SUBMERSIBLE SCIENCE STUDY

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SUBMERSIBLE SCIENCE HAS MADE A REMARKABLE CONTRIBUTION DURING THE LAST DECADE TO OUR UNDERSTANDING OF THE ORIGIN OF THE OCEANS. THE MOST PRESSING NEAR-TERM PROBLEM IS THE REPLACEMENT OF THE DEDICATED SUBMERSIBLE SUPPORT SHIP.

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EXECUTIVE SUMMARY

Submersible science has made an unchallenged contribution during the last decade to our understanding of the continuing evolution of our planet, the structure and volcanic activity of the ocean floor and the manner in which the cooling of the earth's crust involves an interaction with the hydrosphere and atmosphere.

The success of submersible science is due, to a great extent, to the availability of a block-funded UNOLS national facility capable of putting the powers of deductive reasoning aboard a deep-sea exploration vehicle with unique capabilities for close up observation, measurement and sampling.

In order to provide U.S. scientists with both an access to distant and remote geographic areas with high scientific priority and a greater payload for new tools and experiments, there is an urgent need to replace the existing dedicated support ship for the submersible ALVIN.

This study, prepared by oceanographers, submersible engineers and submersible operators offers the following **near-term recommendations:**

- Modify ALVIN, as soon as practical, to a single point lift to allow launch and recovery from a single hull oceanographic research vessel.
- Retire R/V LULU and replace her with either the conversion of one of the large UNOLS vessels (R/V MELVILLE, KNORR or ATLANTIS II) or an existing dedicated submersible support ship available for lease from industry. The replacement ship requires, as a minimum, a range of 8000 nautical miles, a cruising speed of 10 knots, an endurance of 30 days independent from an escort vessel, low speed maneuverability, a scientific party of 10 persons, a submersible support crew of 10, and 1750 ft^2 of scientific work space.
- The replacement support vessel should be equipped to operate unmanned tethered and autonomous submersibles alternately with the manned submersible.
- The replacement support vessel should be outfitted with a hydraulic powered stern-mounted A-frame for launch and recovery of submersibles in Sea State 4.
- ALVIN should be progressively upgraded with improved scanning sonars, navigation, additional video cameras, improved tools, onboard electronic instrumentation and telemetry to the surface ship and "bottom landers".
- The ALVIN and its replacement support vessel must continue to be funded as a single dedicated facility, managed and operated by a leading oceanographic research institution.
- Shallow-water manned submersibles and vehicles for mid-water and under-ice missions should be acquired on an individual and part-time basis by lease from industry. Further technological development of submersible subsystems and robotic vehicles needs to be encouraged within the peer-review proposal system because the existing track record shows numerous examples where scientific discoveries follow in the wake of the technical improvements to remote observational and surveying instrumentation.

The principal **far-term recommendations** are:

- Availability of a manned submersible with improved mission capabilities and a depth limit of 6000 meters. Federal agencies should assist, wherever possible, qualified U.S. scientists in obtaining some access to the U.S. Navy's SEA CLIFF and foreign submersibles under construction which can explore the ocean to a depth of 6000 meters.
- Today's technology with titanium hulls and syntactic flotation places weight restrictions on launch and recovery systems, and impacts the support vessel itself, the submersible endurance, speed and maneuverability. Because there will be a minimum of two 6000 m submersibles by the end of the decade (one which is clearly thought of as an oceanographic research tool) there is no perceived disadvantage to a "wait and see" attitude. New technologies such as fiber composite materials, fuel cells, artificial intelligence, and advanced hull designs for support vessels have the potential to offer tremendous advantages to the mission capabilities of far-term manned and unmanned vehicles.
- Only after it is demonstrated that the ocean beyond 4000 meters holds a scientific promise which neither existing U.S. nor foreign manned or unmanned submersibles can adequately address should a new dedicated deep-ocean UNOLS national facility be constructed.
- Continuing technological innovation should not be sacrificed at the expense of only funding science as federal budgets are reduced. The ground work necessary for the design and fabrication of future deep-ocean submersibles should have many beneficial spin-offs to the non-diving oceanographic community during the next two decades.

1. INTRODUCTION

The mandate for this Submersible Science Study was to first review the past, present and then predict the future requirements for a national technical facility which gives access to the ocean from submerged "manned" vehicles. The study was given sufficient breadth for consideration of alternative and complimentary "unmanned" submersibles. In this report you will find specific near-term and far-term recommendations which, after evaluation of their estimated effectiveness and cost, have been assigned priorities.

1.1. Project Team

The study was accomplished with the interaction of a Science Panel, a Task Force and a Project Office. The Science Panel consisted of a team of research scientists. As submersible users they were asked to draw from their experience and scrutinize the role that observation, measurement and sampling from a submersible platform plays in the larger context of describing and understanding how the ocean works. The Task Force, on the other hand, comprised engineers, operators and designers of submersibles. The technical team represented government, private industry, academic institutions and research foundations. Their responsibility was to translate scientific objectives and mission requirements into specifications for submersible systems, including the support vessels. Their objective was to look not only at the submerged vehicles, but at their suite of instrumentation, life support and control subsystems, launch and recovery operations, logistics, maintenance and managerial procedures. The Project Office served as an anchor for the study. It organized the various meetings, assembled the draft reports, obtained external reviews and took responsibility to edit and pare down all the research materials into this final document.

2. PAST AND PRESENT RESEARCH REQUIRING SUBMERSIBLES

The great success story for submersibles has been the unraveling of the volcanic processes and hydrothermal activity that take place during the creation of the ocean's crust. The submersible has turned out to be an ideal tool for observation of the fundamental structure of the deep-sea floor on the same visual scale that we are accustomed to on land. The manned submersible provides direct eyeball observations, a high degree of maneuverability and the manipulation necessary to make accurate measurements and collect precisely located samples. It is the latter feature - manipulation - that gives the manned submersible the unique advantage over any other deep ocean "probing" tool presently available to the academic research scientist.

2.1. Mid-Ocean Ridge

The focal point in the study of the Mid-Ocean Ridge has been the exploration of the axial rift valley. By concentrating on young terrains where sediment is absent or relatively thin, the geologists have had the opportunity to conceptualize the three-dimensional spatial relationships of the volcanic flows, fissures and faults which create and then shape the oceanic crust. The submersible has not returned any rock types that have compositions significantly different than those recovered by conventional dredging or deep-sea drilling. The submersible has, however, allowed the great variability of surface rock composition and texture to be deciphered in the context of local structure, morphology and proximity to centers of magma extrusion. Perimeters of individual out-pourings have been circumnavigated, guided by the visual estimates of the freshness of the volcanic glass. Magnetic transition zones have been shown to be exceedingly narrow by using gradiometers positioned in known orientation just a few centimeters from the bedrock surface. The presence of a buried magma chamber has been deduced from a profile of on-bottom gravity stations. The temperature of water ejected from hydrothermal vents has been measured by inserting needle probes into chimney walls. The vents themselves have been found by sensing the presences of fish and seeing shimmering water.

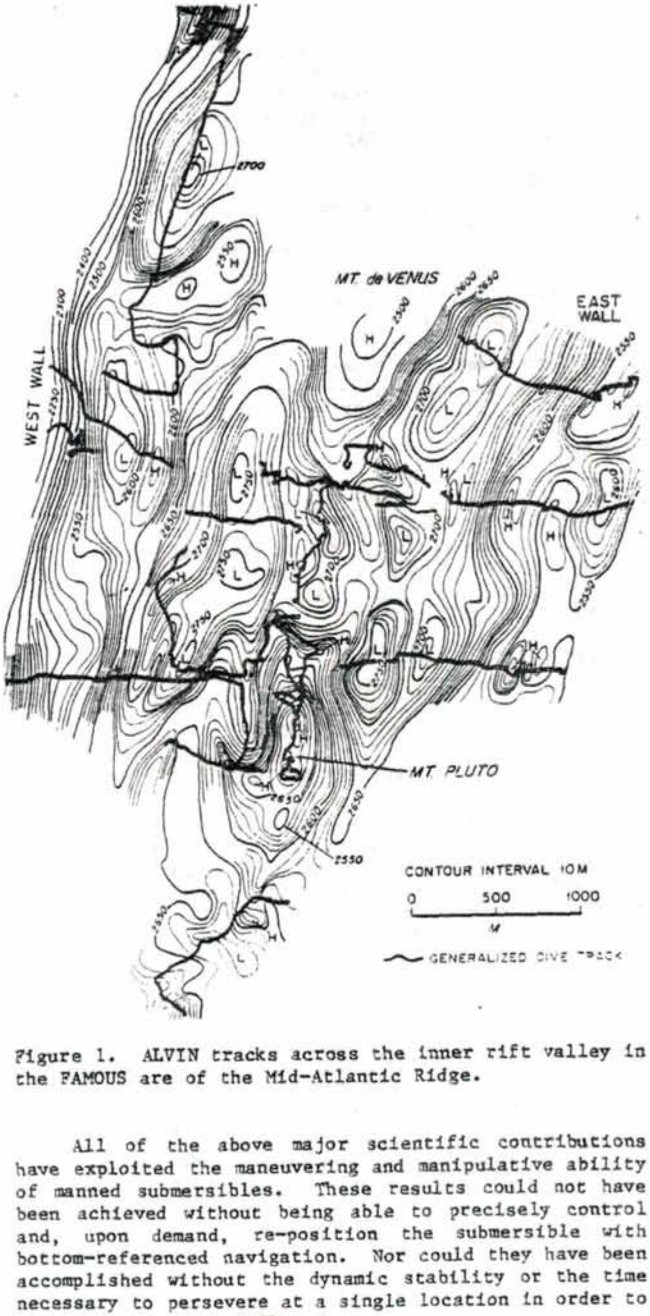

Figure 1. ALVIN tracks across the inner rift valley in the FAMOUS are of the Mid-Atlantic Ridge.

All of the above major scientific contributions have exploited the maneuvering and manipulative ability of manned submersibles. These results could not have been achieved without being able to precisely control and, upon demand, re-position the submersible with bottom-referenced navigation. Nor could they have been accomplished without the dynamic stability or the time necessary to persevere at a single location in order to obtain repeatable results.

Unmanned vehicles have also played their own important role in our understanding of the tectonics and volcanism of the Mid-Ocean Ridge. Deep-towed side-looking sonars and narrow beam echo-sounders show the asymmetric listric fault blocks, fissures and split volcanoes which reveal the extensive stretching of the basaltic layer of the ocean crust. Near-bottom towed magnetometers convincingly demonstrated the narrowness of the zone of lava extrusion and dike injection. Tethered cameras have been extremely efficient in mapping out the distribution of thermal springs and their associated biological communities. Away from the Mid-Ocean Ridge crests at sites with an appreciable overburden of sediment, the deep-towed sub-bottom reflection profiler has allowed mapping of the buried volcanic bedrock structure which is otherwise hidden from direct visual observation. The robotic systems, in particular, excel at covering relatively large tracts of seafloor compared to the manned submersible, by their ability to operate in severe weather that prohibits diving, and from the systematic broad scale coverage that they offer. The unmanned remote sensing systems have greatly assisted in targeting the manned dives to interesting, representative and productive locations.

The constructive and fruitful combined use of manned and unmanned submersibles has accelerated our understanding of the circulation of sea water deep within the crust of the Mid-Ocean Ridge. The tethered vehicles provide mosaic photography, mapping of thermal plumes, and the overall picture of tectonic lineations and fabrics. Scientists in manned submersibles have captured in situ hot venting waters rich with minerals and chemicals leached from the igneous crust. They have also analysed the behavior and nature of unique and rather astounding biological communities that graze on sulfur-reducing bacteria reproducing in the anoxic subsurface waters.

The metallic ore deposits brought up by manned submersibles are not very different than those occasionally cored by GLOMAR CHALLENGER at the base of the sediment layer above the Mid-Ocean Ridge flank. These ores, in fact, are rather similar to those exploited for centuries on land in proximity to ophiolite complexes (i.e. slivers of ancient ocean crust incorporated within thrust sheets of terrestrial mountain belts). It is, however, the overall combination of the sub-sea visual observations of the hydrothermal activity, the controlled geophysical measurements and geological, chemical and biological sampling, and the conceptual picture of the active physical environment characteristic of the Mid-Ocean Ridge rift valley made by submersible users which gave us the breakthrough knowledge that the very chemistry of our ocean and atmosphere may somehow have been controlled by the thermal springs which precipitate the metallic ores.

2.2. Ocean Basin Floor

Submersibles have been productive in the exploration of oceanic rises, seamounts, and fracture zones. Again, manned and unmanned systems have been used effectively together. Important insights to the Benthic Boundary Layer and the susceptibility of pelagic clay to erosion from abyssal geostrophic currents have been gained with the ability to examine in place the undisturbed sediment/water interface. Towed sonar imaging systems display the geometry of the large erosional and depositional bedforms such as sediment ridges and furrows. Manned submersibles permit particle by particle flocculation to be observed, the "fluff" layer to be sampled, and such small bedforms as individual ripples to be recovered for textural study and hydrodynamical modeling. Manned submersibles lack the endurance to make critical long-term observations. To this end oceanographers have substituted bottom-moored observatories to measure variations in currents, fluctuations in the amount of sediment in suspension, water chemistry, thermal structure and even physical changes on the sediment carpet captured with time-lapse photography. These self-recording "bottom landers" are recalled to the surface after periods of days to months. Manned submersibles have been vital on occasion to move the moored instrumentation to specific target locations such as valley axes or seamount crests. Once in a while manned submersibles are called on to service or retrieve instrument packages that will not return on their own. The great investment made in recording long-term measurements has made these rescue missions cost-effective.

2.3. Continental Margins

Perhaps submersibles have been most widely used for the study of the continental margins. The continental shelf and slope contain potential oil and gas reserves, as well as living resources with commercial value. Direct seafloor visual observation is considered necessary for baseline studies of benthic ecosystems. Questions of scale effects of environmental heterogeneity in space and time are important. Submersibles have been particularly helpful on the continental slope where gullies and canyons offer unique substrates and patchiness is the rule. Submersibles were responsible for the discovery of "Pueblo Village" communities which offer important nurseries and habitats-shelters for a great many species. Seafloor observations have shown episodic recruitment patterns characterize many, if not most, benthic ecosystems.

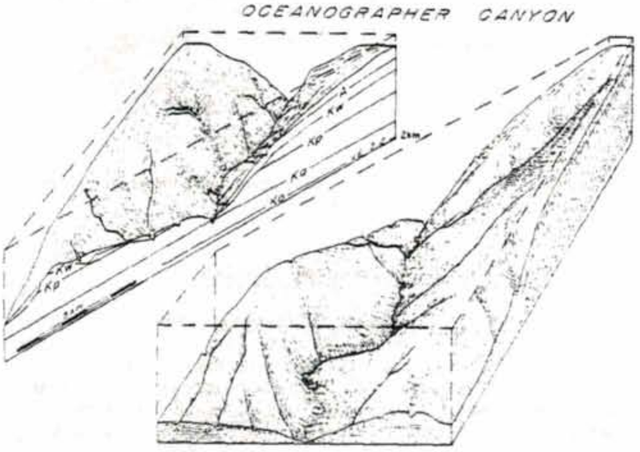

Figure 2. ALVIN tracks in Oceanographer Canyon on the continental slope of New England.

Although bottom-towed photographic sleds have been dragged through many submarine canyons and have taken tens of thousands of still photographs, manned submersibles are needed for behavioral studies and for particular problems with taxonomical identification. The interplay of manned and unmanned observational vehicles has been successful for the assessment of the size and areal distribution of benthic populations, particularly the attached epi-fauna which is substrate controlled.

Certain deep-sea corals and anemonies signal the exposure of firm and generally ancient substrates as the result of erosion and slumping. Other fauna have been shown to concentrate on canyon walls where they can gather in nutrient-rich material maintained in suspension by tidal currents.

Manned submersibles have been used in an opportunistic mode to pluck geological samples from local outcrops on canyon walls and along the near vertical face of carbonate escarpments. In certain frontier areas such as Georges Bank the stratigraphy of the buried shelf was first revealed prior to commercial exploratory drilling by carefully targeted sampling with respect to multi-channel seismic reflection profiles. Several representative samples from thousands of meters of the precipitous Bahama and Blake Plateau Escarpments have been recovered by the submersible manipulator. These stratigraphic cross-sections record the subsidence history of the continental edge and the past changes of sealevel extending back in time more than 100 million years.

Figure 3. Stratigraphic sampling of Heezen Canyon using the manipulator arm of ALVIN.

2.4. Baseline Environmental Studies

Considerable "mission-oriented" research takes place on the continental margin (i.e., research required by congressional mandate or the specific needs of industry). Among the "mission-oriented" programs there have been fundamental biological programs to determine the rates of growth, mortality, fecundity, reproductive cycles, and longevity for species of commercial value and dominant species of particular importance in maintaining optimal community structure. Other federally funded projects are presently attempting to deduce the population structure and distribution of benthic communities and species geographically and with depth and relate these population characteristics to substrate or habitat. A manned submersible has recently located and surveyed the talus mound of a borehole of the Deep Sea Drilling Project to try to quantify the rates of community development, colonization and life span. A few seafloor stations have been re-occupied on almost an annual basis to investigate biotic relationships between species (e.g. predator-prey, commensal and parasitic relationships) and interspecific and intraspecific competition of component species of the ecosystem for food and shelter.

Federal agencies have chartered UNOLS submersibles to assess the natural hazards to oil and gas exploration activities resulting from slope instability and slumping. Other projects include the monitoring of industrial and municipal waste disposal activities. In this regard the unique manipulative capability has permitted the recovery of canisters containing low-level radioactive materials to learn the results of twenty years of corrosion, dissolution and decay. Tethered photographic vehicles have been used to search for and document the condition of disposed munitions as well as vessels scuttled at sea with toxic wastes. Deep-tow scanning sonars equipped with magnetometers were used effectively in the past to locate imploded submarines and other vessels with archeological interest, such as the Civil Was iron-clad ship MONITOR. Bronze Age to Industrial Age artifacts have been photographed and a few objects have been recovered for museums.

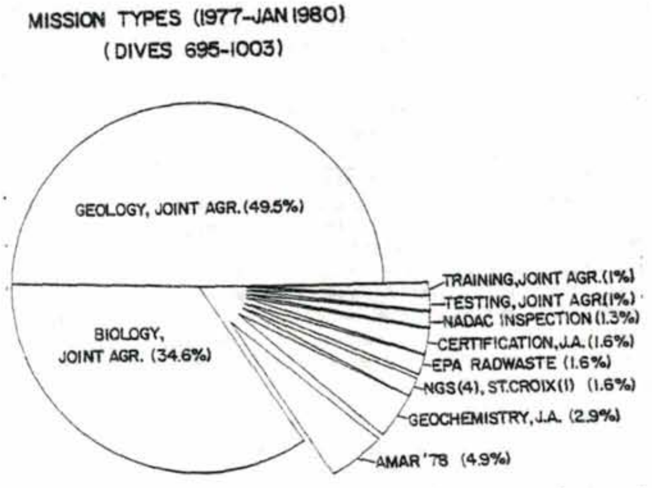

Figure 4. Distribution of ALVIN dives according to mission and scientific discipline.

2.5. Water Column

There has been only a modest use of manned submersibles to study mid-water biology, chemistry and physical oceanography. One of the several problems is that large, well-lit and heat-generating vehicles perturb the local environment and create undesirable turbulence. Another drawback is that submersibles have difficulty maintaining a static relationship with floating objects. Special optical devices for enlargement are needed. Nevertheless, the invention of the "slurp gun" has been a great boon for the collection of tiny planktonic protozoa and gelatinous organisms. Along with basic descriptive information, the submersible-related activities have included behavior, reproduction, feeding relationships, commensals, energy budget and nutrient studies. Extremely delicate large organic aggregates up to 20 meters in length have also been successfully captured and returned to the surface intact.

Vertical eddy diffusion in the ocean interior has been visualized by using dyes and camera or video photography. Kelvin-Helmholtz type rolls on high density-gradient "sheets" have been seen in the Mediterranean seasonal thermocline.

3. WHAT PAST SUBMERSIBLE STUDIES HAVE IN COMMON

Submersible studies generally encompass small "postage stamp" investigations of the ocean floor. In almost every case the area of interest is selected on the basis of data collected from surface ships, often on a reconnaissance basis. The next step is the generation of a good working map, at least on the scale of 1:100,000 or more detailed. The map is made either by hand-contouring with a conventional tight grid of ship sounding lines, with a multibeam automatic bathymetric contouring system or by using a deep-towed geophysical survey. Remote seafloor photography has been an indispensible tool to broadly characterize the visual seafloor into provinces that required further observations with manned submersibles.

The tethered and autonomous vehicles serve the purpose of providing "ground truth" to the large-scale survey and various geophysical models. Sometimes they provide a unique measurement and sampling capability.

The complexity of submersible studies is bimodal. About 50 percent of the DSRV ALVIN operations in the last five years required a large specialized oceanographic research vessel as an escort ship (usually a UNOLS fleet vessel). The scientific party may total to 30 persons. At-sea analysis of data and simultaneous ancillary data collected keep the escort ship fully occupied. On the other half of the expeditions, the scientific team averages fewer than six persons and is berthed entirely on the support vessel R/V LULU. The less complicated projects still have, for the most part, well-planned agendas and specific objectives.

In the past the submersible investigations have benefited from accurate bottom-referenced navigation. Such acoustic navigation using recoverable transponders has been expensive, so it is not routinely funded and has, in fact, been deployed for less than one half of the diving projects.

Submersible users commonly study small scale features such as individual seafloor structures or discrete animal communities. In a given year about 15 percent of the ALVIN dives have been spent at a single site (e.g. either re-occupying a biological station or intensively sampling a hydrothermal mound). Another 20 percent of the dives have taken place along a transect such as across the rift valley or systematically sampling outcrops from the wall of a submarine canyon). Approximately 50 per cent of the dives wander around in a single one square mile box (e.g. mapping the plan view shape of volcanic flow deposits or measuring the lineations of faults at a ridge/transform intersection. Only a minority of the dives are carried out on a "look, sample and move on" basis with all the directives originating from the scientists in the submersible.

The dives that are designed to study "sea floor processes" have been handicapped because of the non-steady state behavior of currents, animal behavior and tectonic or volcanic activity. Except for the U.S. Navy's nuclear research submarine NR-1 which has been made available on a limited basis to some academic scientists, bottom observation time for manned submersibles is limited to several hours.

The principal gain to "basic research" has been accomplished by bringing observation and sensors closer to ephemeral or intermittent phenomena than permitted by any other type of robotic exploration vehicles. If one asks for the single capability that makes the manned submersible necessary, the answer most often heard is the ability to manipulate sensors and sampling devices interactively using human vision and judgement.

Some manned submersibles can get down into fissures and in canyon thalwegs that are otherwise unnavigable by tethered systems. Past submersible usage has concentrated on controlled sampling and the benefits of actually observing the sampling process. External video cameras have significantly assisted this activity and continuous video and audio recording has been widely used to document the dives. If one asks for the single attribute which links the use of manned submersibles with good science, the most often heard answer is the confidence one has in knowing the orientation and spatial relationships of the object that is being measured or sampled.

4. PRESENT TECHNICAL LIMITATIONS AND DEFICIENCIES

The most serious limitation which is perceived to confront present users of ALVIN is the operational range and mission logistics which can be provided by the support vessel R/V LULU. There exists a well-articulated and widely-shared desire to carry out diving missions in remote areas of the oceans and at higher latitudes where there are significant weather considerations. Remote areas require long transits that consume too much time and too many expendables by R/V LULU. On far-ranging expeditions there must be the capability to undertake more comprehensive field maintenance and repair than can be supported from R/V LULU. The past and present necessity to have an escort vessel accompany the submersible support ship has meant that more tha $1 M/year of additional ship operating costs have been assignable to ALVIN diving operations. Increase in transit speed to 10 knots would increase potential "on-station" days by 25 per cent and would translate to approximately two more expedition legs per year.

The remote areas for which excellent scientific proposals have been received include missions to the marginal seas, aseismic plateaus and seamounts of the Western Pacific, the Juan de Fuca Ridge in the Northeast Pacific which has the only discovered hydrothermal deposits within the U.S. economic zone, fast-spreading Mid-Ocean Ridges in the South Pacific, and continental margins in the eastern North and South Atlantic. Proposals for the Indian Ocean and Norwegian Sea have simply not been written, because the prospects that logistics would allow with expeditions have been unrealistic.

Past and present schedules have been greatly influenced by weather conditions. There is a strong correlation from year to year of latitude with season (Fig. 5). The somewhat fewer dives accomplished in some summer months reflects long transits of R/V LULU at times of optimum weather (Fig. 5). More time is spent, for example, in the Bahamas each year than would be justified by a greater mobility and weather tolerance for the submersible/support ship system.

A majority of submersible users report that they feel spacially disoriented when looking obliquely at the seafloor from side viewports. For this reason the submersible has not been a particularly successful visual survey platform. Forward-looking video cameras have helped to address the problem of mentally tracking the movement of the submersible. Seafloor relief is perceived as altitude relative to the viewer, instead of depth relative to a fixed horizontal reference plane. It has been difficult for many users to obtain a good "real time" sense of quantitative changes in seafloor morphology. The optical viewports and wide angle lens of external cameras distort the size and shape of objects. Experience eventually provides an acceptable solution to the psycho/optical problems.

Many users reiterate a frustration at the lack of being able to sample rocks from the face of outcrops. Attempts to deploy a hammer and rock drill have not yet been fruitful. Sampling consumes a major percentage of bottom-time and sampling is, on many occasions, inhibited by clouds of mud stirred up by submersible-produced turbulence. Present submersibles are unable to cling to steep cliffs.

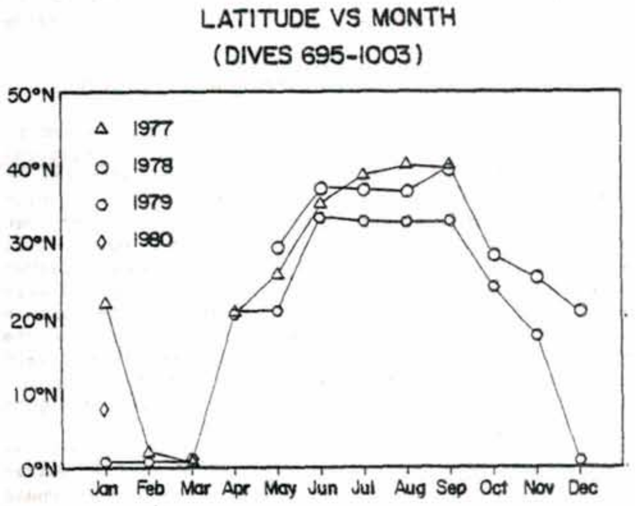
LATITUDE VS MONTH
(DIVES 695-1003)

Figure 5. The latitude distribution of ALVIN dive sites shows a preference to go to the equator in the winter for good weather.

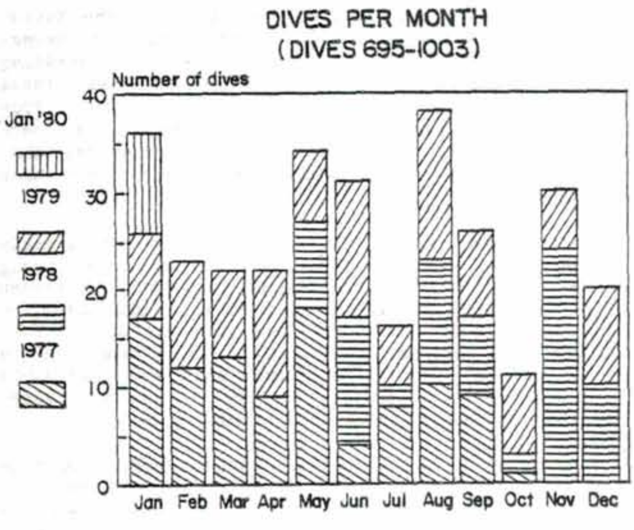
DIVES PER MONTH
(DIVES 695-1003)

Figure 6. The distribution of ALVIN dives during the year reflects maintenance periods and long transits in certain seasons.

Some researchers would like autonomous navigation in the submersible which did not have to rely on ship to submersible voice communication. In ALVIN there is no provision to continuously record the CTFM sonar scanning data. On-bottom time is a function of dive depth. At present average descent/ascent rates of 27 meters/minute for ALVIN, bottom time for a 4000 meter dive is only a few hours (Fig. 7). Although dives range up to 11 hours surface to surface, the greatest number of dives last between 7 and 8 hours (Fig. 8). As mentioned above, the endurance of manned submersibles (a function not only of life support systems and battery power, but also of human fatigue) limits the amount of research that can be accomplished in any one dive day.

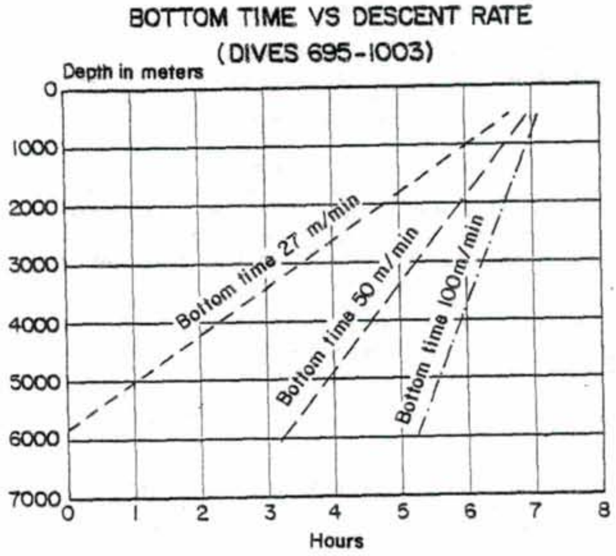
BOTTOM TIME VS DESCENT RATE
(DIVES 695-1003)

Figure 7. The present ALVIN descent rate of 27 meters/minute considerably shortens the bottom time for deep dives.

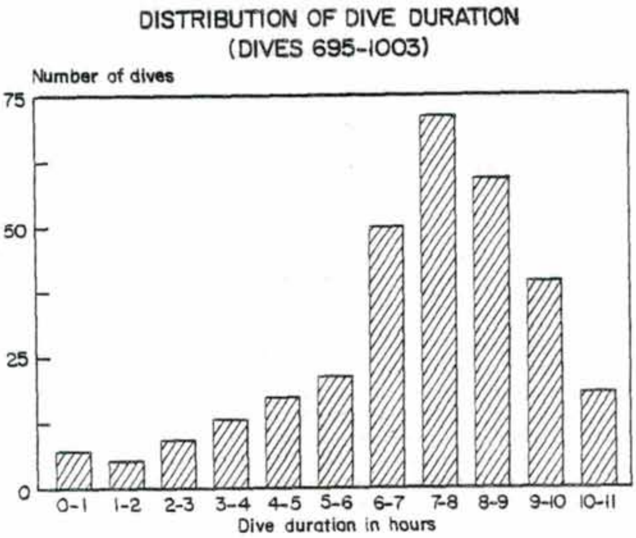
DISTRIBUTION OF DIVE DURATION
(DIVES 695-1003)

Figure 8. The distribution of the length of ALVIN dives from departure to the return to the surface shows a peak between 7 and 8 hours.

5. PAST AND PRESENT ADVANTAGES OF THE VARIOUS SUBMERSIBLE FUNDING MECHANISMS

The existing two-level peer review process has been considered reasonably successful. Those academic proposals which first pass through the review process of the funding agencies are judged on their scientific merit, the significance or relevance of the project study and the qualifications of the investigators. The parallel scrutiny given by the ALVIN Review Committee has acted as an additional filter to help address the age-old question of whether the science being proposed really needs a submersible or whether a submersible can in fact obtain the data which is thought to be the prerequisite to reaching a new level of scientific insight. The peer review process has some critics, but most submersible users believe that it has been advantageous in keeping U.S. submersible science in the forefront of oceanographic science.

For the most part, the "mission-oriented" projects proposed by researchers from agencies which assure grant support without peer review and those projects which automatically get ALVIN scheduling because of intergovernmental funding agreements have not been judged to be as scientifically innovative, productive or fundamental. There are exceptions to the above generalizations.

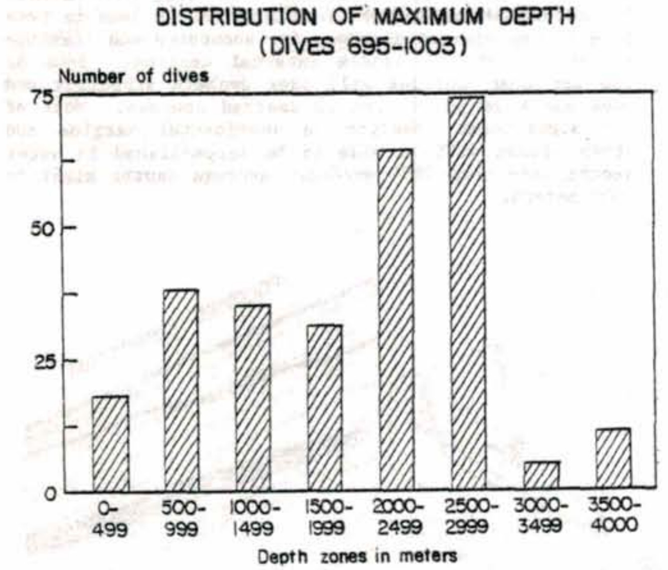

Figure 9. Very few ALVIN dives so far are deeper than the Mid-Ocean Ridge crest.

Manned submersibles have been easy to use. In particular, the operating institution for ALVIN and SEA LINK have been quick, friendly and attentive in their response to the needs of the user. Most of the logistics, most of the purchasing for consumables, and practically all the maintenance and mobilization effort and costs have been transparent to the user. Like the GLOMAR CHALLENGER many of the ALVIN principal investigators have been "suitcase" scientists who have only had to worry about getting themselves, their team, good ideas and a modest amount of technical gear to sea. The challenging and time-consuming process of "interfacing" has been attended to by the operating institution.

When the diving expeditions have required a second large oceanographic research vessel, scientists have had to become considerably more involved in technical and managerial details. Unmanned submersibles have always required that the principal investigators be essentially their own operating organization. They have had to be responsible for both the engineering side and the scientific side of complex and expensive projects. Such investigators have a record of associating themselves with sufficient numbers of first-rate colleagues to assure that excellent proposals get written and funded for both field programs and development projects.

There is a consensus that where as the "block funded" manned submersible programs streamline the technical red tape and make for efficient use of the scientists' time and involvement, the unmanned submersible programs produce the most new technical innovation which sets the stage for scientific breakthroughs. For example, underwater cameras, strobes, video, sonars, transmissometers, geophysical and geochemical sensors, acoustic navigation and digital data logging were all first invented for unmanned vehicles. Today advances in force/position feedback for manipulators and microprocessors for measurement and control applications are being made in the context of subsea robotic systems with the operators remote from the site of observation. New technology in composite fibers, artificial intelligence and fuel cells is being motivated for application to autonomous vehicles.

It has been advantageous that complex missions using manned and unmanned submersibles have drawn the scientist and engineers together. The benefits are: (1) most scientists have remained free from time-consuming technical and logistical entanglements and have therefore accomplished good and productive science; (2) in most situations, innovation has been driven by the requirements of the scientific projects.

The engineering "cart" in the world of U.S. submersibles cannot be accused of pulling the scientific "horse" - a statement that cannot be made about submersibles in France or the new submersibles being constructed in Japan.

6. FUTURE RESEARCH REQUIRING SUBMERSIBLES

Those who gaze at the crystal ball predict five arenas for future research using submersibles.

6.1. Ocean Crustal Studies and Associated Biology

The first arena is the Mid-Ocean Ridge and marginal seas. The projected science is a near-term continuation of the study of the genesis and evolution of the oceanic crust. Many more segments of the ridge system will need to be visited so as to encompass the range of slow-spreading to fast-spreading rift zones, hydrothermal activity in areas of high sedimentation, off-axis volcanism, ridge crest propagation and transform intersections. The emphasis will be placed on regional variability, predictability and the development of tectonic and geochemical models. Biologists will continue to study the unique life forms and ecosystems associated with thermal springs. The activities will ask fundamental questions about the origin of life, energy pathways and opportunistic/adaptive hypotheses which might possibly probe the fabric of evolutionary theory.

We should anticipate the demand for an improved measurement sampling capability, navigation within the submersible, low light-level color video, and some data transmission with acoustic links. Sampling programs will request in situ filtration of water to look at chemical precipitation and organic particulates. Flow meters will be placed within thermal plumes.

We should also expect programs to study seamounts as both indicators of mid-plate volcanic/tectonic activity and sea-level history. Most certainly there will be proposals to investigate the flux of water, heat and geochemical tracers within the layer of sediment that drapes the flank of the Mid-Ocean Ridge.

The formation of igneous crust in back-arc basins is poorly understood at present. It is highly probable that projects will be proposed to survey zones of accretion and strike-slip faulting in several of the marginal seas adjacent to Southeast Asia.

Another field of growing interest includes shale and salt diapirism, mud volcanoes, and brine and gas seeps.

Practically all of the aforementioned research should be able to be accomplished within the 4000 meters depth limitation of ALVIN. Several of the proposed studies will be linked with unmanned submersible surveying and ocean floor drilling.

6.2. Continental Margin Erosion

The second arena of future research encompasses the physical, chemical and biological processes which result in mass-wasting on the continental margins and on the other first order topographic features with steep slopes (e.g., plateau margins and fracture zone walls). The understanding of the mechanisms and time scale of natural catastrophes such as slumping, sliding, rock avalanching, turbidity currents and abyssal storms is still not within grasp. Considerable new high-resolution on-bottom data is needed in the fields of geo-hazards, stratigraphic unconformities, bioerosion, and environmental impact. We should expect a demand for tools to be inserted into the seabed for in situ subsurface measurements, the servicing of long-life observatories to detect and measure episodic events, installation of scanning and subbottom sonars with digital recording on the submersible and the repeated surveying of small geodetic networks to detect creep or liquification of sediment in precarious settings. The manned submersible will probably be called upon to position long-life time-lapse photographic systems to witness the activity rate and effectiveness of the animals that bore into the seafloor and eventually undermine ledges. Advances in the performance of tethered submersibles are likely to include better resolution for side-scan sonars using synthetic aperture processing, improved detail and penetration in subbottom profiling using near bottom sources and receivers with variable frequency outputs, and the development of logging sensors to be towed across the seafloor to reveal information on porosity, compaction, permeability and organic content. As the data rate of the tethered systems increases, we can expect to see the application of fiber optics for telemetry over long tow cables. The autonomous submersibles will be called upon to have more stored electrical power for endurance and flexible hydraulic power to handle external devices. Some of the tethered vehicles will seek dynamic stability and some means to guide them on desired courses. Most of the significant research on continental margins and steep slopes will be able to be accomplished in water depths less than 4000 meters. Average depths might be 2000 meters.

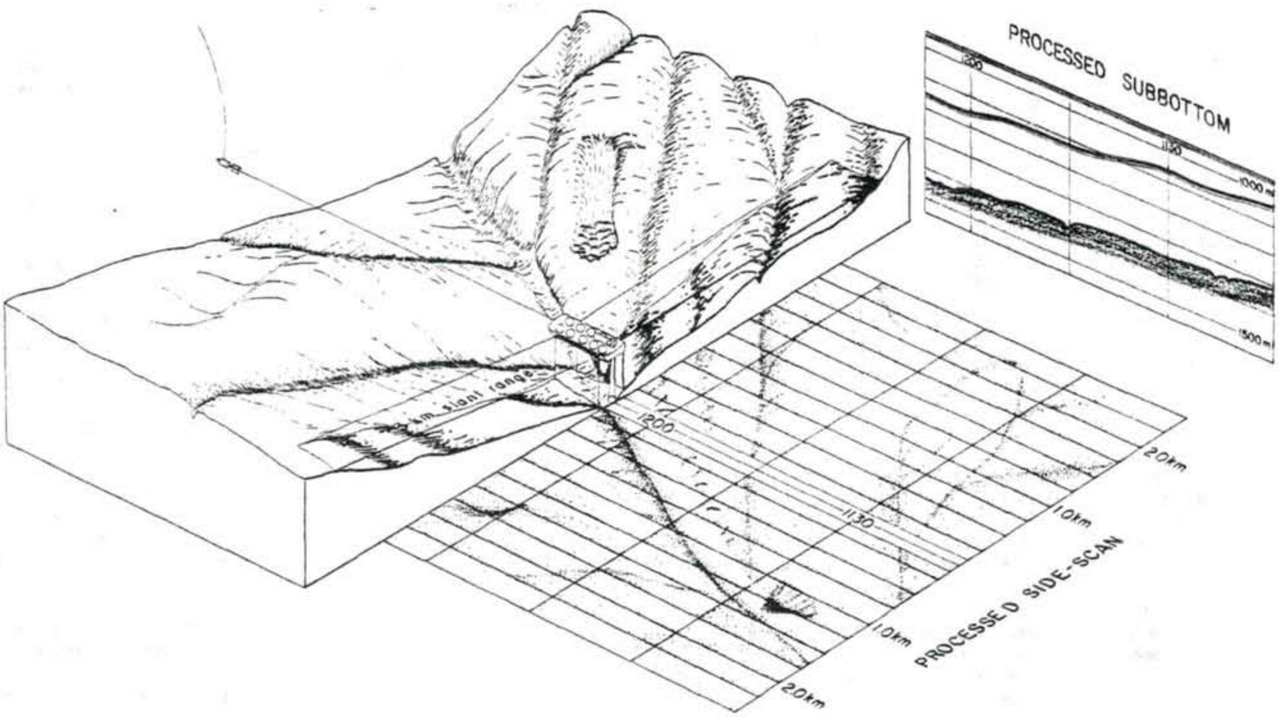

Figure 10. An illustration of how an unmanned deep-towed side-scan sonar creates a plan view image of the seafloor and a subbottom reflection profile.

6.3. **Abyssal Sedimentation**

The third arena of future research will generate a requirement for a depth capability beyond 4000 meters. There are signs of increased interest in the processes of abyssal sedimentation involving fine-grained pelagic and authigenic materials which prevail below the level where calcareous oozes are preserved (Calcium Compensation Depth). Study areas are likely to be both in regions with vigorous bottom-water circulation such as the lower continental rises, mid-ocean canyons or abyssal gaps and areas with tranquil environments such as the centers of mid-ocean gyres. Emphasis will be placed on the sediment water interface and the shallow substrate. Most of the surveying and observation will be done by tethered unmanned submersibles. Because of great water depths, autonomous vehicles will be used for very small-scale systematic surveys which require overlapping or statistically valid areal coverage. Technological advances will include motion-compensation for cable handling systems, automatic piloting to control altitude and heading, and transmission of sonar or photographic images with acoustic telemetry.

Expensive and sophisticated bottom landers are being developed for the study of manganese nodules and hardgrounds. It probably will be imperative that some of these packages will have to stay in place for long periods of time, because removal and re-deployment at different locations will not allow very slow processes such as diffusion of tracers or biological interactions to be satisfactorily monitored. Manned submersibles will be called upon to service these landers, replace or recharge power cells, recover the data by remote hook-up, and make modest repairs or adjustments. Manned submersibles in abyssal environments will play analogous roles to the Space Shuttle. Unmanned probes are still likely to dominate the abyssal arena. If at-sea low-level nuclear waste and toxic waste continues to take place, and if high-level waste disposal becomes a reality, the sites of disposal are likely to be quiet, non-tectonic abyssal settings below 4000 meters. Certainly unmanned vehicles will have a job for site-specific surveys and monitoring. We do not know if manned submersibles will be called upon to serve as a means of verification. Recovery of inadvertently disposed materials is not an unrealistic possibility (i.e. a vessel carrying high level waste for insertion into the seabed is in a collision and sinks). If the present trend continues, the survey needs for deep-sea mining will be accommodated for the most part by industry or some international sea-bed authority. Academic institutions might still contribute to technological innovation or "basic research" using available data.

The deep manned submersible will find a scientific application in deep-sea trenches, exploring the mechanisms of subduction, thrusting and trench faulting. The submersible could be expected to emplace strain meters, tilt meters or networks of high-resolution "sing-around" acoustic beacons to measure rates of strike-slip, uplift or creep.

Manned submersibles which dive to 6000 meters can cover 97 per cent of the ocean floor (Fig. 10). We can forecast the requirement for faster ascent/descent rates, improved video if it can replace or limit the number and/or size of viewports, greater mission endurance to compensate for transit time, and technology to cope with or compensate for problems with "backscatter". Some exploration sites will be in the axis of strong currents with dense nepheloid layers. Manipulation and payload are likely to be more important than maneuverability in the abyssal environment. If the new pressure hulls significantly increase size and weight, there will be impacts on the launch and recovery systems and support vessels that need to be accommodated in advance.

Some of the abyssal sedimentation studies can be accomplished at depths above 4000 meters, but others will necessitate a diving capability to at least the ocean basin centers at 5600 meters.

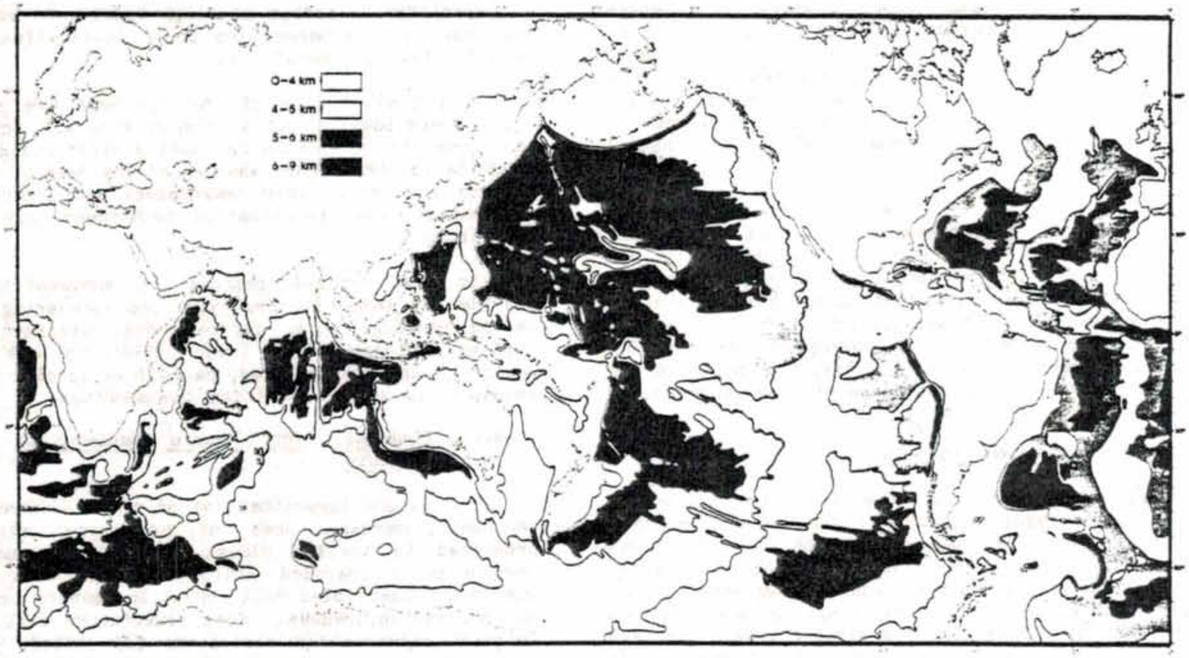

Figure 11. Whereas only 55 percent of the seafloor can be presently visited by ALVIN, 97 percent could be explored with a 6000 meter submersible.

6.4. Mission-Oriented Research

Perhaps the most uncertain field to predict is "mission-oriented" activity using submersibles. Oil and gas exploration has already advanced rapidly across the shelf and down the slope to water depths beyond 2000 meters. The Department of Interior has congressional mandates to lease, monitor and regulate the offshore Economic Zone. The Department of Commerce has responsibilities to fisheries, deep-sea mining, coastal charting and weather forecasting. The Department of Energy has thermal conversion projects and is looking for practical solutions to nuclear waste disposal. The Environmental Protection Agency funds broad areas of basic research where there are potential disturbances to the oceans, the substrate and the atmosphere. The Department of Defense has major oceanographic research and development projects and submersible facilities which involve academic scientists and engineers.

Some members to and consultants for this study expressed a concern that there should be accessible manned shallow-water submersibles capable of exploration of the continental shelf and slope to depths of 700 meters. Although such vehicles would be used for biological and fisheries research (probably under the sponsorship of NOAA), and certain types of studies would require at-sea programs throughout the year, full-time utilization is not anticipated. Shallow-water research requiring submersibles is planned for the Bering Sea, Gulf of Alaska, Gulf of Mexico and Georges Bank.

The Geological Survey and Bureau of Land Management expect to continue to fund assessment and baseline studies related to hydrocarbon exploration and production. Such studies have used deep-towed sonars and camera sleds to map canyons and potential areas or slope instability. Manned submersibles have been chartered to obtain "ground truth" and to assist in the evaluation of risks to drill platforms and pipelines.

The National Oceanic and Atmospheric Administration has specific responsibilities related to the National Ocean Survey and seabed mining. This agency should continue to fund manned and unmanned submersible exploration of Mid-Ocean rift valleys, transform faults and seamounts and, possibly, programs in the Clarion to Clipperton Fracture Zone segment of the Equatorial Pacific.

If the past is the key to the future, the "mission-oriented" researchers will conduct their business more as "followers" than as "innovators" in the use of submersibles to obtain bold, new scientific insight. The outlook that federal agencies engaged in "mission-oriented" programs will come forth with a sufficiently long range plan or commitment for shallow-water submersible science or engineering to influence the improvement or development of new submersible facilities is not optimistic.

6.5. Mid-Water and Under-Ice

There is a visible lobbying by marine biologists for improved methods and greater accesses to the life within the sea that does not reside on the ocean bottom. Their specific programs do not necessarily require a large deep-diving manned submersible. The principle objective of future research will be the observation and collection of mid-water life. Measurement of the in situ physical and chemical environment will be part of these missions. Preservation of the organisms, some of them extremely delicate, is a major challenge.

Another area of both biological and geochemical interest, and in which deployment of manned vehicles is valuable, is the investigation of suspended particles in water, especially of extremely delicate and fragile "sea snow", which has so far eluded chemical identification. Because of its fragile nature, the "sea snow" is not identifiable in the samples collected by currently available samplers such as sediment traps and deep-sea filtration systems operated from surface vessels.

The quantitative significance of "sea snow" in oceanic material transport flux must be evaluated. Manned submersible vehicles with deep or shallow operational capabilities, equipped with a special sampler can serve effectively for the investigation of "sea snow". In some areas of the oceans, "sea snow" accumulates at the water-sediment interface.

Small-scale structure of the water column can be explored with miniature temperature, salinity and flow sensors arranged as spatial arrays. Double-diffusion processes could be investigated with Schlierien techniques. Most physical oceanography experiments could be accomplished with unmanned vehicles or instruments.

Manned or extremely advanced autonomous submersibles, however, provide the only practical means for studies under the ice, which at any one time may cover 3 per cent to 4 per cent of the sea surface. The mechanisms of formation of sea-ice and bottom water could be investigated with studies of the base of the ice (including sampling) and studies of convection in the water column by detailed measurements of salinity and temperature, investigation of double-diffusion processes and of the maintenance of the sharp halocline found at 50-200 meters depth in areas of sea-ice formation.

Research in almost all the topics considered could be conducted in ice covered regions, if there were a submersible having an ice-breaker mother ship and/or extensive range (over 1000 miles). Large range would be especially desirable to allow studies to be carried out under the permanent ice shelf (navigation methods need special consideration).

Profiling studies of the ice would be conducted with upward-looking and side-scan sonars. Studies of the formation of sea-ice and bottom water would require a device to obtain core samples of the base of the ice, sensors to record water temperature and salinity, and the use of flow visualization techniques (see discussion above).

In ice covered regions, a submersible could provide the means for deploying and recovering instrumented moorings (e.g. current meter strings), but a payload capacity of at least 50-100 kgm per mooring would probably be required, as well as special gear for transporting and manipulating the moorings.

6.6. Timescale for Future Submersible Science Projects

The future investigations of the Mid-Ocean Ridge, seamounts, marginal seas and continental margins is predicted to involve almost a continuous use of a progressively upgraded ALVIN into the late 1980's. Unmanned submersibles will expand in number, capability and cost-effectiveness. Some researchers will abandon "manned" submersibles altogether for robotic systems, but a hard core of manned submersibles will remain for science projects that require specialized manipulation, station-keeping and sampling.

Tethered survey vehicles and bottom landers will initiate the studies of abyssal sedimentation by 1984. Diving by U.S. scientists will occur by invitation onto Navy's 6000 meter SEA CLIFF, possibly by 1985 and by 1986 onto the French submersible presently in design and construction.

For the most part, "mission-oriented" research will charter vessels and systems of opportunity. It is difficult to predict if there will be a national SEALAB facility for shallow-water research. Commercial submarines and those of private research foundations (i.e. SEA LINK of the Harbor Branch Foundation and DIAPHUS of Texas A & M University) could fulfill some of the manned submersible diving needs of NOAA and BLM. The use of >700 meter manned submersibles will be intermittent with an estimated commitment for less than three months a year of total work.

Mid-water observation could commence in 1982, but this activity will be intermittent with probably less than one month per year of facility rental being requested. It is beyond the capability of the project study team to comment on the availability of nuclear submarine science projects beneath the ice, except that we are hopeful. We expect that the first vehicles beneath the ice for non-military applications, will be leased, remotely-operated vehicles on long neutrally buoyant tethers.

7.1.4. Ascent-Descent Rate needs to be increased to 40 meters/minute to maintain an efficient distribution of transit and observation time for an increasing number of dives between 3000 and 4000 meters.

7.1.5. Payload should be increased to 200 kilograms for special missions which must recover malfunctioning "bottom-landers" or for missions with heavy external sampling gear. More battery power may be needed for special missions which have "piggy-back" electronics for sonars, recorders and logging tools.

7.1.6. Viewing should be improved to allow scientists to have a viewing area identical to that of the pilots. Close-up viewing of sampling activities and selected objects is desirable for geological facies and taxonomic species identification and for the study of behavior. Color video is imperative to biologists, in particular because speciation is often recognized by color variations.

7.1.7. Manipulators available to trained scientists could make more time-efficient dives by allowing duplicate sampling or macro-photography with one manipulator to accompany a simultaneous activity under the pilot's direction with the other manipulator.

7.1.8. Scientific Instrumentation which displays time, depth, altitude and heading on the video image being recorded would be very helpful during the de-brief and post-dive analyses. A complete data playback system for both digital and video tapes is required on the support vessels so that the dive activity and accomplishments can be reviewed and enhanced by the entire scientific and support party. Voice activated audio-recorders and well-maintained viewport cameras would assure that key observations are not lost. At present, the scanning sonar provides an important real-time function in guiding the submersible to targets. A sonar image which can be continuously and permanently recorded would greatly increase the ability of the observers to reconstruct the three-dimensional spatial setting with quantitative measurements of distance and size. If time, heading, altitude and depth were displayed on the scanning sonar image, more detailed and accurate maps of the dive area could be efficiently reconstructed. Instrumentation which could allow the submersible to send and receive data by acoustic link not only to the surface support ship but also to "bottom-landers" or deployed instrument packages would allow greater interaction, more reliability and more redundance. A vertical incidence reflection profiler

TABLE I. PROJECTED FUTURE MANNED SUBMERSIBLE SCIENCE PROGRAMS AND DEPTH REQUIREMENTS.

	1982	1983	1984	1985	1986	1987	1988	1989	1990
Mid-Ocean Ridge Studies	all <4000 meters Mid-Ocean Ridges, seamounts, marginal seas, diapirs							?	
Continental Margin Studies	all <4000 meters Submarine canyons, debris flow aprons, escarpments							?	
Abyssal Sedimentation Studies		<4000 meters passing to >6000 meters with Navy and French Submersibles						?	
"Mission-Oriented" Research	mixture of <700 meter and <4000 meter submersibles baseline studies of continental shelves, slopes, island platforms								?
Mid-Water and Under-Ice	intermittent use of leased systems			?	possible missions of, opportunity on nuclear submarines				

7. SUBMERSIBLE SCIENCE FACILITY REQUIREMENTS

7.1. Near-Term Requirements for Deep-Sea Manned Submersibles

Submersible science could be improved and made more efficient and cost-effective with the following capabilities for DSRV ALVIN.

7.1.1. Maximum Depth can remain at 4000 meters with deeper dives being accommodated on SEA CLIFF and the future French submersible.

7.1.2. Forward Speed should be sufficient to work in regions of strong benthic boundary currents with peak velocities of 1.5 knots.

7.1.3. Endurance needs to be brought up to 8 hours on-bottom time at 1 knot and 4 hours at 2 knots so that continental margin dives can cover sufficient transects in submarine canyons, or fracture zone dives can follow long tectonic lineations.

could assist in the study of continental margin debris flows and hydrothermal mounds by providing subsurface layer identifications, thickness and bedding structure. A resolution of 20 centimeters and a penetration of 20 meters in relatively soft materials would be sufficient for most applications. A small grey scale CRT display for the subbottom and scanning sonar signals is an adequate substitute for electrosensitive graphic recorders. Reasonable hard copy could be provided with video recording techniques.

7.1.9. Navigation and Positioning which is displayed visually and in real time on-board could allow the submersible to efficiently follow prescribed courses and make quantitative bed form measurements. The scientists who have used doppler-sonar tracking of manned submersibles have been extremely enthusiastic about the ability to direct the vehicle to specific sites and to revisit locations for future analyses or cross-checking purposes. At present in ALVIN when one goes by an interesting object (possibly something not on the agenda) one risks saying "good-bye" to it forever. There are many instances where a similar object, later recognized to be important, never appears again during the dive. There is a strong requirement to have well-navigated transects which can be considered longer than an acoustic transponder baseline and which take place in rugged terrain where acoustic shadowing is a handicap. Navigation should facilitate scientific observation and not confine it to pre-determined relatively small areas.

7.1.10. Sampling needs the following tools:

- Cylindrical core tubes for the recovery of 0.3 meters of soft sediment 6 cm in diameter.
- Box corers with self-actuated top and bottom lids to recover the undisturbed seafloor/water interface.
- Percussion hammer to fracture hard rocks.
- Shears or cutters to sever line and wire for instrument recovery operations.
- Slurp gun for the snatching of soft buoyant organisms.
- Pry bars and pitons to attach the submersible to vertical walls.

Optional but desirable items include:

- Rock drill to recover 10 cm long by 2 cm diameter rock borings.
- Hydraulic anchor to attach the submersible to steep slopes for extended sampling or observational activities.

7.2. Near-Term Requirements for Unmanned Submersibles

Unmanned submersibles will continue to be developed and utilized as specialized facilities. In the near term there is no requirement that there be dedicated facilities which receive "block funding" support and special scheduling. There is a need, however, for certain support equipment.

7.2.1. Cable Handling Systems will be required on several vessels to allow for flexible scheduling and surveys to remote areas. Cable handling systems are not needed for autonomous robotic vehicles. A cable handling system on the near-term ALVIN support ship would enhance the amount and variability of geophysical, geological and biological surveys and observations that could be accomplished in any one 24-hour period. Unmanned submersible systems generally have less of a weather constraint, and thus they can replace manned submersible operations on many non-dive days. Cable handling systems should permit towing at speeds of 0.5 to 6 knots (depending on water depth) with cable lengths from 3,000 (minimum) to 10,000 (maximum) meters. Cables should be armoured (10,000 kg minimum breaking strength) co-axial (RG 58 equivalent or better) and slip rings need to be low noise to handle video-signals, currents up to 10 amperes and voltage up to 1000 VAC. Payout and payin speeds for winches should be at least 30 meters/minute with >50 meters/minute for short emergency periods. Towing should be arranged from articulated cranes or A-frames so that the vessel has maneuverability to make turns in all directions. Bow thrusters and/or active rudders greatly reduce the time to make turns with strong winds and seas, and they permit tracks to be carried out along pre-plotted survey lines. Cranes are needed for launch and recovery of instrument vehicles with weights in air of up to 3000 kg.

7.2.2. Navigation Systems will generally be supplied by the user or operator of the unmanned system. Interfacing to the ship's gyrocompass, speed log, wind direction and speed sensors, and engine or shaft RPM is a prerequisite for ship-handling operations. Access to 12 Hz and 3.5 kHz hull mounted or towed transducers is needed for acoustic navigation and acoustic telemetry systems.

7.2.3. Air-Conditioned Laboratory Space is needed for electronic instrumentation (from 2 to 5 full height, 48 cm wide electronic racks), display recorders and terminals (up to 10 m^2 of desk-top area), equipment maintenance, photographic film developing and data analysis. Specific space requirements will vary from mission to mission and from system to system. Some operators will bring 1 to 2 dedicated deck vans. Clean electrical power isolated from surges caused by motors or winches is an absolute necessity.

7.2.4. Berthing Space for a scientific/technical support party of 8 is a minimum for non-full time operations which supplement other underway or manned diving programs. A party of 12 is a minimum for full-time unmanned submersible operations. Many deep-tow surveys have had up to 24 persons.

7.3. Near-Term Requirements for Submersible Support Ship

The size and configuration of the support vessel involves a compromise between an exclusive tender for the submersible or a ship with sufficient capability to support the complete scientific mission. Size must be sufficient to allow for expeditions to geographically remote areas. Future sea kindliness must compensate for a scheduling that will be less flexible in terms of weather and proximity to port for emergency repairs.

In the past the operating institution set a policy whereby the R/V LULU would be accompanied by an escort vessel on all distant port cruises. The second vessel served as the platform from which most of the scientific programs took place. Past history also showed that scientific missions ranged in complexity and size, with some expeditions requiring 4 to 6 scientists/technicians and other expeditions needing more than 28 persons. A statistical study of the past mission size and proposed missions for 1981 revealed a broad median centered around 12-14 persons.

It was also the consensus of the study teams that advances in electronics would minimize the manpower for navigational tracking/communications and the improved design of subsystems and alternate launch and recovery systems would reduce the size of the submersible support crew. Furthermore, without the requirement of an escort vessel, the impetus to accomplish simultaneous multiship programs would diminish. Most scientists agreed that in fact it was preferable to complete all phases of reconnaissance survey prior to initiating the diving phase. Large expeditions which incorporate labor intensive inter-disciplinary programs with large laboratory space needs can continue to be undertaken with an escort "dormitory/laboratory" ship. The choice of dedicated versus combined oceanographic capabilities for the submersible support vessel will determine the size of the support vessel. The available laboratory and deck space will establish the degree to which the support ship can engage in ancillary survey programs using unmanned submersibles.

The needs of the majority of near-term submersible projects using ALVIN and/or unmanned tethered submersibles can be satisfied with a vessel of the KNORR/MELVILLE/ATLANTIS II class. The maximum scientific needs would be most cost-effectively solved by the occasional charter of a "dormitory/laboratory" vessel.

TABLE II. SUMMARY OF MINIMUM AND MAXIMUM NEAR-TERM SUBMERSIBLE SUPPORT SHIP REQUIREMENTS

	Minimum	Maximum
Range of operations, N. Mi.	8,000	12,000
Scientific Party*	10	25
Cruising Speed	10	12
Maximum Speed	15	15
Range, days	30	30
Scientific Work Space, sq. ft.:		
Dry Laboratory	850	2,000
Wet Laboratory	400	500
Storage	500	800
Open Deck**	2,200	2,600
Fresh Water (Science needs only) Gals/day	1,000	1,500

Minimum Oceanographic Equipment

Hydrographic winch with CTD system. 12 & 3.5 kHz echo sounders. Navigation systems, computers and plotters. Playback systems for video-tape and digital data logged in submersible.

Maximum Oceanographic Equipment

Main large winch with 10,000 meters of armored coaxial cable. Towing crane or over-side A-frame. Deep-towed side scan and photographic survey vehicles and ROV with manipulators. Electronic laboratory. Sample preparation laboratory. Microscopy laboratory. Seismic reflection profiler and magnetometer.

* Does not include submersible support crew of 10 persons.

** Depends on configuration of launch and recovery systems, hanger for the submersible and winches for tethered vehicles.

7.3.1. Range and Endurance. The near-term immediate exploration of the Mid-Ocean Ridge, seamount and marginal seas requires a support vessel for ALVIN with a range of at least 6000 nautical miles (preferably 8000 nautical miles), an at-sea endurance of 30 days and the option of not having an escort vessel.

7.3.2. Cruising and Operation Speed. A significant number of additional dives per expedition and a significant number of additional expeditions per year could be accommodated with a cruising speed of 10 knots. The economics of fuel consumption versus fixed operational costs of support crew will determine if a 12 knot cruising speed is feasible. Launch and recovery require low speed maneuverability in winds up to 20 knots routinely and 35 knots in emergencies. Deep-towing is accomplished at speeds of 0.5 to 6 knots. Towing vehicles below 3000 meters is done usually at speeds of less than 2 knots. Low speed for launch and recovery of tethered vehicles (<1 knot) is the most critical requirement, because towing puts a considerable drag on the vessel which effectively slows it down once vehicles are at operational depth.

7.3.3. Science and Support Party. The forecasted scientific programs, many of them envisioning the increased use of unmanned submersible both individually and alternately with manned submersible diving with a 24-hour per day scientific field program, will require a minimum scientific staff of 10 persons (preferably 12) in addition to a technical team of 10 persons for ALVIN operation and maintenance.

7.3.4. Maneuverability. The most reliable and efficient maneuvering system should be adopted by the surface support ship to give the maximum number of maneuvering options during launch and retrieval operations. Combinations of bow thrusters, active rudders, infinitely variable prop speeds, or cycloidal propulsion are minimum requirements. All components should be engineered to be instantly available once put "on-line" during launch and recovery operations.

7.3.5. Power Availability. The science requirements are dependent on electrical or hydraulic power for launch and recovery systems (A-frames and constant tension winches) and for cable handling systems for tethered vehicles. The sensitive nature of microprocessor-based instrumentation, however, will require a science-dedicated "clean" power supply system designed into the power network of the support vessel.

7.3.6. Navigation and On-board Submersible Tracking. A navigation system that provides real-time submersible tracking in a geodetic coordinate system is essential for future operations that will stress complementary pre-dive surveys including SEABEAM, deep-towed side-scan sonar and photographic vehicles. A submersible tracking system which does not involve time-consuming deployment and surveying of multiple transponder nets and which allows the operations to take place with flexibility over large areas would permit more science per mission to be accomplished.

7.3.7. Launch and Recovery. The importance of improving the ability of the launch and recovery system to function safely in heavy weather is emphasized. Operation in Sea State 4 would provide approximately 20 per cent more geographic coverage than Sea State 3. There are numerous sites of interest for investigation using a submersible at moderate to high latitudes which are seriously impaired at present by the incidence of poor weather which leads to cancelled dives. These include such areas as the northeastern U.S. Continental Margin and the Juan de Fuca/Gorda Ridge off the northwest U.S. and the Norwegian Sea. The weather limitations impose a serious restriction on submersible operations.

7.3.8. Scientific Work Space. The submersible support ship needs adequate deck space for the launch and recovery system, hanger for submersible maintenance out of the weather, cable handling system and towing arrangements for tethered vehicles and a hydrographic winch. Interior space with a modest machine shop is required for maintenance of submersible subsystems. The navigation tracking, communications and unmanned submersible electronics control center should be air-conditioned and relatively accessible to the deck. Wet laboratory space serves for photographic processing, sample preparation and microscopy. The support vessel will have to have sufficient facilities to permit the processing of perishable biological and chemical materials. Some hyperbaric capability might be requested. A modest library is essential because of the vast amount of equipment documentation and software necessary for complex systems.

7.3.9. Planning, Scheduling and Coordination. An operational office encompassing scientific, engineering and logistic coordinators is essential to the wide acceptance of the national deep ocean submersible facility. Of particular importance is the creation and support of a well-equipped shore-based maintenance shop that can design, develop and improve submersible subsystems and special "single-mission" equipment. An efficient planning procedure is needed with the flexibility to adapt to weather, operational and unforeseen schedule difficulties. A centralized data library is desirable with the following running requirements:

- navigation tracks of all dives
- copies of external camera films and video tapes
- scientific logs and transcripts of observations
- documentation to the whereabouts of samples
- updated documentation of the existing submersible subsystems to assist in the design and interfacing of instrumentation.

7.4. Near-Term Requirements for Manned Submersibles at Abyssal Depths Below 4000 Meters

Manned programs during the 1980's below 4000 meters will require the National Science Foundation, the National Oceanic and Atmospheric Administration, and the Office of Naval Research to assist with scheduling, clearances, travel expenses and any necessary intragovernmental agreements that facilitate and encourage the use of these vehicles of opportunity.

7.5. Near-Term Requirements for Shallow-Water Manned Submersibles

Manned programs for shallow-water depths of <700 meters which cannot be satisfied or scheduled by ALVIN will require the assistance of the responsible funding agency to secure a satisfactory lease agreement for a safe submersible system including support vessel. The type of submersible and support vessel will vary according to specific mission requirements. We should anticipate that the majority of users will request an integrated system that comes with its own operators, engineers, navigators, pilots, etc., and which allows for the attachment of some specialized oceanographic equipment such as cameras or sampling devices. The following is a list of desirable items that have made certain shallow submersibles successful as scientific research platforms.

7.5.1. Maneuverability should permit the submersible to turn horizontally 180° on its own axis and move vertically upward and downward.

7.5.2. Viewports which give access to the sediment-water horizon and diagonally down (40-50°) to the substrate are the minimum requirement for observation. An additional conning tower with a 360° view through individual flat ports is desirable, but the large transparent spheres or hemispheres for the submersible personnel are preferred.

7.5.3. Capacity for one scientist is usually sufficient (except during lock-out operations).

7.5.4. Photographic capability with external cameras, strobes, and in-hold cameras is a standard requisition for practically all shallow-water missions. There should be an adequate power supply to operate incandescent lights nearly continuously for observation and video recording.

7.5.5. On-bottom duration for 4 hours while filming, using the mechanical arm, steaming at 0.5 knots is reasonable.

7.5.6. Manipulation of sampling devices or other tools can be accomplished by a single manual or hydraulic arm with a 5 to 10 kg lift capacity.

7.5.7. Special instrumentation will be supplied by the scientific user and might include sensors for temperature, conductivity, light transmission, current direction and velocity and sonars.

7/5/8. Total payload of 350 kg would satisfy practically all potential missions, even the most specialized ones.

7.5.9. Navigation of the submersible by coordinates sent down over voice channel is sufficient provided that the submersible is able to re-occupy observation sites.

7.5.10. Diver lock-out capability would be selected by only a few thoroughly trained users. Systems that offer this function are so specialized that the leasee will not have much flexibility with regards to special instrumentation. The most unique requirement will be for long term submergence (up to 4 days).

7.6. Near-Term Requirements for Mid-Water and Under-Ice Missions

Technology is required for observers (i.e. people or cameras with other sensors and manipulators) to follow and hover at levels of equal density, temperature and salinity for up to 6 hours at a time. New optical viewports or lenses will be requested for magnification and color stereo viewing, as well as sampling containers that can maintain in situ temperature and pressure. Support-ship aquariums with motion compensation will at least slow down the rate which most of the delicate organisms disintegrate in captivity by colliding into the walls of their containers.

Under-ice investigations comprise a whole range of activities from conventional exploration of the ocean floor, to mid-water biology and physical oceanography to the sonar profiling and plan-view mapping of the underside relief of the ice cover. Long periods of submergence, greater range and endurance and autonomous navigation all pose challenging technological problems. Near-term mapping projects could be initiated with access to nuclear submarines. Vertical profiling can be done from floating ice stations. Environmental sensors are, for the most part, conventional. Insufficient information exists at the present time to allow the specification of more detailed mission requirements.

8. NEAR-TERM SUBMERSIBLE FACILITIES, OPTIONS, COSTS AND RECOMMENDATIONS

At the present time a fairly large number os submersibles were first used for oceanographic research. A report regarding existing submersibles has been compiled by Frank Busby and published by the U.S. Navy in 1978[1]. This report describes more than one hundred manned submersibles, many of them no longer in operation once they began to be replaced by less expensive remotely operated vehicles for commercial offshore oil and gas applications. Busby gives a summery of design, construction, instrumentation and operational procedures, including compendiums of support vessel, descriptions of unmanned submersibles and illustrations of launch and recovery systems.

8.1. Near-Term Deep-Sea Manned Submersibles

8.1.1. Facilities. DSRV ALVIN is the near-term deep-ocean manned submersible most accessable to UNOLS scientists.

[1] Busby, F. R., 1976. Manned Submersibles. Published by Office of the Oceanographer of the Navy, 764 pages.

TABLE III. CHARACTERISTICS FOR ALVIN/LULU SYSTEM

ALVIN	
Length	7 meters
Extreme Beam	2.6 meters
Air Weight	17 tons
Depth	4000 meters
Payload	450 kg
Personnel Capacity	3
Normal Dive Duration	6-10 hours
Life Support Duration	210 person-hrs.
Speed	0-2 kts
Endurance	2 hr @ 2 kts 8 hr @ 1 kts

LULU	
Length Overall	32 m
Beam	14.6 m
Draft	3.3 m
Displacement	460 tons
Personnel Capability	22 (crew)
Speed	6 kts (calm sea)
Endurance	14 days
Range	2000 nautical miles

8.1.2. Options. The available options are: (1) to terminate the ALVIN submersible program; (2) continue using ALVIN as presently configured; (3) steadily upgrade ALVIN with improved performance and instrumentation to fulfill the proposed near-term scientific requirements; (4) replace ALVIN with a new unmanned submersible; (5) replace ALVIN with a new manned submersible.

8.1.3. Costs. In 1981 the estimated operating, maintenance and upgrading cost for ALVIN (exclusive of the support tender) was $1.0M. There were approximately 150 operating days.The total cost of ALVIN and LULU was $2.0M. The average day charge was $13.3K for the system.

The costs for a near-term program to upgrade the instrumentation, payload and performance of ALVIN is estimated at $600K. The costs of replacing ALVIN with unmanned submersibles is difficult to evaluate, because no single system comes close to duplicating all of the capabilities of a manned submersible. Complex deep-ocean tethered vehicles with manipulators and thrusters such as the U.S. Navy's CURV might cost upwards of $5M exclusive of a cable handling system with heave compensation (>1.5M). Deep-ocean autonomous vehicles such as Epilarde have very unique and inflexible survey capabilities (photographic and vertical profiling), but cost upwards of $1M including engineering and design.

Costs of constructing, testing and making operational a new replacement submersible with equivalent performance would exceed $15M.

8.1.4. Recommendations. The Submersible Science Study recommends option #3, that is, a steady upgrade of ALVIN over a period of five years or more which might take place with the following priorities to achieve the following goals:

- Conversion to a single-point lift to allow launch and retrieval in Sea State 4.
- A greater understanding from all funding agencies and the operating institution that maintenance and at-sea repair of the submersible sub-systems which collect or display scientific data is vital to successful field programs. Diving with an operational submersible and inopperative cameras, mechanical arms or navigation is not cost-effective.

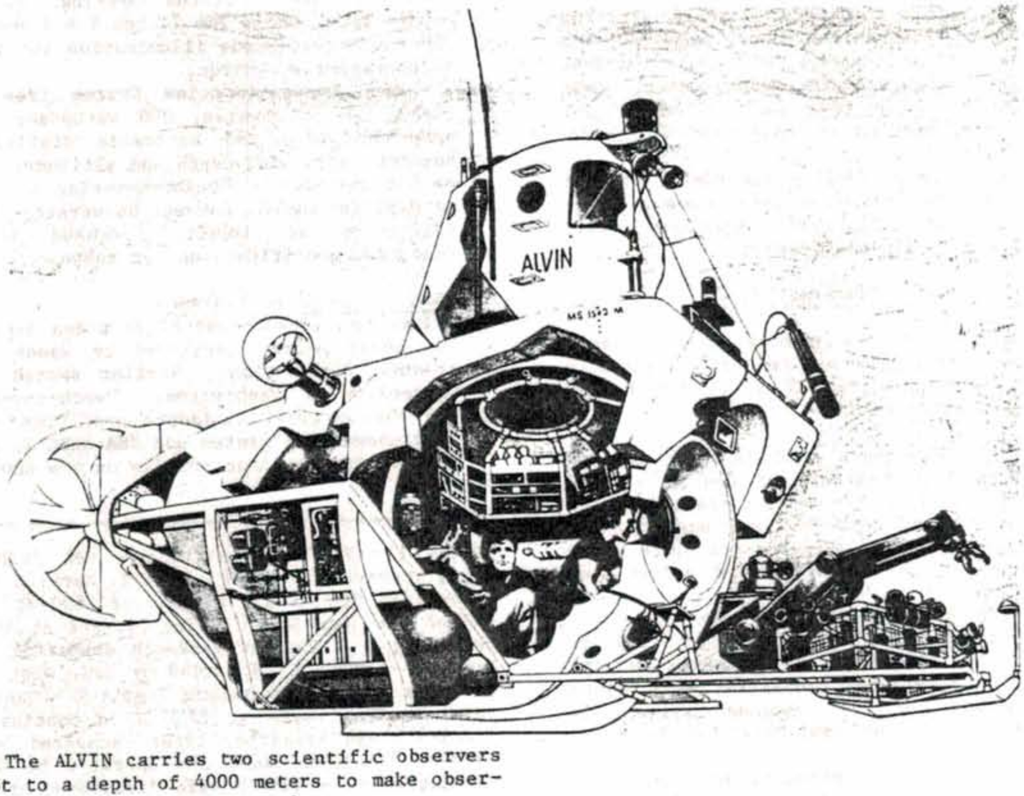

Figure 12. The ALVIN carries two scientific observers and one pilot to a depth of 4000 meters to make observations, measurements and return samples.

- Replacement of the continuous transmission frequency modulated (CTFM) sonar with a digital scanning sonar with annoted CRT display and capable of being continuously recorded on a VCR.
- Improved navigation, beginning by replacing out-dated receivers and computers, addition of a short baseline system on the support vessel, followed by doppler sonar on the submersible and ending with a short baseline system on the submersible. The support vessel's Loran-C and Nav Transit Satellite Navigation should be supplemented with a Global Positioning Satellite System by 1984.
- Improved viewing using a video camera which shows the pilot's forward view, annotation of time, heading, and depth on video-tapes, external trainable color video, macro-video on one manipulator and a video viewfinder for trainable 35mm external cameras. Small cabin monitors visible by each scientist should be able to swiftly select any video camera.
- Addition of a modest sub-bottom reflection profiler (4 to 5 kHz) with CRT display and capable of being recorded on tape.
- Improved tools commencing with percussion hammer, rock drill and one manipulator to be operated at times by trained scientists. We envision that many tools will be designed independently by principal investigators. Sciencific requirements should continue to push the development of this equipment. We recommend that funding agencies be receptive to good second-party proposals for improved ALVIN sampling and measurement capabilities.
- Installation of microprocessors in the submersible which can display data being logged, accept manual inputs and updates and provide real-time soft-copy dive track information. Great flexibility ought to be given to the ALVIN support group to allow maximum creativity and moderate costs. There should be industry-standard electronic interfaces (e.g. IEEE 448, RS 232, etc.).
- Development of acoustic telemetry, perhaps starting initially with some standardized on-off functions for "bottom landers", then the use of "smart" moored transponders for range/azimuth measurements, then range/azimuth/depth to or from surface vessel and eventually the transmission of snap-shot video and sonar scanning data.
- Research and development leading towards a greater power/weight ratio for batteries which have a practical application for ALVIN-type operations (i.e., let others fund exotic alternatives).

8.2. Near-Term Unmanned Submersibles

8.2.1. Facilities. There are several tethered deep-ocean unmanned submersibles within the UNOLS community and others in industry. Table IV lists the better known scientific survey systems.

By the end of 1982 there will be four winches capable of handling 10,000 meters of double armored 1.73 cm dia. coaxial cable: permanent installations on R/V THOMAS WASHINGTON, R/V MELVILLE and one portable winch at SIO and one at L-DGO. Winches are planned for WHOI and URI. There are two Navy-owned articulated towing cranes at SIO.

8.2.2. Options. The available options are:

(1) continue in the mode where unmanned systems are developed individually at various laboratories and institutions; (2) set up national facilities with "block funding"; (3) request that all unmanned systems be developed by industry and be available for lease to oceanographers.

8.2.3. Costs. The costs for option #1 are the burden of individual investigators, and the systems they

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TABLE IV. UNMANNED TETHERED DEEP-OCEAN SUBMERSIBLES

Side-Scan Sonar Systems

Deep Towed Instrumentation System developed and owned by Scripps Institution of Oceanography, produces 1.5 km swath, 110 kHz, 6000 meter depth capability, has magnetometer, CTD, transmissiometers, plankton nets and water samplers.

SEA MARC I developed by International Submarine Technology and owned by Lamont-Doherty Geological Observatory, produces 1, 2 or 5 km slant-range corrected swath, 27 and 30 kHz, 6000 meter depth capability.

Digi-Tow developed by Jet Propulsion Laboratory and now owned by Woods Hole Oceanographic Institution. Detailed specifications unknown, but similar in many respects to Deep Towed Instrumentation Systems at Scripps.

Deep Tow developed by EDO Western Corporation owned by Racal-Decca Surveys, Inc. and available for lease, produces a 400 meter swath, 100 kHz, 6000 meter depth capability, buoyant tow fish. Other proprietary systems developed by International Nickel, Lockheed, Deep Sea Ventures, Institut Francais du Petrole and the **Teleprobe** of NORDA.

Photographic Survey Systems

ANGUS developed and owned by Woods Hole Oceanographic Institution. Acoustically navigated, 35 mm color film with 1000 watts/sec, strobe, more than 3000 pictures/lowering, 6000 meter depth capability, compass and altitude recording.

Cheep Tow I developed and owned by Lamont-Doherty Geological Observatory. Acoustically navigated, 35 mm color film, 500 watts/sec, bottom-towed with more than 3000 pictures/lowering, 400 meter depth capability. **Cheep Tow II** has B & W and color video, 250 watts continuous illumination and self-contained video-cassette recorder.

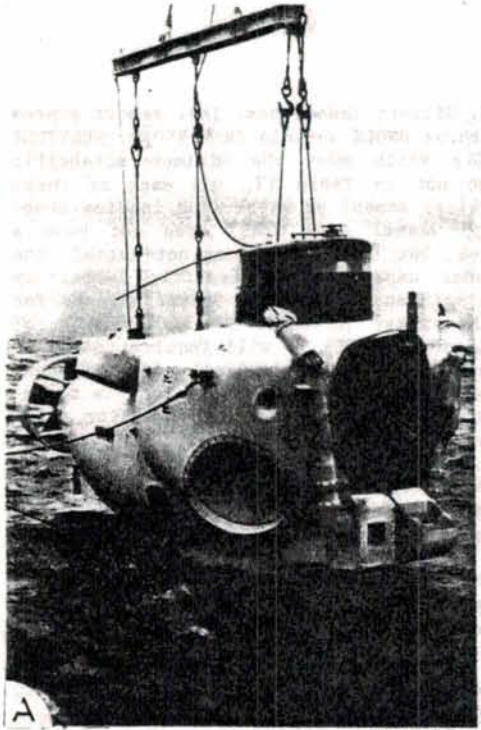
Deep Towed Instrumentation System (see above) with stereo 33 mm cameras, 200 watts/sec illumination, snapshot video and automatic digital logging of heading, pressure, depth and altitude.

Other bottom-towed or bottom-hovering vehicles operated by U.S. Geological Survey, University of Washington, University of Hawaii, Lockheed and Deep Sea Ventures, specifications not known.

Sub-Bottom Profiling Systems

Low frequency single-channel deep-sea hydrophone array and sound source developed by Woods Hole Oceanographic Institution. Similar system developed by University of Washington. Depth-normalized 4 and 4.5 kHz vertical incidence profilers on **Deep Towed Instrumentation System** and **SEA MARC I**, respectively. Raw 3.5 kHz attitude profile on the EDO Western **Deep Tow**.

Figure 13 (Facing Page). A - SEA CLIFF, presently being converted to 6000 m by U.S. Navy; B - Deep-diving bathyscaph TRIESTE II, capable of 7000 m; C - Bore hole #98 of the Deep Sea Drilling Project at 2650 m visited by ALVIN; D - Nuclear research submarine NR-1 of U.S. Navy; E - DSRV ALVIN, owned by U.S. Navy and operated by Woods Hole Oceanographic Inst.; F - Canister of low-level nuclear waste at 2750 m on continental rise of western North Atlantic, later recovered by ALVIN; G - JOHNSON SEA LINK owned and operated by Harbor Branch Foundation; H - Exotic life discovered at hydrothermal spring at the Galapagos Rift.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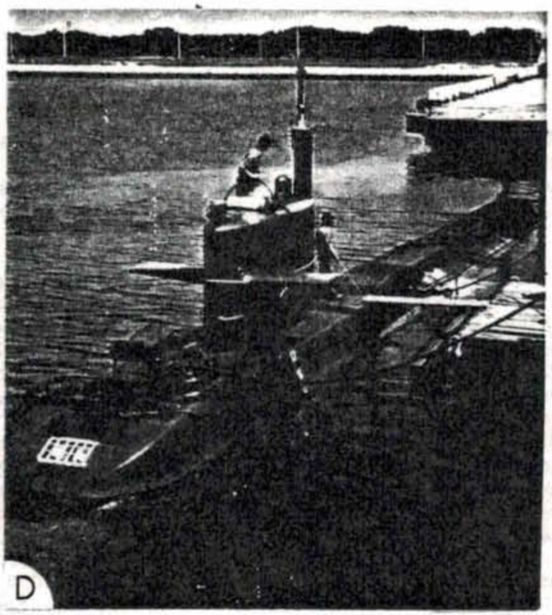
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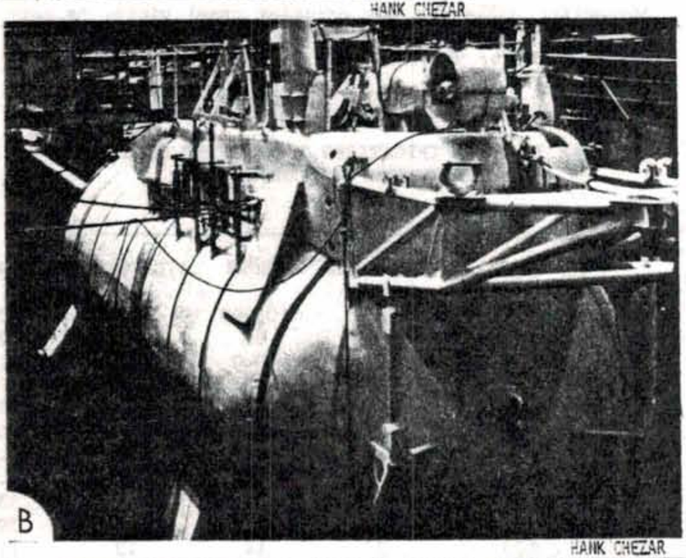
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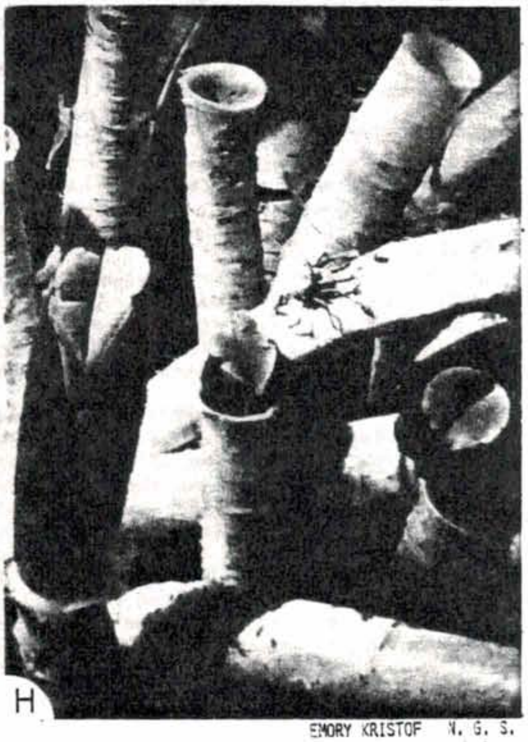
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develop reflect their ability to raise funds for technical development and scientific field programs. The cost for option #2 is dependent on the number and complixity of the unmanned systems to be developed and operated by national facilities. The Deep-Towed Instrument System requires an annual budget of more than $700K. ANGUS costs approximatly $50K per month, just for operation and expendables. Very few systems are available for lease from industry. The 90-day side-scan and sub-bottom reflection survey completed by Racal Decca for Shell Development Company in 1981 is an example of option #3, and this survey costs more than $2M, including the research vessel day charges.

8.2.4. Recommendations. The Submersible Science Study recommends option #1 because it is the most assured route whereby science continues to remain in the driver's seat. There is no evidence that industry's technology is exclusive or its field experience is superior to that of the academic laboratories, as might be alleged for multi-channel seismic reflection surveying and processing. The various systems developed at academic laboratories have been widely shared between user groups. Most of the field programs have been multi-institutional. It is recommended that the submersible support ship be equipped, when feasible, with an appropriate cable handling system to allow some of these deep-sea unmanned vehicles to be used in conjunction with ALVIN diving programs.

8.3. Near-Term Submersible Support Ship

The most pressing requirement of the Science Panel is the immediate replacement of R/V LULU as the support vessel for ALVIN. In spite of her record of past accomplishments, LULU is the most serious hindrance to carrying out a world-wide mission of high priority ALVIN research programs that have been rejected as unfeasible due to the limited capabilities of the support vessel.

8.3.1. Potential Facilities and Options. There are several choices for a replacement vessel.

(1) Upgrade of LULU to meet science requirements.
(2) Conversion of a suitable and available vessel from the UNOLS fleet.
(3) Lease of an existing submersible support ship from industry.
(4) Conversion of a commercial bare boat (built or modified to specification).

OPTION #1 - LULU UPGRADED. Within the funds available over the years, there has been a concerted effort by the Woods Hole Oceanographic Institution to upgrade the LULU in operational capacities and habitability. Considering the space and load possibilities available, LULU has in fact far surpassed all the original parameters that were expected. The facts remain, however, that no increase of power will significantly affect the transit times of LULU, nor will any modifications to the present living and working spaces make LULU a long range vessel that could remain at sea unattended by an escort vessel for the periods being considered for future expeditions.

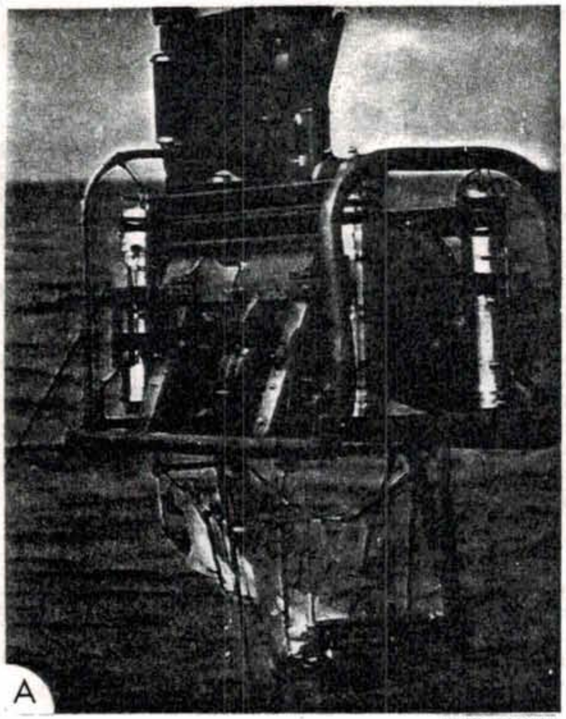
OPTION #2 - UNOLS VESSEL CONVERSION. In order to evaluate the conversion option, the ALVIN Review Committee, following the recommendation of the Submersible Science Study, requested in May 1981 that the National Science Foundation fund a marine architect to conduct an engineering study of the entire UNOLS fleet. John W. Gilbert Associates, Inc. was selected, and they delivered their report to NSF in October 1981. The scope of their report was to evaluate the feasibility of conversion, the recommendation of the most suitable ships presently in the fleet, to list the structural work required for the conversion, the costs and time-scale.

The John W. Gilbert Associates, Inc. report states that there are three UNOLS vessels (R/V KNORR, MELVILLE and ATLANTIS II) which meet the minimum scientific requirements set out in Table II, but each of these vessels has vertical moment or water-line loading problems. A fourth vessel (R/V GYRE) does not have a stability problem, but this vessel can not satisfy the required personnel capacity or scientific laboratory and submersible maintenance space. Specifications for the four vessels appear in Table IV. Conversion of KNORR, MELVILLE, or ATLANTIS II will require considerable superstructure and conventional oceanographic support equipment to be removed so as to be able to accommodate the added weight of ≈93 long tons for ALVIN with its estimated submersible support outfit and launch/recovery system, another ≈ 18 long tons for a tethered unmanned submersible (ANGUS was used as an example of a typical tethered system) and an additional ≈20 long tons for a winch with 10,000 m of armored conducting cable. For the conversion to be sufficient to handle a 6000 meter submersible such as SEA CLIFF plus ANGUS, the total weight to be compensated for is 158 long tons. ATLANTIS II will need to have fixed ballast added and attention given to a new or improved or auxiliary low speed maneuverability for launch and recovery or towing operations. Weight savings could be accomplished by substitution of the towing winch with conducting cable for the existing trawl winch, by converting an existing winch (if not already suitable as is the case for MELVILLE) and by incorporating ALVIN

TABLE IV. SPECIFICATIONS OF EXISTING UNOLS SHIPS CONSIDERED FOR CONVERSION.

	MELVILLE	KNORR	ATLANTIS II	GYRE
Range (NM)	9,181	10,000	10,000	11,000
Endurance (days)	37	60	60	42
Speed (kts)	11.0	10.0	12.0	11.0
Crew	20	25	25	12
Scientists	30	25	25	18
Total Manning	50	50	50	30
Full Speed	13.0	12.0	13.0	12.0
Std Speed	10.4	10.0	12.0	11.0
Length (OA)(meters)	75	75	64	53
Length (DWL)	67	67	59	50
Breadth (MLD)	14	14	13	11
Depth (MLD)	7.6	7.6	6.4	4.6
Design Draft (MM)	4.6	4.6	4.9	3.4
Displacement (DWL)	1948	1948	2300	1087
Dry Lab (Ft^2)	1950	3000	4300	VANS
Wet Lab (Ft^2)	1950	400	400	VANS
Storage Science (Ft^2)	923	923	704	none
Open Deck (Ft^2)	3592	3592	2632	3300
Fantail Length	19.5	19.5	12.2	31
Width at Stern	11.9	11.9	8.8	9.8

Figure 14 (Facing Page). A - Deep Towed Instrumentation System of Scripps Institution of Oceanography with sonars, cameras and plankton nets; B - Cheep Tow I, a bottom-towed photographic sled belonging to Lamont-Doherty Geological Observatory; C - Portrait of a soft coral in axis of Oceanographer Canyon; D - Sea MARC I, a neutrallay buoyant near-bottom tethered sonar mapping system designed by International Submarine Technology; E - Cheep Tow II, a video and photographic vehicle built by Lamont-Doherty Geological Observatory and Colmek Systems to photograph the TITANIC; F - Soft coral on avalanche debris in Baltimore Canyon.



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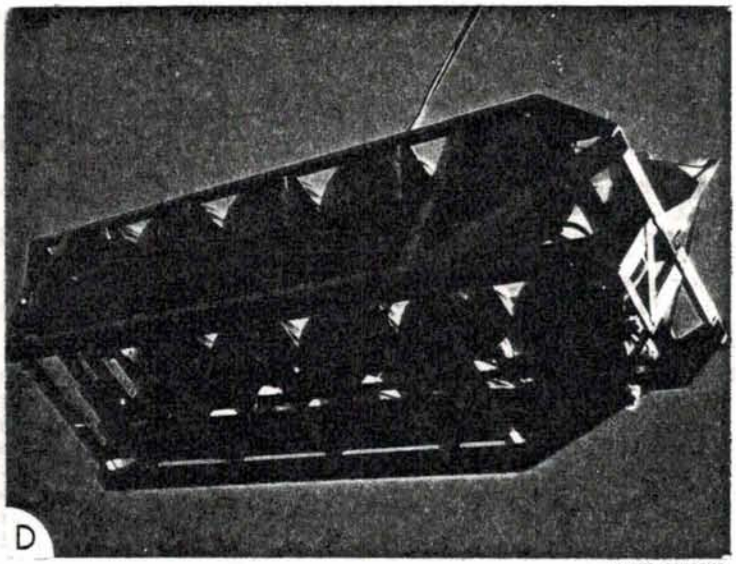

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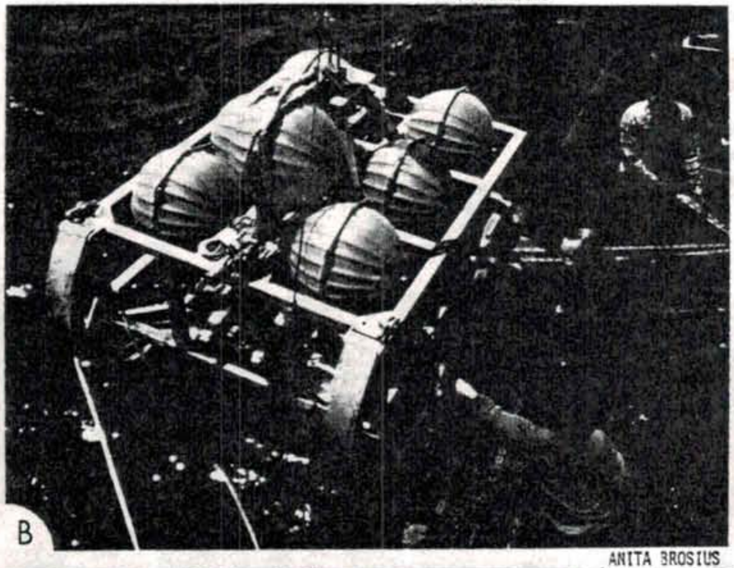

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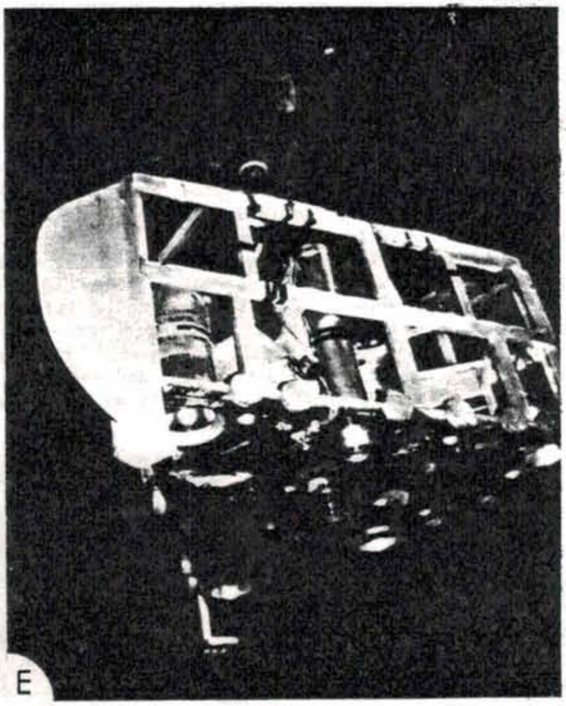


maintenance facilities (machine shops, etc.) into existing enclosed laboratory space.

R/V GYRE cannot accommodate a submersible and a tethered unmanned submersible together, and its sea kindliness is marginal. Deep-tow operations alone have been difficult in a Sea State 3 and impossible in stronger seas or winds beyond 20 kts. The bow thruster must be beefed up for greater power and sustained operation. The freeboard of the after deck needs to be substantially raised. Presently GYRE is a very "wet" ship and maintenance and repair of equipment on the after deck is only possible in calm seas.

The suitability of any UNOLS vessel is predicted on the installation of a launch and recovery system that permits: (a) repaid lifting from the water with a constant tension device; (b) absorption of shock due to sea motion of the submersible and the ship; (c) lock-in wave lifted position to prevent dropping back; (d) attachment to a controlled rigid pin or socket when clear of the water; (e) transfer to the ship's deck for servicing.

At present, ALVIN is configured for underside support (cradle lift) during launch and recovery which is provided by an "elevator" on LULU (Fig. 15). Replacement of the cradle lift by an over-the-side crane or an over-the-stern A-frame system will greatly reduce the complexity and cost of conversion. The cradle lift on LULU was developed to maintain the design consideration of ALVIN because its strongest support came from the skids rather than the upper padeyes. Some load shock is encountered because of the slow cradle lift speed; also the launch and retrieval procedures are extremely labor intensive. Nevertheless, the cradle lift was the best system that could have been devised with the funding and platform that was available at the time.

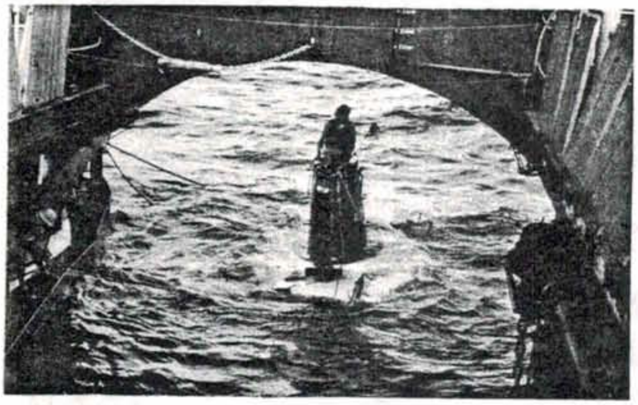


Figure 15. ALVIN entering between pontoons of LULU. The submersible will then be raised to the main deck by an "elevator-type" of cradle lift.

Today, after much experience, submersible operators world-wide prefer a hydraulic powered stern mounted A-frame (see Table V). The A-frame has a hinged vee strut hanging from the top of its cross member (Fig. 16) that contains the initial lifting line for shock absorbed removal or placement in the water. When the submersible is lifted clear of the water, a hydraulic vertical arm with a socket attachment rigidly grabs the submersible (Fig. 18). Articulation of the A-frame allows the submersible to be set on rails which then transport the submersible into a sheltered hanger.

ALVIN can be adapted to such a system by means of a single point lift. Modification will have to be made to the submersible's frame in addition to a semi-permanent rigid bridle whose lift point is immediately aft of the conning tower. Stern A-frames have been used successfully in adverse weather in the North Sea to recover 40 ton submersibles in conditions up to seven meter significant wave height, Wind Force 7 and wave frequency of six seconds.

According to John W. Gilbert Associates, Inc. report to NSF,

> "the capability of these commercial A-frames and their control systems are satisfactory for reasearch submersibles. Their drawbacks are weight, size and power requirements. The weight of an A-frame is approximately 2.35 the dry weight of the submersible; thus, about fifty tons for the ALVIN. This weight includes the power winches, accumulators, rams, deck mounted unit frame and the A-frame with vee strut. The engineering and service experience of the manufacturers of these units is impressive."

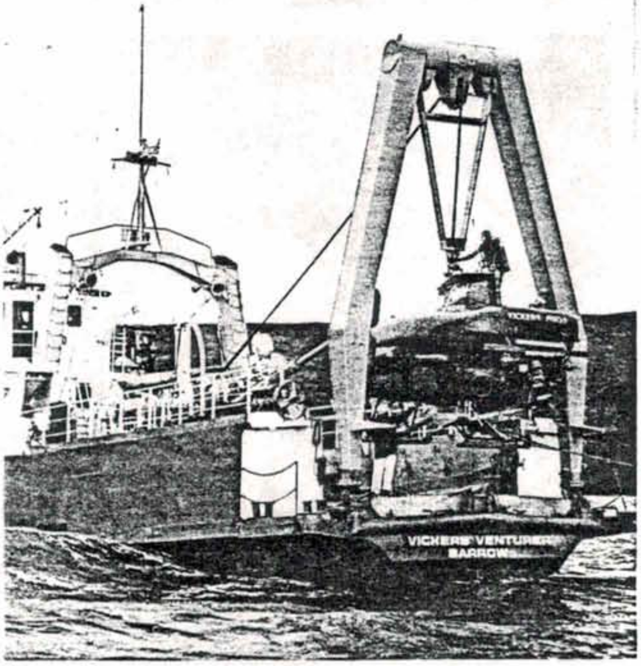
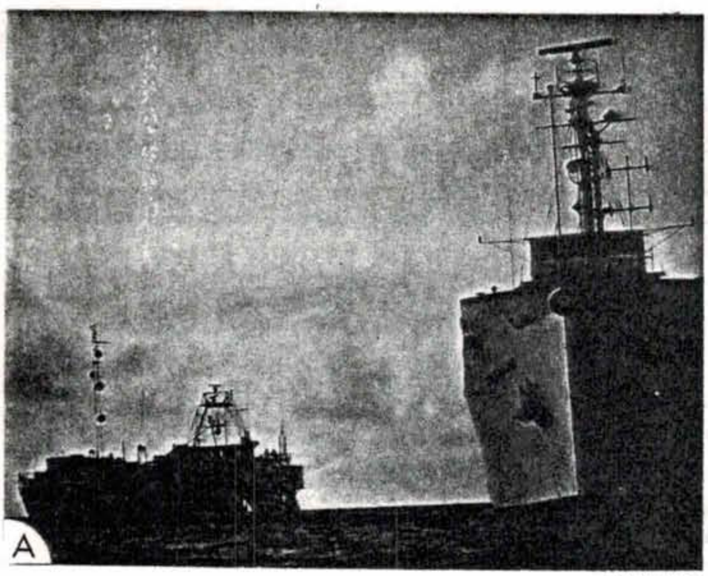


Figure 16. A stern mounted A-frame with a hinged vee strut hanging from the top of its corss-member. The strut provides lateral support to the submersible.

Figure 17 (Facing Page). A - R/V LULU and the "escort-hotel" ship, R/V ROBERT D. CONRAD on site at the Equator over the Galapagos Rift; B - R/V KNORR, being considered as a potential candidate for conversion to a dedicated submersible support ship; C - M.S. PANDORA II, a commercial submersible support vessel available for lease; D - R/V GYRE equipped with winch and towing crane for near-bottom side-scan sonar surveys; E - DSRV ALVIN entering between pontoons of R/V LULU in preparation for recovery; F - JOHNSON SEA LINK onboard afterdeck of its dedicated dedicated support vessel; G - High-Hoe towing crane owned by U.S. Navy, operated by Scripps Institution of Oceanography, submerged in moderate seas onboard R/V GYRE while launching a tethered unmanned submersible.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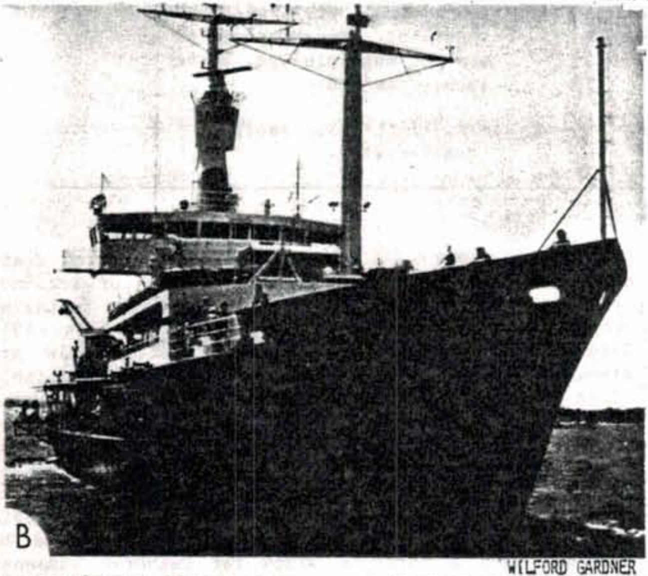
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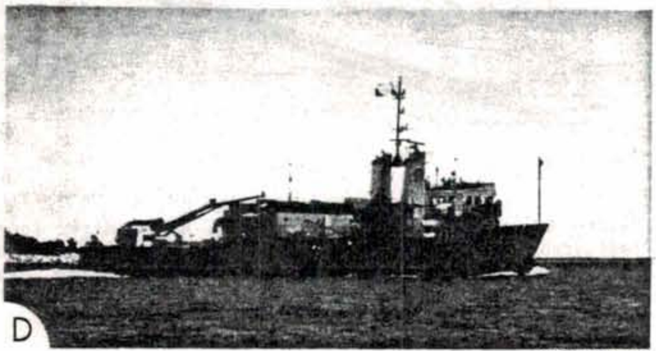
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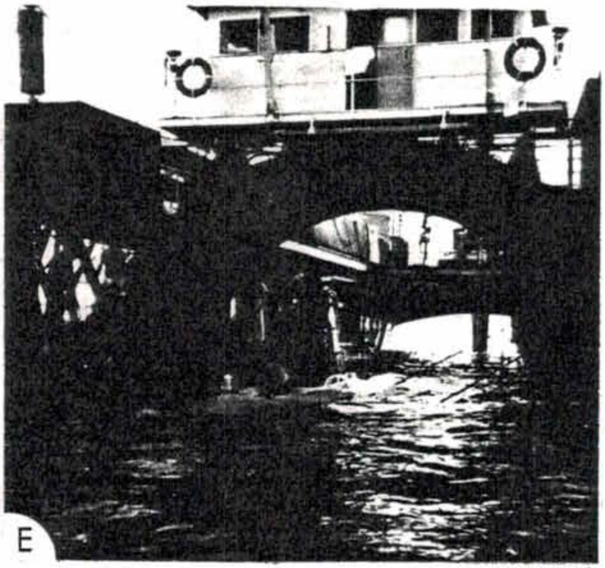
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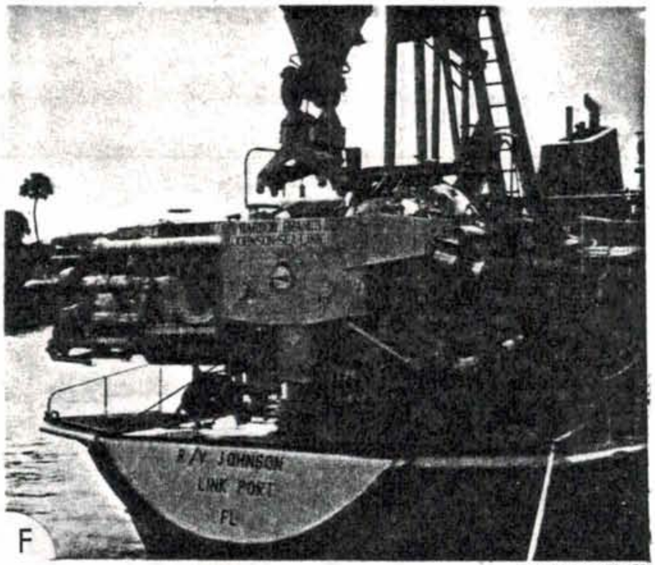

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TABLE V. SUBMERSIBLE HANDLING COMBINATIONS

System	Ship Location	Probable Support Ship Mods	ALVIN Mods	Comments
Elevator	Center Well or Stern	Moderate to significant	None	S.S. limit 3-4 stern location most likely; handling system not transferrable
Ramp	Stern	Significant	Slight	System not transferrable S.S. limit 3
A-frame	Stern	Slight	Significant. Single or multiple top pick pts.	S.S. limit 4-5 w/single pt.; would require moajor frame mods; handling system could be transferred
Boom crane	Stern or Side	Moderate	Significant. Single or multiple top pick pts.	4-5 w/single pt. transferrable, single pt. preferred due to simpler ops but multiple pts. better for subm. fram mod.
Gantry	Center Well or Stern	Moderate	Same as A-frame and boom crane	S.S. limit 4-5; possibly transferrable.

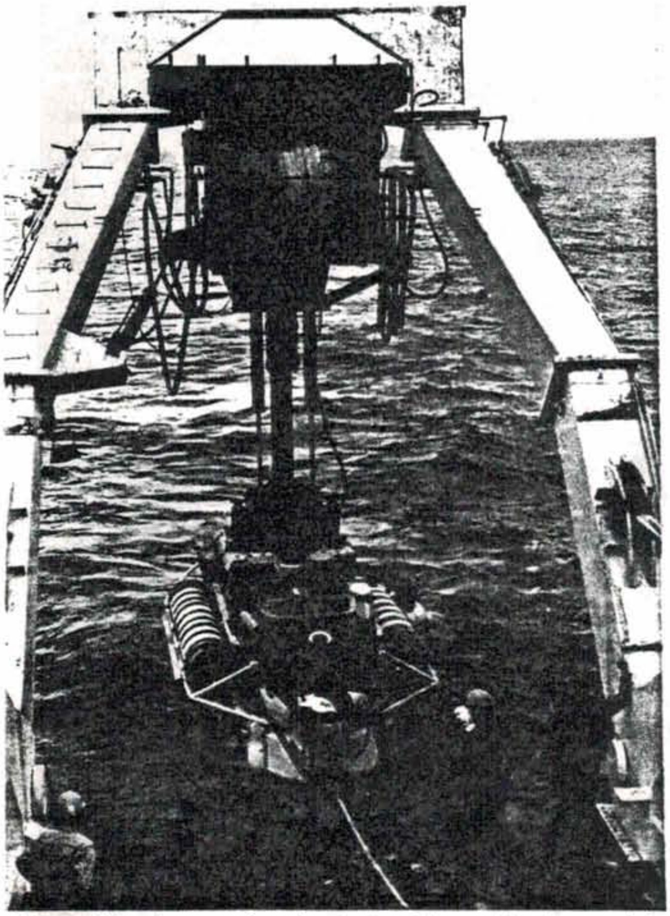

Figure 18. An example of a hydraulic vertical arm with a socket attachment that rigidly grabs the submersible. The constant-tension lifting winch is an integral part of the stern mounted A-frame.

OPTION #3 - COMMERCIAL LEASE. There are several dedicated submersible support vessels capable of accommodating a 17 ton submersible with permanently installed stern A-frame launch and recovery systems (Fig. 19). Specifications for two such commercial vessels are given in Table VI. M.V. PANDORA II has been available since April, 1981 for long-term charter (C. R. Ward & Assoc., P.O. Box 2308, Sidney, B.C. Canada, 604-656-3322). These vessels can readily handle ALVIN and meet the specified science requirements for space, range, speed, etc. Some additional berthing in a van would have to be added to M.V. PANDORA II for submersible crew or scientists. Both ships would have to be equipped with a portable winch for tethered unmanned submersibles.

Figure 19. The R/V VICKERS VOYAGER, an 84 meter long dedicated submersible support ship fully fitted out to handle two submersibles in adverse weather and sea conditions such as those encountered the North Sea.

TABLE VI. SPECIFICATIONS FOR COMMERCIALLY LEASABLE SUBMERSIBLE SUPPORT SHIPS

BASIC DETAILS	M.V. PANDORA II	R/V VICKERS VOYAGER
Overall Length	58 meters	83.5 meters
Length Between Perpendiculars	53.3 meters	71.6 meters
Beam	13.7 meters	14.6 meters
Draft	5.2 meters	6.7 meters
Displacement	2100 tons	4500 tons
Propulsion	twin screws, 2605 B.H.P. each	single screw, three 1401 B.H.P diesel electric
Bow-thruster	500 H.P.	unknown
Maximum Speed	13.5 knots	12.5 knots
Cruising Speed	10 knots	10 knots
Launch/Recovery	Over-the-stern A-frame 18 tons in Sea State 4	Over-the-stern lift 18 tons in Sea State 5
Navigation	Satellite, Loran-C, Radar	Satellite, short-baseline acoustic, doppler sonar
Accommodations	12 scientific	20 scientific
Laboratories	Electronics Lab	Electronic, mechanical, shop, dark room

OPTION #4 - CONVERSION OF A COMMERCIAL SHIP. If a long-term (up to 5 years) charter is considered, one can requisition a leased vessel to be constructed from scratch using basic pre-determined plans with the contractor-requested modifications included. The conventional offshore supply vessel in the size range of 55-60 m is widely available, but has a major disadvantage of low free-board, which makes the work and maintenance areas very wet even in moderate sea states (Fig. 20). The U.S. Navy has chosen to lease a 58 meter long commercial "mud boat" and modify it as a support vessel for SEA CLIFF. They have also opted for a "man-rated" pedestal boom crane for a launch and recovery system, eventually to be operable in Sea State 4. The Navy's mission requirements do not mandate as long a range, endurance or as large a support team or as much laboratory space as considered necessary for open-ocean deep-sea sustained scientific research. Conversion of a fixed design "mud-boad" is considerably less expensive than initiating construction from a new design.

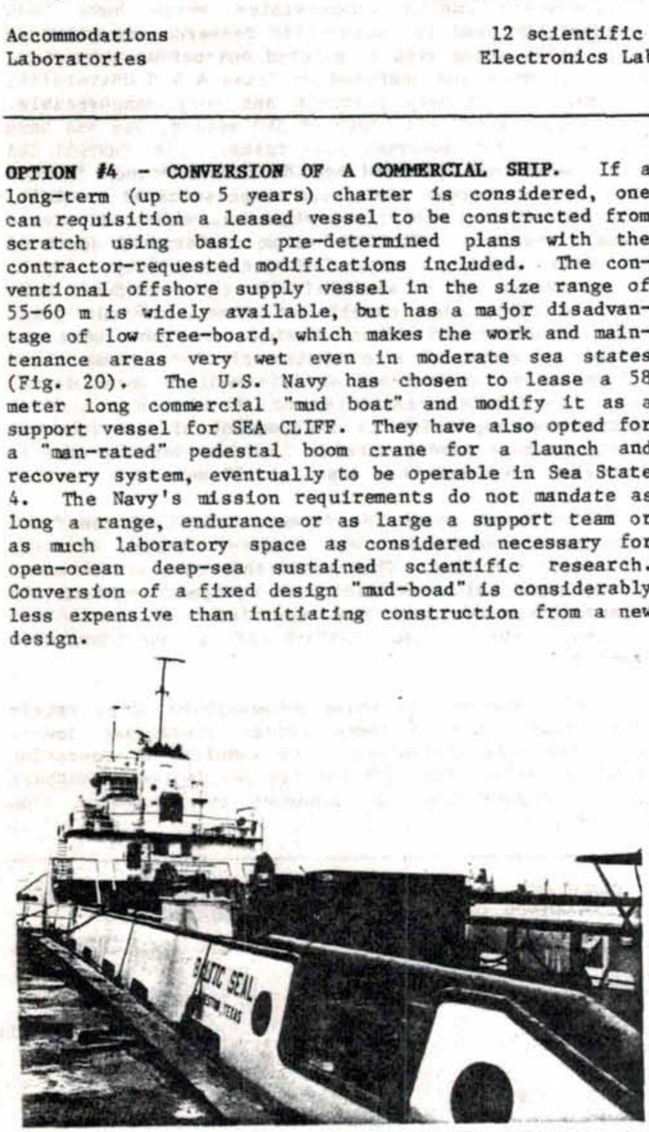

Figure 20. A typical "mud boat"available for lease but having a very low freeboard which makes the work and maintenance area on deck wet and even moderate Sea States. This type of vessel has been chosen by the U.S. Navy as the support ship for SEA CLIFF.

8.3.2. Near-Term Support Ship Costs. Serious consideration has not been given to an upgrade of LULU; therefore, no costs are presented for Option #1.

Conversion of an existing UNOLS vessel for Option #2 depends upon the vessel chosen. Table VII lists approximate costs for conversion of KNORR/MELVILLE and ATLANTIS II, based on analyses initiated by John W. Gilbert Associates, Inc. and review by the Task Force and Project Office of this study. Conversion costs range from ≈ \$1.55M for ATLANTIS II to ≈\$1.7M for KNORR/MELVILLE. This one time cost is roughly 65 percent of the present yearly operational cost of either vessel. In the first year of use, 60 percent of the conversion cost could be paid from the savings of not having an "escort/dormitory" ship in addition to the submersible support ship.

Lease of a commercial submersible support ship in Option #3 ranges from ≈ \$11,000/day for M.V. PANDORA II and ≈\$15,000/day for R/V VICKERS VOYAGER. These prices assume an 11 knot transit speed, but do not include costs of the submersible support team. A one-time charge of ≈\$130K is needed for construction and installation of a portable conducting cable winch for unmanned tethered submersibles.

The cost of a leased and modified commercial bare boat is much more difficult to calculate, because there are many unknowns (size, length of charter, extent of modifications). It is estimated that averaged over 5 years (minimum length of charter which includes substantial modifications) the cost of conversion and rental would equal the ATLANTIS II conversion and yearly operational charges. The cost would be less for a longer charter because of a reduced day charge and reduced fuel consumption. At the time the charter agreement expires, the vessel would have to be put back into original condition, which might account for a one time cost of ≈\$0.7M in 1982 dollars.

8.3.3. Near-Term Support Ship Recommendations. Insufficient information exists at the present time to make an ultimate choice between Option #2 (conversion of an existing UNOLS vessel) and Option #3 (lease of an existing commercial support ship). Since either option can provide a satisfactory solution which meets the projected near-term science requirements, we recommend

TABLE VII. ESTIMATED CONVERSION COSTS (1982 DOLLARS) FOR KNORR/MELVILLE AND ATLANTIS II

Tasks	KNORR/MELVILLE	ATLANTIS II
Removal of superstructure, unnecessary winches, labs	$250K	$50K
Addition of Fixed Ballast	$50K	$80K
Construction of Hanger and Interior Workspace	$100K	$75K
Deck Strengthening	$100K	$50K
Electrical-Mechanical	$100K	$75K
Construction or Purchase of A-frame with hydraulics, tensioning winch, etc.	$900K	$900K
Submersible Maintenance Outfit	$50K	$40K
Construction and Installation of conducting cable winch for unmanned submersibles	$130K	$130K
Additional or improved lateral propulsion for launch and recovery	N.A.	$150K
Reconditioning vessel	$20K	$20K
TOTAL ESTIMATED CONVERSION COST	$1.70M	$1.57M

selection of the option which, after further consideration, is most cost-effective, feasible and politically acceptable.

Neither the "new construction" support vessel or conversion of a commercial bare boat (yet to be constructed) is considered to be a viable choice for the near-term deep-water facility systems as the short time-frame for immediate replacement of LULU necessitates the utilization of existing facilities. If the near-term time frame were extended, it would be feasible to construct a support vessel that would fulfill both the near-term and far-term requirements. Considerable merit is seen in the operational experience that would be gained by the use of an intermediate platform, and the lessons which could then be incorporated into the support vessel for the 1990's and beyond.

MELVILLE and KNORR are Navy-owned vessels which are operated by oceanographic institutions under charter agreements. The Submersible Science Study cannot presume whether the Navy would allow conversion, nor can the Study request that the respective operating institutions offer these vessels for conversion. We will assume, however, that if a commercial vessel is leased, NSF will request that one the large AGOR class research vessels will be retired from the UNOLS fleet on an indefinite basis. LULU will also be retired.

If a charter agreement for PANDORA II could be secured, this option offers a potential immediate short-term solution. The projected day costs for PANDORA II are less than the projected KNORR/MELVILLE or ATLANTIS II day costs. The charter option is attractive, because the yearly commitment could be reduced (with financial savings) if submersible science in the 1980's does not turn out to be as productive as it was in the 1970's. This vessel could potentially be shared part-time with France, the U.S.S.R., Japan, the U.S. Navy, or other commercial users.

If there are no offers from any of the institutions to voluntarily retire one of their large researc ships, then Option #2 is a viable solution.

The Submersible Science Study recommends that the ultimate choice between Options #2 and #3 only be made once a charter agreement has been explored in detail with price and performance quotations, and after an institution voluntarily comes forth with a proposal (including costs and time scale) for conversion of one of their large oceanographic vessels. If their opinion is solicited, the Submersible Science Study members are agreeable to look at the new data and assist in further evaluating the selection of the near-term submersible support ship.

8.4. Near-Term Shallow Manned Submersibles

There are numerous shallow submersibles, large and small, available for commercial charter. Some of the submersibles can be leased as stand alone vehicles, others as complete "turn-key" systems including the submersible support vessel.

8.4.1. Facilities. The specifications for two shallow-water manned submersibles which have been successfully used for scientific research are given in Table VIII, along with a tethered one-person submarine. DIAPHUS, owned and operated by Texas A & M University, is small, relatively portable and very maneuverable. It has an operational depth of 365 meters, and has been used mostly for observational tasks. The JOHNSON SEA LINK, owned and operated by the Harbor Branch Foundation, is a larger and more sophisticated vehicle, equipped with an acoustic navigation, video and photographic systems. SEA LINK has an operational depth of 300 meters and has a diver lock-out capability. Depths to 900 meters can be achieved with the InterSub's submersible PC16, also capable of diver lock-out (Fig. 21). Mobility and diver working time have been extended by means of a submarine platform clamp which allows divers to lock-out at intermediate water depths rather than being restricted to the seabed. A diver heating system, which is independent of the submersible's battery power, extends lock-out working time to typically 3-4 hours at a depth of 150 meters.

Divers are under the direct control of the front compartment personnel who monitor their activity throughout the dive. This means that complex tasks can be performed using sophisticated equipment onboard the submersible, and under the supervision of specialists in the security and comfort of a one-atmosphere chamber.

All three of the above submersibles offer excellent viewing within hemispherical plexiglass domes. All three have manipulators for sampling or operating external tools. SEA LINK has its own dedicated support ship. DIAPHUS has been launched and recovered from R/V GYRE.

TABLE VIII. SPECIFICATIONS FOR NEAR-TERM SHALLOW-WATER AND MID-WATER MANNED SUBMERSIBLES

BASIC DETAILS	DIAPHUS	SEA LINK	JIM
Length	5.9 m	7.0 m	vertical suit
Beam	0.9 m	2.4 m	1.0 m
Height	2.4 m	3.3 m	2.0 m
Weight (in air)	5 tons	9.5 tons	500 kg
Speed	1 kts	1.8 kts	tethered
Life Support	60 man-hrs	72 man-hrs	16 man-hrs
Operating Depth	365 m	300 m	400 m
Observers	1	3	1
Diver Lock-out	no	yes	no

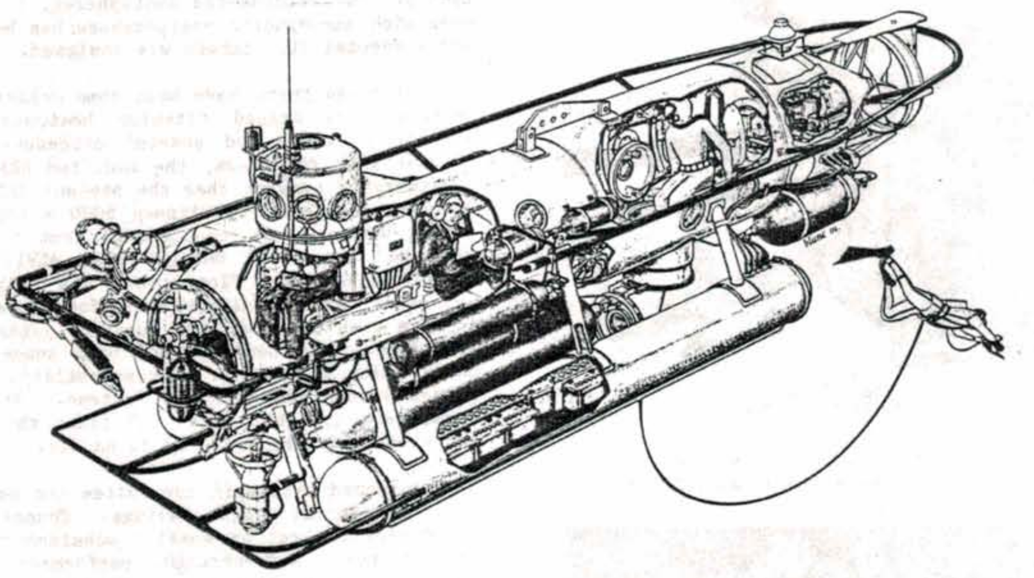

Figure 21. InterSub's PC16, a shallow water manned submersible capable of diver lock-out, observation and manipulation with a team of three scientific observers and two pilots.

8.4.2. Options. We propose two options for near-term use of shallow-water manned submersibles.

(1) Submersible is obtained by charter agreement between scientific user and commercial or institutional operator.
(2) UNOLS funds an office which obtains charter agreement for scientists and assists with planning, scheduling, installation of special equipment and logistics.

8.4.3. Costs. The DIAPHUS day/charge is approximately $3K, which must be added to the support ship costs. A single time mobilization/demobilization of the submersible and its launch/recovery system on R/V GYRE is approximately $10K (without shipping). The GYRE day/charge for 1982 is approximately $8K.

The JOHNSON SEA LINK charters for $8.7K/day including its dedicated support vessel. Commercial vehicles range from $6K to $20K per day depending on system complexity and operational area.

8.4.3. Recommendations. The Submersible Science Study recommends Option #1 primarily because we do not forecast a sufficient number of shallow submersible requests to justify the expense of an UNOLS office for shallow diving.

8.5. Near-Term Mid-Water and Under-Ice Facilities, Options, Costs and Recommendations

Facilities. Mid-water research can presently be accomplished by one-person submersibles operated from a tether to the surface support ship. There are configurations where the observer is vertical in a rigid but articulated suit with legs and arms (JIM) or horizontal using articulated manipulators (unnamed vehicle built for Canadian Forces by International Submarine Engineers, Ltd. shown in Figure 22). Mid-water science can also be accomplished using robotic systems. These remotely operated vehicles have become very popular with offshore companies involved in oil and gas exploration and production activities. Some robotic systems (TREC) are equipped with manipulators that have configurations ranging from 3 to 7 functions (Fig. 23). Other vehicles are dedicated to observation using video and a photographic camera/flash (Fig. 24).

Options. The only realistic option is for each scientific project to decide on the most affordable, suitable and cost-effective equipment and then enter into a lease agreement for its use once a proposal has been funded.

Costs. The tethered manned vehicles range in cost from $1K to $6K per day, exclusive of the support vessel. The unmanned vehicles lease from $0.3K to $4K per day, depending if one requests to have operators or a bare system.

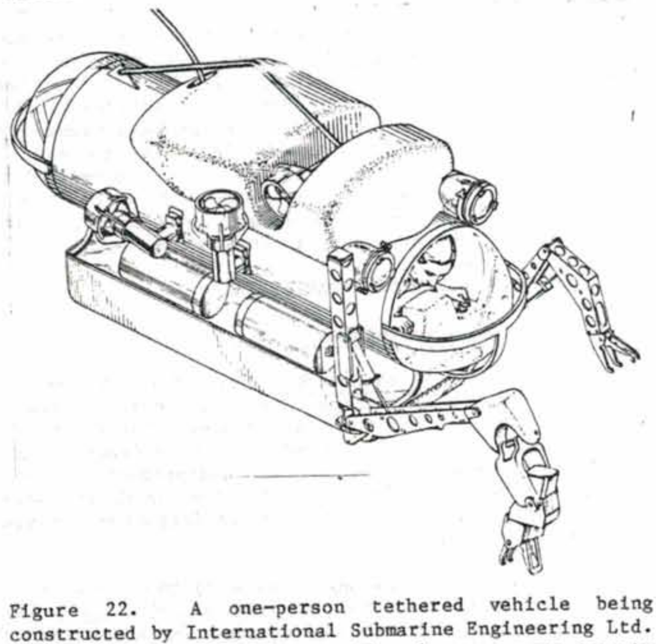

Figure 22. A one-person tethered vehicle being constructed by International Submarine Engineering Ltd. for mid-water applications. The observer must operate external tools and instrumentation with force/position feedback manipulation.

Figure 23. An unmanned tethered remotely operated vehicle equipped with thrusters and a manipulator arm.

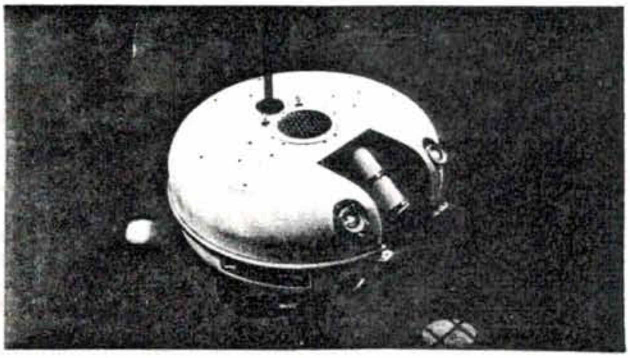

Figure 24. An unmanned tethered observational vehicle built by Benthos Inc. for shallow-water, mid-water and under-ice missions.

Recommendations. The Submersible Science study recommends that each principal investigator or group of investigators contracts individually for the system which will best fulfill the specific objectives of the scientific project. Some economics can be achieved by scheduling projects sequentially in order to reduce mobilization/demobilization costs. The Submersible Science Study recommends that the Office of Naval Research assist in obtaining access, when possible, on nuclear submarines that patrol beneath the ice.

9. LONG-TERM SUBMERSIBLE FACILITIES

9.1. Manned Submersibles

9.1.1. Far-term Personnel Spheres. The U.S. Navy's SEA CLIFF is presently being converted for a 6160 meter depth capability. Much design and manufacturing information has already been learned and can continued to be learned from the experiences and end-product of this conversion project. The design for the SEA CLIFF modification required 21 months; the manufacturing process is expected to last 23 months.

The SEA CLIFF personnel sphere is being constructed from titanium alloy 6-2-1 which is the same alloy used on ALVIN. The two hemispheres are first forged and then machined to an 8.5 cm wall thickness. They are later welded together. The proof of welding procedures and the certification of welder has taken 18 months. For welding the hemispheres, a special "clean" room with atmospheric overpressure has been established and a special jig fixture was designed.

Although there have been some delays for technical reasons, the welded titanium hemisphere concept is already a "tried and proven" procedure. Because of greater wall thickness, the modified SEA CLIFF will be considerably heavier than the present ALVIN. It is our understanding that the French 6000 m submersible under design will also be constructed from titanium, and it will be longer and heavier than ALVIN. Added hull weight means added flotation. The weight of a given volume of cnventional syntactic foam in air is typically more than two times the buoyancy gained in seawater. Weight and size penalaze not only submersible performance which depends on maneuverability, but they also impact launch and recovery systems. Stern-mounted A-frames are typically 2 to 2.5 times the weight of the submarine they are designed to handle.

Advanced synthetic composites can potentially provide substantial weight savings. Composites depend to a substantial part on special manufacturing methods to achieve their high-strenght performance; thus, it is necessary to manufacture a very large number of prototype specimens and subcomponents for evaluation. Since composites have their high strength in essentially one direction, there is a need for ply orientation at various degrees to get the total strength desired. As a result of reasearch and testing programs, there are now available materials and process specifications as well as miltile soures and materials. Safety coefficients and design allowables have been published, general fabrication experience has increased and inspection procedures have been established.

The most common advanced composites are graphite-epoxy units, Kevlar-epoxy, and hybrid units of aluminum and graphite epoxy. Carbon fiber composites have been used for masts and a composite design of hollow aluminum shafts with carbon fiber reinforced plastic have been used for rudder shafts on racing sailboats. It is uncertain whether the experience of composites for this application is of much value since the use of these components is very limited in terms of cycles of load applications, and the structural loads are not well defined.

In considering its high strength-weight ratio, an advanced composites hull could have 1/3rd the wall thickness of a similar size titanium hull. With less total weight, the composite hull would need considerably less flotation material.

A submersible personnel sphere manufactured of composites would require a material development program and substantial testing before it could be "man-rated".

9.1.2. Far-Term Submersible Frames. As is the case for hulls, substantial weight savings would be made by using composites for the submersible frame. Their components are being used in ever increasing number by the aero-space and yachting industries. There is no cost-effective weight-saving replacement for syntactic foam on the distant horizon.

9.1.3. New Submersible Instrumentation. In the next ten years we can expect to see further miniaturization for electronic subsystems and substantial advances in microprocessor operated peripheral equipment.

Video cameras will become solid-state and be much smaller in size with greater than 400 line resolution. We can expect even cameras requiring less than 10 lux of faceplate ullumnation and much less lag retention.

Solid state cameras will have increased depth of resolution and improved macrocapability. On-bottom navigation should be able to be accomplished entirely with on-board sensors and computers, thereby making obsolete the large networks of bottom-moored transponders which are time consuming to deploy and recover. Advances in low-power acoustic telemetry will allow the progress of each dive to be reviewed in "real-time" by a mission control center on the surface ship. Interaction between the surface and the submersible would potentially be less distracting and more informative.

9.1.4. Far-Term Submersible Energy Supply. The critical factor for the time and distance that a submersible can operate is the power supply. Conventional submersibles today are utilizing lead acid batteries which have an "optimum" energy density of 10 watt-hours/pound. Both SEA CLIFF and TURTLE will have silver zinc batteries (42 whrs/lb) in their newly modified configurations. Advanced technology energy storage systems such as lithium Thionyl chloride (300 whrs/lb) would provide considerably more electrical capacity but would require additional materials testing and certification. DEEP QUEST, howver, has recently conducted tests with fuel cells.

9.1.5. Far-Term Safety Features. It should no longer be necessary to consider personnel sphere release as an ultimate safety back-up system, thereby making frame design simpler and lighter and smaller. Far-term submersibles should consider possible use of cryogenically stored liqued oxygen to greatly reduce the weight and space needed for life-support consumables. Better design and new materials are expected to improve habitability and ultimately the scientific productivity of the observers.

9.2. Far-Term Submersible Support Vessels

There are several improved ship designs which give promise for financial savings with construction and operation and one of these offers significantly improved sea kindliness. The Submersible Science Study reviewed essentially two basic types of hull designs.

TABLE IX. MONO HULL SUBMERSIBLE SUPPORT VESSEL SPECIFICATIONS

Characteristics	O/S Supply Boat Conversion	Shelter Deck Vessel
Dimensions LOA × B × dr	73 × 14 × 3m	73 × 13 × 2.5m
Displacement Long Tons	1,300 LT	1,600
Speed-Cruising (Knots)	10	12
Mission Duration (Days)	30	40
Range @ Cruising Speed	8,000 NM	12,000 NM
Fuel Consumption @ Average Speed/Day	1,200	1,500 gal
Total Lab Space (Ft^2)	1,000	3,000
Gross Registered Tonnage	300	300 GRT
Total Number of Persons On Board	33	49-54
Ships Crew	12	25-30
Sub Crew	9	10
Approx. Ship Constr. Cost	$14M	$12M
Approx. Annual Op. Costs	$2.5M	$2.7M
Approx. Cost/Day w fuel	$8,500	$9,000

9.2.1. Conventional Mono-hull Ships. Several configurations of a mono-hull vessel can be adapted to use as a far term dedicated submersible support ship. Conversions of the offshore supply ship design have been proposed as LULU replacements. An alternative is the keel-up design of a "shelter deck" vessel for submersible support. Specifications of the two approaches are outlined in Table IX.

A "shelter deck" vessel has most of the superstructure tacked onto the displacement hull, rather than it being an integral part of the ship structure. This concept allows one to construct a vessel with significantly greater room for personnel and laboratories and qualify with the minimum tonage requirements necessary (300 GRT) for crews of less than 12 persons.

The "shelter-deck" design would provide potential for more comprehensive submersible maintenance at sea with larger shops, hangers and more spares and increased habitability, especially for the permanent ship and submersible support crew. Experience with LULU has shown that for the long (three to four month) cruises that are not unusual for research vessels, habitability, or lack of it, is the primary contributor to morale problems with the resultant high crew turnover rates.

Although stability associated with the launch and retrieval operations would have to be carefully computed, there are no serious engineering objections to these operations being feasible from vessels which fit within the above specifications. This is assuming that the single-point lift over the stern will be chosen as the launch and recovery system. The incorporation of maneuverability aids such as twin screw variable speed propellers and bow thrusters, maximum Sea State operations would be four for the conversion and five for a new design shelter-deck vessel.

The choice between "existing" and "new construction" support ships also involve qualitative and quantitative judgments, the former basis being considered at this point. The "existing" ship alternative can be expected to have significantly lower acquisition costs than a "new construction" ship -- providing a suitable ship can be found. If extensive conversion work is required to enable the ship to meet criteria, a substantial portion of this advantage disappears and it may be preferable to build a new ship rather than accept an older one. On the other hand, new construction" provides an opportunity to meet science requirements and other criteria in an optimal manner and to introduce new technological concepts into the design. For a mono-hull "new construction" ship the acquisition costs could be lower if a standard, or class, design were used.

9.2.2. Semi-submersible Support Ships. The following advantages of a semi-submersible support ship over an equivalent mono-hull should be considered:

(1) Reduced motion either underway of on station
(2) Larger deck area (available for submersible and support systems)
(3) Reduced power in large waves
(4) Reduced power in calm water at moderate to high speeds
(5) Reduced crew fatigue

Several disadvantages are:

(1) Deeper draft
(2) Less range
(3) Lower payload
(4) Less static resistance to asymmetric loading

At present the U.S. Navy is operating a semi-submersible ship, the KAIMALINO. A support vessel being

TABLE X. SEMI-SUBMERSIBLE SHIP: BASIC SCIENCE REQUIREMENTS

Item	Minimum	Maximum
Persons on Board (Total)	30	70
Enclosed Spaces Sq. Ft.	8,000	14,000
Open Deck Spaces Sq. Ft.	4,000	16,000
Range, NM at Cruise Speed	8,400	7,000
Dimensions	145m × 62m	65m × 30m
Displacement, LT	500	1,000
Cruise Speed, Knots	12	11
Power, HP	1,900	5,400
Payload, Tons	50	200
Cost, $ Construction	5M	20M
Operating/yr.	1.5M	2.5M

designed for the Japanese deep diving research submersible is of a similar design.

To fit within the minimum, median and maximum Science Panel requirements, the basic information for semi-submersible type vessels is presented in Table X. These parameters assume that the vessel will fit within the 300 Gross Registered Tons requirement for a support vessel.

This preliminary information points up the problem of payload; it is reported that one additional ton of fuel can be carried at the cost of one ton of payload. This would have the effect of decreasing the range of the vessel if payload is increased above that shown. The fuel consumption, and resultant ranges, can vary dependent on the type of engines (diesel or turbine). The powering formula shows that there should be little power increase needed for a semi-submersible ship in conditions which change from calm to rough water.

The problem of asymmetric loading, such as the launching and retrieval of a 20-30 ton submersible, has been addressed with the possibility of using a compensating counter balancing ballast during the operations. An alternative would be an arrangement to launch and recover through a "moon pool" located on the geometric center of the water plane area. This would eliminate the trim problem but still affect ballasting as the weight of the submersible is either added or subtracted from the displacement tonnage of the vessel.

Best estimates for a semi-submersible ship indicate that most anticipated science work could routinely be conducted in Sea State 5 for all sizes shown above and submersible capabilities (Sea State 6) due to superior platform stability.

Aside from the increased satiblity, which is an important consideration for the well-being of crew and support personnel as well as providing a stable work platform on which to perform the daily maintenance tasks necessary for the upkeep of the research vehicle, the most attractive prospect of the multi-hull vessel is the deck space. A review of the Science Panel requirements shows that the smallest proposed semi-submersible ship specifications would offer enclosed and open deck space far exceeding even the maximum science requirements. Assuming that a multi-purpose research vessel/submersible support ship were the choice as far-term support vessel, this parameter would offer more than adequate space within which the various activities could be placed.

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