Understanding Our Planet through Ocean Drilling
A Report from the United States Science Advisory Committee

Executive Summary

The United States Science Advisory Committee vigorously endorses the scientific and organizational framework outlined in the Initial Science Plan (ISP) of the Integrated Ocean Drilling Program (IODP). Our conviction is based on the fact that U.S. participation in IODP will serve several of our country's vital national interests.

- IODP promises an unprecedented level of international cooperation in Earth science research, particularly between the United States and Japan. Co-leadership of IODP will sustain our nation's position at the forefront of ocean science and technology. To assure this leadership role, however, the United States must capitalize and operate part of a multi-platform drilling fleet.

- The research initiatives described in the ISP provide a bold and innovative plan for IODP. Its scientific goals focus international resources on a broad range of interdisciplinary themes that are both challenging intellectually and of great strategic significance. The sampling and monitoring capabilities of IODP will be indispensable components of many of our country's most noteworthy science plans. Examples of such programs at NSF and DOE include RIDGE-2000, MARGINS, *Earth System History*, *Life in Extreme Environments*, *Biocomplexity in the Environment*, *Arctic Natural Sciences*, *Information Technology Research*, and the *National Methane Hydrate Multi-Year R&D Program*.

- Broadening the interdisciplinary capacity of IODP will result in expansion and cross-fertilization of our country's ocean-drilling constituency. A diverse spectrum of specialists (e.g., microbiologists, hydrologists, polar experts, earthquake seismologists) will be drawn into IODP as imaginative new projects begin to take full advantage of a drilling fleet that includes riser-supported and mission-specific platforms.

- The science of IODP is ideally suited for cultivation of partnerships between academia, government, and industry. Opportunities now exist for application of drilling results in such growth industries as biotechnology and information technology. U.S. participation in IODP will serve our country's strategic interests through improved mitigation of geologic hazards within the EEZ, and additional spin-offs are likely in domestic energy exploration.

- Because of its interdisciplinary nature, and its diverse international flavor, IODP represents the perfect mechanism for teaching Earth systems science to U.S. students at all levels of the curriculum. Not only will the drilling program allow direct student participation in scientific discovery, the high-technology data acquisition and management systems of IODP will provide a method to introduce information technology into science education.

USSAC acknowledges that the tasks of organizing, financing, and implementing IODP are weighty, but the future health and prosperity of the United States depend on investments in precisely this type of adventurous and visionary research and development. The success of this plan requires increases in federal funding, but those increases are commensurate with the program's expected scientific impact, its developments of technology, and its contribution to a broad range of environmental challenges facing U.S. society.

I. Introduction

The Integrated Ocean Drilling Program (IODP) presents scientists worldwide with an unprecedented new opportunity to investigate the dynamics of Earth systems. Significant discoveries by the Ocean Drilling Program, over the past decade, place us close to major breakthroughs in a number of research fields. At the same time, scientific ocean drilling currently is limited to a single platform without riser capabilities. In response to this background, the Science Plan Working Group and the IODP Planning Subcommittee (IPSC) have formulated a comprehensive Initial Science Plan (ISP) to help participants prepare for the first decade of IODP activity (2003-2013). The Initial Science Plan reflects widespread international participation in a protracted planning process; it expresses the current global consensus regarding the future of scientific ocean drilling. Scientists from the United States helped lead the conceptual development of each scientific initiative, and they will play vital roles during the implementation phase of each part of the ISP.

The foremost responsibility of the United States Science Advisory Committee (USSAC) is to oversee our country's participation in the Ocean Drilling Program, which ends in 2003. Acting as the collective national spokesperson, USSAC enthusiastically endorses the scientific priorities and organizational framework set forth in the ISP. In doing so, our report distills the viewpoints of several important planning documents (Figure 1). Broad-based input also comes from the diverse membership of USSAC (Table 1), and we have solicited critical feedback from the country's leading Earth scientists in academia, government labs, and industry. Our report demonstrates how U.S. leadership in IODP will enhance existing U.S. commitments to a broad range of programs in basic and applied research, science education, and information technology.

The Initial Science Plan resonates with intellectual excitement from the U.S. science community. Its scientific objectives are of fundamental intellectual importance. Exciting new discoveries will occur on a variety of fronts because the plan challenges the logistical boundaries of basic research in many subdisciplines of ocean science. Creative utilization of new multi-platform drilling capabilities will invigorate the mission of federally funded scientific research. We fully expect drilling-related science to impact national policy decisions regarding short-term climate change, sea level fluctuation, and mitigation of geologic hazards within the U.S. EEZ. We expect to see associated economic developments in mineral resources, domestic energy resources, and biotechnology. IODP also promises an unprecedented level of international cooperation in Earth science research, particularly between the United States and Japan. Co-leadership of IODP will sustain our nation's position at the forefront of ocean science and technology.

A multi-platform drilling strategy, as described in the Initial Science Plan, is absolutely necessary if scientists and policy makers expect to meet the increasingly complicated demands and expectations of U.S. society in the 21st century. The interwoven components of Earth systems obviously extend beyond the shorelines of the present-day ocean basins. Ocean drilling is just one tool, but it is an essential tool for any global-scale, interdisciplinary research program in Earth science. Justification for this claim appears in the NSF FUMAGES Report *(The Future of Marine Geology and Geophysics*), which explicitly mentions scientific ocean drilling in its vision of every major research initiative for the coming decade. These shared priorites between FUMAGES and ocean drilling have also been merged into the NSF Division of Ocean Sciences *Decadal Synthesis Report* (Figure 1).

Addressing an even broader national mandate for basic scientific research, the NSF Directorate for Geosciences has issued a report entitled *Geosciences Beyond 2000: Understanding and Predicting Earth's Environment and Habitability*. The agenda of the Geosciences Directorate focuses on four fundamental areas of knowledge: planetary structure, planetary energetics and dynamics, planetary ecology, and planetary metabolism. Many intellectual and technological objectives are nested within these themes:

- Determine the structure and composition of the solid, liquid, and gaseous components of Earth, particularly in the geologic past.
- Enhance the resolution of lateral and vertical variations of fine structure throughout the solid Earth.
- Document evolution of the deep Earth and the interactions between planetary interior and exterior.
- Understand the dynamics of climate and paleoclimate, including the effects of atmospheric constituents and oceanic processes.
- Understand natural changes in the biogeochemical and hydrological cycles.
- Determine how the biogeochemical cycles of carbon, nitrogen, oxygen, phosphorous, and sulphur are coupled.
- Develop sufficiently sophisticated models to explain the historic evidence and to predict future changes in planetary metabolism.

Most of these objectives link unequivocally to the science and technology of ocean drilling. In fact, ocean drilling is the only means of providing scientists with the ground truth they need to reconstruct long-term records of global environmental change and biogeochemical cycles. Direct measurements and long-term monitoring of *in situ* physical, chemical, and biological conditions in the deep subsurface are impossible without boreholes. In short, *Geosciences Beyond 2000* cannot reach successful fruition unless the United States participates in IODP.

The foresight of the NSF Geosciences Directorate also includes a challenge to our nation's educators. To paraphrase, "a new and innovative program of training and education in Earth system science should be initiated and developed now to ensure an informed citizenship in 2010. Such readiness demands a broad array of educational activities ranging from graduate and undergraduate education to K-12 and public geoscience literacy." As active ocean explorers and educators, USSAC members know from experience that the sea around us captivates the imagination of students of all ages. U.S. shipboard participants during the drilling legs of DSDP, IPOD, and ODP have made innumerable contributions to our local and national teaching mission at all levels. The scientific themes of the ISP are intrinsically interdisciplinary and fit perfectly into the instructional paradigm of Earth systems science. Implementation of the ISP, moreover, will go hand-in-hand with development of new information technology. For all of these reasons, the U.S. educational system should be poised to take full advantage of an expanded and innovative educational component of IODP.

II. The Science of IODP

We herein endorse the three themes described in the ISP and use each to: (1) illustrate the breadth and foresight of drilling-related research within the United States; (2) describe how ocean drilling will address vital strategic interests of the United States; (3) identify explicit links between drilling science and broader U.S.-funded research initiatives, and (4) explain why a multi-platform drilling program is needed to achieve the scientific goals.

Theme A. The Deep Biosphere and Sub-Seafloor Ocean

Aqueous fluids and gases occupy fractures and pore spaces below the seafloor and play governing roles in a wide range of physical and geochemical processes. This "sub-seafloor ocean" not only transports heat and chemicals through virtually every marine geologic environment (i.e., active mid-ocean ridge, ridge flank, subduction zone, rifted margin, mature passive margin, carbonate platform), it also affects cycles of the Earth’s coupled ocean-atmosphere system. Two of the IODP research initiatives focus special attention on this theme: microbes of the deep biosphere and gas hydrates. Microbes and gas hydrates depend on pore fluids for their creation and maintenance. Deep microbes may comprise as much as two thirds of Earth’s entire bacterial biomass, yet the depth limits and community structure of that part of the marine biosphere remain unknown. Gases produced by microbial activity and thermal maturation of organic matter contribute to enormous reservoirs of gas hydrate as well as free gas. Some studies indicate that gas hydrates sequester twice the carbon of all known hydrocarbon resources and 15 to 20 times the carbon in the entire terrestrial biosphere, yet our understanding of solid hydrate and associated gases is not refined enough to predict its global distribution or model its budget.

The deep biosphere and gas hydrates are topics at the frontier of scientific inquiry and strategic planning. The effects of changes in temperature, pressure, pH, and redox potential on the quantity and variety of microbes remain largely undocumented, so basic research projects must focus on microbial community structures, turnover rate, adaptation to wide ranges in available energy sources, and influence on metal cycling. Microbial genotypes older than 5 Myr may be preserved in the deep subsurface; this truly fascinating prospect provides evolutionary biologists with an unprecedented opportunity to trace evolutionary patterns and processes directly. Successful isolation of bacteria from such extreme environments as active hydrothermal fields has impacted the biotechnology industry in the United States by providing enzymatic catalysts for the polymerase chain reaction. Microbial processes also contribute methane to the global gas hydrate budget Gas hydrate may be linked to global changes in climate, for example through dissociation during warming events or as a source of greenhouse gases. Of more immediate concern to the United States is the risk of large-scale submarine slope failures and tsunamis due to destabilization of hydrate and associated free gas. Investigations of geohazards throughout the U.S. must consider whether or not anthropogenic perturbations affect seafloor destabilization; this issue will become increasingly important as hydrocarbon exploration pushes into deeper areas of the Gulf of Mexico and elsewhere. If economical extraction technologies become available, gas hydrate deposits within the U.S EEZ will be exploited as a domestic source of energy. Realization of this prospect will impact foreign and domestic economic policy, foreign trade, and national security.

Deep ocean drilling provides a remarkable opportunity for cultivation of synergistic connections among several of our country's most prominent and broad-ranging scientific endeavors. The Department of Energy's *National Methane Hydrate Multi-Year R&D Program Plan*, for example, identifies four priorities with IODP connections: to assess the resource potential of gas hydrates, to develop extraction technology, to unravel the relation between hydrates and the global climate cycle, and to address safety and seafloor stability issues. Similar potential for interagency collaboration exists within DOE programs in carbon sequestration, marine biotechnology, and microbial genomics. At the National Science Foundation, the role of microbes in global chemical cycles is a central component of the Global and Environmental Change portion of the *Biocomplexity of the Environment* Program. *Life in Extreme Environments* (LExEn) strives to enhance understanding of microbial systems on Earth, particularly with respect to mechanisms that allow survival under extreme conditions. Another LExEn objective is to develop new methods to study ancient microbial life and paleo-environmental conditions. All of these programs require samples of material (solids, fluids, biota) from depths far below the seafloor. Proper documentation of *in situ* conditions, moreover, requires accurate measurements of core temperatures, well logs, and borehole geophysical experiments.

Drilling platforms provide the only means of collecting suites of sediment and fluid samples that are diverse enough to achieve the broader goals of NSF and DOE. State-of-the-art studies of mid-ocean ridge hydrothermal cells, sediment diagenesis, volatile cycling through subduction zones, gas hydrates, and the deep biosphere will all require installation of long-term borehole observatories to measure pressure, temperature, and chemical fluxes *in situ*. Riser systems and blow-out prevention will expand safe scientific drilling to organic-rich and hydrate-bearing sediment as well as active hydrocarbon provinces that are characterized by high pore pressure such as the U.S. Gulf of Mexico, Gulf of Alaska, and Bearing Sea. Thus, meaningful progress toward our understanding of the "sub-seafloor ocean" absolutely depends on a multi-platform drilling program.

Theme B. Environmental Change and Its Impact on Life

The threat of global warming presents the United States with one of the era's more serious and controversial political-economic issues, but our instrumental records of climate are far too short (~100 years) to discriminate clearly between natural variability and anthropogenic acceleration. Ocean sediments, at all water depths, provide a unique archive of Earth's climatic variability. A rich ensemble of DSDP and ODP discoveries in paleoceanography has enhanced our understanding of internal and external causes and consequences of natural climate variations. We know that this record spans a broad spectrum of time scales, from annual cycles to millions of years, but many fundamental questions remain, such as: How and why do climates change? How abrupt are the climatic transitions? How have past climatic changes influenced biotic systems? How did climate change affect the evolution of humans? Some mechanisms of change are internal or natural to the Earth's system (e.g., tectonic uplift of mountain belts, rapid eruption of Large Igneous Provinces, sea level change), whereas others are external or imposed (e.g., orbital forcing, bolide impacts). Many of these mechanisms, such as uplift of the Himalayan Mountains and Tibetan Plateau, are recorded best in ocean sediments accessible only by drilling. Recent discoveries demonstrate that climate can shift far more abruptly than previously thought. Glacial terminations and millennial-scale climate oscillations, for instance, have occurred in less than a decade. The history, impacts, and implications of global environmental change cannot be deciphered without a high-quality, high-resolution sampling record from the full spectrum of marine environments (i.e., deep sea, continental margin, coral reefs).

Extreme perturbations of climate, toward either greenhouse warming or glaciation, trigger collateral changes in sea-surface temperature, deep-water circulation, biogeochemical cycling, community evolution, and extinction. Correct predictions of future paths of environmental change hinge on our understanding of geologic and biotic history. Future research must be able to show how community structure, biogeochemical feedbacks, and nutrient cycles respond to global warming. Greenhouse transients of significance occurred during the Late Paleocene Thermal Maximum (at ~55 Ma) and the early Aptian Oceanic Anoxic Event (at ~120 Ma). Catastrophic release of methane from dissociated gas hydrate may have accompanied those events, and subsequent oxidation of the methane may have triggered oceanic anoxia, wholesale changes in the fertility structure of the oceans, and abrupt changes in alkalinity. Roughly 3 million years ago, the onset of high-latitude glacial cycles and their attendant changes in ocean-atmosphere circulation created arid conditions in Africa. The timing of that shift coincided with the first appearance of *Homo* and stone tool use. On a shorter time scale, the El Nino/Southern Oscillation (ENSO) dominates inter-annual variability of the ocean-atmosphere in the tropical and subtropical Pacific. Our ability to predict forthcoming ENSO events depends, in part, on evaluations of ultra-high resolution (annual to centennial) sediment records from the Pacific; these cores are needed to estimate rates, phase relations, and basin-scale synchroneity**.**

Scientific ocean drilling is an indispensable component of our country's research strategy in the overall field of climate change. NSF's initiative in *Biocomplexity in the Environment*, for example, must sample the products of complex interactions among human, biological, geological, and climate systems over extended periods of time, as well as characterize the dynamics of biogeochemical cycles. Of similar importance is the *Earth System History* (ESH) Program, which is part of the U.S. Global Change Research Program. This inter-agency program coordinates research in three divisions of the NSF Directorate for Geosciences, plus the Office of Polar Programs and NOAA. Three areas of emphasis in ESH (rapid climate change, extreme warm conditions, and Arctic paleoclimate) depend upon ocean drilling for acquisition of high-resolution cores. *Life in Extreme Environments* (LExEn) and *Environmental Geochemistry and Biogeochemistry* (EGB) also will utilize IODP samples, as will several international co-operatives with heavy U.S. involvement (e.g., PAGES, Pole-Equator-Pole transects, IMAGES, and continental drilling).

To document the history and global effects of climate change, pristine fossil materials must be recovered from the world's ocean basins for geochemical analyses. Coring records must be complete, and their resolution must be high enough to reveal orbital to sub-orbital (millennial) scale variability. Most such materials are buried at relatively shallow depths, so a conventional platform (*JOIDES Resolution* type) will no doubt be the primary tool of choice. Aggressive progress, however, will also require paleoclimate records from a greater variety of environments (including continental shelves) and a wider range of latitudes (including the Arctic Ocean). Drilling Arctic and shallow-water targets, including coral reefs, is impossible without mission-specific platforms. These indispensable new targets will reveal how glacial-interglacial cycles impact shoreline migration, ecosystems, nutrient cycling, and carbon sequestration on margin-wide scales.

Theme C. Solid Earth Cycles and Geodynamics

Motion of the Earth's lithosphere is another driving force for global change on both geologic and human time scales. The creation and evolution of oceanic crust affects geochemical interactions among the Earth's mantle, crust, hydrosphere, atmosphere, and biosphere. Continental breakup forms sedimentary basins that host many of the world's most prolific petroleum reservoirs. Voluminous eruptions of magma (known as Large Igneous Provinces or LIPs) have probably been responsible for shifts in global climate. In addition, events of tremendous destructive power (earthquakes, volcanic eruptions, and tsunamis) punctuate the solid Earth cycle every year; their effects on human society are both dramatic and profound.

Oceanic crust records a 200-Myr history of upper mantle melting, but marine sampling programs thus far have concentrated on younger portions of that record and the upper 30% of the total depth range. If we can sample oceanic crust across broader and deeper ranges of time and space, it could revolutionize our view of mantle dynamics; it will also shed light on poorly understood geochemical interactions between mantle and crust, clarify the three-dimensional nature of hydrothermal activity, and resolve the relation between igneous stratigraphy and seismic stratigraphy. Of more immediate strategic and economic concern is the fact that virtually all of the major metropolitan areas within California, the Pacific Northwest, and Alaska fall within zones of high risk for violent volcanic eruptions and/or large-magnitude earthquakes. Present-day plate motions can be monitored very accurately using modern geodetic instruments and GPS technology, but scientists in the United States are not yet able to predict sudden releases of long-term strain accumulation along plate-boundary faults. Before this goal can be realized, scientists must acquire fundamental knowledge regarding *in situ* physical and chemical conditions and monitor changes in fault zones that lead up to sudden rupture. Similarly, measurements of volatile fluxes through subduction zones could improve our ability to understand and predict explosive volcanic eruptions in the Aleutians and Cascade Range. Hazard-mitigation issues such as these are a first-order national priority and of immense importance to residents of the western United States.

The central goals of many high-profile science initiatives in the United States hinge on the technologies of deep Earth sampling and borehole geophysics. For example, the SEIZE (*Seismogenic Zone Experiment*) science plan (NSF MARGINS Program) not only requires both conventional and riser-supported drilling for sample acquisition (including fluids), it also includes *in situ* measurements of physical and chemical conditions, plus long-term monitoring of pore pressure, temperature, stress, fluid chemistry, and tilt-strain at depths up to 8 km below the seafloor. The MARGINS *Subduction Factory* science plan requires drilling to characterize the inputs of geologic solids, aqueous fluids, and gases into the subduction zone. RIDGE 2000 requires borehole samples to characterize the eruptive history of mid-ocean ridges and to explore the extent of the sub-seafloor biosphere in igneous rock. Borehole observatories must be installed at mid-ocean ridges to monitor active tectonic, magmatic, hydrothermal, and biological processes, including those associated with chemosynthetic ecosystems. Long-term monitoring projects will contribute significantly to our understanding of normal fault mechanics and continental rift dynamics. Permanent observatories in the deep ocean will yield a more uniform global view of mantle dynamics and earthquake seismology. Most such objectives demand deployment of sensors hundreds of meters beneath the seafloor for optimal data quality [e.g., the Dynamics of *Earth and Ocean Systems* (DEOS) initiative, the *Ocean Seismic Network* (OSN), NEPTUNE, the *Ocean Hemisphere network Project* (OHP), and the *International Ocean Network* (ION)]. These efforts will be thwarted without IODP.

Aggressive investigation of the solid Earth cycle depends upon a multi-platform drilling capability. We need mission-specific shallow-water platforms, for example, to recover rifted margin sequences from previously inaccessible regions, and riser technology must be utilized in basins prone to hydrocarbons. Conventional (non-riser) drilling is the only way to sample and characterize three-dimensional inputs into subduction zones, to determine the exact timing and volume of LIP production, and to piece together linkages among tectonic, volcanic, chemical, and biological agents of global environmental change. The SEIZE experiment must deploy riser technology to drill through an active seismogenic fault. This promises to be an unusually dramatic achievement of science and technology, and the societal impact will be comparable to deep continental drilling across the San Andreas fault in California (as envisioned in the NSF *EarthScope* MRE Proposal). Those two projects place the United States at the precipice of quantum advances in the science of earthquake hazards. The prospects for overlapping partnerships and cross-fertilization of data, personnel, and technology are exciting. Their ultimate success, however, depends on a national commitment to deep drilling.

III. The U.S. National Role in IODP

For IODP to succeed, individual scientists, research institutions, and funding agencies in the United States must commit their leadership skills and resources to several key functions within the proposed organizational framework. To begin with, the National Science Foundation must provide the funds for capitalization and operation of a new drilling platform to replace the current D/V *JOIDES Resolution*. No other country is prepared to do so, and only through such up-front financial support can the U.S. attain co-leadership status in IODP as an equal partner with Japan. The Japanese government will be responsible for capitalization of a new riser-supported drilling vessel. Contribution of U.S. funds to the capitalization and operation of mission-specific platforms also needs to be considered. Capitalization, however, is just the beginning. Once the platforms are operational, we envision two primary roles for the United States resulting in three fundamental benefits.

Role I: *The United States will share co-leadership of science planning with Japan.*

IODP will draw together a very large community of U.S. and international scientists. USSAC welcomes the partnership with Japan; we also believe that it is essential for the U.S. to have an equal voice with Japan in the science-planning process. Organizational leadership begins with the formulation of scientific concepts and hypotheses, but it continues through all phases of project implementation and management. From the scheduling of individual projects on each platform to the coordination of post-cruise science, the depth and breadth of our collective national experience with DSDP, IPOD, and ODP places U.S. scientists in a favorable position to handle these planning responsibilities effectively.

Role II: *The U.S. will operate part of the multi-platform drilling capability.*

Japan will build and operate a riser-equipped platform capable of drilling very deep holes in previously inaccessible environments. The U.S. will bring to IODP a non-riser vessel of the *JOIDES Resolution* class, but with significantly enhanced capabilities. USSAC appointed the *Conceptual Design Committee* (CDC) to formulate the generic design characteristics of such a non-riser drilling vessel. The new vessel will be configured to address the widest possible range of conventional drilling objectives. The CDC report (http://www.joi-odp.org/USSSP/cdc) defines the performance specifications for a non-riser vessel. Once the most appropriate ship is identified and refurbished, the U.S. will be responsible for its operation. The possibility also remains for the U.S. to contribute to capitalization and/or operation of mission-specific platforms (e.g., ice barges, geotechnical rigs, and shallow-water jack-up rigs) on a case-by-case basis.

Benefit I: *Access to a multi-platform drilling program will invigorate geosciences research in the United States.*

The Committee on Post-1998 Drilling (COMPOST) issued a report to USSAC that included the following pivotal conclusions:

- Drilling is an essential tool of the marine Earth science community in the U.S. and should continue beyond 2003.

- The U.S. community requires a drilling program that is global in scope and internationally organized and funded.

These national interests were reaffirmed in 1998 in *A New Vision for Scientific Ocean Drilling, A Report from COMPOST-II*. In the meantime, the Japanese government paved the way by committing approximately $500 million to the capitalization of a riser-equipped drilling platform. Scientific justification for riser-supported drilling was crafted during the 1997 *Conference on Cooperative Ocean Riser Drilling* (CONCORD), and in 1999 the *Conference on Multiple Platform Exploration* (COMPLEX) was held to develop strategies for non-riser drilling vessels, including mission-specific platforms. Community response to COMPLEX was impressive, drawing additional scientists from sub-disciplines of the Earth sciences such as microbiology, hydrology, hydrocarbon exploration, seismology, and artic and coral reef research. These scientists are likely to promote the potential of ocean drilling within their respective communities.

The success of any large research program can be measured, in part, by the contributions of its individual members and smaller co-ops. U.S. participation in ocean drilling has grown steadily throughout the history of DSDP, IPOD, and ODP. Hundreds of U.S scientists participate in the current program each year. Countless shorebased researchers request core samples, downhole logs, and other data. Enthusiasm and commitment of time and energy certainly will grow if scientists are given access to multiple drilling platforms. The constituency will expand, moreover, because the goals outlined in the ISP dovetail with those of the NSF Geosciences Directorate (e.g., MARGINS, DEOS, RIDGE-2000, Global Seismic Network, ESH, LExEn). Definitive tests of crucial hypotheses within those NSF programs have never been attempted or completed because of the limitations imposed by former technologies. Expansion of our capability to drill, core, and conduct downhole measurements will encourage imaginative tests of existing ideas and germinate new hypotheses.

Difficult logistical challenges lie ahead as we strive to sample deeper and move into more hostile geologic environments on ridge crests, beneath continental margins, and at high latitudes in the polar oceans. The flexibility of a multi-platform program, however, will spark the imaginations of a talanted group of scientists. Blending new scientific perspectives and technology into the IODP community will create a new era of innovation. Such vitality is evident already with the participation of microbiologists on nearly every recent ODP leg. Examples of other important new constituencies include Arctic scientists and experts in shallow shelf-shoreface sedimentation and fluid flow. The objectives of those groups can be achieved only through deployment of mission-specific platforms (e.g., ice barges, shallow-water rigs). Of keen interest to Arctic geoscientists are prospects for improving plate-tectonic reconstructions and deciphering the geologic record of environmental change in the ancient polar regions, particularly during the Late Cretaceous (~97-66 Ma) and Cenozoic (66 Ma to present). Progress on those fronts will be limited unless ocean drilling is combined with geophysical surveys of the ice-covered Arctic.

Benefit II: *IODP will be a focal point for involvement of U.S. scientists in international research collaborations and partnerships of research and development with U.S. industries.*

Just as with DSDP-IPOD and ODP, the Integrated Ocean Drilling Program will be a focal point for international scientific collaboration. We imagine IODP as an international university where groups of scientists pool their resources to tackle global problems and test important hypotheses. Each expedition provides a truly unique environment of synergy, as scientists from many disciplines discuss concepts and interpretations even as new data are acquired. ODP is a model of success for fostering international cooperation. IODP, similarly, will bring scientists together from all over the world, along with their knowledge, imaginations, instruments, and financial resources.

Regardless of where, geographically, fundamental discoveries are made during a given drilling leg, the results can be applied to focused investigations of geohazards, earth resources, and environmental problems within U.S. territorial jurisdiction. Knowledge about the relations between the sub-seafloor ocean and the deep biosphere, for example, clearly will influence flourishing U.S. industries in biotechnology. In addition, we are now poised to create working partnerships with the petroleum industry, as exemplified by recent USSAC-sponsored workshops with representatives of the major U.S. oil companies. Operational lessons learned during one drilling experiment will lead to refined strategies for experiments to follow. As another example, knowledge gained from deep riser-supported drilling offshore Japan will be exported to comparable studies of the seismogenic zones of Cascadia, the Aleutian Trench, and the San Andreas fault system.

Benefit III. *U.S. involvement in IODP will lead to unexpected economic and public-policy applications.*

Basic research in virtually all scientific fields serves as a foundation for the development of innovative technologies. The United States space industry has provided well-publicized documentation of this type of broad-ranging economic benefit for the past 30 years. Unexpected spin-offs from IODP, therefore, are likely, and the applications will not be restricted to the Earth sciences. For example, there will be economic links between IODP and the U.S. biotechnology industry. Improvement in drilling technology, particularly learning how to make and use deep water riser vessels, will have a major impact on the ability to extract hydrocarbons from the deep ocean. The potential economic gains from research on gas are likewise noteworthy. It seems clear that ocean drilling will become increasingly important to the Department of Energy as that federal agency considers the oceans as a potential sink for carbon sequestration. IODP sampling capabilities will provide collaborators at DOE with unparalleled opportunities to test the potential impacts of replacing methane hydrates with CO_2, liquid injection, or sinking of CO_2 hydrate laden droplets to the ocean floor. Thus, federal officials should expect to see ramifications of U.S. involvement in IODP that include domestic energy consumption, foreign trade, U.S. participation in international treaties, and national security.

Alternative**:** *What if the U.S. fails to adopt a leadership role in this program?*

The payoffs from U.S. investments in the new drilling program promise to be at least as rewarding as the scientific returns on our past investments in DSDP-IPOD-ODP. But what if we choose not to participate? Simply stated, we will become scientific spectators rather than participants in frontier exploration. As such, we will lose our position of distinction at the forefront of ocean science and technology. Professional training. will suffer in the earth and ocean sciences within the U.S. Top students, as well as scientists, will migrate to those countries leading the cutting-edge scientific activities. The goals of ocean drilling are becoming increasingly interwoven with those of the most ambitious international programs in the geosciences [e.g., Past Global Changes (PAGES) Project of the International Geosphere-Biosphere Programme, Inter-RIDGE, Inter-MARGINS). Those groups are now entering a new age of ocean exploration with carefully chosen natural laboratories on and beneath the sea floor. To be a leader in science of the environment, the United States simply must participate in such international consortia.

As our collective understanding of the world's oceans continues to improve, the focus of scientific drilling will become more refined. On the other hand, the wildcard of basic research has always been the unexpected discovery. DSDP-ODP has a rich history of such discovery. Recent extraction of living organisms from more than 1000 meters below the seafloor, for example, raises fundamental new questions about the origins of life and the possibilities of extraterrestrial life forms. Through this type of pioneering work, unlimited opportunities have been created for life scientists to characterize new species and communities of living microbes and apply their results within the biotechnology industry. Our nation's prosperity and status as a world economic leader will be eroded if we fail to sustain vigorous programs of basic research in these types of fields.

IV. U.S. Mission in Education

Mission A. Instruction at the Frontiers of Science

Students and teachers of all ages will be beneficiaries of U.S. participation in the IODP. The scientific themes of IODP are compelling to most citizens (e.g., climate change, deep microbiology, active faults and earthquakes, polar exploration), but effort must be exerted to communicate important discoveries more effectively to the general public. U.S. participation in IODP, therefore, should carry with it an expectation of expanded public outreach and continuing education, following in the fledgling footsteps initiated during ODP of wide distribution of CD-ROMs and other educational materials. This can be accomplished in a variety of ways, using, for example, displays in science museums, video documentaries, and web sites. The National Science Foundation supports such efforts through its Informal Science Education component of the ESIE Program (*Elementary, Secondary, and Informal Education*).

As federal and state agencies consider their educational agendas for the future, more emphasis undoubtedly will be placed on effective instruction in the fundamental principles of Earth resources, climate change, land-use adaptation, and geo-hazard mitigation. Transfer of knowledge about the Earth must keep pace with the political and public demand for solutions to the environmental problems that cloud our future. Leaders of the United States must have the necessary scientific background, information, training, and tools to make informed decisions. Science education is the key because today's students will become the policy makers of tomorrow. It will be those new leaders who must help decide the fate of the current "experiment" with global climate change, deal with Earth's dwindling natural resources, and mitigate natural geologic hazards.

Today's classroom teachers, beginning with elementary and secondary education, cannot describe any of the axiomatic concepts of plate tectonics, marine geology, paleoclimate, or oceanography without using examples that are rooted in the success of DSDP, IPOD, and ODP. The forthcoming discoveries of IODP will continue to enhance teachers' subject matter knowledge. We at USSAC can also imagine a broad range of innovative methods for K-12 instruction in ocean science (e.g., use of digital libraries, modeling and visualization of shipboard data, and creation of virtual shipboard environments). The impressive spectrum of shipboard data types, and the diverse scientific objectives of IODP, will create a perfect backdrop for promoting investigative, inquiry-based learning in the classroom. A strong correlation also exists between teachers' professional development opportunities and their growth and effectiveness as leaders of education reform. With a larger multi-platform program, some of the U.S. berths on the ships can be reserved for enhancement projects that recruit from our country's pool of outstanding K-12 teachers. Encouraged by the NSF-CCLI (*Course, Curriculum, and Laboratory Improvement*) Program, we also expect general undergraduate education in colleges and universities to benefit from IODP data and technology as professors develop innovative textbooks, CD-ROMs, interactive software, and laboratory materials.

Mission B. Teaching Earth Systems Science

Methods of teaching science are changing from a traditional mode of factual compartmentalization to the pedagogy of "systems science". This new strategy promotes an interwoven integration of geology, oceanography, chemistry, physics, biology, and atmospheric science. The environmental problems encountered by modern society are complicated; solutions depend on an interdisciplinary understanding of how humans affect, and are affected by, natural systems. The ODP approach to science has been inherently interdisciplinary from its inception. IODP, in turn, will continue to provide a perfect method for teaching Earth systems concepts. IODP will also demonstrate successful cooperation among nations, government agencies, universities, professional societies, and the private sector. We know of no other comparable science program that is better suited to show a budding generation of American scholars and research scientists how large interdisciplinary projects are planned and implemented. Similarly, IODP provides a mechanism for senior scientists, who may have trained in a single discipline, to broaden their interests to include multidisciplinary thinking.

Mission C. Student-Teacher Participation in Scientific Discovery

Our ability as research scientists to stimulate curious students requires more than up-to-date textbooks and lecture notes. Hands-on learning and inquiry-driven instruction are staples of reform movements in science education. Even more essential, however, is the opportunity for college students in the United States to participate directly in the processes of scientific discovery and development of technology. One such opportunity rests with the ATE (*Advanced Technological Education*) Program at NSF. This avenue could be used, for example, to support internships for marine technicians on the drilling platforms, to design and implement new shore-based training modules, and to provide shipboard training experiences for both students and teachers in a wide range of technical fields.

In the current configuration of ODP, USSAC exports the excitement of shipboard science to dozens of college campuses each year through the *JOI-USSAC Distinguished Lecture Series*. Graduate students from U.S. universities sail on virtually every drilling leg as invited shipboard scientists. Even larger numbers of students assist their professors during post-cruise research projects as graduate research assistants and undergraduate lab assistants. The funds needed to support such students come from both USSSP (U.S. Science Support Program) and NSF core programs (e.g., Marine Geology and Geophysics). Direct student participation in ODP triggers infectious enthusiasm within Earth Sciences departments across the country. Some of the brightest young minds in the geosciences, moreover, have been drawn into ODP-related dissertation projects through the USSSP-funded *Schlanger Ocean Drilling Fellowship* program; most of those fellowship recipients have cultivated distinguished research and teaching careers of their own. We believe with conviction that this JOI-USSAC tradition of experiential academic achievement should be expanded in IODP.

One final education program at NSF is worthy of special note, the IGERT Program (*Integrative Graduate Education and Research Traineeship*). Its objectives and expectations mesh exceptionally well with the multi-disciplinary science and organizational framework of IODP. IGERT was developed to catalyze a cultural change in U.S. graduate-level institutes by "establishing new, innovative models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries." IGERT projects are expected to emphasize multi-disciplinary collaboration across departments and institutions and maintain a problem-oriented rather than discipline-oriented focus. The field-based aspects of IODP certainly satisfy all of those expectations, and more. IODP will expose hundreds of graduate students to state-of-the-art research tools, improve their communication and teamwork skills, and amalgamate individuals into an international and multi-cultural learning environment. IGERT must have been conceived with IODP in mind.

V. Information Technology

With the culmination of new multi-platform drilling capabilities, IODP will be at the forefront of both marine technology and information technology (IT). The NSF program in *Information Technology Research* possesses obvious potential for symbiosis. Some of its goals include information technology and education, computer simulation of real-world geologic systems, scientific data analysis, visualization of large data sets, and better use of online data sets, particularly as applied to modeling and integration of Earth systems data. ODP has taken significant steps forward with their recent deployment of the Janus database, but the information technology of IODP will have to go even farther to manage larger and more diverse databases emanating from a multi-platform fleet. In addition, there are unlimited prospects for high-tech communication and public outreach, including simulations of shipboard activities via virtual-reality, distance learning, and real-time links from drilling platform to PC. A pilot program of distance learning is already underway at ODP-TAMU, and with advances in wireless communication, IODP will be able to link their drilling platforms and scientists to the world.

VI. Concluding Remarks

Hundreds of pages have been written already to support the notion of continuing the international commitment to ocean exploration through drilling. USSAC endorses the Initial Science Plan of IODP with vigor because its basic scientific goals are captivating. The science, moreover, will impact a broad range of U.S. national interests and societal needs, and there are compelling prospects for economic spin-offs in applied industries and information technology. The intrinsic interdisciplinary nature and advanced technology of IODP also blend perfectly into the mission of improving science education in the United States.

Our status as international leader in the ocean sciences demands our continued participation in ocean drilling. A strong U.S. commitment to IODP amplifies the scientific priorities already articulated in the NSF FUMAGES report, the Division of Ocean Sciences Decadal Synthesis, and the Geosciences Directorate's vision of *Geosciences Beyond 2000*. Many prominent research groups in the United States (MARGINS, RIDGE, ESH, etc.) depend on ocean drilling for sampling, *in situ* measurements, and installation of long-term observatories. The enhanced capabilities of riser-supported drilling and mission-specific platforms will attract an even larger and more diverse community of scientists. Interdisciplinary synergy, as yet largely untapped, will invigorate such NSF programs as BE (*Biocomplexity in the Environment*), LExEn (*Life in Extreme Environments*), ESH (*Earth System History*), and ANS (*Arctic Natural Sciences*). The challenges of organizing, financing, and implementing the science of IODP are significant, but the future health and prosperity of the United States depend on its commitment to exactly this type of ambition and vision. Without U.S. leadership, there is a very real danger that ocean drilling will end, along with its inherent international cooperation and range of remarkable science that can be achieved with this technology.