is needed now are i) the development of more sophisticated (multiple) samplers and ii) vehicles able to "hover" to collect data/samples systematically within a buoyant plume.

b) Capabilities that should be generally available?

The biggest UK problem, until now, has been to have any capability at all! I am currently part of a 3-PI bid from the SOC, however, to acquire a new ROV (in essence a "Jason-II" duplicate) for the UK marine science community. Our basic capabilities/ requirements (beyond the vehicle itself) will be: seafloor image acquisition and centralised/standardised basic post-acquisition support, to include navigation and scale/orientation determinations for quantification of features observed (structures as well as organisms). Geochemical sampling capabilities (my interests) would include: fluid samplers for all of inorganics, organics, gases; diffuse flow samplers (Medusa +/- Manifold approaches - or better?); plume sampling equipment (including dissolved vs. particulate separation); "templates" for emplacing in situ experiments; new generation chemical sensors as they come on-line.

c) Research in the next decade.

I see two areas for obvious development. The first is the move toward seafloor observatories. There is scope (finally) to gather international enthusiasm in this direction because communication/power issues are becoming tractable and, perhaps more importantly, because of the development of new instruments that can do more than just a basic OBS and CTD measurements. Key areas will be - sensor development (what to install) and ROV capability (how to install it).

The second area I foresee is in AUV development. This will be pertinent not just to Observatories (routine operations) but also to exploration work in remote areas of the global MOR. Over the next ten years this area of research may also attract the attention (and tax-dollars) of those agencies interested in searching for hydrothermal vents on Europa. (Europa Orbiter will confirmed whether oceans exist ca. 2006; lander launch = 2013). It is timely, therefore, to start thinking about how to develop AUV capability - particularly in terms of control, maneuverability and development of a relevant/pertinent payload.

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**James Gill**


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| Organization: | University of California, Santa Cruz |
| Address: | Social Sciences 2, Room 150 |
| City: | Santa Cruz |
| State/Province: | CA |
| Country: | USA |
| ZIP Code: | 95064 |
| Email: | jgill@es.ucsc.edu |


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1. Field of Expertise: Petrology
2. Submergence Platform(s) Used: ALVIN
3. Workshop Questions: Island arc seafloor volcanism
4. Region of Interest: Izu-Mariana
5. Types of submergence systems anticipated for work/technology development: unfocused

6. Abstract:
DESCEND Abstract

I wish to attend as a former and potential user of submersible technology, and as a science administrator wanting to be well informed about a field that is strategically important to my institutions. (I am the Research Vice Chancellor at UCSC, and Chair of the Monterey Bay Crescent Ocean Research Consortium, which includes several institutions with relevant interests and capabilities.)

(a) Current technological limitations on "my" science. Synoptic geochemical and geophysical measurements are essential to the development and testing of hypotheses in the earth sciences. Consequently, the design, deployment, serving, and interrogation of seafloor and mid-water observatories are essential objectives. My personal interests center on seafloor and seamount volcanism. Scientific requirements include rapid response capability, and the ability to sample volcanic rocks (lavas and volcaniclastics) remotely but with good visual control and high spatial resolution. Scientific opportunities created thereby include temporal information and process inference about volcano construction leading better understanding of the most common but least studied volcanic processes on the planet.

(b) New capabilities. I would like to see more standardized ROVs capable of deployment from more vessels of convenience, and that can be remotely interrogated, thereby enabling work in more geographic areas. For example, the island arc system chosen by the international scientific community for collective effort (the Izu-Mariana) is difficult to access by non-Japanese scientists for technological reasons.

(c) New directions. I would like to see more integrated and long-term studies of a few specific areas of the seafloor, chosen to illustrate processes that are critical to the evolution of the planet -- e.g., seafloor observatories and transects. Submersible technologies should be developed to serve the scientific needs of such focused activities. One such activity is volcano evolution, from seamount formation to caldera development, at convergent plate boundaries. In situ geophysical and geochemical monitoring, and precise geological sampling for land-based study, are essential submersible requirements.

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**Chris Goldfinger**

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| Organization: | Oregon State University |
| Address: | Ocean Admin Bldg 104 |
| City: | Corvallis |
| State/Province: | OR |
| Country: | USA |
| ZIP Code: | 97331 |
| Email: | gold@oce.orst.edu |


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1. Field of Expertise: Marine Geophysics

2. Submergence Platform(s) Used: ALVIN, SEACLIFF, TURTLE, ATV DELTA, ROPOS, and SCORPIO

Sidescan sonars: SeaMARC 1A, AMS-60, AMS-150, Klein.

3. Workshop Questions: How can we make major advances in seafloor sampling technology?

4. Region of Interest: I presently work mostly in Cascadia.

5. Types of submergence systems anticipated for work/technology development:
Vehicles I will use:
Deep-towed Sonars
ALVIN
ROPOS
Technology development:
Seafloor drilling
Improved deep-towed sonars, real-time processing.
Add-on tools for sonars such as multichannel streamers etc.

6. Abstract:
Seafloor drilling: Combination of ODP and ROV technology

Technology for subsurface seafloor sampling over the past few decades has consisted primarily of two methodologies: wire-line gravity or piston coring and DSDP/ODP drilling. Coring techniques have improved over the years but present capabilities remain limited. Long coring techniques in the US can presently recover cores to about 15m in hemipelagic sediments, limited by wire strength on UNOLS vessels. Four sets of piston coring gear have been lost in the past 3 years from UNOLS vessels due to this limit (two by WHOI and two by OSU). The longest conventional piston core ever recovered is 55m, recovered recently (July 1998) aboard a French vessel (Marion Dufresne). ODP hydraulic piston coring is effective at recovering shallow sediments (typically to 150-200 m), and ODP is capable of deep rotary drilling, but the cost, lead-time, and effort involved in an ODP leg is formidable. Not all worthy projects can be accommodated by ODP. Thus, there is a gap in sampling capabilities desired by marine scientists who wish to sample more than 10-15 meters of sediment, but cannot mount an ODP drilling leg for each desired sample.

Filling this gap is a class of seafloor drills, the latest of which is a new device called the Portable Remotely Operated Drill (PROD). This device, described further below, will use rotary drilling or hydraulic piston coring from a sea-floor lander to collect cores up to 150 m in length. PROD can be deployed from a ship of opportunity, including the larger UNOLS vessels, at a small fraction of the cost of the ODP drill ship. This is new technology, which offers a quantum leap in our abilities to sample the sea floor with great

cost savings relative to other methods. Not only is PROD a drill, but to some degree it is a powerful ROV with a range of capabilities different from those we are used to.

The PROD drill is the result of 15 years of development and prototyping. This technology is now reaching a state of maturity that makes it useful for a variety of marine geologic programs. It is a sea-floor lander system, tethered to the ship, which can drill or core up to 150 m into the sea floor. A prototype for the remote corer was built by Williamson & Assoc. in 1990 with funding from NSF and the Washington Sea Grant Program (Johnson, 1991). This 3 m corer was deployable to depths of 5000 m, and utilized diamond bit drilling techniques to core igneous substrate. This tool was successfully deployed on the Juan de Fuca Ridge, on the EPR, and off Hawaii. Although successful, the drill was lost when the umbilical fouled on an ODP re-entry cone on the seafloor.

In 1995, Williamson & Assoc. constructed a larger system for the Japanese government called the Benthic Multi-Coring System (BMS). The BMS expanded on its predecessor, carrying enough drill rod, core barrel and casing to penetrate 30 m into the seafloor. The new system incorporates computer controls that allow semi-automated build up and breakdown of the drill string as sampling progresses. This system has now been tested and is installed aboard the Japanese research vessel Hakurei Maru No. 2, operated by the Metal Mining Agency of Japan (MMAJ). Cores have been taken on a basalt flow in 1200 m of water off Atami, Japan (Petters and Asakawa, 1997), and drilling operations have continued. The BMS drill is now (summer of 1999) being used off Okinawa.

The first-generation PROD drill improves on the BMS by increasing penetration to 50-150 m (depending on casing needs) and increasing core diameter to about 2 inches. Benthic GeoTech Ltd., the commercial/academic consortium that has built the PROD system, has recently constructed a hydraulic piston corer (HPC) for the PROD system that will allow much improved coring of soft sediments. The addition of HPC capability makes it possible to consider PROD for use in paleoceanographic work, and other disciplines requiring complete recovery of soft sediments in longer sections than available with conventional coring techniques.

The new technology corer potentially solves several problems inherent in both traditional coring methods and drilling from a surface ship. Gravity, piston, and vibra corers can only be used in relatively soft substrate and are limited by the length of a single core barrel. The PROD drill eliminates this problem by applying conventional rod drilling techniques used on land to the marine environment. With this technology, drill pipe is added sequentially in 2m lengths, and coring proceeds sequentially in 2m increments. The primary innovation with PROD is the ability to rack drill pipe and rods, and recovered cores, in twin "carousels" on a sea-floor lander. In addition to penetrating the sea floor deeper than traditional coring methods, PROD eliminates a problem inherent in ODP style drilling, that of ship heave, which makes for variable bit pressure, impedes core recovery, and disturbs the recovered sediment. ODP has spent millions of dollars on

heave compensation, and although partially successful, shipboard heave compensation will never be perfect. The PROD lands on the sea floor, and is decoupled from the ship. Thus, it is not influenced by heave, and can apply pressure as needed while being monitored in real-time by the drilling operator. The likely result is superb recovery of essentially pristine sediments, even in difficult "hard/soft" alternating lithologies.
Seafloor drilling not only fills a gap in present technology, but also opens the door to new types of investigations. Seafloor drills can case holes, insert and remove tools and instruments, suck or push fluids into holes, re-enter holes, and other things that have yet to be devised, at a fraction of the cost of the drill ship. It seems likely that such a tool will have such wide utility that it will become part of the US pool of deep submergence tools at some time in the future.

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## G. Ross Heath


| | |
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| Organization: | University of Washington |
| Address: | Box 357940 |
| City: | Seattle |
| State/Province: | WA |
| Country: | USA |
| ZIP Code: | 98195-7940 |
| Email: | rheath@u.washington.edu |


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1. Field of Expertise: Marine Geology
2. Submergence Platform(s) Used: ROVs Ventana, Tiburon, ROPOS

3. Workshop Questions: The use of AUVs and ROVs to install, service, remove and augment long time series experiments on the sea floor supported either by cable or powered buoys

4. Region of Interest: Northeast Pacific (primarily)

5. Types of submergence systems anticipated for work/technology development:
ROVs to service experiments on cable systems
AUVs to augment cabled nodes and provide rapid response capability in areas such as MORs

6. Abstract:
a) Ability to dock and operate AUVs for extended periods at cabled nodes which can provide power and download data

b) ROVs, both sophisticated (c.f. Tiburon) and "workhorse" (c.f. off-the-shelf oilfield types), as well as Rovers

c) More reliable ROVs (less bailing wire and duct tape) and less expensive manned submersibles

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**Thomas A. Hickson**


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|---|---|
| Organization: | St. Anthony Falls Laboratory |
| Address: | University of Minnesota |
| City: | Minneapolis |
| State/Province: | MN |
| Country: | U.S.A. |
| ZIP Code: | 55414 |
| Email: | hicks007@tc.umn.edu |


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1. Field of Expertise: Marine Geology
2. Submergence Platform(s) Used: None

3. Workshop Questions: For a given submarine drainage area (Monterey Canyon, for example), what is the magnitude and frequency of sediment-gravity flow events?

What are near-bed sediment concentrations like for a variety of sediment-gravity flows, turbidity currents in particular?

4. Region of Interest: California coastal margin

5. Types of submergence systems anticipated for work/technology development:
ROV
Calibrated ultrasound or laser-Doppler systems for near real-time estimation of sediment concentration profiles in active sediment-gravity flows.
Geophones or other technology that might allow us to 'listen' for the signature of a sediment-gravity flow event.

6. Abstract:

In my research on sediment-gravity flow sedimentation mechanics, one question in particular continues to come up: what are the concentration profiles of actual sediment-gravity flows in nature and how do their concentration profiles vary? Laboratory experiments provide some insight into this matter, but the issue of scaling seems to prevent, or at least call into question, the applicability of scale models to real world flows and their deposits. The technology, at present, does not appear to exist to measure the concentration profiles of a turbidity current or other sediment-gravity flow, particularly in the region of the flow nearest the bed. Tethers have been used to measure

concentration profiles well above the bed, but the relationship between these data and the near-bed concentration is speculative at best, yet it is the near-bed concentration that is most responsible for the deposit that the flow leaves behind. For sedimentologists to make informed and appropriate interpretations of deep-water sequences, the current models of sediment-gravity flow deposition must be calibrated by observations of modern turbidity currents, debris flows, and other exotic flow types that include measurements of concentration, velocity, and acceleration.

In general, it seems that we need several capabilities if we are to obtain quality data on sediment-gravity flow and other seafloor processes: (1) efficient data telemetry from or large data storage devices on seafloor instrumentation packages; (2) ultrasonic, laser-Doppler, or other devices for the measurement of sediment concentration profiles; (3) velocimeters/accelerometers to measure the near-bed velocity and accelerations of extremely energetic flows; (4) instrumentation packages that can withstand extended periods in the submarine environment (on the order of years or even decades) that are capable of telemetering data to shore-based facilities; and (5) geophones or other instrumentation that allow us to 'listen' to sediment-gravity flows and make estimates of the magnitude/frequency relationships for a range of flow events. Over the next decade I would expect that most of these capabilities would be met. In addition, I imagine that we will see improvements in ROV technology that allow cheaper, deeper access to submarine sites for more scientists.

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**Ray Highsmith**


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| Title: | Director, West Coast & Polar Regions Undersea Research Center |
| Organization: | University of Alaska Fairbanks |
| Address: | School of Fisheries & Ocean Sciences |
| City: | Fairbanks |
| State/Province: | Alaska |
| Country: | USA |
| ZIP Code: | 99775-7220 |
| Email: | highsmith@ims.alaska.edu |


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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: We have chartered: ALVIN, ATV, ROPOS, DELTA, JASON, SEA CLIFF, TURTLE

3. Workshop Questions: I am primarily an observer from a funding agency. A major goal is to find out what the science community feels is high priority undersea research and

what vehicles and tools are needed to carry out that research.

4. Region of Interest: West Coast and Polar Regions

5. Types of submergence systems anticipated for work/technology development:
ROVs, AUVs, manned submersibles, imaging and mapping systems, telepresence capability, and seafloor observatories

6. Abstract:
From the standpoint of someone who funds research and charters vehicles to carryout the research:

a) Vehicle availability is limited, costs are high, competitive scheduling is often a problem, improved undersea mapping and imaging systems are needed

b) Would like to see more highly capable, deepwater ROVs available. Also, an approx. 9000 m ROV for work in such places as the Aleutian Trench. Improved AUV capability.

c) Increased use of ROVs, AUVs and development of seafloor observing systems. Improved instrumentation. Long-term studies at sites.

As we receive proposals for a broad range of research off the West Coast and in Polar Regions, I would prefer to be able to move between sessions.

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**Susan E. Humphris**

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| Organization: | Woods Hole Oceanographic Institution |
| Address: | Clark S. 285 |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | shumphris@whoi.edu |


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1. Field of Expertise: Geochemistry
2. Submergence Platform(s) Used: DSL-120, ARGO II, Jason/Medea, and Alvin

3. Workshop Questions: 1) What is the best way to integrate deep submergence assets to optimize finding new hydrothermal systems and then imaging and sampling them?
2) What are the roles that ROVs and AUVs could/should play in observatory science?

4. Region of Interest: Global mid-ocean ridges
5. Types of submergence systems anticipated for work/technology development:
My main interest is in assessing the extent of hydrothermal alteration of the oceanic lithosphere and the resulting chemical exchanges between rocks and seawater. This requires knowledge of (i) the volcanic and tectonic controls on the distribution and nature

of hydrothermal activity so that their abundance can be predicted; and (ii) the kind of rocks altered and the nature of the alteration process. In order to address (i), I need to use nested survey strategies to find and describe the geologic and tectonic settings of hydrothermal vent sites along the mid-ocean ridges. This requires acoustic and photographic imaging at large scales as well as detailed work to describe the style of hydrothermal alteration. I envisage various combinations of DSL-120. ARGO-II, ROVs and AUVs for such a study. In order to address (ii), I need to be able to pick up many rocks that are well located. This requires the submersible, although ROVs could be used if they had better payload or better elevator capabilities.

6. Abstract:

The demand at present for deep submergence equipment often results in long waits before a field program can be conducted. Hence, the number of available suites of vehicles needs to be increased. Available vehicles should include towed imaging systems, at least one submersible, and several ROVs. In addition, AUVs should be developed that are sufficiently inexpensive that they can be used extensively for mapping and sensor data collection globally.

The key to successful operations is excellent navigation, so state-of-the-art navigation systems are absolutely critical to every deep submergence cruise. Improvements or changes in navigational techniques are needed to deal with problems, such as acoustic shadowing, watch circles of tethered transponders, etc.

The developments for submersibles that should be considered include:

a) More power and better propulsion to allow longer bottom times and greater transit distances;
b) state-of-the-art imaging systems;
c) better (more common?) visibility so that the scientist can see where the pilot is collecting the samples;
d) enhanced sensitivity of the manipulator in order to be able to pick up samples ranging from "fragile" to very hard (this also applies to ROVs).

There are several important issues in the further development of ROVs:
a) they need a greater payload and the ability to pick up samples larger than can currently be managed;
b) the tether lengths need to be increased so that there is a larger radius of operation without having to move the ship;
c) the elevator used for transport of equipment and samples to and from the seafloor when conducting ROV operations needs to be improved, both in terms of ease and efficiency of ROV-elevator interactions and in better locating the elevator near the site of interest;
d) 3-dimensional viewing of the seafloor would be extremely helpful in terms of understanding the geologic context of a particular site, and in high-resolution and spatially controlled sampling of specific features.

AUVs need to be developed to reliably carry out seafloor mapping, data collection using attached sensors, and also data collection from, and servicing of, seafloor and downhole instrumentation.

In the next decade, deep submergence science needs to develop the flexibility to serve exploratory science as well as be an integral part of seafloor observatories, both in terms of collecting data, and servicing seafloor and downhole instrumentation. This will require significant expansion in our capabilities, particularly of ROVs and AUVs, in order that the fieldwork in different geographic areas can proceed at the same time as site-specific observatory work.

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**S. Kim Juniper**


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|---|---|
| Organization: | Université du Québec à Montréal |
| Address: | C.P. 8888, Succursale Centre-Ville |
| City: | Montréal |
| State/Province: | Québec |
| Country: | Canada |
| ZIP Code: | H3C 3P8 |
| Email: | juniper.kim@uqam.ca |


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1. Field of Expertise: Hydrothermal Vent Biology

2. Submergence Platform(s) Used: Alvin, Nautile, Pisces IV, ROPOS, Jason

3. Workshop Questions: - Fine-scale spatial relationships in areas of irregular topography - Centimetre to millimetre scale thermo-chemical gradients in the hydrothermal vent environment

4. Region of Interest: Juan de Fuca Ridge

5. Types of submergence systems anticipated for work/technology development: ROVs, manned subs. Interested in high-resolution seafloor navigation and fine scale manipulation technologies

6. Abstract:

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**Miriam Kastner**


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|---|---|
| Organization: | Scripps Institution of Oceanography UCSD |
| Address: | 9500 Gilman Dr. 0212 |
| City: | La Jolla |

State/Province: CA
Country: USA
ZIP Code: 92093-0212
Email: mkastner@ucsd.edu

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1. Field of Expertise: Geochemistry
2. Submergence Platform(s) Used: Alvin, Nautile, and MBARI's ROV

3. Workshop Questions: Future availability of platform(s) for shallower and deeper water gas hydrate and subduction zone related research, especially for long and short range in situ experiments and monitoring of processes and kinetics.

4. Region of Interest: Mostly NE Pacific & near Aleutians; off Peru

5. Types of submergence systems anticipated for work/technology development: Like Alvin or ROVs with depth range from 500 to >6,000 m. Interested in easy access to in situ geochemical and geohydrological short and long-range monitoring systems, and in situ experiments and analyses of rates of processes that may affect global warming and ocean chemistry.

6. Abstract:
In. U.S.A.
* Alvin depth and maximum bottom duration are limiting. Greater depth range and longer bottom time would be most helpful.
* Accessibility of one submersible is extremely limiting, long pre-planning and waiting are necessary; impossible to plan experiments that need frequent visits in a specific area.
* I see submergence science going in the direction of greater versatility and geographic distribution. This is essential for visits to observatories and for studying and monitoring non-steady-state processes.

I would particularly concentrate on:
(1) in situ kinetic geochemical processes of methane hydrate formation and dissociation in margin slopes at a range of water depths, monitor the impact on water column chemistry and loss of remaining methane to atmosphere.
(2) On the global importance of fluid seepages in margins, the associated geochemical fluxes, and contributions to key geochemical cycles. Directly related to this objective is the need to improve assessments of fluids from continent into ocean and interactions.
(3) On the role of fluids in subduction zone processes; for example, to monitor fluid chemistry and fluxes through major thrust faults zones and vicinity and during an earthquake cycle.

**William J. Kirkwood**

Title: Associate Director of Engineering
Organization: Monterey Bay Aquarium research Institute
Address: 7700 Sandholdt Road
City: Moss Landing
State/Province: California
Country: USA
ZIP Code: 93950
Email: kiwi@mbari.org

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1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used: ROV Ventana
ROV Tiburon
ROV Jason
ROV Phantom
AUV Draper Labs
AUV Odyssey II
Other - military applications

3. Workshop Questions: What are the anticipated science directions and goals for the next generation of platforms? What new places are of interest and why?

4. Region of Interest: Pacific Rim

5. Types of submergence systems anticipated for work/technology development:
My interests are in telepresence and temporal expansion for science during use of submerged observational platforms. What are the real-time monitoring and requirements for an active platform capability allowing science to alter mission profiles and parameters as observations are occurring? How can technology best support science experiments that wish change criteria during a given time sequence without platform recovery?
Proper application of multi-platform coordinated missions for science to expand spacial measurements on a given cruise or for a particular experiment.

6. Abstract:

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**Martin Kleinrock**

Organization: Vanderbilt University
Address: Box 1805 Station B

City: Nashville
State/Province: TN
Country: USA
ZIP Code: 37235

Email: kleinrock@vanderbilt.edu

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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: Alvin, Jason, DSL-120, Argo-II, Deep-Tow, Various Camera sleds.

3. Workshop Questions: My primary focus is ridge processes and microplate tectonics. In addition to the passive and convergent margins, we must include transform margins.

4. Region of Interest: EPR, MAR, Active margins

5. Types of submergence systems anticipated for work/technology development: submersibles, AUVs, ROVs, near-bottom sidescan with good bathymetry

6. Abstract:

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**Val Klump**

Organization: U WI-Milwaukee Great Lakes WATER Institute
Address: 600 E. Greenfield Ave
City: Milwaukee
State/Province: WI
Country: USA
ZIP Code: 53204

Email: vklump@uwm.edu

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1. Field of Expertise: Geochemistry

2. Submergence Platform(s) Used: Johnson Sea Link II, Pices (Russian), ROVs, benthic lander

3. Workshop Questions: temporal dynamics of the benthic boundary layer in coastal systems; in situ monitoring of hydrothermal venting activity; exploration of large lake

systems

4. Region of Interest: Great Lakes; Large Lakes of the world; coastal mar

5. Types of submergence systems anticipated for work/technology development:
Primarily ROVs; low cost AUVs; and intelligent in situ instrumentation for real time and near real time data collection and high resolution time series; micro-sensor technologies; telemetry technology

6. Abstract:

Submergence science in lacustrine (freshwater) environments.

One of the major gaps in the current understanding of coastal systems is in the realm of short term, mesoscale physical/biological dynamics. The Great Lakes, for example, are characterized largely by their coastal nature and the biological, chemical and geological interactions occurring at and within coastal fronts, boundaries and interfaces. Processes like vertical and horizontal mixing, riverine inflow, alongshore transport by coastal jets and squirts, and sediment resuspension are often dominated by episodic events induced by wind stress and runoff (storm events) within the natural oscillation of seasonality. In the past researchers have been restricted to point-in-time sampling via surface vessels. Severe weather often is the triggering mechanism and driving force for many of these processes, yet, these are also the conditions that preclude operations of small coastal research vessels. To extend our understanding of coastal dynamics and begin to develop long time series data sets with high temporal resolution is a major challenge for Great Lakes and coastal research science. Long-term data sets may allow us to differentiate variance from true ecological change. The technology which can allow us to begin to fill this gap is varied, e.g. in situ instrumentation with high temporal measurement frequency, remote telemetry capabilities, either via hard wire (e.g. fiber optic) or cellular telephone links; a variety of measurement capabilities, including in situ biomonitoring; and a variety of deployment strategies, including AUVs, in situ monitoring station arrays and intelligent networks. The efficiencies and advantages of these technologies include: reduced man-power requirements, real time or near real time data collection and display, high frequency collection and observation. The availability of high-resolution time series data will usher in a new era in Great Lakes science. Within the next 2 decades, the Great Lakes will become "instrumented ecosystems" -- acoustic hydrophone networks that track fish and zooplankton populations for improved conservation and management; acoustic Doppler current profilers that map the 3-dimensional current structure of the lake and link to satellite images of surface current structure alerting intakes around the shore of sediment-laden plumes headed their way; in situ chemical/physical
analyzers, optical systems and biomonitoring systems using live organisms to track conditions with increasing sensitivity in areas like critical spawning habitats, for example, charting the abundance of zooplankton forage for highly susceptible larval fish, giving fisheries biologists early signs of recruitment strength, etc. In addition, the impact of climate change on the Great Lakes is currently subject to considerable speculation. Long term trends in localized and system-wide temperature fields, seasonal transitions, and ice cover, etc. are susceptible to subtle changes with significant impacts.

In addition, large lakes represent a unique set of ecologically and geographically diverse systems that are largely unexplored, including, in addition to the Laurentian Great Lakes, some of the oldest intact freshwater ecosystems in the world -- Lake Victoria and the rift valley lakes of east Africa (Tanganyika, Malawi), Lake Baikal (Siberia). With manned systems generally difficult and expensive to mobilize to remote areas, the portability and flexibility of ROVs, AUVs and instrument packages with state-of-the-art observational and experimental capabilities would be extremely useful for exploration and research. While relatively shallow compared to the oceans, these systems do reach depths of ~1700
meters in the case of L. Baikal.

Our lab has used both manned submersibles and remotely operated vehicles in large lake systems. In the last several years we have used ROVs extensively. This research has included: the exploration and sampling of sublacustrine hydrothermal vent systems in the Yellowstone caldera (Yellowstone Lake); studies of benthic biogeochemistry in large lake systems, including in situ studies of chemical sediment-water exchange using benthic flux chambers, micro-electrode profilers and sediment coring; and studies of particle dynamics in coastal plumes using in situ sampling techniques for short lived radionuclide particle tracers (Th-224, Be-7, Th-229, etc.). Deployments have been carried out both aboard ship during the open water season and through the ice in winter. Limitations on sampling are dictated by manipulation capabilities, payload, tool packages and sensor technology. Improvements in bottom topography (multi-beam sonar), precision navigation, and dynamic positioning would also be a great help.

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**Lisa A. Levin**

| | |
|---|---|
| Organization: | Scripps Institution of Oceanography |
| Address: | 9500 Gilman Dr. |
| City: | La Jolla |
| State/Province: | California |
| Country: | USA |
| ZIP Code: | 92093-0218 |
| Email: | llevin@ucsd.edu |


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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: ALVIN, SeaLink, Delta, Pisces, Sea Cliff, Scorpio, and Phantom

3. Workshop Questions: What improvements can be made in deep submergence sampling and manipulative capabilities?

Can extended bottom time be achieved for manned submersibles working deep (4000-6000 m)?

4. Region of Interest: N. Pacific, S. Pacific, and Indian Ocean

5. Types of submergence systems anticipated for work/technology development: Submersibles, ROVs - sediment-sampling capabilities.

6. Abstract:
I will forward this at a later time. (Right now I'm between cruises and workshops).

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**Don Liberatore**


| | |
|---|---|
| Title: | Chief Submersible Pilot & Manager, Undersea Vehicles |
| Organization: | Harbor Branch Oceanographic Institution, Inc. |
| Address: | 5600 U.S. 1 North |
| City: | Fort Pierce |
| State/Province: | Florida |
| Country: | USA |
| ZIP Code: | 34946 |
| Email: | liberatore@hboi.edu |


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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: Johnson-Sea-Links I & II, Research Submersible Clelia (PC1204), Hysub 40, HBOI Rescue ROV

3. Workshop Questions: How can currently available shallow water (i.e., less than 1500 m) submergence technology be better utilized by the scientific community?

4. Region of Interest: "shallow"(i.e., less than 1500 m) worldwide

5. Types of submergence systems anticipated for work/technology development: Manned submersible systems with benthic collection platforms, adapted for collection and transport of organisms from extreme environments (e.g., high pressure, low temperature).

6. Abstract:
Capabilities for UNOLS supported submergence science should include access to vehicles and platforms for research at all depth zones. Advancements in submergence science in the next decade should be a coordinated and complementary approach to

addressing questions not only related to physical and geochemical processes, but also to the plants, animals, and microbes (both benthic and pelagic) that are affected by and which have an effect on those physical and geochemical processes. Enhancements of manned submersibles, ROVs, and AUVs should be complementary to developments in remote platforms and sensing systems.

Technological limitations of the platforms I currently use are related to the collection and maintenance of organisms from extreme environments. Development of tools for more precise collection of benthic invertebrates, sensors for monitoring physiological processes in situ, and in situ preparation of samples for molecular and cellular biology would enhance the research I currently conduct on deep water benthic invertebrate models to investigate fundamental processes in cellular and molecular biology.

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**Dave Lovalvo**


| | |
|---|---|
| Title: | President |
| Organization: | Eastern Oceanics |
| Address: | 25 Limekiln Road |
| City: | West Redding |
| State/Province: | CT |
| Country: | USA |
| ZIP Code: | 06896 |
| Phone Number: | (203) 938-9902 |
| Email: | eoceanics@compuserve.com |


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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: Alvin
Jason
Pisces
Oceanic Explorer
Hydrolab
Minirovers
Phantoms

3. Workshop Questions: ROV capabilities needed by the Science comunity1

4. Region of Interest: Various

5. Types of submergence systems anticipated for work/technology development:

6. Abstract:

**John Lupton**


| | |
|---|---|
| Organization: | NOAA/PMEL |
| Address: | Hatfield Marine Science Center |
| City: | Newport |
| State/Province: | OR |
| Country: | USA |
| ZIP Code: | 97365 |
| Email: | lupton@pmel.noaa.gov |


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1. Field of Expertise: Geochemistry

2. Submergence Platform(s) Used: Alvin, Shinkai 6500, Pisces, Sea Cliff, Navy's ATV, ROPOS

3. Workshop Questions: pro and cons of ROVs vs. manned submersibles, development of new technologies for seafloor sampling. Future use of AUVs

4. Region of Interest: Mid-ocean ridges, mainly in Pacific Ocean

5. Types of submergence systems anticipated for work/technology development: both ROVs and manned submersibles, possibly AUVs. Interested in development of technologies for vent fluid and hydrothermal plume sampling


6. Abstract:
The principal technological limitations in the use of submersibles and ROVs in my research include: a) limitations in the ability to collect reliable fluid samples on the seafloor, especially using ROVs, and b) the absence of any capability for seafloor observations and sample collections in a rapid response mode. The problem of collection of fluid samples is improving slowly, mainly through development of new sampling systems by scientists working in conjunction with submersible engineers. However, currently very little capability exists for rapid response observations on the seafloor. For example, one scientific problem that could be solved by rapid response observations is the question of how hydrothermal event plumes or megaplumes are formed. These huge hydrothermal plumes, which have been observed in the water column immediately after seafloor eruptions, are assumed to be generated by the rapid release of a large volume of hot water. However, it is still being hotly debated whether they are formed as a direct result of a seafloor lava flow, or by sudden release of fluid contained in a subsurface crustal reservoir. The use of the SOSUS submarine hydrophones has provided the capability to detect volcanic/hydrothermal events on the mid-ocean ridge system in real time. The rapid deployment of an ROV or AUV immediately after such an event is detected would probably allow the direct observation of megaplumes as they

are being formed.

Capabilities which should be generally available for submergence science include high quality video in real time, precise navigation, the ability to collect a wide variety of samples (biological, fluid, rock, etc.) and convey them to the surface, and the ability to make a variety of measurements such as temperature, acoustical measurements, etc. In general, the ideal submersible platform should have the versatility to accommodate a wide variety of scientific instrumentation and the payload to use it on the seafloor.

For the future, the trend seems to be toward increasing use of ROVs rather than manned submersibles. For my science, the most serious drawback of ROVs seems to be one of limited space and payload and therefore limited sample collection capability. However, this limitation is improving slowly through the use of elevators and the development of new, compact sampling devices. The continued development of autonomous or untethered vehicles is also very exciting, since these are the platforms that are likely to be the most useful for rapid response observations on the seafloor and in the water-column.

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**George W. Luther, III**

Organization: University of Delaware
Address: College of Marine Studies
City: Lewes
State/Province: DE
Country: USA
ZIP Code: 19958
Email: luther@udel.edu

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1. Field of Expertise: Ocean Chemistry

2. Submergence Platform(s) Used: DSV Alvin Eastern Oceanics' ROV

3. Workshop Questions: Interaction of chemistry with biology - including origins of life and life in extreme environments

4. Region of Interest: N EPR, S EPR, Guaymas basin, Juan de Fuca

5. Types of submergence systems anticipated for work/technology development: submersibles, ROV, AUV
development of analytical tools that can be deployed at a site for short term and long term monitoring and which can be left unattended

6. Abstract:
A) current technological limitations

For short term and long-term continuous deployment of analytical equipment, we need to find ways to do real time monitoring and downloading of data if we are to react to subsurface events that can occur. Telemetry could be used for changing an instrument's settings to collect data and to transmit the data to a ship or land based laboratory. Having multiple types of one chemical analysis system would allow information to be collected at one site while another system could be used in survey mode. The cost of chemical analyzers can be high when multiple chemical species are being measured, but this is exactly what is needed in many environments to understand geochemical and biological processes. The speciation of an element is an important indicator of whether that element is essential to different life forms. Electrochemical methods have been underutilized to date.

A major problem in analytical equipment design is incorporating in one device the ability to measure biological, chemical and physical data, which needs to be incorporated with video displays of the environment.

B) Capabilities available for submergence science

Integrating in situ biological, physical and chemical analyses/data to better understand biological and biochemical processes is necessary. There has not been an extensive literature demonstrating this integration. Better methods to show the chemical forms of an element are also necessary. For example, the complexation of sulfide with metals affects the uptake of metals (for enzymes) and/or sulfide (chemosynthesis) by organisms that require these chemical species.

C) Submergence science is heading in several directions. I note a few possibilities: (1) better chemical sensors need to be developed for short term and long term monitoring needs, (2) better chemical sensors that can make reliable measurements at high temperatures and pressures and that can give information on the chemical speciation of an element, (3) better integration of the oceanographic sub-disciplines is necessary to tackle problems/questions in a concerted effort, (4) an increased effort directed at diffuse flow systems at vents/seeps to understand the development and sustaining of biological communities.

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**Richard A. Lutz**

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|---|---|
| Organization: | Rutgers - The State University |
| Address: | 71 Dudley Road |
| City: | New Brunswick |
| State/Province: | NJ |
| Country: | USA |
| ZIP Code: | 08901-8521 |

Email: rlutz@ahab.rutgers.edu

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1. Field of Expertise: Hydrothermal Vent Biology

2. Submergence Platform(s) Used: Alvin; JASON; Atlantis II; Atlantis; Turtle; Lulu; Shinkai 6500; Nautile

3. Workshop Questions: What successional changes occur in biological, geological and chemical parameters and/or features over the "life" of a hydrothermal system?

4. Region of Interest: 9 degrees 50' N along the East Pacific Rise

5. Types of submergence systems anticipated for work/technology development: Alvin, JASON, and ABE. Specific interests include development and testing of state-of-the-art imaging systems.

6. Abstract:
Current technological limitations on my research include the lack of high-quality, state-of-the-art imaging systems as standard equipment on Alvin and JASON. The lack of such systems severely limits our ability to document temporal changes in biological and geological features present at deep-sea hydrothermal systems. To date, we have been forced to rely on the use of imaging systems, which are not part of the "standard equipment" arsenal of either Alvin or JASON, and the associated logistical and financial difficulties have been problematic. Given the widespread utilization of imaging systems across essentially all oceanographic disciplines, state-of-the-art systems should be much more readily available for submergence science. Given the recent compelling evidence for the existence of past and present oceans on extraterrestrial bodies, I see over the coming decade a much closer tie between NSF and NASA-sponsored research.

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**Alexander Malahoff**

Title: Director
Organization: NOAA's National Undersea Research Center for Hawaii & the Pacific
Address: University of Hawaii, 1000 Pope Rd, MSB 319
City: Honolulu
State/Province: HI
Country: USA
ZIP Code: 96822
Phone Number: (808) 956-6802
Email: malahoff@soest.hawaii.edu

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1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used: MIR I & MIR II, Sea Cliff, Turtle, NR-1, Makali'i, Pisces IV, Pisces V, Shinkai 2000, Shinkai 6500, Alvin

3. Workshop Questions: Hydrothermal vent monitoring & sampling

4. Region of Interest: Pacific Ocean

5. Types of submergence systems anticipated for work/technology development: Manned submersible, ROVs, ocean bottom observatories

6. Abstract:
My current research work involves detailed chemical and microbiological sampling of the hydrothermal vent environment. I would like to develop a working model for the relationships between microbiological density and diversity, hydrothermal deposition, and the rate of fluctuations in distribution and temperature and chemistry of the vent waters. I would like to see long-term observations and monitoring of specific vents, especially those on Loihi submarine volcano where I am currently working. The technologies I am seeking include contamination-resistant probes, contamination-resistant time-lapse photography, and a system to transmit the data acoustically from the observatories to the surface.

I am particularly interested in the long-term fluctuations of the metal content of the vent fluids. Furthermore, I would like to see supplemental data on the seismicity, temperature, and inflation and deflation of the volcanic structure on which the vents are located.

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## Laurence P. Madin

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|---|---|
| Name: | Laurence P. Madin |
| Title: | Senior Scientist |
| Organization: | Woods Hole Oceanographic Institution |
| Address: | |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | lmadin@whoi.edu |

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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: Alvin
Johnson Sea Links
Deep Rover
WASP

3. Workshop Questions: Submersible assets for midwater investigations

4. Region of Interest: any part of the open ocean

5. Types of submergence systems anticipated for work/technology development:
manned submersibles with exceptional visibility and maneuverability for water column work ROVs equipped for survey and transect work, including multifrequency acoustics and high-resolution video improved collecting equipment for delicate organisms

6. Abstract:
My research interests include the biology of meso- and bathypelagic zooplankton and fishes, particularly gelatinous forms. These organisms inhabit the largest habitat on earth, but are often sparsely distributed and extremely fragile, making them difficult to sample and to study alive. Net and trawl collections provide limited insights into the diversity and ecology of this fauna, and even these are rarely made nowadays below the photic zone, or 1000 m at best. Because of the size of the water column environment, and the fluid distribution of organisms within it, biological investigations there are still largely explorations. Unlike benthic or vent habitats, the midwater offers no fixed "sites" to return to and use for manipulative or time-series studies. Study areas can be predetermined to some extent based on depth, or acoustic information, but midwater research unavoidably involves considerable time searching for organisms and situations of interest. At present a major technological limitation for this research is the inability to scan large volumes of water and detect relatively small and sparse organisms, many of which are rather invisible to both light and sound. Another limitation is the artifact effect of a large, illuminated and noisy submersible within a normally dark and silent environment. A third constraint is the cost and and logistical difficulty of spending enough time at midwater depths to make the kinds of collections and observations that are required to understand diversity and function in these organisms.

Submersibles like the Johnson Sea-Link and the Deep Rover have proven to be valuable assets for midwater exploration, offering excellent panoramic visibility, specialized collecting and recording tools, pilots experienced in midwater operations, and relatively low operating costs. Their availability is limited mainly by a lack of funding for midwater research programs, and to some extent by their depth limitations. Time limits on manned submersible use could be alleviated by the coordinated deployment of ROVs to do the larger scale survey work, and help pick times or depth ranges for manned submersible operations. ROVs or smaller submersibles could alleviate the artifact

problem or noise and light, but may lack the necessary payload for sampling and other gear.

The U.S. submersible science assets need to include vehicles optimum for use in the midwater environment as well as on the bottom. Depth capability to at least 4000 m would be desirable for future midwater work, but a great deal could still be accomplished with greater funding support for use of the existing 1000 m subs. Remote or autonomous vehicles will be important new assets, used either alone or in support of manned vehicles. As with benthic investigations, there will remain a need for a human presence in midwater for some time to come.

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**Russell McDuff**

Organization: University of Washington School of Oceanography
Address: Box 357940
City: Seattle
State/Province: WA
Country: USA
ZIP Code: 98195-7940

Phone Number: 206-543-3058
Email: mcduff@ocean.washington.edu


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1. Field of Expertise: Geochemistry

2. Submergence Platform(s) Used: ALVIN, Jason

3. Workshop Questions: What are the fluxes of heat and mass from hydrothermal systems?

4. Region of Interest: NE Pacific for development, elsewhere on the MOR.

5. Types of submergence systems anticipated for work/technology development: ROVs and especially AUVs. Needed is the ability to conduct very long dives with closely spaced (1-10 meter) lines.


6. Abstract:
My principal current interest is the measurement of fluxes of heat and materials from hydrothermal vent systems using an approach of making measurements of velocity and tracer fields in rising plumes. We are still at the stage of establishing methods and protocols to yield adequate precision; ultimately it is important to make time series measurements.

This kind of work has proven to be unwieldy and inefficient from ALVIN, is conducted with substantial difficulty from Jason, and we expect to find in Summer 2000 quite feasible from ABE. However the state of development of ABE is far from the ultimate goal of unattended operation at the seafloor for extended periods of time, a necessary prerequisite to producing meaningful time series data. A wide variety of time series studies could make a very effective transition to AUVs if sufficient resources were put in this direction.

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**Jon D. McWhirter**


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|---|---|
| Organization: | Idaho State University |
| Address: | Campus Box 8060 |
| City: | Pocatello |
| State/Province: | ID |
| Country: | USA |
| ZIP Code: | 83209 |
| Email: | mcwhjon@isu.edu |


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1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used: US Navy Nuclear Submarine

3. Workshop Questions:

4. Region of Interest: Worldwide

5. Types of submergence systems anticipated for work/technology development: Development and design of autonomous, long-duration submersible research platforms

6. Abstract:
a)

b) I believe that the oceans should be explored at a much faster pace than is presently possible. This pace can only be increased by expanding the total underwater on-station time duration. This increase can be accomplished by increasing the on-station time duration of each submersible and by increasing the total number of submersibles. I believe we can accomplish this by developing a long-duration research submersible with lab facilities on-board. Such a submersible could be "parked" at a position of scientific interest, and multiple ROVs deployed to accomplish a very intense exploration of the position, as well as bringing aboard specimens for other study, and not to dismiss simple visual observation.

SO, to put an exclamation point on this, I believe we should have between 10 and 100 long-duration (3-6 months) 6000 m capable research submersibles.

c)

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**Hugh Milburn**


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|---|---|
| Title: | Engineering Division Leader |
| Organization: | NOAA/PMEL |
| Address: | 7600 Sand Point Way |
| City: | Seattle |
| State/Province: | WA |
| Country: | USA |
| ZIP Code: | 98115 |
| Email: | milburn@pmel.noaa.gov |


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1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used: ALVIN ROPOS

3. Workshop Questions: NONE - we provide engineering support for science.

4. Region of Interest: Primarily NE Pacific

5. Types of submergence systems anticipated for work/technology development: Advocate ROVs for most subsea tasks. See growing role for AUVs.

6. Abstract:
An engineer's perspective:


ROVs will play and increasingly important role in deep submergence science but must become more user friendly with decreased complexity, generic tools, 3D viewing, improved manipulative capabilities, and other natural evolutionary improvements. However, I feel the most significant advancement we will make in deep submergence in the next decade will be with AUVs. They will map and image the seafloor, sample and observe the water column, and generally probe the depths at low costs and throughout the seasons. At present we are technically challenged by communications and power limitations, which will continue to plague the integration of these tools. However, autonomous vehicles are the ideal tool for event response and significant efforts should be focused on this application.


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**David Naar**

Organization: University of South Florida
Address: 140 Seventh Avenue South
City: St. Petersburg
State/Province: FL
Country: USA
ZIP Code: 33701-5016

Email: naar@marine.usf.edu

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1. Field of Expertise: Marine Geophysics
2. Submergence Platform(s) Used: Nautile

3. Workshop Questions: Can Alvin be used to investigate deep (6km) tectonic windows into the lower crust and upper mantle in areas such as Pito Deep and Terevaka (4500m+) transform zone where peridotite was obtained?

4. Region of Interest: Fast seafloor-spreading areas in the South Pacific

5. Types of submergence systems anticipated for work/technology development:
Alvin with 6500-meter water depth capability
Rock Drilling
Paleomagnetic measurements
Oriented Samples

6. Abstract:
a) What are the current technological limitations on your research, and what science could you do if these problems did not exist?

Alvin cannot go deep enough to look at the lower portions of tectonic windows at Hess Deep, Pito Deep, Endeavor Deep, and some relict deep holes in the south Pacific at failed rifts, failed propagating rift tips, transform faults and fractures zones.

b) What capabilities should be generally available for submergence science?

The ability to dive deeper will not only be of use in regards to exploring tectonic windows formed at propagating rift tips, but also along fracture zones and even in trenches where one might be interested in the actual contact between a subducting plate and the overriding plate. Potential to discover new life forms also seems likely in deeper water depths.

c) Where do you see submergence science going in the next decade?

Deeper, longer duration, complete digital data acquisition, and more deliverables in terms of different type of sensors, especially physical and chemical measurements of the water column and sediment water interface. I envision long expanding telescopic probes sampling deeper and deeper into the fractures, sediments, in an effort to better understand the edges of the crustal biosphere.

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**Dr. Donald Nuzzio**


Title: President
Organization: Analytical Instrument Systems, Inc.
Address: P.O. Box 458
City: Flemington
State/Province: New Jersey
Country: USA
ZIP Code: 08822-0458
Email: ais@aishome.com


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1. Field of Expertise: Ocean Chemistry

2. Submergence Platform(s) Used: ROVs Alvin

3. Workshop Questions: What analytical instruments will be required for deep-sea research in the future

4. Region of Interest: none

5. Types of submergence systems anticipated for work/technology development: Development of analytical methods and instruments for the analysis of the water column or sediments.

6. Abstract:

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**Scott Olson**


Title: Systems Engineer, Marine Operations Division
Organization: Harbor Branch Oceanographic Institute
Address: 5600 North U.S. Highway One
City: Fort Pierce
State/Province: Florida
Country: USA
ZIP Code: 34946
Email: olson@hboi.edu

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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: Johnson Sea Links HOV
Clelia HOV
Scoop ROV
Low Cost ROVs

3. Workshop Questions: organizational

4. Region of Interest: U.S. out to 1000m

5. Types of submergence systems anticipated for work/technology development:
HOVs and ROVs with the best tools and operating efficiencies possible.

6. Abstract:

This is the perfect opportunity for science users of all types of underwater vehicles, regardless of their depth capability, to let their needs and desires be heard at a national level. DESSC currently only represents the National Deep Submergence Facility (WHOI) and thus all other assets are not represented by any agency on any level. Without funding, scheduling, technical, or safety coordination, how can the scientific community obtain the most efficient and cost effective tools for its research?

Two years ago DESSC sent out a questionnaire to 420 u/w vehicle scientific users. The results are published on the UNOLS website in the Sea Cliff Work Group report. Of the 120 responses, just about as many scientists reported a need for access to the continental shelf/slopes as they did for access to abyssal depths in the next ten years. Yet, to this day, other "Human" Occupied Submersibles are not eligible for NSF funding because they are not UNOLS "classed" vessels. Meanwhile other agencies do not hesitate to fund all available platforms. Perhaps the DESSC charter should once again be broadened to include eligible systems that meet peer controlled standards, much as UNOLS presently does with its research vessel programs and committees.

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**Daniel Orange**

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| Organization: | U.C. Santa Cruz |
| Address: | Dept. Earth Sciences - UCSC |
| City: | Santa Cruz |
| State/Province: | CA |
| Country: | USA |
| ZIP Code: | 95064 |

Email: dano@es.ucsc.edu

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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: HOV: ALVIN
ROV: Ventana, ROPOs, JASON, ATV

3. Workshop Questions: Seeps, seafloor instability, canyons, shelf-slope sediment accumulation and modification.

4. Region of Interest: USA (west coast, gulf of Mexico), Australia

5. Types of submergence systems anticipated for work/technology development:
Heavy (work-horse) ROV
improved seafloor mapping systems (resolution, bathy, backscatter)
Remote interrogation of instrumentation

6. Abstract:

a) What are the current technological limitations on your research, and what science could you do if these problems did not exist?

Limitations can be lumped into a few categories, and are not shared by all platforms:

- Payload. More is better.
- Real-time navigation. Specifically Alvin - we need to be able to see where we are on our base maps in the ball.
- Returning to sites. A minor point, but long-term beacons left at sites of interest would be an asset.
- Field of view/operations. Anthropogenic ROVs, with a work area and cameras pointed to the front, do not take full advantage to the 360 degree/full spherical operational and visual area. I would like to be able to deploy and peer in various directions during operations.

b) What capabilities should be generally available for submergence science?

My preference, after considering the trade-offs, would be to maintain ALVIN as a 4500 m sub, but improve its power, manipulation, etc.

I would prefer a suite of ROVs so that I could select the one appropriate for a particular project (a light, nimble one for surveying, and a heavy brute for sampling).

c) Where do you see submergence science going in the next decade?

I would like to see the development of a survey AUV capable of deployment from a platform-of-interest. I would like to see a range of ROVs, and an improvement in our surveying capabilities.

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**Michael Perfit**


Organization: University of Florida
Address: Box 112120, Dept. of Geological Sciences
City: Gainesville,
State/Province: Florida
Country: USA
ZIP Code: 32611-2120

Email: perfit@geology.ufl.edu


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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: ALVIN, ROPOS, Makalii, SeaMarkII,

3. Workshop Questions: What types of tools do we need to develop for research in the near future? For the next 20-30 years? Do we need to expend limited funds and energy to develop a 6000+ HOV? Do we need another national facility on the west coast? How can we best use the existing facilities to do time series experiments, service observatories and continue global exploration? How can we enlist the support (financial!) of the Navy and NOAA to strengthen and expand our deep submergence facilities and science programs?

4. Region of Interest: Northern and Southern Pacific, W. Pacific

5. Types of submergence systems anticipated for work/technology development:
HOVs, ROVs,
Wide area photo / video documentation tied to high-resolution side-scan images, rock sampling and coring devices, in-situ chemical analyses of rock samples, eruption monitoring, new mapping techniques,

6. Abstract:


As previously stressed by both the SEACLIFF Working Group and the DESSC during the past few years, 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:

- A focused, cost-effective, and technically capable national deep submergence facility or facilities and operator(s),
- 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 unified submergence program in the 21st century.

I would like to summarize some of the important concerns and objectives that the scientific community raised in response to a questionnaire regarding the future of deep submergence science in 1997. I believe these points remain true today.

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 that 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 ~2500-4000 m 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 5-7 years.

Community response indicated there is strong support for HOV depth capability to 6,000m, and deeper for ROVs, to allow for research over a wide range of tectonic, sedimentologic and geographic environments. The continued need for an HOV at abyssal depths and possibly as deep as 6000m. 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, will be critical.

There has been a shift from expeditionary and exploratory work to time-series studies and establishing seafloor observatories that are visited at yearly or bi-yearly intervals to observe and record temporal variations and interrelationships between various physical and biological processes. The establishment of ocean bottom observatories, the capability of long-term monitoring of specific sites and the interdisciplinary nature of current studies are trends in deep-sea research that will continue to grow over the next decade. For these reasons the community will need more vehicles that can accomplish a wide variety of tasks. However, this same scientific impetus will likely reinvigorate the exploratory style of deep-ocean science, given the very small percentage of the deep ocean floor that has been surveyed and sampled in detail. I believe that in order to be successful in the coming decade (at least) we need new fiber-optic based ROVs and tethered systems that can be used in with other vehicles (such as AUVs) in nested investigations that will allow us to map and sample at many different spatial (and temporal) scales.

The biggest technological limitation to my current research is obtaining enough, well-located samples during a dive. Time on bottom, manipulator difficulties, limitations of sample storage and the trade-off between time used for sampling versus distance traveled all influence the number of rock samples recovered. During multidisciplinary cruises, these factors also negatively impact scientists with other specialties. "Hardrock" marine geologists are also limited because there are no current methods of "in situ" chemical or mineralogic analysis in the abyss. New developments in optical sensors may be adapted to the deep-sea which would allow us to map individual flow units, determine extents of chemical variability, locate regions of mineralization and alteration and to estimate ages of the seafloor.

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**Richard F. Pittenger**


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| Title: | Associate Director for Marine Operations |
| Organization: | Woods Hole Oceanographic Institution |
| Address: | Mail Stop #37 |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | rpittenger@whoi.edu |


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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: ALVIN, ROVs

3. Workshop Questions: What are the five-year, ten-year, fifteen-year projections of scientific requirements for deep submersible tools?

4. Region of Interest: Wherever science wants to go.

5. Types of submergence systems anticipated for work/technology development: HOVs, ROVs, AUVs, towed imaging/sensor systems and associated shipboard and shore-side support, control and post-processing infrastructure.

6. Abstract:
6a. N/A
6b. The community should be served with a family of affordable, reliable, accessible

tools that include the following:
- One HOV with 6000+ meter depth capability that builds on the present good features of ALVIN (reliability, adaptability, low cost) and improves manipulators, navigation, payload and propulsion power, comfort and "in-ball" ergonomics. The community has repeatedly stated the need for human cognitive presence in the benthic abyss. They have further stated the concern that ALVIN not be degraded in the process of "upgrades" - "Don't screw it up in the process of trying to make it better!" By that, I take it to mean, "Keep ALVIN adroit and functional, as it is today."
- A very capable ROV that takes advantage of the population of .680 winches and fiber optic wires now in the academic fleet. Deeper, more propulsion/payload power, better manipulators and sampling, more easily adaptable to changing science packages. This is the program now underway to build the next generation ROV (JASON II) at WHOI with WHOI, NSF and ONR funding.
- Perhaps a less capable ROV for simpler benthic projects.
- Towed instruments for nested benthic surveys with acoustic phase bathymetry, backscatter, photometry, magnetics, gravimetry and other physical and chemical sensor packages.
- AUVs. This is a maturing field that will, in the next decade become increasingly capable of expanding the capabilities of research ships. AUVs should have the ability to sample in better detail than is possible by any other means and should be left in place for periods of up to six months as part of deep ocean observatories.

6c. Deep submergence is one of the most dynamic and forward-thinking/moving branches of oceanography. The discoveries in the mid-ocean ridge portion (plate dynamics, seismicity, volcanism, and vent chemistry and fauna have only begun. This work has been enabled by benthic science tools (ALVIN, ARGO/MEDEA/JASON and Deep-Tow in particular). More vents are being found as new portions of the ridge are explored, each has its own characteristics. The community is beginning to show interest in the deeper portions of the ocean; in the trenches and the deep abyssal plains. The science in these regions has only been scratched. I expect deep submergence will do the following:
- Continue to study and explore the 50,000 km long mid ocean ridge system;
- Expand its research in the deeper portions of the oceans - trenches, margins and abyss;
- Demand increasingly more capable vehicles and instruments.
- Eventually deep submergence will outgrow the array of tools presently on hand and in development. Extrapolating, I foresee the generation-after-next tools being:

. deeper . remote
. cheaper . more power
. stronger . more adroit
. tele-connected

- Through all of this evolution, we should remain mindful and responsible as to the cost of these science tools and not over-stretch our (the Federal Agencies) ability to ensure at least one set of well-maintained and effective tools in the community.

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**Shirley A. Pomponi**

Title: Division Director
Organization: Harbor Branch Oceanographic Institute
Address: 5600 U.S. 1 North
City: Fort Pierce
State/Province: Florida
Country: USA
ZIP Code: 34946
Email: pomponi@hboi.edu

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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: Johnson-Sea-Links I & II, Research Submersible Clelia (PC1204), Hysub 40

3. Workshop Questions: What platforms are available from UNOLS for scientists who wish to work in depths less than 15000m? How can currently available shallow water (i.e., less than 1500 m) submergence technology be better utilized by the scientific community?

4. Region of Interest: "shallow" (i.e., less than 1500 m) worldwide

5. Types of submergence systems anticipated for work/technology development:
Manned submersible systems with benthic collection platforms, adapted for collection and transport of organisms from extreme environments (e.g., high pressure, low temperature)

6. Abstract:
Capabilities for UNOLS-supported submergence science should include access to vehicles and platforms for research at all depth zones. Advancements in submergence science in the next decade should be a coordinated and complementary approach to addressing questions not only related to physical and geochemical processes, but also to the plants, animals, and microbes (both benthic and pelagic) that are affected by and which have an effect on those physical and geochemical processes. Enhancements of manned submersibles, ROVs and AUVs should be complementary to developments in remote platforms.

Technological limitations of the platforms I currently use are related to the collection and maintenance of organisms from extreme environments. Development of tools for more precise collection of benthic invertebrates, sensors for monitoring physiological processes in situ, and in situ preparation of samples for molecular and cellular biology would

enhance the research I currently conduct on deep-water benthic invertebrates. I am specifically interested in the development of deep-water marine invertebrate models to investigate fundamental processes in cellular and molecular biology.

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**Frank R. Rack**


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| Title: | Assistant Director |
| Organization: | Joint Oceanographic Institutions, Inc. |
| Address: | 1755 Massachusetts Ave., NW; Suite 800 |
| City: | Washington |
| State/Province: | D.C. |
| Country: | USA |
| ZIP Code: | 20036-2102 |
| Email: | frack@brook.edu |


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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: None

3. Workshop Questions: What combination of deep submergence assets is needed to support observatory science and future ocean drilling activities?
What are the engineering design requirements for tools and human/mechanical interfaces to support future scientific programs using ROVs, AUVs and research submarines?

4. Region of Interest: Worldwide

5. Types of submergence systems anticipated for work/technology development:
I anticipate a wide range of submergence systems and instruments might be used to support observatory science and drilling activities. I seek a general understanding of all such systems.

6. Abstract:
I hope to develop a better understanding of the present and future needs, capabilities, and limitations of submergence systems at this workshop. I think it is important to maintain the appropriate mix of technologies and submergence systems to address the many challenges that our community will face in the next decade, as we proceed to deploy long-term, time-series measurement systems and observatories to address scientific questions outlined in recent reports and planning documents.

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**Anna-Louise Reysenbach**


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|---|---|
| Organization: | Portland State University, Dept. Environ Biol. |
| Address: | 1719 SW 10th Ave |
| City: | Portland |
| State/Province: | Oregon |

Country: USA
ZIP Code: 97201
Email: reysenbacha@pdx.edu

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1. Field of Expertise: Microbiology

2. Submergence Platform(s) Used: Jason
Alvin
Shinkai 6500
Nautile

3. Workshop Questions: Is barophily an important consideration for deep-sea research?

4. Region of Interest: Global

5. Types of submergence systems anticipated for work/technology development:
ROV and manned submersibles
Tech development:
- rock/sulfide corers
- in situ measuring of microbiology (activity, biomass etc) and geochemistry

6. Abstract:

a) What are the current technological limitations on your research, and what science could you do if these problems did not exist?
Includes limited (or no) ability to:
take discreet microbiological samples
set up in situ measurements (biological and geochemical)
do short-term microbial monitoring
effective coring into sulfides
maintaining samples under pressure
Science that could be accomplished would include
Long and short-term microbial monitoring (activity, diversity, biomass etc) which would be tied to geochemical and macrobiological in situ monitoring
Explore the extent and distributions of microorganisms in the hydrothermal field (at the surface and subsurface)
b) What capabilities should be generally available for submergence science?
Routine sampling tools (includes new technologies that are developed and that become routine in different disciplines)
Obviously all these require maintenance, and the level of use will vary with the type expedition. This is not very different from the capabilities available to science today, however, a number of new developments have been made by individual investigators, such as multiple water samplers (Butterfield), or plume water samplers (Chris German) that could perhaps be developed as routine shipboard equipment.
c) Where do you see submergence science going in the next decade?
In situ technologies
Short and long term monitoring (Observatories)
Increased ROV capabilities

## Veronique Robigou


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|---|---|
| Organization: | University of Washington |
| Address: | School of Oceanography, Box 357940 |
| City: | Seattle |
| State/Province: | Washington |
| Country: | |
| ZIP Code: | 98195-7940 |
| Email: | vero@ocean.washington.edu |


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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: Submersible Alvin
Submersible Sea Cliff
Submersible Turtle
Medea/Jason ROV platform
ROPOS ROV platform

3. Workshop Questions: I have "non-traditional" deep-submergence questions but questions that need to be addressed to bring deep-submergence into the consciousness of the public and to attract the reconnaissance it deserves after having been one of the major tools enabling the drastic evolution of ideas about the dynamics of our planet and about life in the last 20 years. Deep-submergence has an incredible attraction on the intellect of the general public and as a community, we have not seriously addressed how to entrain and sustain the curiosity of the public to support the efforts of the deep-submergence community.

4. Region of Interest: NE Pacific and mid-ocean ridges in general

5. Types of submergence systems anticipated for work/technology development:
For today's exploratory mode (i.e.: cruises and use of ships)
1- Better, faster, cheaper communications from platforms (vessels, subs, AUVs) to labs on land. The web is starting to be used as a repository to access resources, data, etc. during cruises but this development is still in its infancy, expensive and cumbersome despite the progress made in the last few years. For the future (i.e. cables, satellites, remote observations, data acquisition etc.)
2- Thinking about ways in which the community can involve classrooms and the general public without overwhelming them with raw data and routine data collection and still capture their wonder about the deep ocean.

6. Abstract:

The REVEL Project: Research and Education - Volcanoes, Exploration and Life. An example of deep-submergence outreach.

The mission of the REVEL Project is to integrate middle and high school science teachers into bona fide, fully funded research cruises designed to study the full spectrum of processes associated with submarine volcanoes. A major new research theme has emerged in the Earth and Life Sciences in the past half decade that encompasses broadly interdisciplinary exploration of the deep crustal processes capable of supporting extensive microbial activity within the volcanically active portions of the earth. This work is germane to issues related to origin of life, to the formation of ore deposits, to the flow of heat and chemical mass from the interior of the planet, to the discovery and use of extreme enzymes in laboratory and pollution control situations, and to the search for life on other planets. Our program allows direct access of a number of teacher-leaders to the forefront of this exciting arena of inquiry, by-passing textbooks to inject into the classroom not only the issues and ideas associated with this rapidly growing research effort, but the first-hand exposure to the approaches, successes, failures and essential tenacity that are the integral components of successful research into the unknown. Major by-products of the REVEL experience have been the overwhelming enthusiasm of teachers and scientists involved, and the lasting commitment of both for sharing the materials, insights and experiences gained in REVEL with the communities from which they come. Teachers are teamed with university scientists in oceanographic research programs designed to explore the nature and evolution of volcanoes, and life forms they support, along the Juan de Fuca spreading center.

Since 1996, the REVEL Project funded by the National Science Foundation, Division of Ocean Sciences and the University of Washington have entrained 38 teachers at sea on 6 different expeditions on the Endeavour Segment of the Juan de Fuca Ridge. In 1998, the Pennsylvania State University and the American Museum of Natural History joined forces with the University of Washington providing additional cruise opportunities for teachers to experience the research process and collaboration with professional educators at the Museum to translate the teachers' experiences into products usable by all teachers and all students in their classrooms. Part of the REVEL mission is to inspire a large audience with the excitement of deep-sea exploration, to invite them to witness life at sea and to ignite their curiosity with questions such as the origin of life on our planet and the possibility of life in the solar system. REVEL has experimented for the last four years with sharing the sea-going experience and the science done onboard research vessels while cruises are taking place on the ocean. A web site available all year round provides background material to teachers, students and the general public and proposes access to a daily log summarizing the cruise activities while the research vessels are on site and working under the sea surface with ROVs or manned submersibles. The web site has been very successful with more than 50,000 hits per week during the cruises and it is a powerful tool to introduce oceanographic research to an enthusiastic public. In the last couple of years, other groups have followed the lead of REVEL by developing cruise-specific sites (2 sites in 1996, 8 sites in 1998, and 4 so far in 1999) http://www.ocean.washington.edu/outreach/revel

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**Bruce H. Robison**

Name: Bruce H. Robison
Title: Senior Scientist
Organization: MBARI
Address: 7700 Sandholdt Rd.
City: Moss Landing
State/Province: CA
Country: USA
ZIP Code: 95039
Email: robr@mbari.org

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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: Alvin, Turtle, Sea Cliff, Pisces, Mir, Shinkai 2000, Johnson Sea-Link, WASP, Deep Rover, Deep Worker, Ventana, Tiburon, etc.

3. Workshop Questions:
    1. Composition, structure, and function of midwater communities.
    2. Behavior and ecology of midwater animals.
    3. The role of midwater communities in organic carbon flux.
    4. Region of Interest: open ocean and under-ice regions

5. Types of submergence systems anticipated for work/technology development:
Manned vehicles with midwater capabilities (e.g. Deep Rover, J-S-L, Deep Worker). ROVs with midwater capabilities (e.g. Ventana, Tiburon). AUVs with midwater capabilities. Technological development is needed for small, light, manned vehicles that do not require massive support systems and dedicated support ships. AUV development is needed to provide real-time communication through pulsed acoustics, and broad-scale midwater surveys.

6. Abstract:
Most of the animals that live in the ocean are in the water column and not on the bottom. Of these, the majority occurs in the upper 1-2,000 m. midwater research has reached the limits of what can be learned from conventional methods based on nets and acoustics alone, and the field has stagnated. What are needed are the new kinds of information that can only be generated by in situ methods. More fundamental knowledge about the biology of the ocean remains to be learned from in situ midwater research than from work on the bottom.

In situ research is dominated by benthic studies. The principal U.S. assets for in situ research are benthic vehicles, and the granting processes of the funding agencies are structured to provide support and access principally for those vehicles. The historical reasons for this situation are: 1) it is easier to work on the bottom, 2) serving the needs of both geologists and benthic biologists provides a strong support base within the research community, and 3) it has been cost-effective to focus the limited funds available on just one or two vehicle systems.

Access to deep submergence assets has been strongly biased to support benthic research, despite the results and recommendations of studies that have called for the increased accessibility, use, and development of midwater research technologies and methods (e.g. UNOLS Submersible Science Study - 1990, UNOLS Global Abyss Report - 1994, NRC Undersea Vehicles and National Needs - 1996). DESSC, UNOLS, and the federal funding agencies must address this problem and make it as easy for researchers to gain
access to suitable midwater-capable research platforms, as it is to access Alvin or Jason.
The principal limitation on my own research is the lack of access to a suitable manned vehicle for midwater research. Were such a system available, I could address the questions of diel vertical migrations, the use of bioluminescence, the spatial patterns of midwater community structure, and the ecology of taxa not tractable for study with ROVs (e.g. fishes).

With regard to what capabilities should be generally available, the adage "use the right tool for the job", fits the question. For some applications, manned vehicles are the best research platforms, for other needs, AUVs or ROVs are best. Likewise, it is not efficient to use a vehicle system rated to 5,000 m for work at a depth of 500 m, when less expensive, more efficient alternatives exist. The research community should not be
constrained because virtually all of our resources are invested in one deep-diving, benthic vehicle of each class. Deep benthic science is a relatively mature enterprise and in the currency of major scientific advances, I see the next decade as an area of diminishing returns unless we change the status quo. To sustain the momentum generated by deep submergence science in the past, we need to diversify the vehicles we make available for deep-sea research.

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**Peter A. Rona**

Organization: Institute of Marine and Coastal Sciences, Rutgers University
Address: 71 Dudley Road
City: New Brunswick
State/Province: New Jersey
Country: USA
ZIP Code: 08901-8521
Email: rona@ahab.rutgers.edu

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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: Alvin, Mir 1, Mir 2, Nautile, Shinkai 2000, Shinkai 6500, Turtle, Sea Cliff, ATV (U.S. Navy), Jason

3. Workshop Questions: 1) How to effectively use various types of deep submergence vehicles to study seafloor hydrothermal flow regimes involving remote acoustic imaging techniques combined with in situ measurements in short time series and long time series

modes.
2) What is most effective use of deep submergence assets to map geologi settings and controls of seafloor hydrothermal systems?
3) What is the most effective use of deep submergence assets in long-term seafloor observatories?

4. Region of Interest: Central North Atlantic, E. and W. Pacific, Indian

5. Types of submergence systems anticipated for work/technology development:
A mix of submergence systems is anticipated as described in my abstract. My interest is in acoustic technology to image hydrothermal flow regimes and interfacing this technology with submersibles, ROVs and long time series seafloor monitoring stations.

6. Abstract:

A. What are the current technological limitations on your research, and what science could you do if these problems did not exist?

Acoustic Imaging of Seafloor Hydrothermal Flow Regimes: Short- and Long-term Time Series
Peter A. Rona and Karen G. Bemis (Institute of Marine and Coastal Sciences, Rutgers University), Darrell R. Jackson and Christopher Jones (Applied Physics Laboratory, University of Washington), and Kyohiko Mitsuzawa (Deep Sea Research Department, JAMSTEC)
We are developing innovative new acoustic methods using deep submergence facilities that have the potential to synoptically image and map buoyant hydrothermal plumes in 3-D and diffuse flow in 2-D discharging from seafloor hydrothermal systems (Rona et al., 1991, 1997). Coordinated with the acoustic imaging we are developing computer visualization techniques that are enabling us to make quantitative measurements of parameters that describe how these flow regimes discharge from the seafloor, rise in the water column, and mix with the surrounding ocean. Current technological limitations of our research pertain to sonar system, platform, and duration are, as follows:
1) Sonar system: Our experiments to date have used a sonar system (modified Mesotech 971) that requires tens of minutes to image a buoyant plume and limits data recording to the duration of a submersible dive. The next step is to make the transition to a state-of-the art sonar system (Simrad SM2000), which will reduce imaging time to seconds enabling synoptic reconstruction of flow regimes and providing the basis for time series analysis of flow structures (eddies, etc.). At the same time, this new sonar system can serve the community for seafloor mapping and related functions.

2) Platform: To date we have used a submersible as a platform for the sonar system. The next step is to adapt the next generation sonar system (Simrad SM2000) to an ROV (Jason) for short time series images and versatility.

3) Duration: The next step is to adapt the sonar system to a long term seafloor monitoring mode (days to 1 year) to obtain long time series images of the seafloor hydrothermal flow regimes. It is known from the few sites studied that focused and diffuse flow exhibit temporal and spatial variations on a wide range of scales related to geologic events including dike injection and crustal extension (Fox et al., 1995; Delaney et al., 1998; Embley and Baker, 1999).

In sum, overcoming present technological limitations will enable us to record short time series for plume dynamics and mapping of diffuse flow, and to record long time series (days-year) for temporal/spatial variations of individual vents as well as entire seafloor hydrothermal fields. To accomplish this requires engineering to adapt the appropriate sonar systems to the long-term seafloor monitoring mode, and deployment as part of seafloor observatories at hydrothermal sites on multiple spreading segments of different ridge types. The monitoring of seismicity at spreading axes using SOSUS and OBS/OBH arrays is producing new insights to relations between seismicity, dike injection, spreading events and hydrothermal activity (Fox et al., 1995; Embley and Baker, 1999). Coordinated acoustic monitoring of hydrothermal flow regimes will follow these events from the ocean crust into the water column and advance understanding of their physical, chemical and biological impact on the ocean environment.

B. What capabilities should be generally available for submergence science?
Deep submergence science needs the capabilities to carry out event response, short- and long-term time series, and exploration from continental margins to the deep ocean. Complementary tools to achieve these capabilities that should be generally available to the community comprise ROVs, AUVs, instrument arrays for deployment as long-term seafloor observatories, and manned submersibles as the ultimate capability. The deep submergence vehicles should be designed for versatility and mobility.

C. Where do you see submersible science going in the next decade?
1) Expansion of the use of ROVs and AUVs for high-resolution seafloor surveys, in situ measurements and sampling. It is important for human occupied submersibles to hold their own while the number and use of other types of deep submergence vehicles increases.
2) Improvements in mobility of the various types of deep submergence vehicles to support global expeditionary science and in versatility to accommodate a wide range of scientific applications.
3) Specialization of deep submergence science to support long-term seafloor observatories including instrumented drill holes.

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## John D. Rummel

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|---|---|
| Organization: | NASA Headquarters |
| Address: | Code S |
| City: | Washington |
| State/Province: | DC |
| Country: | USA |
| ZIP Code: | 20546 |
| Email: | jrummel@hq.nasa.gov |

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1. Field of Expertise: Astrobiology

2. Submergence Platform(s) Used: Alvin

3. Workshop Questions: What are the relationships between planetary processes and the nature and distribution of life on a planet.

4. Region of Interest: Various (Earth, Mars, Europa)

5. Types of submergence systems anticipated for work/technology development:
Autonomous underwater vehicles
Remotely operated vehicles (and combinations)
Human-rated submersibles
Deep-Sea Observatories

6. Abstract:
a) I am interested in the development of increasingly capable instrumentation for physical, chemical, and biological components of deep-sea ecosystems. Eventually, NASA would like to have such sensors available for the exploration of oceans on other bodies, but the same parameters (lower mass, power, and volume) that drive space instrument development are important for use in undersea systems, especially AUVs. Combined with better sampling technologies for deep-sea microorganisms, such instrumentation could provide the basis for improved in-situ measurements of biological

function, as well as improving our capabilities in simulating deep-sea environments in the laboratory.
b) I believe that it is in the interests of the community to be able to conduct measurements, manipulations, and sample retrievals in the deep sea environments wherever they occur on Earth. Some combination of ship-supported (or submarine-supported) and autonomous robotic capabilities should allow access to all environments in the sea, building from the current capability and extending downward (and out!). We should do a better job of assuring repeated access to long-term study sites by the emplacement of deep-sea observatories for routine monitoring (but building to routine robotic access), while ensuring that assets are available to continue the exploration of deep-sea environments worldwide.
c) I would like to see better sensors, more regular monitoring of long-term study sites via robotic technologies, and no relaxation from the exploration of the deep places of the Earth by oceanographers, wherever they may be found.

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**William B. F. Ryan**


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| Organization: | Lamont-Doherty Earth Observatory |
| Address: | Route 9W |
| City: | Palisades |
| State/Province: | NY |
| Country: | USA |
| ZIP Code: | 10964 |
| Email: | billr@ldeo.columbia.edu |


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1. Field of Expertise: Marine Geophysics

2. Submergence Platform(s) Used: Alvin
NR1
ABE
SeaMARC
Deep-Tow

3. Workshop Questions: The role and need of national facilities versus institutional facilities

4. Region of Interest: Atlantic, Mediterranean, Pacific

5. Types of submergence systems anticipated for work/technology development:
High resolution mapping and imaging and digital photographic with manned, tethered and autonomous instruments and a capability for spatially dense sampling in steep rock and sedimentary environments.

6. Abstract:
I have been both an instrument developer and an instrument user. In my opinion the goals of my scientific inquiry drive the development and use of new tools, and that one doesn't create technology to look for problems to solve. It is realistic that some facilities have short lifetimes where one or just a few deployments solves the problem or gets the needed measurements and other tools with more utilitarian and general use capabilities have long lifetimes. With the latter type of instrument or system, that is often a national facility, what is needed is an engineering and operational team that can adapt to user needs by either installing/integrating the users specific tolls or by designing and building the tools for the user based on a mission requirement. Capabilities that should be generally available for submergence science are winches with appropriate wires for towing and telemetry, a manned submersible for delicate maneuvering and manipulation of tools, packages, samples, navigation that lets more that one vehicle operate at a time in an area larger than a typical long baseline net, and instruments to map and image relief with resolutions of a meter or better.

Submergence science should go where the intellectual problems drive it. No more, no less. We need access soon to accretionary prisms, fracture zones and ridge/transform intersections and hostile localities such as brine seeps and anoxic basins. I see moving multibeam sonar technology from surface ship hull-mounted configurations to towed and autonomous vehicles.

As a member of DESSC my assignment at DESCEND is to help Dana Yoerger chair the session on Day 2 titled: "Manned and Unmanned Vehicles: Mapping" and help to write the report for this session. I see myself as needed more for listening than to give my own input.

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## Frank Sansone

Organization: Oceanography Dept., Univ. of Hawaii
Address: 1000 Pope Road
City: Honolulu
State/Province: HI
Country: USA
ZIP Code: 96822
Email: sansone@soest.hawaii.edu

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1. Field of Expertise: Ocean Chemistry

2. Submergence Platform(s) Used: ALVIN
Pisces V
Sea Cliff
ATV

3. Workshop Questions: What NEW scientific questions will require submergence platforms over the next decade?
Are any of these outside the range of the current user group?

How do our present platforms need to be improved to handle these new areas of research?
What would be the most cost effective improvements?

4. Region of Interest: Pacific

5. Types of submergence systems anticipated for work/technology development:
I will have need for submersibles, and also ROVs if they have greater payload, dexterity, and high-band communications than commonly available now. My technology development interests are in chemical sensors for seafloor research and fine-scale sampling tools for mid-water work.

6. Abstract:
Current Limitations
One significant improvement of the present situation would be the development of some degree of interchangeability for tools and samplers used on the wide variety of available manned and unmanned vehicles. Presently, equipment generally needs to be developed for a specific vehicle, thereby limiting flexibility in choosing vehicles for a field operation. This is a major limitation in designing sensor systems (one of my research interests).

Interchangeability is an issue at a variety of levels: size/weight, electrical/hydraulic power requirements and connectors, data communication interfaces and connectors, need for certain kinds of manipulators, etc. Some degree of standardization of designs (or establishment of minimum design specifications) for future vehicles, or for vehicles undergoing refits, would be a major step forward. As a first step, perhaps the workshop could recommend a priority for standardization (e.g., standard data interfaces and electrical/hydraulic hookup would be relatively easy to address). One obvious (insurmountable?) problem, however, is convincing the disparate vehicle operators that this kind of standardization is in their best interest. Encouragement from this workshop, however, would be a good first step.

Where is Submergence Science Going?
Clearly there will be a continuing need for "more of the same"(e.g., research on hydrothermal vents/plume, submarine seeps, benthic communities, submarine geology/geophysics), and proposal pressure for these types of research will undoubtedly continue or increase. However, there are other applications for submergence platforms that will likely develop over the next decade if the proper tools are available. For example, there is an increasing interest in the oceanographic community on fine-scale water-column work in deep water (e.g., the role of particle layers and marine snow in controlling vertical fluxes of carbon and nitrogen). Samplers lowered via winches from surface ships are largely useless for these studies because of heave and surface waves; the only practical approach is via submersibles and ROVs. Unfortunately, submersibles must be rated for the full water depth at the site, making them a very expensive way to sample chemical/biological fine-scale phenomena occurring at depths of less than 500m. ROVs with greater payload, dexterity, and high-band communications than commonly available

now could be much more cost effective means of doing this work. Our presently funded work on this type of research would be much more effective if we access to such devices.

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**Daniel Scheirer**


| | |
|---|---|
| Organization: | Brown University |
| Address: | Dept. of Geological Sciences, Box 1846 |
| City: | Providence |
| State/Province: | RI |
| Country: | USA |
| ZIP Code: | 02912 |
| Email: | scheirer@emma.geo.brown.edu |


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1. Field of Expertise: Marine Geophysics

2. Submergence Platform(s) Used: DSL120, ARGOII, Jason, Alvin

3. Workshop Questions:

4. Region of Interest: Pacific and Indian Oceans

5. Types of submergence systems anticipated for work/technology development: unmanned vehicles with sonar, potential field, and visual imaging sensors

6. Abstract:

a) Technological limits?

Demand for deep submergence tools in the UNOLS fleet exceeds supply, with a result that proposed programs compete with each other, at times, on logistic rather than scientific grounds. This often boils down to competition between, say, repeated visits to some sites ("time-series" mode) vs. visits to new and sometimes remote sites ("expeditionary" mode), with scientific objectives that are perceived to be lower-risk vs. higher-risk, respectively. While this limit is not purely technological nor is it unique to the allocation of deep submergence assets (by any means), I believe that investigations in the next decade of both the temporal and spatial variations of deep ocean phenomena will benefit enormously with the availability of more assets which are compatible with more ship platforms.

Of a more directly technical-limitation nature, I view the maximum track-length capabilities of existing systems (in field programs of reasonable durations) as a limitation to studying the seafloor morphology of interesting-sized features (with potentially large depth extent) such as large seamounts and entire mid-ocean ridge spreading segments. Perhaps AUVs are the answer to this large-study-area limitation; I don't think you can do it with a deep human presence, nor with a tether connection.

b) What capabilities should be generally available?
It is essential that deep submergence tools incorporate the technological advances that will be made in the upcoming decade -- enhanced power, data rates, imaging (quantity and quality), and reliability. A spectrum of oceanographic tools should be used on all programs on a routine basis; we visit the benthos infrequently enough and in few places, so maximizing the data (and sample) return is important. If AUVs are the next wave, enhancing real-time communication and real-time data transmission will greatly benefit their scientific return.

c) Where do you see submergence science going?
These are "hopes": I hope it expands into less traditional study areas, such as mid-ocean ridges away from the half-dozen or so well-studied ones, mid-plate volcanoes, and subduction zones. Many of these areas will require deeper-capability assets. I think that seismic monitoring of plate boundaries (esp. divergent and convergent) will improve and expand in coverage, but that the compelling nature of their follow-up with deep submergence studies will wane towards the end of the upcoming decade. Finally, I think that it will be essential to present and justify our studies to a broader audience than the deep submergence community; substantial (and successful) efforts to-date will be continued, mimicked, and expanded.

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**Daniel S. Schwartz**


| | |
|---|---|
| Title: | Manager of Marine Operations |
| Organization: | University of Washington |
| Address: | School of Oceanography, box 357940 |
| City: | Seattle |
| State/Province: | Washington |
| Country: | USA |
| ZIP Code: | 98195-7940 |
| Email: | schwartz@ocean.washington.edu |


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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: Johnson Sea-Link, Clelia, JASON, and ROPOS

3. Workshop Questions: What is the impact of emerging ocean observations systems and observatories on the need for deep submergence vehicles?
What are the implications for operators of support and oceanographic vessels to serve the needs of Investigators utilizing both conventional deep submergence assets and future tools such as AUVs?

4. Region of Interest: worldwide

5. Types of submergence systems anticipated for work/technology development:
Manned submersibles.
AUVs.
ROVs.
Large, tethered submersible drilling systems (e.g. PROD).

6. Abstract:
Submergence science is entering an era that will see increased demand for vehicle assets, requirements for intensive data throughput, and substantial commitment of time to labor-intensive undersea research and observing projects. It is perhaps that last point that should concern our community with respect to the quantity of submergence vehicles available and, perhaps more important, their geographical distribution in response to science demand. Ocean observation systems, fiber-optic undersea instrumentation networks, plate-scale to basin-scale operational installations (such as NEPTUNE), and long time-series data acquisition are impossible to conceptualize with the asset inventory and distribution available today. Responsiveness to these emerging requirements, while continuing to meet the needs of Investigators pursuing high-quality science outside of these major programs, will continue to be our defining challenge--rather than technology per se--as the submergence science community (including those who provide essential services to this community) moves into the 21st Century.

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**Timothy M. Shank**

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|---|---|
| Organization: | Woods Hole Oceanographic Institution |
| Address: | Biology Department, MS34 |
| City: | Woods Hole |
| State/Province: | MA |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | tshank@whoi.edu |

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1. Field of Expertise: Hydrothermal Vent Biology

2. Submergence Platform(s) Used: Alvin, Jason, ARGO-II, and DSL120

3. Workshop Questions:

4. Region of Interest:

5. Types of submergence systems anticipated for work/technology development:

6. Abstract:

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**Andrew Shepard**


| | |
|---|---|
| Title: | Associate Director |
| Organization: | National Undersea Research Center at UNCW |
| Address: | 7205 Wrightsville Ave. |
| City: | Wilmington |
| State/Province: | NC |
| Country: | USA |
| ZIP Code: | 28409 |
| Email: | sheparda@uncwil.edu |


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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: We have contracted for Alvin and Jason use

3. Workshop Questions: continental slope work including geochemical and ecological studies of a depocenter off Cape Hatteras NC and hydrocarbon seeps in Gulf of Mexico

4. Region of Interest: Southeast US

5. Types of submergence systems anticipated for work/technology development: use of Jason off vessels of opportunity

6. Abstract:

a) What are the current technological limitations on your research, and what science could you do if these problems did not exist? We are very limited in the availability of funding and systems capable of doing science below 1,000 meters. Specific areas of interest to our funded scientists include slope depocenters, submarine canyons, and vents and seeps. The biggest challenge is getting to these sites. We have many tools developed during shallower studies that can be applied to deeper communities. For example, a slope depocenter off Cape Hatteras has been studied down to 1000 meters, the depth limit of the available submersibles.

From ship samples, we know that the majority of carbon is ending up further down slope. Modeling of the rate and magnitude of carbon (and other materials) flux requires understanding of this end point. In the Gulf of Mexico, we have supported submersible programs that defined hydrocarbon seep communities. Again, these investigations and discoveries are artificially cut off at 1000 meters. Evidence from seismic records suggests that seepage and associated communities may be more prevalent below this depth.

b) What capabilities should be generally available for submergence science?
The scientists we support need to work for hours on a specific location doing a variety of complicated tasks. To date, we have had most success with manned submersibles. Whereas ROVs can work from most vessels of opportunity on the shelf, deeper ROVs require a support ship with dynamic positioning. These are complicated, costly

operations. Alvin is the only sub now available for deep work in our region, and then only when it heads home for refurbishment.

Our scientists require high-quality video (digital, minimum of 500 lines of resolution), and a variety of in situ samplers. Between cores, grabs and specimens, payloads often exceed 50 kg. The vehicle must have the sub-systems to support these capabilities (e.g., power, hydraulics). The success of manned submersibles lies in their lack of a tether, optimal payload, and sampling capabilities.

c) Where do you see submergence science going in the next decade?
Robots without tethers (AUVs) for visual and instrumented surveys. Lighter, deeper manned submersibles for site-specific sampling and experimentation.

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## Craig R. Smith

Organization: University of Hawaii
Address: Department of Oceanography, 1000 Pope Road
City: Honolulu
State/Province: HI
Country: USA
ZIP Code: 96822
Email: csmith@soest.hawaii.edu

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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: ALVIN
SEA CLIFF
TURTLE
ATV
SCORPIO
EPAULARD
PISCES V

3. Workshop Questions: Manipulative experimentation to evaluate processes of faunal succession, deposit feeding, species interactions and maintenance of biodiversity in the deep sea
Manipulative experiments to evaluate sediment geochemical processes at the deep seafloor
Experimental studies of anthropogenic impacts (e.g., nodule mining, sludge
disposal, etc.) in the deep sea

4. Region of Interest: North Pacific, Antarctica

5. Types of submergence systems anticipated for work/technology development:
Manned submersibles able to work to depths of 6000 m

ROVs with high payloads (at least 250 kg in water), precision manipulators, and depth capabilities to at least 6500 m.

6. Abstract:
Current technological limitations on my research:
Current technological limitations on my research fall into four main categories.

1) Depth capabilities: Much of the deep-sea floor of scientific interest falls below ALVIN's 4500-m depth rating. In particular, I am presently planning a study with the International Seabed Authority to experimentally evaluate disturbance and successional processes resulting from manganese nodule mining at depths of about 5000. Such a study could be effectively conducted with a manned submersible with a high payload (250 kg) and a depth capability of 6000 m. No suitable submersible exists in the U.S. for such a study. The ability to directly observe and manipulate at depths below 4500 m would substantially benefit our understanding of deep-sea processes.

2) Imaging quality: Although very high-quality video imaging systems exist for deep-sea application, the best imaging systems are not routinely available on the UNOLS workhorse, ALVIN. My research would substantially benefit from higher resolution video in general, and a high-resolution macro system in particular, being routinely available (at no major additional cost) on ALVIN.

3) Payloads for ROVS: The type of vehicle of choice for many/most manipulative studies in the deep sea (once the site has been directly observed via submersible) is an ROV because of longer bottom times and lower costs. I am unaware of any ROV available with the high payload (250 kg or greater) and precise manipulative capabilities desirable for extensive experimentation (biological or geochemical) at the deep-sea floor. The technology exists, but has not generally been made available (an historical exception is SIO's RUM used in the 70's). ATV is perhaps the best ROV for deep-sea experiments, but its payload and work area (basket) are still very limited.

4) Ergonomics and Endurance: I think few of us would argue that ALVIN is comfortable; in fact, pain tolerance (by both scientists and pilots) may play a significant role in the success of manned submersible dives. It is high time that state-of-the-art ergonomic principles were applied to manned submersibles to improve work efficiency. It would also be very useful to apply the latest battery, life-support and electronics technology to increase submersible endurance (i.e., length of individual dives). Especially in deeper waters, science is often limited by bottom time. (Increasing bottom time may not be highly desirable without ergonomic improvements, however).

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## Deborah K. Smith

| | |
|---|---|
| Organization: | WHOI |
| Address: | Dept. of Geology and Geophysics, MS 22 |
| City: | Woods Hole |
| State/Province: | MA |

Country:
ZIP Code: 02543
Email: dsmith@whoi.edu

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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: DSL 120 system
ARGO II system
British TOBI system

3. Workshop Questions: Most of the questions that I am currently focused on have to do with understanding submarine volcanology. Is it possible to define the extent of a submarine eruption using ROVs? This would require sampling, magnetics, imagery, etc. Can we follow eruptions back to their source vents? Can we determine how important lava tubes are in transporting lavas several kilometers from the primary site of eruption?

4. Region of Interest: I am interested in submarine volcanic rift systems

5. Types of submergence systems anticipated for work/technology development: Autonomous (?) systems that can carefully map out sections of the seafloor in great detail. Vehicles that can go into submarine craters that have vertical walls and overhangs. Vehicles that can go into tube systems (for short distances) to map their sides. Far down the road: systems that can provide basic information on the geochemistry of the rocks while on the bottom.

6. Abstract:
Data collected at various scales of observation are critically important for interpreting the morphology of a volcanic rift zone. In many cases in the oceans we only have the morphology as viewed from the ship (Sea Beam system), and the morphology as viewed from the submarine to work with. It is hard to merge disparate data sets such as these. On land, we use many pieces of information at many different spatial scales to interpret the processes occurring at volcanic rift zones there. These include satellite imagery, photographs from low-flying airplanes and helicopters, and readings, mapping and sampling obtained on foot. We need all of these scales of information from the submarine environment as well.

Volcanic rift zones are often characterized by rough terrain, which is technologically challenging to map and sample. How can we improve our submergence capabilities in such terrain? Towing an instrument such as the DSL-120 kHz 100 m off of the seafloor where the topography on short spatial scales is going up and down by as much as 300 m is extremely difficult. It is hard to interpret the data when we don’t even know the towing characteristics of the instruments. In addition, I have found in my own data from the Puna Ridge, HI that navigation from 2 different instruments towed within the same transponder net is off in places by up to 200 m or so. The community needs to

recognize that scientists will be taking the submergence vehicles to more and more challenging environments and needs to respond to this.

Submergence science in the future in my mind will be moving towards autonomous vehicles. I also think that several capabilities should be merged into one system such as mapping, sampling, and in situ rock analyses, for example.

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**Fred Spiess**

| | |
|---|---|
| Organization: | SIO MPL UCSD 0205 |
| Address: | 9500 Gilman Drive |
| City: | La Jolla |
| State/Province: | CA |
| Country: | USA |
| ZIP Code: | 92093 |
| Email: | fns@mpl.ucsd.edu |


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1. Field of Expertise: Marine Geophysics

2. Submergence Platform(s) Used: Aluminaut, Alvin, MPL Deep Tow, MPL Control Vehicle, ATV

3. Workshop Questions: See RIDGE, SEIZE, Multidisciplinary Observatories on the Deep Sea Floor, Ocean Seismic Network and other workshop reports to which I have contributed. Concerned broadly with science and technology requiring long-term sets of observations or experiments, or detailed descriptions of seafloor characteristics.

4. Region of Interest: Deep Sea Floor

5. Types of submergence systems anticipated for work/technology development: Unmanned, cable connected systems for making detailed observations of the seafloor and for precise placement of heavy objects and conduct of other tasks related to installation, maintenance and recovery of deep sea systems.

6. Abstract:
a) What are the current technological limitations on your research, and what science could you do if these problems did not exist? My current research interest is in seafloor geodesy. At present the field is limited by lack of capability to place measuring devices (precision transponders, absolute gravity meters, precise depth sensors) repeatedly on reference points (benchmarks) without disturbing the reference points at the millimeter level. The result is that, specifically in the use of precision transponders, the expensive transponders must be left on station as the primary reference marks, rather than being moved from one site to another as the complex system elements are in terrestrial geodesy.

I see the work of others constrained by lack of capability to install, maintain, repair and recover system elements at the sea floor.

b) What capabilities should be generally available for submergence science?
The community needs a variety of unmanned work and survey vehicles. These should be available in ways that are flexible to schedule and economical to operate. There should be recognition that there can be many vehicles, since the penalty for not having a particular one in operation on a full year basis is small. A variety of institutions should be operating these vehicles in order that the development of new capabilities can be closely related to, and driven by specific science needs.

c) Where do you see submergence science going in the next decade?
Recognition of what we can learn on the sea floor will continue to expand. Multipurpose observatories will continue to be pursued, and should be implemented in collaboration with other investigators concerned with the sea surface and the regions in the air above and the upper reaches of the water column. Proposed observatories (and less grand ones that already exist) will open up questions that we cannot anticipate and that will require new kinds of investigations in special or widely ranging sites remote from the "OBSERVATORY".

Use of manned vehicles will decline substantially if there is access to a capable stable of unmanned vehicles. The present situation is that manned vehicles in the deep sea do not put the scientist any closer to the job than unmanned vehicles with fiber optic cable technology. When one is near the bottom in a manned vehicle one has a better view of what is going on through the vehicle's TV than through the observation ports and a remotely operated manipulator system must be used to do the work. This is different from the situation in space exploration, where the scientist or technician can actually carry out the work as one would on the ground. In many instances Alvin is used for seafloor work that could be done by other vehicles because it does not cost the PI anything in his or her proposal.

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**Gary Taghon**

| | |
|---|---|
| Organization: | Rutgers University |
| Address: | IMCS 71 Dudley Rd |
| City: | New Brunswick |
| State/Province: | NJ |
| Country: | USA |
| ZIP Code: | 08901-8521 |
| Phone Number: | 732-932-6555x547 |
| Email: | taghon@imcs.rutgers.edu |


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1. Field of Expertise:

2. Submergence Platform(s) Used: Alvin, Sea Cliff, and Delta

3. Workshop Questions:

4. Region of Interest:

5. Types of submergence systems anticipated for work/technology development:

6. Abstract:

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**Shozo Tashiro**


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Title:                  Japanese Deep Submersibles Pilot
Organization:           Japan Marine Science and Technology Center
Address:                2-15 Natsushima-cho
City:                   Yokosuka
State/Province:         Kanagawa-prefecture
Country:                JAPAN
ZIP Code:               237-0061
Email:                  tashiros@jamstec.go.jp
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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: SHINKAI2000
SHINKAI6500
DOLPHIN-3K (Observation only)
KAIKO (Observation only)
ALVIN (Observation only)

3. Workshop Questions: all

4. Region of Interest: Spreaded area, Subduction zone and Polar region

5. Types of submergence systems anticipated for work/technology
development:
   DSRV, ROV, AUV

6. Abstract:
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**Brian Taylor**


Organization: SOEST
Address: 2525 Correa Rd
City: Honolulu
State/Province: HI

Country: USA
ZIP Code: 96822
Email: taylor@soest.hawaii.edu

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1. Field of Expertise: Marine Geophysics

2. Submergence Platform(s) Used: Alvin, Shinkai 6500 Nautile (next year)

3. Workshop Questions: 4 MARGINS Initiatives
- Seismogenic Zone
- Subduction Factory
- Rupturing Continents
- Sedimentary Processes

4. Region of Interest: Global

5. Types of submergence systems anticipated for work/technology development:
All - subs, ROVs, AUVs, observatories

6. Abstract:

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**Maurice A. Tivey**

Organization: Woods Hole Oceanographic Institution
Address: 360 Woods Hole Road
City: Woods Hole
State/Province: MA
Country: USA
ZIP Code: 02543-1542
Email: mtivey@whoi.edu

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1. Field of Expertise: Marine Geophysics

2. Submergence Platform(s) Used: ALVIN, NAUTILE, SHINKAI 6500, JASON, ROPOS,
DSL120, ARGO, ABE (AUV), Various deep tow systems including magnetics and seismic.

3. Workshop Questions: 1) To understand the formation of ocean crust and its subsequent evolution through time. This includes not only the volcanic layer but also the lower intrusive crust such as the dikes and gabbros. Need magnetic vectors by obtaining oriented rock samples or cores.

2) Better resolution of the history of earth's magnetic field behavior such as the Jurassic aged crust of the proto-Pacific. Better measurements in deep ocean require near-bottom sensors. While deep tow is possible it is a painfully slow method of surveying. AUV technology could speed up this possibly even have multiple concurrent AUV deployment and surveying for "swath mapping".

4. Region of Interest: Deep ocean (Pacific, Atlantic, Indian, Arctic, and Antarctic

5. Types of submergence systems anticipated for work/technology development:
1) Broadening usage and availability of autonomous underwater vehicle (AUV) technology for seafloor mapping and high-resolution measurements of seafloor and ocean column properties.
2) Getting oriented rocks and core samples from the seafloor (Probably requires ROV platforms stabilized for drilling outcrops).

6. Abstract:
Technology has often led to new insight into science and the marine geosciences have been no different in this regard. The invention of acoustic sonars and the sea surface magnetometer following World War II led to the validation of a little known theory of plate tectonics. In the early '80s the proliferation of bathymetric swath mapping systems and GPS satellite navigation allowed for exploration of the midocean ridge system on a global scale. In the '90s, deep submersibles and remotely operated vehicles (ROVs) have become a mainstay of subsea sampling and mapping at mid-ocean ridges. At the same time, deep-towed systems for near-bottom seafloor mapping have also become more commonplace, providing a more detailed picture of the seafloor for in situ sampling and exploration. However, the effort involved in carrying out these deep-towed surveys requires large personnel teams, specialized ships and cables, clement weather and a survey program designed around the capabilities of the tow wire and the ship's towing characteristics rather than the seafloor geology.

Eliminating the tow cable represents a leap in technology from surface dependent sensors to smart robots i.e. autonomous underwater vehicles or AUVs that can function independently on the seafloor. AUVs represent the next wave in technology, which promises to revolutionize the way science is done in the ocean. These relatively inexpensive systems can operate from any ship of choice and do not require sophisticated ship dynamic positioning systems or cable winch systems. They can be deployed for short periods in site survey mode or for an extended period in monitoring mode.

AUVs could also be rapidly deployed in response to events such as seafloor volcanic eruptions, earthquakes or catastrophic hydrothermal venting. The tetherless AUV means that surface sea state conditions and ship operations are no longer the prime logistical considerations. At present only a few AUVs are available to the scientific community and then only in a developmental mode. While there are development issues still outstanding such as battery power and navigation, the basic operational mode are now well known and vehicles currently exist that offer stable platforms for scientific use. The

deep submergence assets of the UNOLS system should seriously look at the implementation of an AUV building program. This is certainly where the technology will have the biggest impact on science.

On another issue, I think it is also time for deep submergence vehicles to get serious about making properly oriented sample collection on the seafloor. Only though the careful orientation of rock samples on land can we determine the tectonic history and interrelationships of adjacent rock units. This has not been done on the seafloor except very recently with remotely operated wireline drilling on Atlantis Bank in the Indian Ocean. These small drill rigs however are limited to very level terrain and only ROV vehicles have the innate capability of being able to drill outcrops on a rugged seafloor.

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**Robert F. Tusting**


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|---|---|
| Title: | Sr. Systems Engineer |
| Organization: | Harbor Branch Oceanographic Institution |
| Address: | 5600 U.S. 1, North |
| City: | Ft. Pierce |
| State/Province: | FL |
| Country: | USA |
| ZIP Code: | 34946 |
| Email: | keen@hboi.edu |


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1. Field of Expertise: Ocean Engineering

2. Submergence Platform(s) Used: JSL I & II, CLELIA, ALVIN, VENTANA, TIBURON

3. Workshop Questions: Can the sampling and collecting tools being developed at HBOI be employed in future deep-ocean research?

4. Region of Interest: Worldwide

5. Types of submergence systems anticipated for work/technology development: Biological & Geochemical Sampling, Quantitative Imaging

6. Abstract:


Over the past 20 years, Harbor Branch Oceanographic Institution has developed a number of specialized scientific sampling, imaging and measurement systems. Many of these have been designed and built or adapted for use on other deep-submergence vehicles such as ALVIN and the MBARI ROVs.

Both the Marine Operations and Ocean Engineering Divisions at Harbor Branch Oceanographic Institution have a long-term interest in further development of tools for submergence science. Attendance at this workshop will help us to anticipate future needs of the research community and will allow us to focus our development efforts.

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**Cindy Lee Van Dover**


| | |
|---|---|
| Organization: | College of William & Mary |
| Address: | 328 Millington Hall |
| City: | Williamsburg |
| State/Province: | VA |
| Country: | US |
| ZIP Code: | 23187 |
| Email: | cindy_vandover@wm.edu |


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1. Field of Expertise: Hydrothermal Vent Biology

2. Submergence Platform(s) Used: Alvin
Sea Cliff
Mir
Delta
Jason
ATV
DSL 120
ARGO

3. Workshop Questions: biogeography, astrobiology, ecology

4. Region of Interest: global

5. Types of submergence systems anticipated for work/technology development:
manned, ROVs, AUVs, observatories

6. Abstract:
Current Limitations:
- Frequency of sampling and of deploying/recovering instruments.
- Ability to access remote sites with suite of deep submergence assets.

Capabilities available for deep submergence science:
- 24-h ROV ops at 6500 m or less with full suite of capabilities (mapping at multiple scales, including imagery, sampling, instrument deployment and recovery)
- manned ops at 4500 m or less with full suite of capabilities

Future:
- maintenance of current level of expeditionary and short time-scale
- observations and expansion of observatory capabilities.  Both approaches are complementary.

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**Karen Von Damm**


| | |
|---|---|
| Organization: | University of New Hampshire |
| Address: | Dept. of Earth Sciences, James Hall |
| City: | Durham |
| State/Province: | NH |
| Country: | USA |
| ZIP Code: | 03824-3589 |
| Email: | kvd@cisunix.unh.edu |


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1. Field of Expertise: Geochemistry

2. Submergence Platform(s) Used: Alvin, Jason

3. Questions Desire Addressed by Workshop: What future mix of tools will best address what the community needs to accomplish the science goals and question they foresee for the next decade.

4. Region of Interest: The global ocean

5. Types of submergence systems anticipated for work/technology development interested in:
Improved ROVs, continued human access, increased ability for remote vehicles to make chemical measurements in situ as well as to collect (and preserve) samples.

6. Abstract:

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**Barrie Walden**


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|---|---|
| Title: | Mgr. Operational Scientific Services |
| Organization: | WHOI |
| Address: | Smith 301 |
| City: | Woods Hole |
| State/Province: | Ma. |
| Country: | USA |
| ZIP Code: | 02543 |
| Email: | bwalden@whoi.edu |

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1. Field of Expertise: Deep Submergence Vehicle Operator

2. Submergence Platform(s) Used: ALVIN
Argo
Jason
DSL120
ABE

3. Workshop Questions:

4. Region of Interest: World wide

5. Types of submergence systems anticipated for work/technology development:

6. Abstract:

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**C. Geoffrey Wheat**


| | |
|---|---|
| Organization: | University of Alaska Fairbanks/NURP |
| Address: | PO Box 475 |
| City: | Moss Landing |
| State/Province: | CA |
| Country: | USA |
| ZIP Code: | 95039 |
| Phone Number: | 831-633-7033 |
| Email: | wheat@mbari.org |


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1. Field of Expertise: Geochemistry

2. Submergence Platform(s) Used: Alvin, Turtle, Sea Cliff, Pices V, Delta, ATV, Ventana, ROPOS, and Jason

3. Workshop Questions: What are the driving forces and effects of seawater circulation through the oceanic crust? This question includes both hydrothermal circulation driven by the intrusion of basaltic magma (Ridges and Hot Spots) and lithospheric cooling (Flanks) and the egress of fluids from seeps that are caused by compressional forces (Subduction Zones) and gradients in hydraulic head (Groundwater).

4. Region of Interest: Pacific Ocean

5. Types of submergence systems anticipated for work/technology development:
ROVs, Submersibles, and AUVs. I am mostly interested in developing the technology that makes AUVs more accessible to scientists, by developing simpler and more robust operational interfaces and a variety of instrument packages that can be tailored for each scientific mission.

6. Abstract:
The US deep submergence community needs to develop additional capabilities. Given the scheduling problems in the past few years for deep submergence vehicles, the periodic refitting that is required of these vehicles, and the possibility of extensive global benthic observing platforms, at least one additional deep submergence vehicle is needed. This vehicle should be a workhorse ROV capable of being deployed to 6000 m and be a hydraulic-based vehicle either with (e.g. ROPOS) or without (e.g., ATV and Tiburon) a cage-tether handling system. No technologic advances are required for operating such a vehicle. At present AUVs have yet to make the significant contribution to ocean sciences given the potential capabilities of these vehicles. The technology involved in operating these vehicles must be transfer to the scientific community. In addition the scope of instrument packages that these vehicles can accommodate must be expanded for broad-based usage. Given the growing interest of scientists, business enterprises, and the general population in the deep sea, the next decade should see expanded requirements and needs for deep submergence vehicles.

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**Dawn Wright**

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| Organization: | Oregon State University |
| Address: | 104 Wilkinson Hall, Dept. of Geosciences |
| City: | Corvallis |
| State/Province: | OR |
| Country: | USA |
| ZIP Code: | 97331-5506 |
| Email: | dawn@dusk.geo.orst.edu |

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1. Field of Expertise: Marine Geology

2. Submergence Platform(s) Used: Alvin, Argo I and II, ABE

3. Workshop Questions: - Pros and cons of ROVs vs. submersibles
- Data mgmt./archiving needs of the deep submergence community

4. Region of Interest: SEPR, NEPR, JdFR, Tonga/Lau Basin

5. Types of submergence systems anticipated for work/technology development:
ROVs, possibly AUVs
navigation systems

geographic information systems

6. Abstract:
a) limitations in ability to rapidly collect seafloor observations in real-time (e.g., post-dive transcribing of tapes a major challenge); data archiving and compilation strategies to improve flow and usefulness of observations (to be discussed in my presentation)
b) high quality video, electronic still camera, 35 mm, and navigation, all in real-time; fluid, sediment, rock, biological sampling at precise locations and readily relayed safely to the surface; CTD, MAPR-type measurements profiled in real-time.
c) Seems as though ROVs and AUVs may take over from submersibles

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## A. Aristides Yayanos

Organization: Scripps Institution of Oceanography-UCSD
Address: 9500 Gilman Drive; Department 0202
City: La Jolla
State/Province: CA
Country: USA
ZIP Code: 92093-0202
Email: ayayanos@ucsd.edu

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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: Only free vehicles, sigh!

3. Workshop Questions: The variety of life in the sea has changed over geological time and in our time. How can we characterize these changes and place them in relation to changes in the physical, chemical, and terrestrial biological environment?

4. Region of Interest: Abyssal and hadal seas

5. Types of submergence systems anticipated for work/technology development:
FIA instruments.
Drifters instrumented for microbiology.
Low-level light detection instruments.
Autonomous vehicles/robots for retrieving live deep-sea animals.
In situ macrophotography and microscopes.
Microscale instruments; instruments on a chip.

6. Abstract:
a)
Maybe the greatest limitation in deep-sea biology is the near inability to find out the natural history of deep-sea organisms. In terrestrial settings, such information is obtained by direct observation and by following organisms as they move about and migrate.
Another limitation is the difficulty of determining the distribution and activity of microorganisms along sections and volumes of the ocean and in conjunction with detailed hydrographic data. Finally, the ability to work with organisms at high pressure is still cumbersome and expensive.

b)
The remarkable developments in the design of unmanned submersibles have not changed the need for manned submersibles. There still are observations and experiments to be done that are impossible without manned submersibles.

c)
(1) I imagine there will be an increased use of cameras, acoustics, FIA instruments, drifters with biological sensors, ROVs, and autonomous vehicles. The data will be increasingly acquired remotely with real-time transmission to the laboratory.
(2) There will be an increased use of `intelligent robots`.
(3) There will be a huge impact of DNA chip technology both in the laboratory and in situ. There will be a drive to archive the DNA and mRNA of deep-sea organisms. The ability to sequence nucleic acids will be extraordinarily simple with new technology. This will open the deep-sea to bioinformatics scientists.
(4) And, I hope, there will be an increasing recognition that a set of key deep-sea environments needs to be identified and studied for a time frame extending at least 100 years. Future scientists will think unkindly of us for not having already started such studies.

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## Dana R. Yoerger

Organization: Woods Hole Oceanographic Institution
Address: Challenger Drive MS #7
City: Woods Hole
State/Province: Massachusetts
Country: USA
ZIP Code: 02543-1109
Email: dyoerger@whoi.edu

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1. Field of Expertise:

2. Submergence Platform(s) Used:

3. Workshop Questions:

4. Region of Interest:

5. Types of submergence systems anticipated for work/technology development:

6. Abstract:

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## Craig M. Young

Organization: Harbor Branch Oceanographic Institution
Address: 5600 U.S. Hwy. 1 N.

City: Ft. Pierce
State/Province: Florida
Country: U.S.A.
ZIP Code: 34946
Email: youngc@hboi.edu

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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: Johnson Sea Link I, II
Alvin
Pisces IV, V
Sea Cliff
Nekton Gamma
Perry Submersibles
Hi-Sub ROV
Ventana ROV

3. Workshop Questions:

4. Region of Interest: Atlantic, Pacific, and Indian Ocean

5. Types of submergence systems anticipated for work/technology development: Improved collecting systems for deep-diving submersibles; ability to collect and maintain discrete, multiple samples in cold (and perhaps pressurized) seawater during ascent.

6. Abstract:

Most deep submergence vehicles have virtually no ability to collect multiple discrete biological samples and keep them healthy and separate during ascent and recovery. This problem has been solved reasonably well on shallow-water vehicles (notably the JSL's) by the use of indexed carousels of specimen buckets coupled with suction collectors. The ability to collect discrete, identifiable samples would greatly enhance exploration and description of communities on small spatial scales, permit collections of healthier animals for on-board experimentation, and encourage the use of deployments, outplants, transplants, and other experimental techniques that give greater insights into biological processes. Good suction samplers also permit multiple replicate collections of early life-history stages that often reside in the interstices of complex communities.

In recent years, work at hydrothermal vents has overshadowed research on other deep-sea systems, even though the latter are overwhelmingly greater in terms of both habitat area and biological diversity. Much of deep-sea biology remains at the descriptive phase, with inferences being based on correlative analysis of often inadequate samples. A greater emphasis on experimentation is needed to understand basic physiological processes such as growth and reproduction, as well as ecological processes that control populations and communities. Continental slopes, with their steep environmental

gradients and relatively easy access, are prime places to conduct experiments that yield insights into basic deep-sea processes; indeed, experiments that are feasible at slope depths are often impossible in the abyss. Although Alvin is capable of working at slope depths, there are much better and cheaper alternatives (both manned and unmanned) that should receive full support from UNOLS and NSF.

From all indications, submergence science will continue to be driven by the desire of geologists and geophysicists to understand the dynamics of the earth's crust. In biology, I hope to see more focus on fundamental, unresolved questions about how deep-sea systems function at all levels of biological integration. We need place increased emphasis on non-vent habitats. The deep sea can be sampled with dredges, sledges, cameras, trawls, etc. The great advantage of submersibles is their ability to conduct in situ experiments that test ideas about the functioning of deep-sea systems.

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**Marsh Youngbluth**


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|---|---|
| Organization: | Harbor Branch Oceanographic Institution |
| Address: | 5600 U.S. 1, North |
| City: | Fort Pierce |
| State/Province: | Florida |
| Country: | United States |
| ZIP Code: | 34946 |
| Email: | youngbluth@hboi.edu |


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1. Field of Expertise: Deep Sea Biology

2. Submergence Platform(s) Used: Johnson-Sea-Link, Pisces V, Cyana, Delta, Ventana, Aglantha

3. Workshop Questions: Why should organisms that live in water column environments be investigated with submersibles?

4. Region of Interest: Coastal seas and open ocean environments

5. Types of submergence systems anticipated for work/technology development:
Highly maneuverable crewed and ROV submersibles adapted for operations in the water column.
High resolution cameras with red light; efficient sampling devices; paired lasers; environmental sensors; instrument offload and retrieval capability

6. Abstract:
a) What are the current technological limitations on your research, and what science

could you do if these problems did not exist? b) What capabilities should be generally available for submergence science?

Science and technology are intertwined. Understanding and predicting how living organisms thrive in the ocean interior or learning how inorganic resources consolidate and disperse at the seafloor are difficult tasks. Applications of submersibles (crewed vehicles, ROVs, and more recently AUVs) enable direct access to deep-water environments.

These mobile platforms, when equipped with a suite of sensors, samplers, lasers, and sonar, provide temporal and spatial perspectives that are impossible to obtain with conventional devices like plankton nets, water bottles; grab devices, and vertical profilers. Judicious use of a broad complement of submersibles should significantly enhance assessments of biological diversity, biogeochemical phenomena and environmental change in pelagic and benthic regimes. However, at the moment major sources of funding favor submersible systems that support benthic rather than pelagic operations. Assuming this impediment to mid-ocean access can be resolved, the technologies on the various undersea vehicles that are available for work in the upper 1000-2000 m of the water column need to be upgraded in order to address ecological questions related to distribution patterns, behavioral responses and population dynamics. Camera systems, collecting devices, environmental sensors and vehicle controls should be improved with state-of-practice systems. Submersibles should be configured for quiet, variable speed, ballast-controlled operation. The ability to offload and retrieve instrument packages should be considered essential.

My research has been focused on mesopelagic zooplankton, primarily sort-bodied species. To better quantify their predatory habits, considerably more attention needs to be given to the use and improvement of high resolution, optical equipment that can operate under red light. Likewise, reliable measurements of their metabolic rates require instrument packages that are configured for replicated experimentation in the natural environment rather than shipboard laboratories. Computerized systems that would simultaneously sense a multitude of environmental cues in near real-time would be advantageous for short-term studies of their behavioral responses to physical and chemical signals. All of these technologies are applicable to benthic investigations.

c) Where do you see submergence science going in the next decade?

Forecasting is risky, but based on my sense of impending scientific challenges in the next decade; deep-diving submersibles will be indispensable for answering several pertinent questions. For example, as fish stocks are depleted or when recruitment is poor are opportunistic gelatinous zooplankton predators likely to out compete fishes? What are
the in situ rates, fluxes and mechanisms that influence biogeochemical processes in water column environments? What are the effects of episodic events on biological, chemical and geological features? Is the magnitude of chemicals and biota that are advected from the ocean ridges important? Should waste from fossil fuel (=liquid CO2) be injected into the deep >3500 m sea?

Future success with direct intervention assumes that a greater array of state-of-practice tools like high-definition digital cameras, optical sensors, dissolved nutrient and gas analyzers, and high frequency acoustics will be adapted to undersea vehicles. Future accomplishments will also depend on being at the right place at the right time, not by chance but by design. One effective strategy would be to implement more responsive deployments of submersibles. For example, since episodic plankton blooms and geothermal events can be detected remotely, opportunistic vehicle mobilization would enhance observations of community evolution and dissolution.

From another perspective, it has been obvious for a long time to everyone who has used submersibles that shallow and deep seas are layered, in physical, chemical and biological dimensions. The "new" discoveries of thin layers via profiling instruments need to be aggressively sea-truthed with direct observations from submersibles in order to optimize and guide the progress of models that target such topics as recruitment, food web dynamics, carbon transport, remineralization, bioturbation, and diagenesis. As more comprehensive in situ programs are developed to observe and record variability in deep ocean environments, there will be a commensurate increase in the need to verify remotely gathered information as well as to service the instrumentation.

One further thought is that in situ exploration should lead to in situ experimentation. That's been a guiding tenet for me and many of my colleagues. It's no surprise that the dynamic and alien nature of deep marine habitats demands careful scrutiny. Using submersibles as eyeballs and elevators is insufficient. Future progress in understanding deep ocean processes will depend on carefully organized plans that focus the application of novel tools and new technologies within representative environments. More cross-disciplinary transfer between biological, chemical, and physical oceanographers seems essential. For example, currents carry cues for both larval transport and settlement. Integrated studies of fluid and hydrophilic signals are just beginning in pelagic and benthic boundary-layer regimes. More extensive use of manipulative field experiments will allow better discrimination between alternative hypotheses.

Future progress in science is always illusive. It's easy to say that access to deep pelagic and benthic environments is available with deep-diving vehicles. Unfortunately, unless these platforms are used frequently, they degrade, technologically and operationally. Coordination, networking, and education should be improved throughout the coming decade to ensure regular deployment and continued development of the meager number of research submersibles that are used to conduct scientific investigations worldwide. Coordination, in the sense of planning and scheduling, is tedious but obvious. Training submersible pilots and technicians is often overlooked but essential. Networking, to me, means communication and interaction on an international scale. New programs and facilities are coming on line in Japan, France, and Norway. Consequently, there are multifaceted opportunities for US and foreign scientists to collaborate and to establish long-term, submersible-based programs. This kind of interaction is limited and yet feasible. Such collaboration can broaden scientific discoveries, which in turn might just promote cooperative development of "next generation" vehicles.

Education about the deep sea, at least nationally, has been superficial.

What does that mean? Well, although various media sources have increased public awareness about interactions between natural and anthropogenic changes that occur in the deep oceans, much of the scientific information provided to the public is outdated or wrong. Why? Perhaps because federal support for deep-water investigations from submersibles has been relatively minor and narrowly focused. This monetary constraint is likely to continue in the future unless programs for in situ work are given higher priority and substantially expanded.

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**Jill Zande**


| | |
|---|---|
| Title: | Program & Outreach Coordinator |
| Organization: | Marine Advanced Technology Education (MATE) Center |
| Address: | c/o Monterey Peninsula College, 980 Fremont St. |
| City: | Monterey |
| State/Province: | CA |
| Country: | USA |
| ZIP Code: | 93940 |
| Email: | jzande@marinetech.org |


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1. Field of Expertise: Hydrothermal Vent Biology

2. Submergence Platform(s) Used: ALVIN, Johnson Sea-Links

3. Workshop Questions: Outreach opportunities with submersibles

4. Region of Interest: Pacific, Gulf of Mexico

5. Types of submergence systems anticipated for work/technology development:

6. Abstract:

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# APPENDIX VI

## Related Website Links

### FUTURES Workshop Reports:

**FUMAGES** (MG&G) =>
**http://www.joi-odp.org/FUMAGES/FUMAGES.html**
**http://www.joss.ucar.edu/joss_psg/project/oce_workshop/fumages/**
**FOCUS** (Chemical Oceanography) =>
**http://www.joss.ucar.edu/joss_psg/project/oce_workshop/focus/**
**OEUVRE** (Biology) =>
**http://www.joss.ucar.edu/joss_psg/project/oce_workshop/oeuvre**
**APROPOS** (Physical Oceanography) =>
**http://www.joss.ucar.edu/joss_psg/project/oce_workshop/apropos/**
**LExEn** (Life in Extreme Environments) =>
**http://www2.ocean.washington.edu/lexen/**

### Observatory Links:

**http://vertigo.rsmas.miami.edu/deos.html**

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