OCEAN EXPLORATION

OBJECTIVES AND PRIORITIES

IN charting a course of discovery we forsee a captivating set of results and products derived from ocean exploration.

EXPLORATION OBJECTIVES

We are faced with fascinating challenges, founded upon the balance of our current understanding and our expectations for future capabilities. These challenges are, by design, ambitious in nature. Four challenges will constitute the objectives of the Ocean Exploration Program:

— ***Mapping at New Scales Emphasizing Regions not Previously Observed;***

— ***Exploring Ocean Dynamics and Interactions at New Scales;***

— ***Developing New Technologies; and***

— ***Reaching Out in New Ways to Stakeholders.***

Mapping at New Scales Emphasizing Regions not Previously Observed

The most notable product of exploration is the creation of new ways to show others what lies beyond our current understanding. This documentation of discovery is typically articulated in a new or improved map. But current and evolving spatial information systems have redefined the standard notion of a map. The Ocean Exploration Program will recognize these new technologies and produce new generations of maps that include all imagery characterizing ocean geography, physics, chemistry, geology, and biology. These maps will also define sites of archaeological significance and define changes in regions over time. The mapping process should be broadly constituted to include:

— ***Archaeological sites***
We will find and systematically explore dozens of new sites.

— ***Resources, living and non-living***
We will explore what they are, where they are, and how abundant they are, within the U.S. Exclusive Economic Zone (EEZ) and continental margins.

— ***New species***
We will discover thousands of undescribed species.

— ***Ecosystems***
We will find and describe several new communities of organisms displaying novel relationships with their physical, chemical, and geological environments.

DISCOVERIES at our BURIED FINGERTIPS

A spectacular geological event took place on the Atlantic margin of North America about 35 million years ago. A giant meteorite, 3-5 km wide, struck the seafloor and blasted a crater twice the size of Rhode Island and as deep as the Grand Canyon. The evidence for this Chesapeake Bay impact crater is now buried about 200 km south of Washington, D.C. The story of the discovery of this sixth largest impact crater on Earth 50 years of exploration, observation, changing hypotheses, rapidly improving technologies, and serendipity.

The anomalous ejecta unit associated with the impact was first observed in drill cutting more than 50 years ago. Three decades later, clear evidence for the chaotic nature of the unit came from continuously cored sections (a technological improvement); the unit was attributed to a giant submarine landslide. In the 1980s, the discovery of 35-million-year-old microtektites suggested an extraterrestrial explanation, although the unit was then thought to be deposited by a super tsunami. Technology again improved our understanding when a series of marine seismic imaging systems revealed the enormous buried circular structure. Serendipity came into play because one researcher was either directly or indirectly involved in many of these observations and discoveries and could link the disparate data sets. The discovery of the impact structure and the difficulty identifying it during 50 years of research show the importance of using new technologies and multidisciplinary approaches to explore and reexamine the Earth at different scales. What other exciting discoveries lay buried at our fingertips, awaiting improved technologies and innovative approaches to reveal themselves?

— ***Ocean's interior***

We will explore the temporal and spatial variability of the ocean as well as variations in the interior of the Earth beneath it.

— ***Ocean floor***

We will completely map the ridges, canyons, faults, and other key features of the U.S. EEZ and the continental margins that have economic, hazard assessment, or other scientific or cultural importance.

More than all the world's museums combined, the ocean holds the artifacts that document mankind's historical relationship with the ocean. The Panel recommends that any new program in ocean characterization document and reference historical shipwrecks, submerged villages, and sites of archaeological significance. While the history of ships that sunk while transporting silver and gold is recorded with some accuracy,

In the winter of 1871, a fleet of whaling vessels was lost off the northern Alaska coast. The fleet of 32 ships became locked

LOST WHALING FLEET

in heavy ice, where they were crushed and sank. Over 1,200 passengers and crew abandoned ship with no loss of life. The sunken

OFF ALASKA EXPLORED

fleet has been located and preliminary surveys using a remotely operated vehicle (ROV) equipped with stereoscopic cameras with

USING 3-D TECHNOLOGY

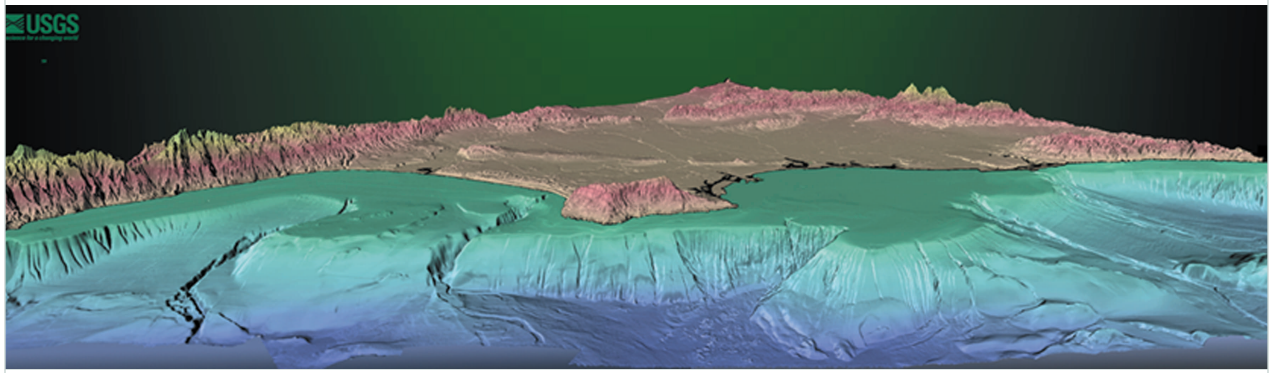
adapted planetary exploration software has been used to document the condition of the whaling vessels.

hundreds of ships that brought slaves to this country also sunk, leaving little or no trace for historians to follow.

A further goal for the Ocean Exploration Program should be to largely complete the mapping of the U.S. continental shelf. Maps that interpret

MAPPING

the shape of earth beneath the oceans



Historically, the seafloor and the water column have been mapped by discrete sampling techniques. Trawls, net tows, leadlines, and echosounders have provided a useful, but very sparse, picture of the distribution of marine life, morphology, and relief of seafloor features. Recent advances in sonar technology, which have been led by industry, have revolutionized our view of the water column and the seafloor. Multibeam sonars have the ability to form many (>100) narrow beams across a wide swath, which permits ensonification of large areas while maintaining high lateral (typically better than 2 – 5% of water depth) and vertical (typically better than .05% of water depth) resolution.

These systems can also collect simultaneous sonar backscatter data, resulting in an added layer of structural and textural information that can provide insight into the nature of the seafloor or mid-water properties. The nearly complete coverage provided by these systems results in unprecedented, detailed images of large volumes of the seafloor and the water column. The inherent density of these data sets permits exploration with interactive visualization techniques, allowing marine scientists to be "virtually immersed" in their data. Even more important, when expeditions are broadcast over the Internet, students, educators and the public can share in the excitement of ocean exploration.

the HENRIETTA MARIE slave ship

In the summer of 1700, the English merchant ship *Henrietta Marie* sank off the Florida coast shortly after unloading a cargo of enslaved Africans in Jamaica. The ship had been traveling along the infamous triangular route favored by slavers: Great Britain to West Africa to the West Indies and back to England.

The *Henrietta Marie* was discovered in 1972 by noted treasure hunter Mel Fisher. She was subsequently researched and excavated by a team of marine archaeologists and members of the National Association of Black Scuba Divers in 1983. The shipwreck and its artifacts have become part of a national traveling exhibit, which is partially devoted to the wreck. The effort to conserve the artifacts recovered from the wreck is highlighted through displays of items in varying stages of the process.

The ship contained no material "treasure" of note. After six archaeological expeditions to the site, divers have recovered only a handful of coins. However, the more than 7,500 items found near the wreck are far more significant than gold or jewels, because artifacts from any aspect of the maritime slave trade are extremely rare. An equally valuable treasure is less tangible: the wealth of information researchers have uncovered about the complex slave trade.

the seafloor provide a fundamental framework for research and management of the world ocean and are a prerequisite for identification of regions that warrant protection. They show composition of the seabed, its shape (topography), areas of anthropogenic impact, and areas of historical and cultural interest. They provide information on the transport of sediment and help to define biological habitats. All this information can be used to develop predictive models to guide habitat and resource management, monitoring strategies, and other research/exploration goals. Obviously, all marine life, ecosystems, archaeological sites, and seafloor features cannot be mapped and inventoried immediately. A strategic hierarchical approach to mapping must be considered, perhaps beginning with larger, more obvious species, features and sites on a large geographic scale, and working toward the finer resolution of the identification of biodiversity within the marine system.

Although the production of high-resolution base maps is the first step in a systematic strategy, it is a daunting task, considering how little of the seafloor has been mapped. For example, less than five percent of the total U.S. EEZ has been mapped in high-resolution. While the United States has always taken great pride in being a world leader in the development of approaches to the understanding and stewardship of the oceans, we now find that other nations are far ahead of us. England, Canada, and Australia are well along in developing plans for the complete mapping of their EEZs, and New Zealand and Ireland have already begun multi-year, multi-million-dollar programs to be systematically explore their EEZs. It is critical that the United States also begin this important task immediately.

On a mission to study marine life associated with oil seeps on the floor of the Gulf of Mexico, scientists recently discovered a brand-new animal living in the cold, deep depths. The discovery was made because scientists using the Johnson-Sea-Link submersible decided to investigate a curious formation they had glimpsed on an earlier dive. What they found were pink worms (now called "ice worms") that are about 1-2 inches long and apparently sculpt the surface of gas hydrates, which are natural methane water ices that form under conditions

of high pressure and temperature in many areas of the ocean floor. It is not yet known to what extent these worm colonies use the hydrate mounds for protection or nutrition, but they are the only known animal to inhabit this unique habitat. Researchers speculate that these worms may graze on chemosynthetic bacteria that grow on the methane, or may live in symbiosis with them. This discovery exemplifies that we must discard the old view that the deep sea bottom is a biologically impoverished zone.

"ICE WORMS" DISCOVERED IN GULF OF MEXICO

A minimum level of exploration would help identify areas of unique value and global importance. The results of these exploration efforts should be sufficient to guide future exploration and action items for resource managers. Systematic preliminary site surveys should be conducted in advance of more focused expeditions to discover new environments inhabited by presently unknown organisms. Information from satellites should also be used to provide maps of surface water characteristics needed to plan exploration of the EEZ.

While these goals focus on U.S. waters, international efforts should not be ignored. For example, the World Conservation Union objectives for Marine Protected Areas are consistent with the goals identified here, and we should investigate collaborations with other national and international efforts.

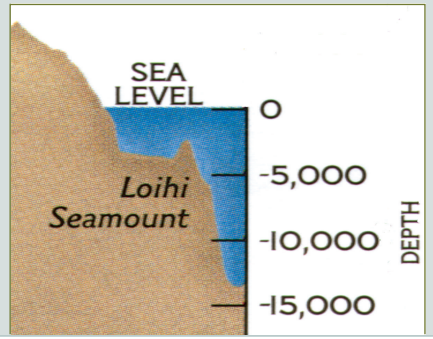
Exploring Ocean Dynamics and Interactions at New Scales

Ocean phenomena, which support complex ecosystems, operate over a broad range of unexplored spatial and temporal scales. Examples of dynamic features to be explored include:

— ***Ocean properties***
We will discover dozens of new oceanographic features changing over spatial scales from 10 to

EXPLORING THE BIRTH OF A NEW HAWAIIAN ISLAND

The recent collapse of the lava dome of the underwater volcano Loihi off Hawaii is giving scientists in a research submersible the opportunity to witness the birth of the next Hawaiian island. Several years after this event, which created an underwater crater more than a half-mile wide and 1,000 feet deep, superheated water and dissolved minerals have



combined to form mats of chemosynthetic life. The bacteria that make up these mats now form the base of elaborate food chains that draw in higher life forms like fish, making the summit of Loihi, some 3,000 feet beneath the surface, a place of rich marine biodiversity.

10,000 km, and temporal scales from picoseconds to millennia. These features include the ocean's interaction with the atmosphere and as a key component of the global hydrological cycle.

— ***Sea surface***

Hyperspectral sensing of the sea surface will reveal unexpected changes in temperature, salinity, photosynthesis, and ocean circulation over a wide range of time scales.

— ***Biological, geological, chemical, and physical interaction***

We will unravel dozens of processes affecting the interactions among species and the cycling of organic materials in the sea and in the coastal zone. We will explore the connection of living and nonliving systems in the largest environment on the planet — the world's ocean.

Until just two decades ago, it was thought that all living things, plants and animals, were supported in a variety of ecosystems that based their supply of energy on photosynthesis, the process by which green plants transform the sun's energy into simple sugars. But in 1977, dives of the deep-sea submersible *Alvin* found marine life thriving in the darkest depths of the ocean on the energy released when chemosynthetic bacteria break down methane and sulfur compounds carried by fluids venting from the seafloor.

In the summer of 2000, biologists discovered yet another mechanism by which marine life can harness energy. As much as 20 percent of the bacterial life in the deep sea might directly convert light to energy for powering cellular processes via a photon pump, thus sidestepping the more complex photosynthesis process entirely. This ability gives these organisms a survival advantage in low-nutrient environments. These discoveries are rewriting the biology and oceanography textbooks. Science can only speculate what other novel means for powering life might exist in the world's oceans, and how their discovery may revolutionize the understanding of energy transfer in ecosystems.

While the discoveries mentioned above had an immediate impact on our understanding of the ocean, the Ocean Exploration Program must also foster observations over long periods of time to discover new processes and systems in the ocean that are not readily apparent. For example, nearly 15 years ago, scientists began collecting oceanographic and atmospheric data in the Equatorial Pacific. Every year, scientists collected salinity, temperature, wind speed, atmospheric pressure, and sea height data. After many years,

Man's ability to intelligently explore the deep sea has been significantly enhanced by the advent of novel, autonomous platforms, remotely operated vehicles (ROVs) that can be submerged for extended periods of time, and satellite communication technology that is used to report data to scientists. Over the past decade, in particular, microelectronic equipment has made it feasible to outfit these platforms with sophisticated sensors that measure a wide variety of chemical, biological, and physical processes over a wide range of time scales. It is now possible, for example, to measure the difference in carbon dioxide concentration in the sea and the air above it over long periods on deep-sea moorings, such as NOAA's TAO-TRITON array in the Equatorial Pacific. Such measurements are required to understand the influence of the ocean on atmospheric carbon dioxide concentrations, the impacts of events such as El Niño, and the feedback processes that act to control the heat balance of the atmosphere.

SENSORS for OBSERVATION of OCEAN BIOGEOCHEMISTRY

In areas closer to land, the extent, frequency, and nature of Harmful Algal Blooms (HABs) have been difficult to document. This is due to the fact that traditional sampling, in order to be effective, had to keep up with the plankton growth rate (the population doubles every 12 hours), and plankton identification was done visually with the aid of a microscope. However, the revolution in biotechnology now makes it possible to conduct rapid, quantitative plankton species identification using only their DNA. A number of HAB species can now be identified automatically from ship-based laboratories. This automation should be adapted for autonomous platforms in the near future to facilitate the remote, quantitative observation of ocean ecosystem structures.

patterns in the data began to emerge and led to our ability to detect the onset of El Niño.

Developing New Technologies

Many of the tools currently used in ocean studies have been borrowed from substantial investments in technology by the Navy and the offshore oil industry. Whereas two decades ago, those tools available to academic researchers were second to none, a number of systems and facilities are aging. Cuts in the budget for Department of Defense development efforts have been felt by the marine technology community that relied on investments in new instruments and platforms by the Office of Naval Research. The deep-sea drilling and multi-channel seismic capabilities in the academic fleet have been eclipsed by new drilling ships and seismic systems routinely deployed in the offshore oil industry and by other countries and foreign investors. Our deep submergence assets are overall older and have shallower depth ratings than those deployed by the Japanese, for example.

What has kept the U.S. marine research program unsurpassed has not been the fact that we equip our investigators with the very best technology, but rather that we have developed the best mechanisms for selecting research programs and for operating our assets for the benefit of those programs. For example, the institutions operating the University Ocean Laboratory System (UNOLS) ships and deep submergence systems have been very responsive to the needs of their user base. Existing systems are constantly being improved, extended, and upgraded. Access to these assets is open to the oceanographic community at large, and program selection is based on some form of merit review. Operations groups in the U.S. pride themselves on the large number of operating days

they are able to provide the science community and the low incidence of mechanical failures. Nevertheless, we cannot continue to depend on the ingenuity of our scientists and the dedication of our operations groups to more than compensate for a steady loss in U.S. position relative to other nations with respect to technical capability. By equipping the best researchers and the best marine operators with technology unsurpassed anywhere in the world, the possible benefits from a U.S. program in ocean exploration would be unlimited.

The Ocean Exploration Program can provide the mechanism for reinvesting in American leadership in ocean technology by supporting the following general development efforts:

— ***Remote sensors and in-situ capabilities***
We will invent, build and adapt the wide array of tools necessary for interrogating (measuring, mapping and exploring) the physical, geological, chemical, and biological parameters of the ocean.

— ***Synoptic 4-D capabilities***
We will create new concepts and methods for viewing the whole ocean through time, from anywhere.

LINKING EXPLORERS... ...WITH THE PUBLIC

Live from Monterey Canyon, a joint venture between the Monterey Bay Aquarium Research Institute (MBARI) and the Monterey Bay Aquarium (MBA), exposes Aquarium visitors to the wonders of deep sea exploration via telepresence. A microwave connection between MBARI's research ships and the Aquarium's auditorium allows two-way communication between the public and the researchers exploring Monterey Bay. Video images from MBARI's ROVs are projected on to a large screen. The researchers and their conversations are transmitted to the audience via cameras on board the vessel, and they are able to hear and respond to questions from the virtual visitors. The success of the program is largely due to the presence in the auditorium of an interpreter who is able to put the day's activities and unforeseen events into an educational context. The interpreter takes advantage of an electronic podium with an interactive, visual encyclopedia for deep-sea research. The interpreter can move back and forth between the live action and the archived material depending on the circumstances and the questions being asked by the audience.

The scientific drama surrounding a human voyage beneath the sea first captured the attention and imagination of the nation in the 1960s. The well-documented voyages of Jacques Cousteau captivated American audiences. These images helped demonstrate the vastness of the oceans and the importance of protecting them against pollution and misuse. During the early days of space exploration, underwater vessels and habitats were built to test human endurance in confined spaces, but funding for most programs was sporadic, and research projects were short-lived. While space exploration has evolved and grown with new tools and technologies since the days

of Apollo, the U.S. effort in human-occupied underwater technology has evolved little since the 1960s.

Not all technologies require placing scientists in-situ underwater. The continued development of remote and autonomous underwater vehicles will allow scientists to study ocean features without actually visiting them. In fact, programs already exist that allow scientists in California to take measurements and manipulate sensors located underwater in the Atlantic Ocean off the shore of New Jersey. Sensors can be deployed to measure ocean parameters and relay data to shore stations that broadcast information in near real-time over the Internet. These capabilities open access to underwater regions in remarkable ways. With the right assembly of underwater tools, scientists can remotely sense episodic ocean events and deploy the means to study them.

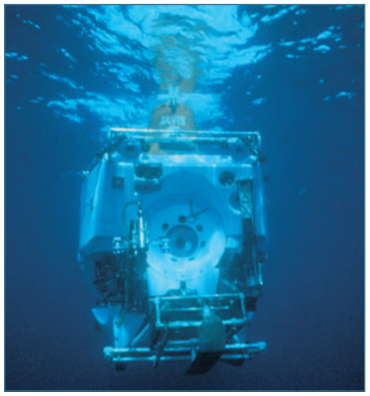
The Ocean Exploration Program will respond to shortcomings in our national underwater infrastructure and capital assets by developing new sensors, vehicles, and capabilities to bring science to the underwater environment.

Reaching Out in New Ways to Stakeholders

The oceans are a common global heritage. The Ocean Exploration Program must build in mechanisms to incorporate the interests and needs of a variety of stakeholders. These stakeholders include state, local and tribal governments, municipal authorities, industries, students, and ocean resource users of all types. Outreach has the potential to transform these stakeholders into concerned and informed constituents of the oceans, who will support the sustained investment that ocean exploration requires. Maintaining open channels of communication with these groups, both for input into the development of exploration plans and output in the form of new information and data products, will strengthen and diversify exploration programs. The program will concentrate on reaching the following stakeholders:

— ***Students***
We will establish the ability to broadcast ocean expeditions to reach every school district in the nation.

— ***The public***
We will lead the world in developing new technologies



that bring scientists and explorers into formal and informal educational settings, and students, educators, and the general public into the field.

— ***Industrial partners***
Petroleum, fisheries, and biomedical industries will make hundreds of discoveries of new materials, pharmaceuticals, and enzymes using the knowledge gained from ocean exploration.

The measure of success in educational outreach will be found in the numbers of new "students" of all ages interested in ocean science. Internet technology and webcasts bring new capacity to outreach programs. Ocean exploration provides rich content that easily captures the imagination of the concerned public. Outreach cannot be viewed as an afterthought of science, but rather a vital step in the scientific process.

EXPLORATION PRIORITIES

The Panel believes that these objectives can be met by establishing a new Ocean Exploration Program. The Program should be comprised of the following critical components within the organizational structure and governance discussed later in this document:

— ***Voyages of Discovery***

— ***Tools for Probing the Ocean***

— ***Data Management and Dissemination***

— ***Education and Outreach***

— ***Capital Investment***

Voyages of Discovery

The Ocean Exploration Program will require a wide range of field and laboratory equipment distributed throughout the United States as well as marine assets deployed around the world. In order to provide a focus for the program, the Panel proposes that the centerpiece of the Program be a Signature Mission -- a multi-year voyage of discovery. Complementary expeditions to the Signature Mission will use a wide variety of ships, submersible vehicles, and other investigative strategies that help foster exploration and provide the information base to capitalize on exploration opportunities.

All of the exploration missions envisioned in the Ocean Exploration Program will meet the highest scientific standards and will be carried out by highly qualified, multi-disciplinary staff. Achieving

the goals will involve individuals from academia, the private sector, and government, and will, at fundamental levels, involve teachers and students so that the fruits of exploration are provided to the broadest audience possible. The goal of the voyages of discovery will be to make the United States second to none in terms of our knowledge of the oceans.

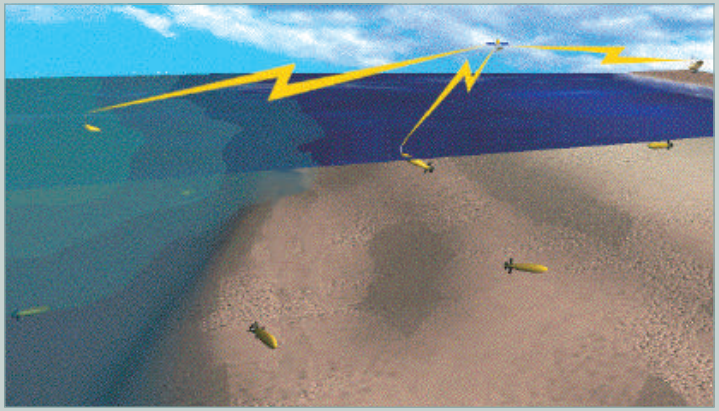
Expeditions that are complementary to the Signature Mission will play an important role in facilitating discoveries in remote areas and in capitalizing on opportunities for multi-faceted investigations. For example, the exploration of the Arctic will require an icebreaker, perhaps a nuclear submarine, active satellite sensors (e.g., radar and laser), or, at a minimum, an ice-hardened ship and AUVs with specialized sensors and capabilities for exploring the harsh Arctic

OCEAN EXPLORERS

QUALIFICATIONS: CURIOSITY, WEB PROFICIENCY, BASIC SCIENCE LITERACY

HEY KIDS!!! Do you imagine yourself as a modern-day explorer, eager to probe uncharted territory and discover new worlds? Join the Ocean Explorer Corps! Pilot your own inner-spaceship and report new findings!

The combined technologies of the Internet, wireless communications, global positioning systems, miniaturized sensors and intelligent, robotic undersea platforms now make it possible for you to purchase and operate your own customized ocean exploration vehicle. Several models and a variety of sensor payloads are available to observe, listen to or measure the vital signs of the oceans. All are affordable, with a number of subsidized financing options. Interactive wizards will help you configure your ship and identify the part of the global ocean you wish to explore. Initial vectors will be pre-programmed into your vehicle for transit from your homeport, but you can change course at any time after launch, using your web-based controller o investigate new discoveries.



You will be registered as an active member of the fleet, and your vehicle's name and position will appear daily on the global grid of operating explorers. The data you collect will be universally available on-line in near real-time, and will be archived in an easily accessible global database. At any time, you will be able to locate from the global grid other explorers throughout the world operating in your region. You may wish to coordinate with them and organize a cooperative expedition to investigate a particular feature or phenomenon. This can all be accomplished interactively on the Web.

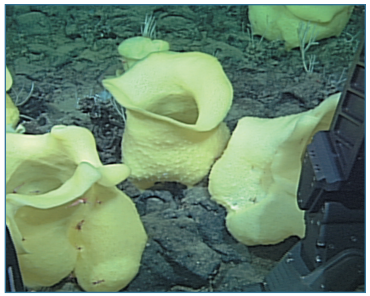
For more information, log on to Ocean Exploration Headquarters today! (www.exploreocean.gov)*

*Note: This is a future scenario and a proposed web site.

Signature Mission

The Panel proposes that a Signature Mission be designed as an important part of the U.S. exploration strategy and as a symbol of U.S. commitment to ocean exploration. Addressing the exploration challenges described in this report, the Signature Mission would explore the global ocean, circumnavigating the globe from pole to pole. It would concentrate on the U.S. EEZ and continental margins, but also take advantage of opportunities for visiting the most unexplored reaches of the global ocean. This mission will actually need to be more than a single shipboard expedition; it will be the first undertaking of its kind. The pole-to-pole routing will require a variety of vessels and platforms over a period of several years. All means of exploration will be folded into the Signature Mission, including satellites, seafloor moorings, specially outfitted ships, and submersible vehicles. Over several years, the Signature Mission would work its way south from Maine, through the North and South Atlantic to Antarctica, incorporating international cooperation with coastal nations along the route. The Mission would then proceed eastward around Antarctica, adding to the southern ocean information void, with expeditions into the southern Indian Ocean and into the western Pacific before exploring the west coast of North America.The final goal of the Signature Mission will be to explore the Arctic Ocean beneath the polar sea ice cover.

environment. Information from a global acoustic monitoring system, a facility that is considered to be critical to global ocean exploration, might guide the Signature Mission to areas where submarine eruptions, earthquakes, or concentrations of marine mammals are occurring. Seafloor observatories, whether deployed as part of this Program or other initiatives, will explore geological, biological, and chemical processes as they occur. These seafloor observatories will be linked to shore-based laboratories and will employ state-of-the-art sensors and AUVs. Real-time results from seafloor observatories will also be used to help guide the Signature Mission.



Tools for Probing the Ocean

In addition to the voyages of discovery, the Ocean Exploration Program should fund the creation of technology to probe the ocean in new ways. In many areas of ocean technology, the systems available to the U.S. research community are no longer state-of-the-art, and the submersibles available to U.S. academic researchers are limited to depths less than 4,500 meters. Engineering development projects will often best be undertaken via partnerships with groups developing technology for other uses (e.g., national defense and the petroleum industry), but the availability of funds under the Ocean Exploration Program will make the difference as to whether the

resulting systems are relevant to, and capable of, ocean exploration. Furthermore, the Panel fully expects that technology developed under this program will lead to spin-off applications elsewhere in ocean research and development (e.g., in-situ sensors for monitoring ocean health).

Data Management and Dissemination

An essential element of this program is data management and dissemination. The database must incorporate a variety of data types, including biological observations. It should be easy to put data into the archive as well as to extract it. A properly designed database should use widely accepted standards, whenever possible, and set new standards when none exist. Flexibility, however, is the key to integrating a broad range of data; rigid conformity to standards can discourage such integrations. The program should incorporate older, historic data sets relevant to exploration into the new database.

A goal for this program should be to develop by 2005, a plan for a Geographic Information System (GIS) for exploration data. Many federal agencies already have made substantial investment in modern data systems (e.g., Navy's Fleet Numerical Data Center, NASA's Earth Observing System Data and Information System [EOS-DIS], NOAA's National Geophysical Data Center). Thus, the first step in building this comprehensive system should be to draw on this collective experience. Furthermore, all federal agencies engaging in activities that lead to the accumulation of oceanographic, biologic, or geological data should commit to placing their data in a compatible system in the public domain. The GIS should include proprietary and classified data, as much as possible. This system must allow for timely access of usable, comprehensive data.

Some mechanism must also be developed to assure timely review of data and responses to recommendations from users. This may include a formal structure, such as a standing committee responsible for biennial or annual review of data within the GIS. To ensure quality data, standards and protocols for data collection, storage, and dissemination must also be developed.

Education and Outreach

The Program should include a coordinated effort to improve and promote ocean science education. Children and adults alike are intrinsically fasci-

Creating an Integrated Sustained Ocean Observing System

The impact of our inadequate ocean knowledge has become increasingly apparent. Following calls by Congress to plan for "a truly integrated ocean observing system," the National Ocean Research Leadership Council approved the establishment of the OCEAN.US office in May 2000.

OCEAN.US will integrate existing and planned observational activities and databases into an integrated observing system. This system will be comprised of real-time operational ocean observations, long-term research observations, technology development, and web-based access to models, algorithms, numerical techniques, etc., for improved predictions by the users. All ocean and ocean-related data — chemical, biological, physical — will be formatted, assimilated, and shared through the program using existing resources, such as the U.S. Global Ocean Data Assimilation Experiment (GODAE) server, to provide vital knowledge to many different users.

OCEAN.US

nated by the ocean and its unfamiliar creatures and habitats. This natural curiosity provides an excellent opportunity to increase science literacy, which is an essential ingredient for U.S. competitiveness in the 21st century. Ocean Exploration Program educational materials and resources should be widely available and easily accessed by teachers, students, and the general public. The program should expand efforts to create discovery-driven interactive web sites. Efforts should be made to build upon and expand partnerships and networks with educational groups (e.g., National Marine Educators Association, National Science Teachers Association, and Association of Zoos and Aquaria) and federal agencies that promote and fund education and outreach in ocean science. A high priority should be placed on interactions with informal science education centers (e.g., museums and aquaria) because of their proven ability to reach large numbers of people, including traditionally under represented groups. Additionally, these centers have demonstrated the ability to reach large numbers of teachers through high-quality professional development programs, and could serve as "portals" through which teachers, students, and the public can become involved in the world of the explorers. In this regard, the Panel recommends launching the Ocean Exploration Program with a national competition to name the Signature Mission.

The creation of an Ocean Exploration Program could reverse the current tendency for graduate oceanography programs in the United States to educate increasingly specialized professionals. Several top programs no longer require students to obtain some proficiency across the allied disciplines of marine biology, geology and geophysics, chemistry, archaeology, ocean engineering, and physical oceanography. Because our modern-

day explorers will be specifically chosen from the ranks of those conversant across fields, graduate programs will need to adapt if their students are to take advantage of this new opportunity. Overall, the Panel would view this adjustment as beneficial, since many new discoveries await at the interfaces of established disciplines.

Capital Investment

Given the long lead time necessary to develop the capabilities and realize the potential for the Ocean Exploration Program, the Panel recommends funding the Program for an initial period of 10 years. The approximate level of new funding for annual operation of the Program should be on the order of $75 million. The Panel believes that this relatively small investment (less than one-hundredth of one percent of the federal discretionary budget) will serve as a magnet to attract other public and private assets that could amount to several hundred million dollars per year. "Seed" money from the federal government will be a critical catalyst in making this happen.

Some assets and capabilities required by the Ocean Exploration Program already exist and can be provided by academia, industry, and the government. The Program should take advantage of these when beneficial; however, some capital investment will be required. With the personnel effort and ship / vehicle time that will be devoted to the Program, it would be imprudent to use anything but the latest technology in platforms,

DIVE and DISCOVER

BRINGING OCEANOGRAPHIC RESEARCH INTO THE CLASSROOM AND TO THE GENERAL PUBLIC VIA THE INTERNET

Using funds from the National Science Foundation's Awards for Geoscience Education Program, the Woods Hole Oceanographic Institution has developed a web-based education and communications platform for providing near real-time access to ongoing oceanographic research at sea. The Dive and Discover website is targeted at middle school students (Grades 6-8) and the public. It is structured to provide multiple layers and levels of information on the basic scientific concepts at the core of the research being carried out. More important, the site provides daily updates from the research ship, including still and video images from shipboard operations and the bottom of the ocean, graphical representations of a wide variety of oceanographic data, explanations about the technology being used, and general information about life at sea for the scientists, engineers, and shipboard support crews that make oceanographic research and exploration possible.

Dive and Discover also provides sea-going scientists with web-based templates so that they can easily incorporate their scientific and field objectives into an expandable and easy-to-use web structure to broadly communicate their work.

http://www.divediscover.whoi.edu

systems, and sensors. There are a number of good arguments for mounting as many of these systems as possible on a state-of-the-art research ship, as a flagship for the Ocean Exploration Program. Outfitting a flagship will avoid the mobilization costs and compatibility problems when new systems are installed on vessels of opportunity. A properly equipped flagship will also facilitate multidisciplinary data management and educational outreach by centralizing much of the data collection and outreach technologies on a dedicated platform. The flagship could be purchased or leased, depending on platform availability and the final list of expedition requirements. In addition to capitalizing this flagship, the Program will need to acquire other technologies, which may include submersibles, sensors and communications, and information technology.

The approximate costs of capitalizing this program over the 10-year period will be two to three times the annual operating costs. Thus, some of the initial capitalization could conceivably be funded in place of operational costs during the first few years of the Program, while operations are starting up.

Priority Sites

The Panel concluded that the following sites are the highest priority areas for the Program:

— ***U.S. EEZ and continental margins***
Americans are the stewards of these areas, and thus, have a moral obligation to concentrate efforts here.

— ***The Arctic***
This region is largely unexplored, and yet is believed to be the most sensitive to climate change of any place on Earth.

— ***Southern oceans***
This vast region of the planet's ocean is also largely unexplored. Opportunities for fundamental discovery are particularly great.

— ***Inland seas, including the Great Lakes***
Other water bodies (e.g., Mediterranean and Red Sea) are also important targets, assuming international collaboration. These regions contain a significant amount of the world's cultural heritage.

RECOMMENDATIONS

The Ocean Exploration Program will be designed to map and document discoveries in new ways that maximize the use of the best technology available for this purpose, and track changes over time. The initial focus of this mapping effort should be the U.S. Continental Shelf and EEZ. Along with mapping the physical features of the ocean, ocean processes and dynamics should be studied

at new scales to help increase our knowledge of the poorly understood energy transfer systems present in this complex environment. The success of the Ocean Exploration Program will also depend on efforts to recapture the public imagination with regard to exploring the vast ocean, and to promote U.S. leadership in this arena. Broad, sustained popular support for investment in the Ocean Exploration Program will ensure that the best possible tools and resources are made available to those who will work to overcome the obstacles in carrying out such an ambitious program.

The Panel notes that the United States currently does not support a program in ocean exploration, despite our inadequate understanding of the ocean, the living and nonliving resources it contains, and its undeniable importance to the health of the planet and the wealth of our nation. Furthermore, in a number of areas, the United States has fallen behind other nations in its capabilities for undertaking ocean research. American leadership in ocean exploration can be achieved by first addressing the objectives of the Ocean Exploration Program discussed above, and then implementing the Program as follows:

The U.S. government should establish the Ocean Exploration Program for an initial period of 10 years, with new funding at the level of $75M / year, excluding capitalization costs. The Panel envisions that a program funded at that level would include the following critical elements:

— ***Interdisciplinary voyages of discovery in high-priority areas***
This includes the U.S. EEZ and the continental margins, the Arctic, and poorly known areas of the southern oceans and inland seas. U.S. knowledge of the living and nonliving resources in the ocean should be second to none, particularly within its own EEZ and continental margins.

— ***Platform, communication, navigation and instrument development efforts***
This includes the capitalization of major new assets for ocean exploration, in order to regain U.S. leadership in marine research technology.

— ***Data management and dissemination***
This ensures that discoveries can have maximum impacts in the research, commercial, regulatory, and educational realms.

— ***Education and outreach***
This will take place in both formal and informal settings to improve the scientific literacy of America's schoolchildren and to realize the full potential of a citizenry aware of and informed about ocean issues.