Major Questions from the 1999 DESCEND workshop are found on the subsequent pages.

II. Science Sessions

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

A. Mid-Ocean Ridge Processes.

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

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

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

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

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

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

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

Global Variability.

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

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

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

B. The Abyss and Open Ocean

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

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

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

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

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

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

- What are the causes of this phenomenon?
- Why are many types of water column communities patchy or confined to narrow depth ranges?
- Why do mesoscale scale ocean processes such as gyres cause large variability in some water column organisms?
- What exactly are the abundance and spatial distribution patterns of biological communities from small to large spatial scales?
- What are the affects, at high resolutions, of the many important inputs to the biological system that are pulsed?
- What is the full picture of seasonal and inter-annual variations? Long time-series observations covering decades are needed to begin to build up a full picture of these variations and their importance.
- What are the influences of physical, chemical and geological environment on biological communities in the oceans?
- What are the consequences of episodic events such as resuspension, upwelling, volcanic activity, and turbidity currents?
- Physical processes in the ocean such as temperature changes or currents may have direct effects on a given community or on its reproductive cycle (i.e. larval transport), or may indirectly affect it through its food supply. What is the nature of biological couplings, including trophic effects such as bloom die-offs?
- What is the relative importance of episodic events as compared to seasonal and inter-annual variability (e.g. El Niño)?

C. Margins

The active and passive margins of tectonic plates and continental masses present the full range of ocean depths from a few meters in estuaries and coasts to >10 km in deep-sea trenches. Margins have extraordinarily high biological productivity and among the greatest human population densities. They are the Earth's principle loci for production of hydrocarbon and metal resources, as well as earthquake, landslide, volcanic and climate hazards. Extreme environmental conditions are prevalent. Margins are the regions where most major fisheries are centered, the areas where human impacts are greatest, and where known species diversity is highest. Major oceanographic features such as boundary currents and oxygen minimum zones often impinge on continental margins. Despite the scientific, societal, and economic importance of margins, many of the mechanical, fluid, chemical and biological processes that shape them, and the way that margins shape ocean life, are poorly known.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

D. Polar Regions

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

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

- What is the hydrographic structure of the Arctic Ocean and adjacent seas?
- What are the physical and biological interactions between the polar oceans and the global hydrosphere?
- What controls the formation and maintenance of the Arctic sea-ice cover?
- What are the characteristics of the formation, movement, and mixing of arctic water masses? How does sea ice grow and decay?
- What are the controls over the exchange of salt and heat with the Atlantic Ocean and the Bering Sea

- What are the interdependencies of chemical and physical processes and marine organisms and productivity in the Arctic Ocean?
- What is character of the Arctic Ocean ridge system and what are the distributions of magnetic anomaly patterns, heat flow and gravity variations in the Arctic Ocean?

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

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

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

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

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

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

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

- What is the extent, timing, and regional differences of the last glacial maximum in the polar regions?
- What rapid or episodic events occurred during the Late Quaternary in both polar regions?
- What are the key forcings and feedbacks that influence the retreat and re-advance of the ice sheets?
- What changes have occurred to ice shelves and outlet glaciers during the Holocene?
- What is the correlation between Late Quaternary polar environmental history and deep-ocean sedimentary records?
- When was widespread continental glaciation initiated in the various sectors of the Antarctic margin?
- What is the stability of the East Antarctic Ice Sheet?
- Are the East Antarctic Ice Sheet and the West Antarctic Ice Sheet fluctuations in or out of phase?
- What is the relationship between Northern and Southern hemisphere glaciations?
- What is the nature of climate variability during the Holocene along the coastal setting of East Antarctica and the circum-arctic region and what was the response of the marine ecosystem to these changes?

- What is the Mesozoic and Cenozoic tectonic history of the East Antarctic margin?
- What is the relative role of shallow banks and cross shelf troughs on sediment supply and benthic ecosystems in polar regions?
- What is the evolutionary history of polar oceans and their flora and fauna?

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

- What are the dynamics of Antarctic ice shelves?

E. Coastal Environment

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

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

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

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

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

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

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

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

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

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

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

Major questions as presented in the 2015 SEA CHANGE: Decadal Survey report

Questions identified in the SEA CHANGE: Decadal Survey of ocean sciences report

- What are the rates, mechanisms, impacts, and geographic variability of sea level change?
- How are the coastal and estuarine ocean and their ecosystems influenced by the global hydrologic cycle, land use, and upwelling from the deep ocean?
- How have ocean biogeochemical and physical processes contributed to today's climate and its variability, and how will this system change over the next century?
- What is the role of biodiversity in the resilience of marine ecosystems and how will it be affected by natural and anthropogenic changes?
- How different will marine food webs be at midcentury? In the next 100 years?
- What are the processes that control the formation and evolution of ocean basins?
- How can risk be better characterized and the ability to forecast geohazards like mega-earthquakes, tsunamis, undersea landslides, and volcanic eruptions be improved?
- What is the geophysical, chemical, and biological character of the subseafloor environment and how does it affect global elemental cycles and understanding of the origin and evolution of life?