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International Program Investigates the Black Sea

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Concern over the environmental condition of the Black Sea has increased markedly since the recent political changes in eastern Europe, as the extent of degradation has become clearer. This concern has led to the creation of the Cooperative Marine Science Program for the Black Sea (CoMSBlack) (Figure 1a), an interdisciplinary, international marine science program that provides the highest quality of oceanographic science for effective and integrated management of the Black Sea.

A complex program of investigation has been outlined by the major marine research organizations of the Black Sea riparian countries, as well as the Woods Hole Oceanographic Institution and other western research laboratories. A series of meetings is being held to clarify the role of CoMSBlack in Black Sea research as well as the sea's role in major international research efforts. Changes in the Black Sea riparian countries have simplified integrated science.

CoMSBlack seeks to attain its goals, including environmental preservation, protection, and optimum utilization, by

- clarifying the fundamental oceanographic processes and rates contributing to the environmental quality, including variability in space and time
- assessing the role of anthropogenic inputs and long-term climatic variability on the changing ecosystem
- developing realistic ecological models coupled with general and regional circulation dynamics in a form usable for management, and
- establishing a long-term data base of fluxes of water and biogeochemically active materials that affect the environment of the Black Sea.

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Condition of the Black Sea

The Black Sea is almost totally landlocked and contains the largest anoxic body of water in the world beneath its oxygenated surface waters. Only about 13% of its waters contain oxygen. The remaining deeper waters (to 2200 m) are rich in hydrogen sulfide, and, except for bacteria, life is absent below 100 or 200 m. The basin's oceanography is driven by river input, atmospheric forcing, thermohaline circulation, strait flows, and topography. A complex circulation results, composed of a basic basin-wide gyre concentrated against abrupt marginal topography and unstable, transient eddies and filaments riding on this basic system [*Blatov et al.*, 1984]. Convective and/or isopycnal mixing processes form the Cold Intermediate Layer (CIL), a crucially important water mass for the ecology of the basin. Double diffusive phenomena may occur in the sinking and spreading of the Mediterranean inflow and the deep benthic boundary layer [*Ozsoy et al.*, 1989].

Severe changes in the Black Sea's ecosystem structure and function have been documented in recent conferences and articles [e.g., *Murray*, 1991]. Some examples of the ecological collapse include loss of vast areas of seagrass meadows; nearly total disappearance of benthos over broad regions of the shelf; dramatic decline in fisheries; loss of diversity in phytoplankton, with blooms becoming monospecific as well as more frequent and intense; and rapid influx and spread of *Aurelia aurita* and a ctenophore, *Mnemiopsis leidyi*, occupying niches left vacant in this declining ecosystem. This biological collapse mirrors changes in ecosystem biogeochemistry; there is an increased influx of nutrients, heavy metals, pesticides, and hydrocarbons, among all, contributing to massive eutrophication and toxicity particularly on the northwest shelf and along the Black Sea margin.

Biological variability, having a broad spectrum of time and space scales, exists in the Black Sea. There are strong seasonal signatures in phytoplankton production; in general, diatom blooms prevail in the spring, flagellate blooms in the summer, and coccolithophorid blooms in the fall. On longer time scales, climatic fluctuations contribute to variability, chiefly fluctuation in freshwater inflow from the major and minor rivers along the margin of the basin. Space scales vary from seagrass meadows or plankton patches up to basin-scale changes encouraged by strong horizontal advection. Physical processes contribute strongly to variability. Research efforts must be performed on both the basin and subbasin scale. The meandering rim current and the eddies and filaments superimposed on the mean circulation indicate that important dynamics affect cross-shelf exchanges. Knowledge of the fluxes across the shelfbreak to the deep interior and of the physical coupling mechanisms will contribute to the understanding of biological variability.

The Black Sea's mesoscale dynamics and interactions take place over relatively small space scales characterized by the Rossby radius—O (20–25 km). Because of this small scale and the limited size of the basin, the Black Sea provides a unique environment for carrying out synoptic investigations with mesoscale resolution. In view of the variety of processes with multiple and interactive scales, the Black Sea may serve as a small-scale laboratory for investigating a series of oceanographic phenomena that are common to different areas of the world ocean. These investigations may be both observational and theoretical. The absence of an open boundary and the availability of basin-wide observations argue strongly for the use of this sea as a test basin for physical and ecosystem model intercomparisons.

The Black Sea is a useful basin for studying long-term oceanographic variability and climatic change, major elements of atmospheric forcing, components of the water balance, and hydrographic characteristics with implications for various biogeochemical processes. Because of the unique characteristics of the Black Sea—sensitivity to water and salt balance, nearly complete enclosure, and limited size—this basin is particularly sensitive to climate change and land-use impacts. Small changes in precipitation, evaporation, freshwater inflow, or flow through the Bosphorus Strait may affect basin-wide processes in relatively few decades.

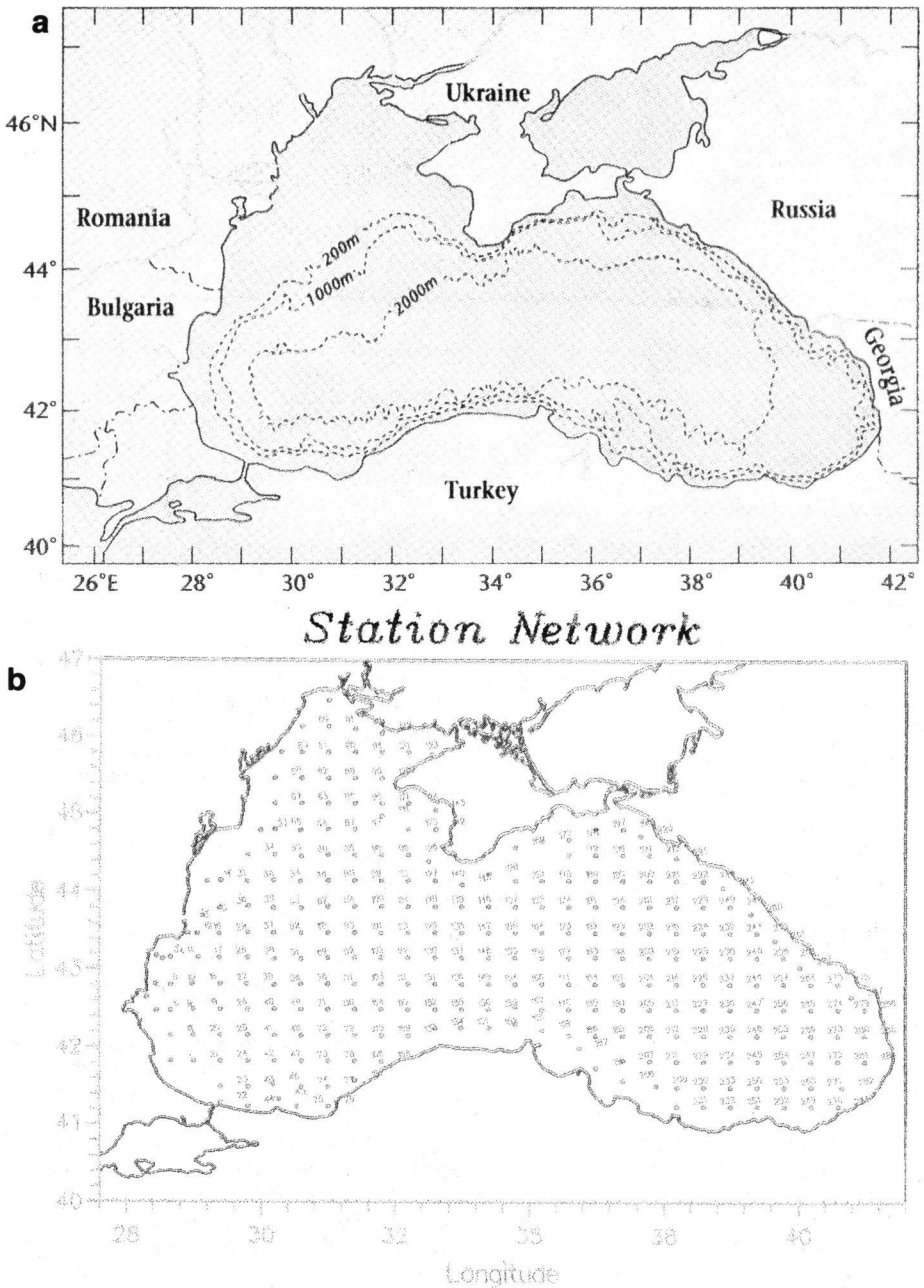

Fig. 1 (a) The Black Sea basin and surrounding geography. (b) HYDROBLACK '91 station network. [Original color image appears in the back of this volume.]

The Black Sea has been subject to considerable human use and influence. Among large marine water bodies, the Black Sea has a significantly higher ratio of drainage area to water basin area, and population density is high, with 162 million people in the drainage basin. Consequently, the Black Sea has an extreme sensitivity to land-use practices. A significant population of the riparian states lives on the coastal zone, and the drainage area of some rivers carrying pollutants to the sea spans most of Europe. Increasing industrialization has placed severe and stringent demands on the living and nonliving resources of the Black Sea. Recent studies document that the basin's physical and biochemical oceanography and subsequently its ecology are being altered by man [*Saydem et al.*, in press, 1993]. In this sense, the Black Sea is interesting because it constitutes a nonequilibrium ecosystem.

In particular, the rapid changes in the environment are manifested by eutrophication of much of the euphotic zone of the Black Sea, frequent hypoxia on the shelves, deterioration of water quality in estuaries, irretrievable loss of some significant deltaic wetlands and marine habitats, and the microbiological and chemical contamination of the water and the living resources. The combined effects of overexploitation of fisheries and increasing pollution have led to dramatic reduction in fish stocks. Major environmental problems have arisen, particularly in the large western shelf (extending from Crimea in the north to the Sakarya River on the Turkish coast), due to the spreading of eutrophication, algal blooms, and detritus generation with consequent high oxygen utilization rates, resulting in hypoxia and/or anoxia in the bottom waters and sediments [*Moncheva*, 1987].

The assessment of environmental variability, whether caused by human activity or natural trends and fluctuations, demands long-term investigation. Basin-wide eutrophication and its consequences seem to be the most threatening and irreversible of the various processes affecting the environment. For an assessment of the sources of eutrophication, the historical and present nutrient fluxes entering the Black Sea, their sources on land, and their redistribution in the basin by dynamical and biochemical processes must be known in detail. This can only be attained through well-defined and carefully implemented monitoring and research.

Because of its size and internal dynamics, there is strong coupling between the various regions of the Black Sea over scales extending up to the entire basin. For example, the CIL serves as a conveyor, increasing horizontal dispersion across the basin. A sound understanding of the marine environment requires cooperative and integrated investigations that begin with the basin scale; hence, the CoMSBlack.

Major Objectives

The major objectives of CoMSBlack are

- to provide an assessment of natural and anthropogenically induced environmental changes using historical data
- to determine past and present fluxes of water, sediment, carbon, nutrients, heavy metals, hydrocarbons, and other selected materials from rivers, atmosphere, straits, and bottom sediments
- to determine the fluxes of carbon, nutrients, organisms, and selected pollutants across the coastal and shelf seas, the shelf break, and within the basin
- to understand the fundamental physical and biogeochemical processes governing the transport, transformation, and fates of carbon, nutrients, suspended sediments, and selected substances
- to provide a quantitative understanding of the physical and biogeochemical processes and nutrient fluxes affecting primary productivity
- to assess man-made and natural influences on the ecosystem structure and function in the water column (phytoplankton and zooplankton) and benthos (selected benthic organisms)
- to develop multiple- and interactive-scale models for general and mesoscale circulation, ecosystem, and regional processes that will be applicable to the studies concerned with the ecology and biogeochemistry of the sea, and
- to assess space and time scales of general circulation and mesoscale features and their energetics and processes leading to the formation, spreading, and transformation of CIL.

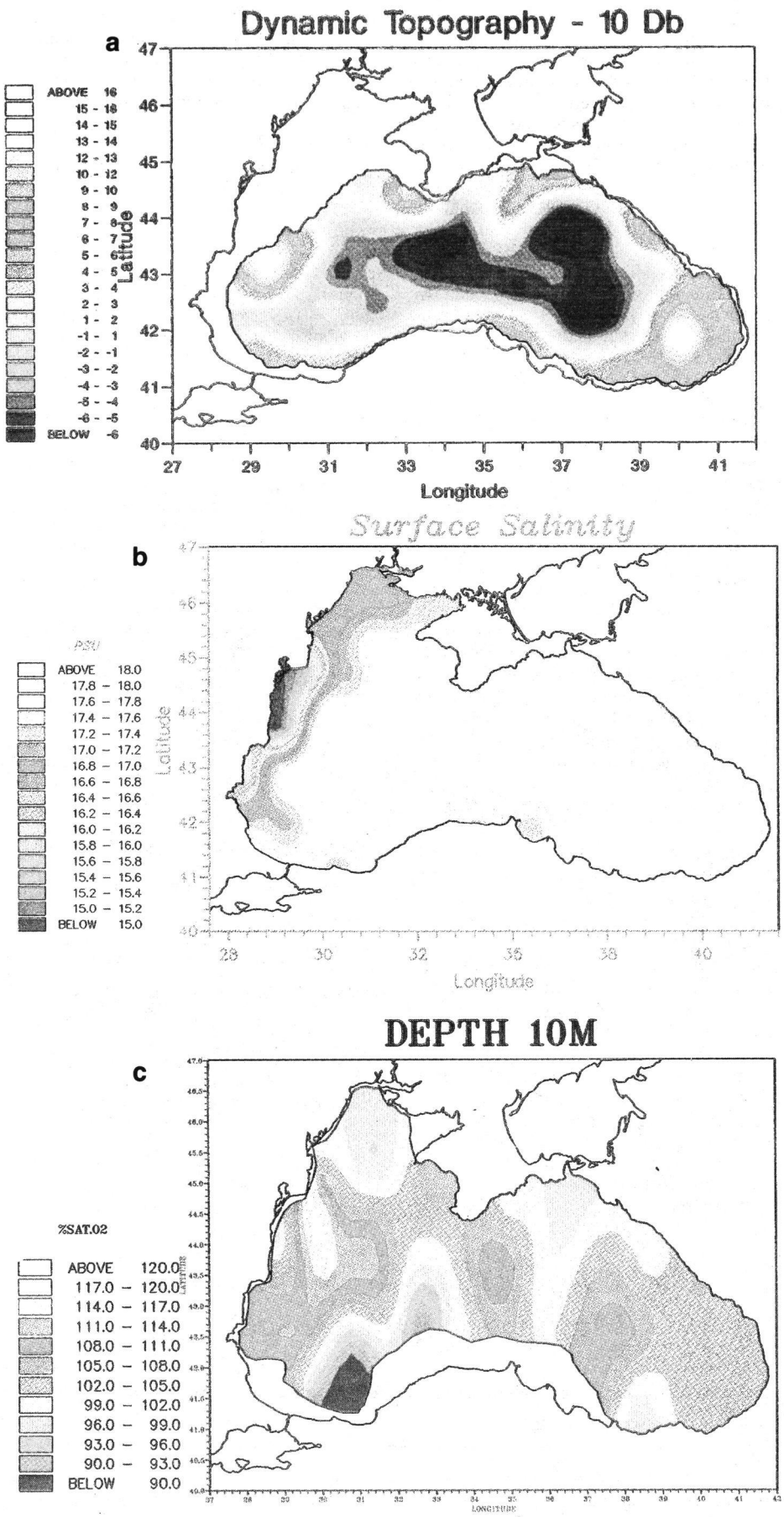

Fig. 2. (a) Surface circulation in the Black Sea, deduced from analysis of hydrographic fields of HYDROBLACK '91. Shown is the dynamic topography at the 5-db level relative to the 900-db level. (b) Surface salinity of the Black Sea during HYDROBLACK '91. (c) Near-surface oxygen distribution for HYDROBLACK '91 (nonsynoptic). [Original color image appears in the back of this volume.]

CoMSBlack's Evolution

CoMSBlack was initiated at a meeting in April 1991 in Sofia, Bulgaria, by an ad hoc committee of scientists from the former Soviet Union, Bulgaria, Romania, Turkey, the United States, and the Intergovernmental Oceanographic Commission (IOC). A series of meetings was held to plan an international scientific workshop and a major field activity in Constantza, Romania, and in Erdemli, Turkey. The international workshop was held in 1991 in Varna, Bulgaria, and the first major field event, called HYDROBLACK '91, in September 1991.

The international workshop brought together 125 scientists and managers to discuss the health of the Black Sea and the possible causes for the degradation of its environment and to assess the state of the basin's ocean science. The CoMSBlack was formalized and a research program was prepared by a series of working groups. The proceedings of the workshop will be published in two volumes in late 1993 [*Aubrey*, 1993a,b] and will contain country profiles describing national research in the Black Sea and working group reports outlining a research strategy for the next decade. A steering committee was formed at the workshop to direct the CoMSBlack program.

The physical oceanographic data obtained during the HYDROBLACK '91 field event were intercalibrated and pooled at a working group meeting in December 1991 [*Aubrey et al.*, 1992]. In February 1992, another CoMSBlack workshop was held in Yalta, Ukraine, where pooled data sets were exchanged, preliminary discussions of the HYDROBLACK '91 were carried out, and the field programs for 1992 were finalized. CoMSBlack '92a data were intercalibrated at a workshop at the Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey, in January. Steering committee meetings are now held twice a year, executive committee meetings are held as necessary, and data exchange workshops are held for each cruise.

In February, CoMSBlack was given the support and endorsement of IOC, which now publishes its workshop proceedings, symposia volumes, and other publications. In fall 1992, CoMSBlack was designated a science program of the Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée (CIESM).

CoMSBlack Field Program

The HYDROBLACK '91 cruise took place from September 2 to 29, 1991. Nearly 300 stations were occupied (Figure 1b), using five research vessels from three different Black Sea coastal states. HYDROBLACK '91 marked the first multiship, quasi-synoptic study of the Black Sea.

Some results from this early work show the types of data acquired. The 10-db surface circulation relative to the 900-db level based on HYDROBLACK '91 data is shown in Figure 2a. Considerable structural features characteristic of the Black Sea are reflected by two subbasin-scale cyclonic gyres and anticyclonic eddies along the margins of the basin. These quasi-permanent anticyclonic

eddies appear to result from the interactions of the rim current with topography and baroclinic instabilities [*Oguz et al.*, 1993]. The surface salinity field shown in Figure 2b clearly displays the regions of influence of the Danube River.

In addition to the salinity and temperature, oxygen, hydrogen sulfide, nutrients, and Secchi disk depth were measured during the HYDROBLACK '91 survey. Figure 2c shows the surface oxygen content from this survey.

Later cruises have been completed. CoMSBlack '92a, conducted in July 1992 by five ships, focused on fish egg and larval surveys, as well as populations of *Aurelia* and *Mnemiopsis* throughout the Black Sea. A two-ship cruise collected water samples for the study of Chernobyl radio-tracers throughout the Black Sea in August 1992. A survey of the spring phytoplankton bloom was held in April 1993. Another cruise was planned for July 1993 to examine ichthyoplankton distribution.

The CoMSBlack field program is to be carried out over a period of at least 5 years, from 1991 to 1996, with three different types of coordinated programs planned: general surveys, process studies, and coastal seas circulation.

General Surveys: General circulation surveys will establish the overall biogeochemical framework, organism distribution and densities, biodiversity, and thermohaline characteristics, and identify and shed understanding on the dynamics of the major transport processes, such as the permanent, recurrent, and transient features of general circulation; that is, the rim current, subbasin-scale gyres, mesoscale, and sub-mesoscale eddies. The effect of cyclonic and anticyclonic flows as sources and sinks of nutrients is the primary concern of these investigations.

General survey cruises will be held biannually from 1992 to 1994. Initial times chosen for these surveys are from September to October for the preceding phase and April for the spreading phase of the CIL. Cruises will be added or rescheduled to obtain full seasonal coverage where possible.

Process Studies: After each general survey in the spring, fine-resolution process studies will be carried out in selected subregions of the sea to investigate various interdisciplinary and disciplinary topics. For instance, physical process studies will investigate the formation of water masses by convection and/or isopycnal mixing or by generation over the shelf regions. The spreading, transformation, and transport of nutrients by CIL will be studied. The investigation of mesoscale and submesoscale structures and their interactions in relation to dispersal of nutrients and productivity will be an integral part of these process studies. The regions recommended for the process studies that have adequate resolution include the Northwestern Shelf region, the centers of cyclonic subbasin scales gyres, the pre-Bosphorus area, and the persistent anticyclonic flow region in the southeastern Black Sea.

Coastal Seas Circulation Dynamics and Fluxes: In this program, special attention will be given to the fine-resolution field investigations in the Black Sea shelf areas encompassing the northwestern, western, and southwestern shelves as well as the southern shelf region extending from the Bosphorus to Sinop peninsula (Figure 1a). The major physical processes affecting the distribution of nutrients and productivity are meandering off the rim current in the form of filaments and other coherent structures, baroclinic-barotropic instability processes, frontal processes including shelf/slope fronts, and dynamics of river plumes.

In all of the field studies described above, extensive measurements of phytoplankton and zooplankton, including fish eggs and larvae, selected benthic organisms, and the predatory species such as *M. leidyi* will be made to investigate species composition and abundance in relation to the nonequilibrium ecosystem of the Black Sea as affected by natural and man-induced processes.

Modeling

A modeling activity has been established to develop a new generation of community models and methodology, but activities are not centered at any specific institution. The ecological modeling group will meet for the first time in Sofia, Bulgaria, in early 1994. The group will discuss

- ecosystem models pertinent to the Black Sea
- long-term climatic change models
- models for carrying out the eddy-resolving general circulation studies that take into account regional processes such the water mass formation
- models that investigate circulation dynamics of the coastal and shelf seas and their interactions with the open sea, which require adequate resolution and special techniques for complexities due the combined effects of stratification and rapidly varying topography, and
- a data base for initialization and intercalibration of models, including representative forcing fields of monthly mean wind stress, heat flux, evaporation, and precipitation, as well as river discharge and inflows/outflows through the straits.

CoMSBlack seeks collaboration with all interested scientific groups. It hopes to facilitate inclusion of other aspects of oceanography into the ongoing studies, to expand on the already broad activities of the current member institutions and member states.

Acknowledgments

CoMSBlack has required the full participation of the governments of the various Black Sea riparian countries, as well as external sponsors. Too numerous to name in full, we would like to identify the academies of science in Bulgaria, Romania, Russia, Ukraine, and the United States, as well as the TUBITAK and NATO Science for Stability Program in Turkey, the Intergovernmental Oceanographic Commission, the National Science Foundation, and the Office of Naval Research (London). Significant private contributors to this effort include the Regional Environmental Center for Central and Eastern Europe, the Andrew W. Mellon Foundation, the Woods Hole Oceanographic Institution (through its director, Craig Dorman), and various private donors energized through the efforts of Rodney Berens of New York.

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Paleoceanographic Record of North Pacific Quantified

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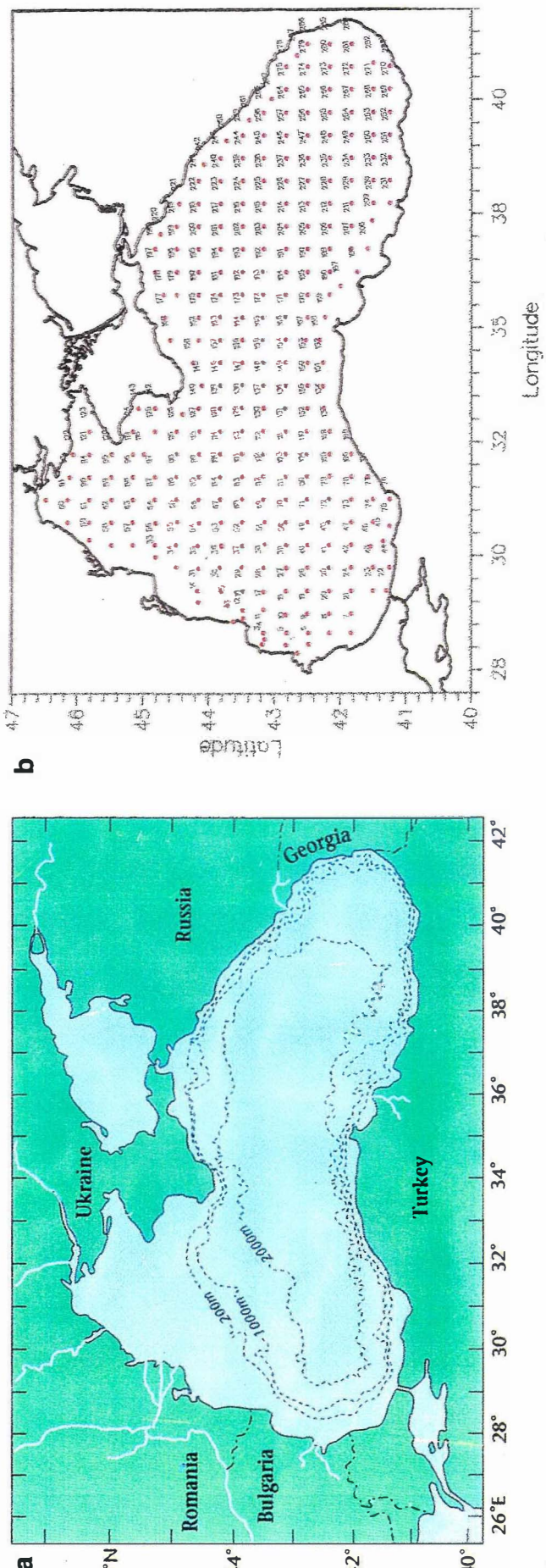
Leg 145 Scientific Party

After a 21-year absence, scientific drilling returned to the high latitudes of the north Pacific from July to September 1992 (Figure 1). The main objectives of the Ocean Drilling Program's Leg 145 were to collect high-resolution records of Miocene to Quaternary changes in ocean circulation, biological activity, and global climate, and to recover high-latitude Paleogene and Cretaceous carbonate-bearing sediments to help decipher



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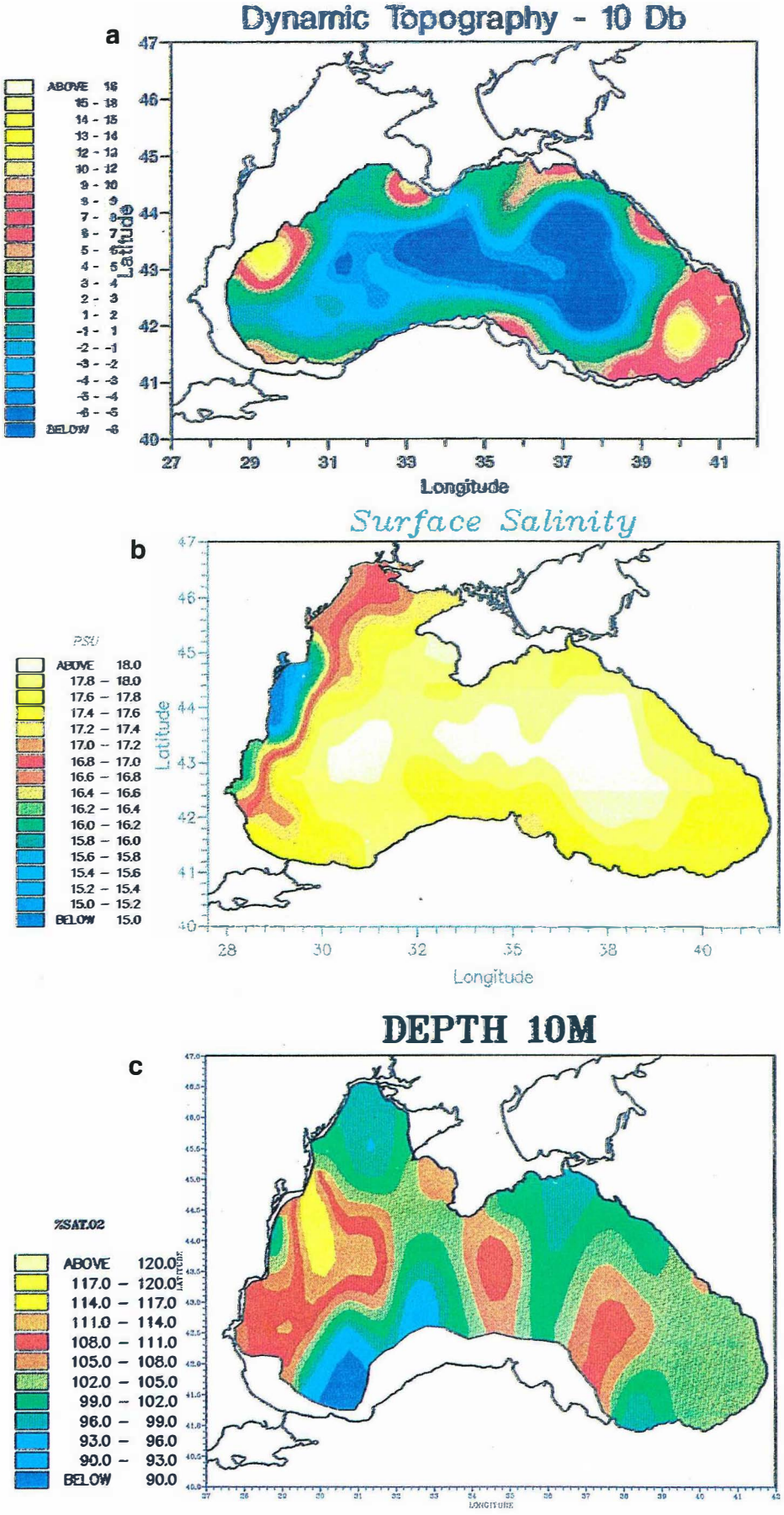

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