JPRS L/8956

29 February 1980

USSR Report

EARTH SCIENCES

(FOUO 3/80)

Selections from 'Progress in Soviet Oceanology'

FBIS FOREIGN BROADCAST INFORMATION SERVICE

APPROVED FOR RELEASE: 2007/02/08: CIA-RDP82-00850R000200050058-1

NOTE

JPRS publications contain information primarily from foreign newspapers, periodicals and books, but also from news agency transmissions and broadcasts. Materials from foreign-language sources are translated; those from English-language sources are transcribed or reprinted, with the original phrasing and other characteristics retained.

Headlines, editorial reports, and material enclosed in brackets [] are supplied by JPRS. Processing indicators such as [Text] or [Excerpt] in the first line of each item, or following the last line of a brief, indicate how the original information was processed. Where no processing indicator is given, the information was summarized or extracted.

Unfamiliar names rendered phonetically or transliterated are enclosed in parentheses. Words or names preceded by a question mark and enclosed in parentheses were not clear in the original but have been supplied as appropriate in context. Other unattributed parenthetical notes within the body of an item originate with the source. Times within items are as given by source.

The contents of this publication in no way represent the policies, views or attitudes of the U.S. Government.

For further information on report content call (703) 351-2938 (economic); 3468 (political, sociological, military); 2726 (life sciences); 2725 (physical sciences).

APPROVED FOR RELEASE: 2007/02/08: CIA-RDP82-00850R000200050058-1

JPRS L/8956

29 February 1980

USSR REPORT

EARTH SCIENCES

(FOUO 3/80)

SELECTIONS FROM 'PROGRESS IN SOVIET OCEANOLOGY'

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 3-49, 87-117, 136-164

[Monograph edited by L. M. Brekhovskikh, Izdatel'stvo Nauka, 1218 copies]

CONTENTS PAGE



CONTENTS (Continued) Page

PROBLEMS OF SOVIET OCEANOLOGY IN THE LIGHT OF THE RESOLUTIONS OF THE 25th CONGRESS OF THE CPSU

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 pp 3-12

[Article by L. M. Brekhovskikh]

[Text] The role of the ocean in the life of man is growing continuously. This arises from a number of circumstances. The biological resources of the ocean, although not unlimited as sometimes is thought, are enormous. We are only just beginning to master the mineral resources of the ocean, but at the present time about 20% of the world production of oil and gas comes from the sea floor. Marine transportation has grown rapidly throughout the world inrecent times. From 1950 to 1975 it increased by fivefold. To a significant degree the ocean determines the weather on our planet. The role of the ocean is exceptionally important as the system which, in the final analysis, receives a significant part of industrial and domestic pollution from the land, a system where, unfortunately, this pollution far from always completely decomposes and is neutralized. Finally, approximately half of the atmospheric oxygen which we breathe comes to us from photosynthesis in the ocean.

It is necessary to study the ocean as completely as possible in order to make proper, efficient use of its resources.

In the "Basic Areas of Development of the National Economy of the USSR in 1976-1980" approved by the 25th Congress of the CPSU, the necessity for "expanding the complex studies of the World Ocean" is indicated. Below, we shall present a survey of the basic areas of study of the ocean in the current five-year period and indicate some of our achievements in recent years.

The basic efforts of the scientists are aimed at studying the physical, chemical and biological processes in the ocean, studying the geological structure of the ocean floor, creating research equipment and equipment for man to penetrate into the depths of the ocean, studies of ocean pollution and the prevention of it.

Ocean physics is faced with a very complex problem -- understanding the laws of motion of varying scales in the ocean, beginning with currents on a planetary scale and ending with turbulence on the millimeter scale in which, in the final analysis, obviously the conversion of mechanical energy of the ocean to thermal energy takes place. The understanding of the problems of the dynamics of the ocean is entirely necessary for the development of other sciences of the ocean. For example, the dynamics of the development of their biological communities is directly connected with vertical and horizontal displacements of water with turbulent mixing of it. Heat transfer by the ocean currents and also the interaction of the ocean with the atmosphere have primary significance for numerical weather forecasting over the land and over the ocean.

It is necessary to consider the discovery of the equatorial subsurface countercurrent in the Atlantic Ocean in 1959 by the expedition of the Marine Hydrophysics Institute on board the scientific research ship "Mikhail Lomonosov" among our achievements in the field of ocean physics. A year later in the Indian Ocean the expedition of the Oceanology Institute on board the scientific research ship "Vityaz'" discovered an analogous current. These currents have come to be called the "Lomonosov current" and the "Tareyev current." On the fifth trip of the scientific research ship "Akademik Kurchatov" the Antilles-Guiana countercurrent was discovered off the coast of South America. Soviet expeditions have discovered characteristic features of these countercurrents and also the subsurface Cromwell current discovered in the Pacific Ocean by American scientists. The depths of these currents, their stability, speed and many other characteristics have been established. Their origin has been explained in general terms. Other numerous expeditions and theoretical studies have made it possible to discover the basic mechanisms of stationary, wind and thermochalinic circulation in the oceans.

In 1970 as a result of the experiment which is now called the "Poligon-70" experiment, Soviet oceanologists made a discovery which cardinally altered the concept of the medium scale circulation of ocean water. In the tropical zone of the Atlantic Ocean gigantic eddies have been discovered with horizontal dimensions of several hundreds of kilometers including energy comparable to the energy of the medium currents known up to the present time, and in some cases, exceeding it by many times. The principal organization for performing the experiment was the Oceanology Institute. These experiments were continued later and developed by American scientists.

The study of the interaction of the atmosphere and the ocean (and also the continents) has defining significance for weather forecasting above the sea and above the dry land. The pioneer in the statement of these problems invariably has been Academician V. V. Shuleykin. A number of the largest research projects in this field, in particular, the creation of the theory of marine hurricanes are accredited to him.

Important projects on numerical simulation of the atmosphere and ocean to improve long-range weather forecasting are underway at the Computer Center of the Siberian Division of the USSR Academy of Sciences directed by Academician G. I. Marchuk.

The Leningrad Division of the Oceanology Institute has developed a version of the mathematical model of atmospheric and ocean circulation considering their interaction.

In order to study atmospheric processes above the ocean and the large-scale interaction of the ocean in the atmosphere two large experiments have been undertaken — the national TROPEX-72 and international TROPEX-74. TROPEX-74 was participated in by 29 ships from 10 countries (including 13 from the USSR) and also aircraft and artificial earth satellites. The materials from these experiments have been partially processed. They have made it possible to calculate the heat transfer and the transfer of water masses by the equatorial currents, the heat budget of the ocean, the variability of the oceanographic parameters in the tropical zone. For example, it was established that a Lomonosov current meanders with periods from 15 days to 1.5 months.

In studying the Arctic and Antarctic Oceans a great deal of attention has been given to the dynamics of the ice cover. The influence of the coast lines at distances of hundreds of kilometers from them, depending on the packing and strength of the ice, was discovered.

A large scale international experiment POLEX-North-76 was performed as a subprogram of the GARP program. Large-scale energy exchange between the ocean and the atmosphere was studied at high latitudes, and the role of polar regions in the general energy balance of the ocean-atmosphere system was determined. Variations of the heat content of the ocean and the atmosphere, the advection of heat and moisture by air masses and the radiation balance were determined in this experiment. On the basis of the data obtained, the heat fluxes from the ocean to the atmosphere and the heat advection by the currents were calculated. It turned out that the heat transfer by the currents plays the primary role in the formation of the heat balance of the atmosphere over the Northern European Basin.

Soviet-American work under the POLEX-South experiment was performed between Australia and Antarctica and in Drake's Passage. They made it possible significantly to supplement the ideas about the structure and dynamics of the Antarctic Circumpolar Current, to estimate the flow rates of this current (105-125 and higher) and to detect the mesoscale vortexes on both sides of the front. The bottom countercurrent in Drake's Passage was discovered. The two-volume ATLAS OF ANTARCTICA was compiled and published from the materials of many years of research.

A broad cycle of works studying the acoustic fiels in the ocean have been published. Studies were made of the characteristics of the underwater sound channel and sound dissipating layers in various parts of the ocean. The laws of the scattering of sound from the ocean floor and surface were defined. Acoustic engineering is beginning to be widely used in studies of the ocean floor, its illumination, when measuring sea currents, turbulence, and so on. Significant progress has been made in studying the optical, magnetic, gravitational and other physical fields in the ocean.

In order to combine the forces of the various organizations to solve the problems stated by the 25th Congress of the CPSU, beginning with the current five-year period, a new system of planning World Ocean research was introduced. An Integrated Interdepartmental Five-Year Plan for World Ocean Research and the Utilization of its Resources developed by the Oceanographic Commission jointly with various departments, investigated and approved by the State Committee on Science and Engineering of the Council of Ministers of the USSR consists basically of large-scale projects. Each such project has a defined specific purpose and will be executed by various organizations with overall coordination by the head organization. Many of the projects are international.

The processing of the materials from the TROPEX-74 experiment will be continued under the international GARP program. The Oceanographic Atlas must be compiled as result. Soviet oceanologists will play a significant role in its compilation and editing. In 1979, a new, still grander, global experiment will begin. In contrast to 1974, the observations will encompass all oceans.

In 1978 studies were continued on the 1976 program under the POLEX-North subprogram which is also part of the GARP program. Studies were made of the radiation balance, the advection of heat in the atmosphere and ocean, heat content in both media. The POLEX-North subprogram calls for an "energy exchange" test area in the Norwegian and Greenland Seas with ship observations and three more test areas with observations from the ice. Laboratory aircraft and artificial earth satellites will be involved in the studies.

An analogous subprogram for the Antarctic Ocean POLEX-South provides for fourfold Soviet-American surveys and test areas in the Davis and Scotia Seas between Africa and Antarctica. This makes it possible to estimate the role of the ocean and the atmosphere in the energy balance of the southern polar region, to discover the mechanisms of energy exchange, the structure of the water masses in the Antarctic Ocean and mechanisms of formation of bottom Antarctic water, to construct physical-statistical and hydrodynamic models of the structure and dynamics of the Circumpolar Current, to estimate the role of seasonal and interyear fluctuations of the propagation of sea ice in the long-period variations of climate, to discover new areas of increased concentration of fish and krill and also to make recommendations with respect to the assimilation of them.

Another important international project is the POLYMODE program implemented as a development of the Soviet work on "Poligon-70" [test area-70] and subsequent American work under the MODE-1 program. The goal of this project is to discover the nature of the synoptic variability of the ocean and, in particular, the causes of the occurrence of medium-scale eddies in the ocean, their interaction with each other and with the medium current and their final fate. In the theoretical part of the program the theory of nonlinear Rossby waves will be developed -- the possible cause of the formation of medium-scale eddies in the ocean. A model of the general circulation of the ocean has been constructed with high spatial resolution. It is shown that this circulation will become unstable after some period of time, as a result of which eddies of a synoptic scale will be generated, moving to the west several kilometers a day.

The experimental work under this program was performed in 1977 and 1978 in the Atlantic Ocean. Experiments of three types were realized: the study of the variability of the basic characteristics of the ocean using long-term (to 1 year) buoy installations, the study of the same variability by multiple hydrologic surveys and, finally, the study of the dynamics of the currents by tracing the drift of acoustic buoys with neutral buoyancy released at various depths. As a result, it is proposed that the structure of the eddy field and geographic distribution of the eddies in the ocean will be more precisely defined, the local energy balance of the eddies will be estimated, and the models of the structure and evolution of a single eddy and groups of them improved. There is hope of creating the principles of a model of large-scale interaction of the atmosphere and ocean with parametric consideration of the existence of synoptic-scale eddies.

The observation data will be used to estimate the nonuniformity of the hydrochemical structure and the bioproductivity of the water in connection with synoptic eddies. Probably it will be possible to make additional recommendations with respect to planning the ocean fishing.

Large studies of the dynamics of the equatorial currents are planned (the DINEKT program). The geographic boundaries of the flows of westerly and easterly transfers of water masses in the deep layers of the oceans must be established, the time-space variability of the equatorial currents, their dynamic and statistical characteristics and their reactions to atmospheric disturbances will be studied, and water and heat exchange in the systems of these currents and between the atmosphere and the ocean in equatorial zone will be investigated.

Another program provides for comprehensive study of surface and internal waves in the ocean -- their time and space spectra. Studies of wave movements in the coastal zone caused by waves coming from the deep sea regions will be continued. The understanding of wave processes on the shelves and shoals is acquiring greater and greater significance for the national economy.

Further studies of the Caribbean region (including the Gulf of Mexico and the adjacent parts of the Atlantic Ocean) are planned under the international MOCARIB program. It is proposed that a hydrodynamic model of the region be created and that maps of the bottom relief, currents, temperature and water density be constructed. Zones of increased biological productivity must be discovered, a prediction must be made of the reserves and distribution of the basic species of tuna, and prospective regions for the fishing industry must be discovered.

The geological-geophysical studies of the bottom of the ocean and its seas have exceptionally important significance. They are being performed in order to understand the laws of composition, structure and development of the oceanic earth's crust and estimate the mineral resources in its depths.

The results of the studies under the international program for deep drilling of the sea floor and the creation of the concept of the tectonics of the lithospheric plates are most impressive in this area. This concept, developing mobilism in geology undoubtedly has progressive significance. It has become the basis for understanding the global tectonics of our planet, although there are still many questions on which work is needed. Our geologists and geophysicists have participated actively in this program for many years. In 1970-1976 Soviet scientists participated in 20 trips on the drilling ship "Glomar Challenger" and they processed the cores obtained on those trips.

It must be noted that before performing the drilling operations in the ocean our scientists established by dredging and studying the material of the rift valleys of the ocean that there are basic basalts (a second layer) under the sedimentary rock in the ocean under which, in turn, there are gabbroids and partially ultrabasites (a third layer). Obviously below that are the ultrabasic rocks of the earth's mantle.

Soviet geologists have worked actively on the problems of a comparative study of the continental and ocean crust and, in particular, they have established similarity of the section of the ocean crust with sections of ophiolites on the continents.

The coworkers of the Oceanology Institute of the USSR Academy of Sciences have completed a large cycle of studies of iron-manganese concretions on the bottom of the Pacific and Indian Oceans and also metal-bearing sediments occupying enormous areas of the ocean floor in the southeastern part of the Pacific Ocean. The concretions and the metal-bearing sediments are of industrial interest in a number of places.

Soviet oceanologists have made many geographic discoveries which have found reflection on the maps. They discovered the maximum depth of the ocean (11,022 meters, the Mariana Trench), the underwater Shirshov Ridge, the Zenkabich Bank, the Academy of Sciences Rise, the East Indian Ridge, the underwater Shatskiy Seamount, the deep water Vityaz' Trough, and numerous underwater mountains.

Schematics of the geological structure and maps of the prospectiveness of oil, gas and metal deposits have been compiled, which made it possible to do prospective planning for marine geological exploration work.

An important problem facing geologists and geophysicists is the development of a general lithologic theory which includes the problems of sedimentogenesis and subsequent transformation of the sediments in the oceans. These studies are forcing reexamination of some of the ideas about the origin of the sedimentary material, the laws of its spatial arrangement, and paleogeography of ancient bodies of water developed when studying the continents.

As is known, large amounts of manganese, iron, copper, nickel, cobalt, phosphorus and certain other elements are concentrated in modern and young ocean sediments. The discovery of the essence of the processes of ore formation and their mechanisms (coprecipitation, sorption, diagenesis, metasomatosis, biological extraction, and so on) has great theoretical significance. A profound study of modern geochemistry by all of the most precise methods not only of ore formations and surrounding sediments, but also the suspensions of the bottom and silt water, the discovery of the relation of ore formation to vulcanism, geothermy and the landscape are required here. The investigation of oceanic ore genesis is not only an independent problem, but it has important significance for understanding the peculiarities of the formation and the placement of a number of minerals on the continents.

The systematic petrologic-geochemical study of magmatic and metamorphic rock is a problem of exceptional significance. It will permit establishment of the composition and the nature of the rock of the upper mantle and lower part of the ocean crust. The understanding of the planetary tectonic laws and cardinal problems of the history of magmatism on the earth's surface requires significant expansion of the petrologic studies in the oceans. For these purposes it is necessary first of all to perform detailed work at the geological test areas located within the limits of different large structures -- on underwater ridges, in the fracture zones of the ocean floor, on ocean islands, and so on, with subsequent detailed comparative petrochemical analysis of magmatic rock of the ocean floor, ocean islands and continents of similar composition.

With the further development of deep sea drilling (in cooperation with the United States and other countries) and dredging in the oceans, it will become possible to study the vertical sections of the magmatic formations, to obtain direct information about the composition and structure of the second and third geophysical layers of the oceanic earth's crust, the development of the general theory of the origin and development of the ocean floor, and the geological history of the ocean.

The expansion of geophysical studies of the ocean floor has great significance. Further observations of the seismic conditions of the ocean plates, troughs and also various sections of the middle ridges are needed. The

study of the details of the magnetic field, the relation of the magnetic anomalies to gravitational state, the relief and specially the geological data on the composition and structure of the ocean floor have special significance. Use of the methods of deep seismic sounding, bottom seismology and other possible methods to study the deep structure of the crust and mantle to the asthenospheric layer is of great theoretical interest.

The studies of the chemistry of the sea have been performed primarily on the regional level. The content and the limits of variation of the nutritive salt and organic materials in various parts of the World Ocean have been discovered. In addition, a study was made of the salt and gas exchange through the ocean-atmosphere interface, and the salt and oxygen balance of various oceans and their seas as a result of advection, continental runoff, exchange with the atmosphere and other processes was calculated.

In the field of biology of the ocean, the primary problem is the development of the problem of controlling the biological productivity of the ocean. At the present time 9/10 of the world catch of fish comes from 1/5 of the ocean, almost exclusively from shoals. In the last decade there have been broad-scale projects to study the ecosystems of the open sea, the processes of the production of the biomass in them, the regions of upwellings to determine the paths of maximum extraction of the biological resources of the ocean without doing harm to the biological communities and the use of them in the food rations of the population and means of conversion to the development of aquaculture. The methods of estimating the structural and functional characteristics of the ecosystems of the pelagic zone have been developed for this purpose, models of the functioning of the ecosystems have been created, and numerical experiments have been performed with respect to the development of them. The energy flux through the system and its dissipation on various trophic levels have been estimated quantitatively. The net and gross production of the entire community as a whole and its various trophic levels has been estimated.

Mathematical models have been constructed of the development of the ecosystems permitting prediction of variation of their productivity and achievement of an increase in it with directional change of individual parameters of the system. There have been experiments in simulation of the simplest bottom communities in order to proceed to the creation of models including the communities of the pelagic zone and the shelf floor required for most effective conduct of mariculture. All of these projects are continuing in the current five-year period.

Other studies will be aimed at the direct estimation of the productivity of various parts of the open sea and the shelf and the fishing reserves of fish. Thus, in 1977-1980 it is necessary to characterize the fundamentals of biological productivity of the Atlantic Ocean, a number of regions of the southern part of the Pacific Ocean and in the Indian Ocean.

Intensive oceanological studies must be conducted on the shelves of the Barents Sea, the Baltic and Black Seas, the seas of the Far East with more precise estimates of the biological productivity, first of all, the distribution of fishing organisms, their feeding base and primary production.

The institutes of the Ministry of the Fishing Industry are doing a great deal of work in this area. Its importance has increased especially in connection with the claiming of the 200-mile economic zones by many countries, as a result of which fishing in the open sea must be expanded significantly.

Oceanology combines many sciences of the ocean. The interrelation and mutual penetration of all of these sciences are characteristic. Biologists cannot solve biological problems of the ocean in isolation, physicists and mechanical engineers cannot develop the dynamics of ocean water, and geologists cannot study the structure of the ocean floor in isolation. All of the processes in the ocean are interconnected. For example, the structure of the sediments on the ocean floor arises directly from the dynamics of currents in the past, which the physicists must define. The biological productivity of various parts of the ocean is connected with the relief of the sea floor, currents, and the rising of deep water. The experiments performed several years ago by our biologists in the deep parts of the Caribbean Sea demonstrated that endemic species of fish correspond to the fauna of the Pacific Ocean. Consequently, some time in the past the Caribbean Sea was part of the Pacific Ocean and not the Atlantic as it is now. This fact obviously follows also from analysis of the movements of the lithospheric plates of this region.

The cooperation of representatives of almost all sciences in the ocean is needed to solve any large-scale problem which the ocean poses for us. The control of pollution of the ocean is a clear example. Chemists, biologists, physicists, specialists in the field of maritime law, and so on must work jointly on this problem.

The commonness of the research method also unites representatives of various sciences of the ocean: in practice all studies are being performed at the present time from a ship. The practice of specialized and complex expeditions has entirely justified itself. In a number of cases the participation of many ships directly in synchronous operations in the test areas is highly expedient. Our scientists have a large number of large research vessels for long-term expeditions at sea. As a result of the efforts of many scientists in recent years various summary publications have appeared -- the multivolume monograph on the Pacific Ocean, the Atlas of the World Ocean, from which the volume on the "Pacific Ocean" has already been printed; in the near future a volume will appear devoted to the Atlantic and Indian Oceans; the Oceanology Institute is completing the preparation of the multivolume monograph "Oceanology."

The new, highly prospective method of studying the ocean from artificial satellites and from manned or orbital stations must also be used complexly by representatives of various sciences. In particular, this method can provide information about the state of surface water, the upper layers of the ocean and also the atmosphere above the ocean immediately over enormous bodies of water. Specialists from the world data gathering centers, collecting all of the information about the state of the ocean water and the air masses in the atmosphere confirm that the volume of current information about the state of the oceans is still a thousand times less than about the atmosphere. Only satellite oceanography can eliminate this gap.

Satellite oceanography can determine by a number of attributes the zones of increased biological productivity in the ocean, it can find points of accumulation of fish, and so on. It can also provide exceptionally valuable data for understanding the geological structure of the ocean floor in the shelf zones.

The means of penetration of man to the depths of the ocean intensively developed at the present time (manned underwater stations, remotely controlled autonomous stations, robots) will be useful for all sciences of the ocean, especially when assimilating the resources of the World Ocean.

From what has been stated it is obvious that oceanology is a federation of sciences -- the physics of the ocean, biology, geology, chemistry, engineering -- which can be successfully developed only with close interaction among each other although it is clear that each part of this federation has its own specific methods and means of investigation, the development of which must also be supported in every possible way.

Collectives of many well-known research institutes of the USSR are working on the solution of the broad class of problems of understanding the oceans. Among them are the Institute of Oceanology imeni P. P. Shirshov of the USSR Academy of Sciences, the Geology Institute of the USSR Academy of Sciences, the Pacific Ocean Oceanological Institute and the Institute of Biology of the Sea of the DBNTs of the USSR Academy of Sciences, the Marine Hydrophysics Institute and the Institute of Biology of the Southern Seas of the Ukrainian SSR Academy of Sciences and also many other institutes of the USSR Academy of Sciences, the Ministry of the Fishing Industry, the Ministry of Geology, the State Committee of the USSR on Hydrometeorology and Monitoring of the Natural Environment.

Soviet oceanologists are combining their efforts to fulfill a goal of great importance -- to study the World Ocean as completely as possible in order to create a scientific basis for using its resources for the good of the Soviet people and all mankind.

LARGE-SCALE INTERACTIONS BETWEEN THE OCEAN, THE ATMOSPHERE AND THE CONTINENTS

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 13-25

[Article by V. V. Shuleykin]

[Text] Divisions of physics of the ocean devoted to the study of large-scale, mesoscale and small-scale interactions between the ocean and atmosphere are noted in the official program of the First Congress of Soviet Oceanologists. After the word "Atmosphere" there is a period. This is remarkable: as a rule, this is a problem of oceanologists. It is silently accepted that atmospheric phenomena above the continents must be an object of research only for specialists in atmospheric physics. On their side, the specialists in atmospheric physics bearing responsibility for improving the methods of forecasting the weather, elemental disasters and climate variation, are forced to be satisfied with any random materials characterizing the boundary conditions on the surface of the ocean when they integrate the differential equations created by them.

As a result, in spite of the enormous work done by the founders of the hydrodynamic theory of long-range weather forecasting (Ye. N. Blinova, G. I. Marchuk, their followers and coworkers), these forecasts are continuing to remain unsatisfactory.

A special section of the Resolutions of the 25th Congress of the CPSU points directly at this disastrous situation in the most important division of modern geophysics.

This is the incentive for the author to write an article on large-scale interaction between the ocean, atmosphere and the continents on which the life and activity of man take place and the vicinity of which is often aggravated by storms in the ocean.

I state categorically that it has long been time to provide an exact solution to the problems of the physical roots of the climate and weather which were stated or solved in the first approximation many years ago

and which up to the present time remain outside the traditional methods of forecasters. These are the problems of the operation of heat machines of the second type in the atmosphere above the ocean and continents for which the surface water of the oceans and seas serves as a heater during the cold part of the year and the continents as coolers. In the warm part of the year the heaters and coolers change place (with the exception of the regions of Antarctica and Greenland).

Beginning with the basic work of Ye. N. Blinova, who studied the dynamics of zonal atmospheric circulation and the "centers of activity" beginning with the given temperature distribution of the underlying surface, the main argument in the hydrodynamic equations of the forecasters is the circulation index which depends in turn on the thermal conditions on the underlying surface. However, these thermal conditions themselves are created not only (and often not so much) by the operation of the first type of heat machines (with heaters in the tropical and equatorial zones and coolers in the high latitudes), but also by the operation of the second type machines. Their roles are the subject of this article.

The seasonal interchange of heaters and coolers leads to interchange of the monsoon seasons known to man since time immemorial. A summer monsoon in countries with a sultry summer was well known. The winter monsoon was faintly expressed there. However, why has so little attention been attracted by the winter monsoon in countries where the winter is especially severe and where the summer monsoon is weakly expressed?

The proposed map (Fig 1) compiled by N. L. Byzova and T. V. Bonchkovskaya at the Marine Hydrophysics Institute gives a quantitative characteristic of the moonsoon activity in the countries of the ancient world.

Above the areas indicated in red, orange and yellow on the map excessive masses of air are concentrated by comparison with the warm part of the year. Above the areas in blue and light blue, there is a decreased quantity of air: it is transferred from the ocean to the continents. The numbers placed next to the isolines indicate what the excess or deficiency of the air is above the corresponding points of the continent and the ocean (in hundreds of ton/hectare). Taken altogether $5 \cdot 10^{12}$ tons of air are carried into the territory of Europe and Asia.

A type of "twin-peaked ridge" is clearly visible on the map in the south and southeast, that is, where there is a powerful summer monsoon caused by strong overheating of the continent. The powerful "ridge" above our country is just as clearly obvious. Undoubtedly, it originates from the winter monsoon, the power of which arises from the sharp cooling of the air above the continent.

However, the continents are arranged asymmetrically on our planet with respect to its axis of rotation. Therefore, the seasonal displacement of the air masses from the ocean to the continents and back causes continuous wandering of the axis of rotation of the earth: this axis describes cones with respect to the average position taken as the geographic axis of the planet. Correspondingly, the North and South Poles of the earth move along complex narrow trajectories around the geographic poles. Using the Euler equations for a freely rotating body, N. L. Byzova calculated this trajectory for the motion of the true North Pole for the first time for the time from January 1907 to January 1909. This curve is highly compatible with the actual trajectory of the North Pole determined by A. Ya. Orlov on the basis of observations of an entire network of astronomical observatories of the variations in latitude of the observatory locations.

The contrastsbetween the ocean and the continent are especially clearly seen on the diagrams constructed as applied to a section of the shoreline directed exactly along the meridian (the Bay of Biscay). Tracing the variations of the temperature gradient with respect to the normal to the shore during various months at various altitudes above sea level, we discover that the amplitudes of the seasonal variations of the gradients are the largest at sea level. The temperature wave is propagated somehow upward. It is noteworthy that at an altitude of about 4 km the gradients in January and in July are identical both with respect to modulus and with respect to sign. Then at an altitude of 10 to 13 km the temperature gradient the year around is directed from the continent to the ocean. This means that the layer at 4 km is the active layer in the second type machines, and third type machines operates above 10 to 13 km.

An analogous diagram constructed for atmospheric pressure gradients supplements our ideas of the seasonal variations of the contrast between the atmospheric conditions above the ocean and above the continent.

What do these contrasts lead to? The results of their effect on the climate of the continents find reflection on the maps of the temperature isanomals constructed, for example, for January and July. If the thermal conditions of the atmosphere over the Eurasian continent were created only by zonal fluxes directed from west to east, the minimum air temperature in January would be observed in the Far East and then it would decrease constantly on going along the meridians to the north. In reality, the minimum temperature is at the Asian "pole of cold" near Verkhoyansk. This means that the heat comes to the continent from the ocean not only from the west, but also from the east and even from the north, from the Arctic Sea. Analogously, in July the greatest heating is observed deep in Asia, far from the sea coast, playing the role of a cooler at this time.

In the ordinary problems of thermal physics, knowing the isotherm field and the coefficient of thermal conductivity of the medium it is possible

to calculate the thermal fluxes penetrating the medium and the quantity of heat released at one point or another of the field. Entirely analogously, knowing the temperature isanomal field and the heat transfer coefficient in this field it is possible to calculate the heat fluxes in the atmosphere from the ocean to the continent or in the opposite direction. It is possible also to calculate the quantity of heat released by the fluxes in a column of air per unit of underlying surface and extending upward to the boundary of the active layer. We made such calculations in their time as applied to the vicinities of Leningrad: the quantity of heat released per unit column of air near the city of Pavlovsk by fluxes from the Atlantic Ocean during one month or another was determined. The quantity of heat released by the fluxes along the meridian from the south was also calculated. The points obtained on the basis of direct observations of the Pavlovsk Aerological Observatory (the residual term of the radiation heat balance of the atmosphere having a negative sign) fit excellently near the summary curve calculated by our theory.

Knowing the quantity of heat released by the fluxes from the ocean to the continent and assuming that the influx of heat from the ocean to such sections of the continent as the vicinity of Verkhoyansk in the central part of the Sahara is entirely absent, it is possible to calculate what the air temperature distribution would be along the meridians (from the equator to the pole) if our planet had no oceans and seas at all.

It is of interest that when the results of our calculations were first published in 1949 they were met with skepticism on the part of the meteorologists. It was claimed that cold of near -80° was unthinkable in the winter in Antarctica. This was motivated by the fact that at the North Pole it is appreciably warmer in the winter. It was forgotten that air at the North Pole is heated more by the heat fluxes coming from the ocean across the ice cover than by the fluxes which run along the meridian from the south. In Antarctica this is not the case. As is known, after the beginning of operations of the stations in Antarctica in 1957 it was established that the air temperature there can drop even below -80°.

On the basis of what has been stated, the idea arises of absolute air temperature anomalies: if the heat from the ocean does not reach the pole of cold in Antarctica at all and a negatively small amount reaches the Asian pole of cold and also the center of the Sahara, then it is possible to stipulate that the air temperature at these points be considered normal for the planet entirely free of the water shell. Then for all points of the earth's surface it is possible to determine by the climatological isanomal maps by how many degrees the air temperature at these points is above the "purely dry land temperature." This characteristic will be called the absolute temperature anomaly.

If we compare the maps of the temperature isanomals constructed for Europe as applied to January and the maps of the climatological isobars

constructed for it also for the same month, then a striking similarity is detected between these maps. They are almost alike. Why almost? Because the climatological isobars, following even the fine details in behavior of the isanomals, are less inclined to the parallels than the isanomals everywhere. Of course, this is no accident. We discover the cause if we consider any isobar intersecting an isanomal and constructed normals to both curves at the intersection point. The gradient of the temperature anomaly is directed along one of them, and the atmospheric pressure gradient along the other (in the opposite direction). The direction of the latter would be exactly opposite if it were created only by the temperature contrast between the ocean and the continent. In reality, the total atmospheric pressure gradient is the geometric sum of two vectors: one of them is directed exactly opposite to the temperature anomaly gradient, and the other, along the meridian to the north. In the regions of our country which are especially subject to the thermal effect of the Atlantic Ocean in the winter, the modulus of the first of the mentioned vectors exceeds the modulus of the second vector (directed along the meridian). Hence, it follows that the pressure gradient controlling the monsoon circulation in the active layer of the atmosphere plays a more significant role than the vector controlling the zonal circulation.

From the equation of state written as applied to the active layer of the atmosphere in the winter monsoon field an approximate expression follows which relates the pressure gradient to the temperature anomaly gradient: $\text{grad } p = -\pi \text{ grad } \tau$. Here Π is a constant which can be calculated, assuming that the thickness of the active layer is equal to 4 km. Actually, $\Pi=1.6$ mb/deg. This expression is valid in the majority of continental regions. It is also applicable to the gradients characterizing the temperature and pressure variations in time.

The joint analysis of the air temperature anomalies above the Atlantic Ocean and above Europe gives very important results. A small section on the surface of the ocean surrounded by the absolute temperature anomaly of 50° attracts attention. Thus, the air is sharply superheated here by comparison with the temperature which would exist at the same latitude (near 66°N) if there were no ocean. In order to discover the physical roots of this phenomenon we tried to calculate the temperature distribution theoretically along the Arctic Circle, being given a simplified model.

A thin imaginary circle was drawn in the active layer of the atmosphere on which two alternate quadrants rested on the ocean surface, and the other two, on the surface of the dry land. In Fig 2 the thin curve represents the result of analyzing the temperature conditions of the atmosphere above two adjacent sections of the underlying surface: above the ocean and above the dry land. In nature they encompass not 180°, but 240° with respect to longitude along the Arctic Circle. The longitudes are plotted on the x-axis. From point "12" to point "13" two segments of cubic parabolas describe the temperature conditions of the atmosphere above the ocean. From point "13" a segment of a straight line

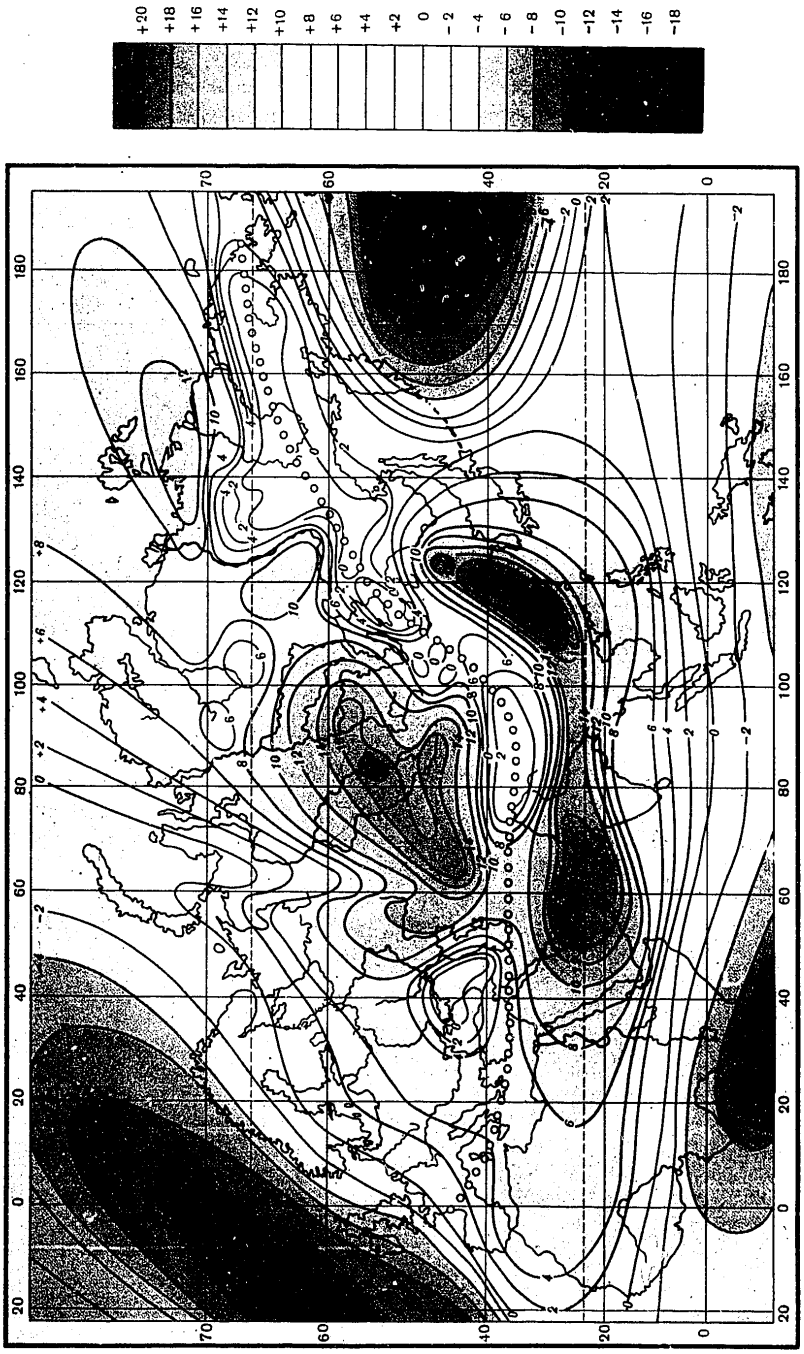


Figure 1. Seasonal transfer of air masses between the ocean and the continent

also obtained theoretically drops to the x-axis. After that another segment of a straight line rises to the point "14." They characterize the theoretically defined temperature conditions of the atmosphere above the dry land. The values of the absolute temperature anomaly are plotted on the y-axis. As has already been mentioned, it is considered that at the continental "pole of cold" the absolute temperature anomaly is equal to zero. On the same figure the heavy curve is the actual air temperature distribution in January along the Arctic Circle. It is constructed by the data from the Great Soviet Atlas of the World. The temperature near the Asian "pole of cold" was taken as zero.

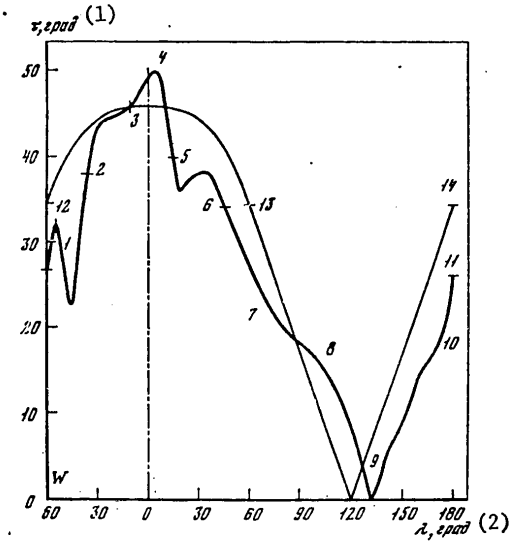


Figure 2. Section of the temperature isanomal field along the Arctic Circle

Key:
1. τ, degrees
2. λ, degrees

The stage at which the Arctic Circle passes across Greenland lies between point "1" and "2." This causes the sharp peak downward; therefore the air temperature there is below that which would occur over the ocean. Over the ocean temperature becomes equal to that theoretically calculated at point "3" and at another same point lying to the east of the sharply expressed type "4." The peak "4" is extraordinarily interesting: it corresponds to a segment of the surface of the Atlantic Ocean surrounded by the 50° isanomal which was mentioned above. Then the heavy curve drops quickly as at point "5." The Arctic Circle enters the Scandinavian

Peninsula. The small amount of warming between points "5" and "6" is caused by the effect of the Baltic and White Seas, and after point "6" the Arctic Circle goes to point "11" over the broad territory of Asia. Here the deviations of the heavy curve from the fine curve theoretically calculated are explained by the relief of the terrain (the presence of the Ural Mountains, and so on). Point "11" lies below the theoretical point "1" because the thermal conditions of the Pacific Ocean are different from the conditions of the Atlantic Ocean: the winter temperatures of the surface water are significantly lower there.

It remains to explain the cause of the interesting deviation of the actual air temperature distribution from the theoretically calculated at point "4" to find what causes the actual center of heat that so sharply superheats the air in the region near the Scandinavian Peninsula.

This problem can be solved by the map presented in Fig 3. A family of isolines can be seen here indicating how much heat the ocean gives up to the atmosphere as a result of turbulent heat exchange between the water and the air at the given point. This amount of heat depends on how many degrees warmer the surface water is than the air and also the wind velocity. The expeditionary materials permit calculation of the desired values with sufficient reliability. The data by means of which it is possible to calculate the quantity of heat picked up from the ocean as a result of evaporation of the water and subsequently released in the atmosphere on condensation of vapor in the clouds which then is transported to the continent are less reliable. However, it is possible to assume on the average without large error that in the investigated region the heat transferred to the atmosphere with this condensation is 1.5 times more than the values which are characterized by the numbers placed on the isolines in Fig 3. This means that the total amount of heat can be obtained by multiplying the numbers on the isolines by 2.5. In Fig 3 it is obvious that the maximum heat removal (160x2.5=400 cal/cm^2-day) takes place from the section surrounded by the inside curve of the family of isolines. This section lies near to the one which is surrounded by the absolute temperature isanomal of 50°. The latter is shifted somewhat seaward for the completely understandable reason of the effect of the cold air which flows in the winter from the Scandinavian Peninsula toward the ocean.

Thus, the "center of heat" which manifests itself when analyzing the air temperature isanomal map over the Atlantic Ocean is created by the loss of a large amount of heat by the ocean to the atmosphere in this section of the ocean surface. However, where did the ocean get this heat? Fig 3 also answers this question.

The midstream of the North Atlantic Current which becomes the warm Norwegian Current is plotted by the broken arrows in Fig 3.

As we see, the midstream runs precisely in the section outlined by the "160" isoline in Fig 3, that is, it runs through the center of the "center of heat" on the ocean surface.

Our calculations show that the most active region of the ocean surface bounded by the "40" isoline on Fig 3 loses heat to the atmosphere which in energy units is expressed as a heat flux power of 78 billion kilowatts. It is understandable that not all of this power goes to the atmosphere above Europe and, in particular, above our country. About 55 billion kilowatts goes to the Scandinavian Peninsula. Some part of this power is expended on radiation into interplanetary space, and about 50 billion kilowatts in all probability reaches our borders. The calculations show that this is approximately 1/4 of all the power received by our country in the heat fluxes from the Atlantic Ocean.

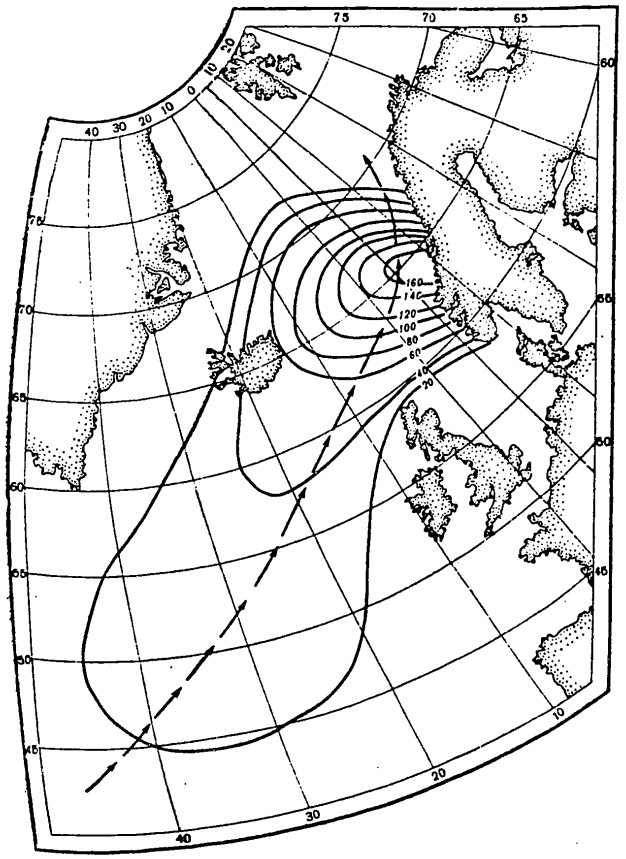


Figure 3. Heat picked up by the air as a result of turbulent exchange with the surface water of the ocean, in cal/cm^2-day

It is quite obvious what a decisive role is played by the variability of all of these fluxes with respect to the long-range forecasting of the thermal conditions of the winter and the long-range forecasting of summer drought. It is just as obvious that full-fledged long-range forecasts will become possible only when the artificial separation of the two divisions of the single physical-mathematical science -- geophysics -- the separation of the physics of the atmosphere and the physics of the ocean, is eliminated.

The necessity for creating a united front of geophysical research is still more persistently dictated by the fact that such problems as the problem of the occurrence of the most severe cold during the thermobaric seiches in the atmosphere over the continent and the ocean will remain incompletely resolved for many years. A correct solution has not even been obtained for the corresponding equations of thermal hydrodynamics describing the nonlinear autooscillatory phenomena in the Coriolis force field. In 1940 these autooscillatory phenomena created extremely serious conditions in our country: the air temperature dropped in places by more than 30° by comparison to the average climatological norm. The approximate theory of thermobaric seiches was constructed in our country even earlier. It was demonstrated that they led to highly regular air temperature fluctuations above the Atlantic Ocean and over Europe which were first described by the Swedish geophysicist Sandström, and he mapped them in 36 "frames" as applied to the various wind directions in Lofoten. Sandström proposed that such variability of the temperature field of the ocean and above the continent (in opposite phases) is caused by certain hypothetical fluctuations in the conditions of the Gulf Stream and that the wind direction serves as a type of indicator of such phenomena. In reality, it turned out that there are no fluctuations of the conditions of the currents with the corresponding period (about 8 days), and we are dealing with a genuine autooscillatory process in the atmosphere over the Atlantic Ocean and Europe. The atmospheric pressure fluctuates together with the temperature. The amplitude of the pressure oscillations is related to the amplitude of the temperature oscillations by the same expression which was mentioned above. Even the numerical value of the constant Π turned out to be approximately the same. Hence, it follows that there should be no apprehension about closing the system of equations of thermal hydrodynamics by the mentioned approximate relation between the gradients. It is hardly possible to avoid it when trying to close the system.

The changes in wind direction at Lofoten taken by Sandström as variation of some argument naturally occurred in complete agreement with the phase variation during the temperature fluctuations, for they were created by regular variations in the baric field over the ocean and over the continent. The integration of our approximate equations in Bessel functions led to the family of isalotherms closely resembling the family of curves in the Sandström "frames."

We were not able analytically to consider the effect of the Coriolis forces, but it was established that this effect causes reciprocal variations of the temperature field and, consequently, the baric field: on the one hand, antinodes and nodal lines occur during temperature and pressure fluctuations; on the other hand, the entire set of the antinodes and nodal lines rotates counterclockwise around some point located at the Atlantic-Europe boundary.

Subsequently it was established that simultaneously with the general fluctuations in the broad Atlantic-Europe system partial seiches occur in the territory of Europe itself and, in particular, in the territory of our country. They resemble the Chladni figures observed during vibrations of thin elastic plates. The oscillation period is equal everywhere to the period of the general fluctuations in the entire broad system. The nodal lines and antinodes rotate everywhere around certain points of the territory and always counterclockwise.

A very long "train" of thermobaric seiches also leading to extraordinarily severe cold was observed from 15 November 1965 to 15 February 1966. S. K. Olevinskaya analyzed 11 successive waves occurring during this 3-month period. The average value of the oscillation period was also about 8 days. The ratio of the amplitude of the pressure fluctuations to the amplitude of the temperature fluctuations was 1.5 mb/deg, that is, it was very close to $\Pi=1.6$. The antinodes and the nodal lines at that time rotated counterclockwise around a point lying in the region between Perm' and Syktyvkar.

General thermobaric seiches were also observed simultaneously in the Atlantic-Europe system. The temperature fluctuations (in opposite phases) in Kursk and in Reykjavik (Iceland) had the greatest amplitudes. The pressure oscillations, as always, occurred in phases opposite to the temperature fluctuations. The amplitude ratio turned out to be the same, close to the theoretical value of Π. The long-awaited completion of the theoretical work on the thermobaric seiches undoubtedly will be helped by analyzing the results also obtained very long ago by N. L. Byzova in Katsivel'. She discovered autooscillatory phenomena in the thermal convection fluxes which were created in a laboratory water trough. The experiments were set up to simulate another, also important and interesting phenomenon: the May cold periods occurring when the winter monsoon season is replaced by the summer monsoon season and the so-called "baby summer" -- a short term warming occurring on replacement of the summer monsoon season by the winter monsoon season.

After the first quantitative investigation of these phenomena by the Czechoslovakian geophysicist N. Konchek, a comprehensive analysis of thermobaric seiches at the change of seasons was performed by Z. I. Gavrilova as applied not only to our country, but also to Western Europe. In essence, on changing of the monsoon seasons the fluctuations occur for the same reasons as for changes in the conditions in other systems connected with the movement of inert masses. All forms of thermobaric seiches

arise because the heat is transferred from the ocean to the continent not by molecular thermal conductivity and even not so much by turbulent heat transfer, but by advection of inert air masses.

The large-scale interactions between the ocean, the atmosphere and the continent are exhibited in the purest form in Australia. On the one hand, this continent lies at the interface between the region of West-East transfer of air masses and the Trade Winds region, and therefore, in practice the air circulation over Australia is connected only with contrasts between the ocean and the continent. On the other hand, the shape of the coastline of Australia and the structure of its surface are very simple. Therefore, the general picture of the thermobaric field above Australia and around it is also simple: both the temperature isanomals and the climatological isobars follow the coastline of the continent to a sufficient degree. The relation between the pressure and temperature anomaly gradients is satisfied well: Π=1.5 mb/deg. The actual temperature conditions of Australia agree well with the theoretically calculated conditions. Divergence is observed only deep in the territory of the continent where the winter temperature turns out to be much higher than calculated.

The basic complications of the monsoon field occur where the coast line differs from a smooth running line: where some large island has a sharply elongated shape or where sharp-pointed peninsulas or capes protrude into the sea.

It is theoretically possible to calculate the increase in the temperature and pressure gradients opposite the ends of an island having the shape of an ellipse with large eccentricities. The gradients opposite the ends of the major axis in this case are as many times larger than the gradients opposite the ends of the minor axis as the major axis is longer than the minor axis. The increase in gradient opposite a cape of parabolic shape was quite precisely determined by Ya. I. Sekerzh-Zen'kovich, who also confirmed the validity of our calculations for an elliptical island.

If the curvature of the coast line at the end of a peninsula or cape is especially large, then the complex equation of the thermobaric monsoon field can be replaced by a Laplace equation with sufficient approximation. This opens up the way to a simple electrical simulation of the monsoon field, for example, to discover the causes of the extraordinary intensification of the monsoon storms opposite Cape Horn. We performed this simulation and obtained interesting results.

The origin of the severe storms opposite the Cape of Good Hope which was called Cape Storm in ancient times, opposite Cape Lopatka in Kamchatka, Cape Farvel (Greenland), Cape Zhelamiya (Novaya Zemlya), Cape Kanin Nos and other similar formations is the same.

Theory indicates that in the territory of the most sharply pointed capes and peninsulas the temperature and pressure gradients must decrease near the tip itself and on the midline of the peninsula. Herein lies the basic cause of the type of "trough" seen on the air mass transfer net (see Fig 1) between two "peaks": rarefaction of the isobars over the Industani Peninsula, the peninsulas of Malacca and Indo China decrease the amount of air on replacement of the summer monsoon season by the winter monsoon season.

The physical essence of the well-known afternoon summer storms (with a completely clear sky) on the shores of the Crimean and Black Seas where the wind velocity often exceeds 25 m/sec and the Yalta harbor master denies the steamships entry to the port is of great interest. Ye. I. and N. S. Potapovy demonstrated that this phenomenon is connected with sharp superheating of the air above the dry land by comparison with the air over the sea, and the greatest superheating occurs at 1400 hours and is accompanied by a maximum increase in wind velocity. We observed such a phenomenon while moored in Gibraltar. The events develop according to a standard schedule. In the early morning there is a complete calm. About 8 or 9 o'clock a slight wind comes up which gradually intensifies and reaches maximum velocity at 1400 hours. This wind velocity gradually diminishes, and a complete calm comes at night. This phenomenon occurs still more sharply on the west coast of Africa. On the one hand this is explained by the fact that, for example, according to the navigational data, in the vicinity of Port-Etienne the air temperature in the daytime can be 10° higher than the night temperature, but primarily by another reason. The sharp fluctuations in the temperature conditions generate inertial oscillations in the significant layer of air with a period which, as is known, depends on the latitude. At a latitude of 30° the period becomes equal to exactly one day, that is, it coincides with the oscillation period in the thermobaric field. It is possible to demonstrate that a genuine hydrodynamic resonance occurs in the summer months in fluxes leading to a significant increase in the oscillation amplitudes of the wind velocities, to the occurrence of a storm wind at the time of greatest superheating of the air above the dry land. The intensification curves we constructed for the wind velocity component normal to the shore and the tangential wind velocity component demonstrated that even at the latitudes of the south coast of the Crimean Sea, outside the region of total resonance, the intensification of the wind must be significant. In addition, noncoincidence of the period of the inertial oscillations with the period of the diurnal oscillations of the temperature conditions must cause beats with the period of which amounts to 3 days here. It is noteworthy that according to the observations of local seamen and fishermen, storms of this type stop either after 3 days, or after 6 days, or 9 days, that is, at the nodes created by the beats.

The storms of described origin play a decisive role in the formation of the Canary Current -- the typical, powerful surging current bringing up

deep cold water to the surface of the ocean. In the southern hemisphere the resonance in the summer monsoon fluxes must intensify still more the storms off the Cape of Good Hope and Cape Horn arising, as was pointed above, as a result of peculiarities in the shape of the shoreline. These capes are at a latitude which is only 5° from the "resonance" latitude. Without a doubt the described effect influences the formation of the Bengel Current and the Cape Horn Current.

INTERACTION OF THE ATMOSPHERE AND OCEAN

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 26-34

[Article by A. S. Monin]

[Text] The interaction of the atmosphere and ocean (IAO) is a grand, majestic natural phenomenon playing a most important role both in the existence of the ocean and in the formation of many of the processes that develop in it and in the process of supplying the atmosphere with heat and moisture (heat primarily in the form of the latent heat of vaporization together with the evaporative moisture), leading, in particular, to the formation of atmospheric phenomena with the greatest concentrations of energy -- hurricanes and typhoons -- and the formation of long-range weather and climatic anomalies.

It is expedient to distinguish the small-scale (local) and large-scale (global) IAO processes. The local IAO consists first of all in the exchange of momentum, heat and moisture through the free surface of the ocean (an important, but somewhat lesser role is also played by gas exchange, primarily carbon dioxide and oxygen, and also the transfer of sea salt from the ocean to the atmosphere and the deposition of aerosols from the atmosphere in the ocean). A quantitative description of these processes is obtained from the coefficients of resistance C_τ, heat exchange C_q and evaporation C_E first introduced by V. V. Shuleykin in 1928 and defined by the following formulas

$$C_\tau = \frac{\tau}{\rho u^2}; \qquad C_q = \frac{q}{C_p \rho u \delta T}; \qquad C_E = \frac{E}{\rho u \delta Q}; \qquad (1)$$

where τ, q, E are the vertical fluxes of momentum, heat and moisture at the ocean surface (τ is also called the frictional stress, and E is called the evaporation rate if the moisture is transferred from the ocean to the atmosphere); C_p and ρ are the specific heat capacity at constant pressure and air density respectively; u is the wind velocity (at the ship mast level, about 10 meters); δT is the difference between

the surface temperature of the water and the air temperature (at the ship mast level); δQ is the difference between the specific saturation moisture of the air at the surface temperature of the ocean and the actual specific humidity of the air (at the ship mast level). The standard values of the coefficients of local IAO (1) are taken equal to $2 \cdot 10^{-3}$, but these coefficients obviously increase with an increase in wind velocity. According to certain data, the resistance coefficient C_τ increases linearly, that is, according to the law $C_\tau = C_{\tau 0}(1+bu)$ where $b \approx (10 \text{ m/sec})^{-1}$. C_q and C_E increase still more rapidly with an increase in u.

If, in addition, we consider that strong winds are encountered noticeably more frequently than would occur in the case of gaussian probability distribution for the wind velocity vector, then it becomes clear that the primary contribution to the exchange of momentum, heat and moisture between the atmosphere and ocean is made by storm regions. This is confirmed by the available few data for measuring the fluxes q and E (for example, the data of M. Garstang 1965). Here the situation turns out to be analogous to the situation with variations in bottom relief in the coastal zone of the sea, negligibly small in calm weather and significant only during several of the biggest storms of the year. From this point of view the interesting result obtained by G. I. Marchuk in 1977 becomes understandable. As a result of numerical integration of the so-called conjugate equations of hydrodynamics, he established that the regions of long-term influence on the weather in the territory of the USSR are the regions of the tropical hurricanes in the Caribbean Sea and the typhoons of the western tropical zones of the Pacific Ocean.

The vertical fluxes of momentum, heat and moisture formed during the local IAO processes together with the quasiconstant "buoyancy parameter" (that is, the product of the gravitational acceleration times the coefficient of expansion of the air characterizing the magnitude of the Archimedes forces) determine the structure of the layer of air just above the surface of the ocean. The similarity theory based on this proposition for the layer of the atmosphere next to the ground was developed by A. M. Obukhov and the author of this article in 1953, and then it became the basis for interpretation of meteorological data on the ground layer of air under various conditions of its temperature stratification. From the point of view of the similarity theory the layer of air next to the water differs from the ground layer only very little (namely, by the possibility of the formation of drift currents and therefore another boundary condition for the wind velocity instead of the condition of adhesion to solid walls and also some inverse effect of the waves on the water surface on the movement of the air over them). The similarity theory permits calculations of the basic characteristics of the local IAO by the data from standard meteorological measurements of the wind velocity and the vertical temperature and moisture differences in the layer of the air next to the water; special nomograms were constructed for these calculations.

The similarity theory for the layer of air next to the water can be expanded so that it will encompass the entire atmospheric boundary layer (ABL). For this purpose, it is necessary to add the thickness of the ABL to the set of defining parameters of similarity theory or in the case of stationary and horizontally uniform (SHU) ABL (this SHU-ABL is called the Eckman boundary layer, EBL), the Coriolis parameter f determining its thickness $h \sim (\tau/\rho)^{1/2} f^{-1}$. This similarity theory was first proposed for the EBL by the author of this article in 1950, and then he developed it in a number of papers jointly with A. B. Kazamskiy and S. S. Zilitinkevich.

The effects of the local IAO determined both the structure of the ABL and the analogous structure of the upper mixed layer of the ocean (UML). In this last case the defining parameters of similarity theory are the vertical fluxes of the momentum, heat and salt and also the buoyancy parameter and the Coriolis parameter (in the dynamic theory, one of the most important additional values turns out to be the vertical turbulent energy flux). The similarity of the temperature and salinity profiles in the UML was established by S. A. Kitaygorodskiy in 1960. The semi-empirical dynamic theories of UML are devoted both to its structure and to the synoptic and seasonal variations of its thickness and also the magnitude of the density discontinuity in the discontinuity layer forming the lower boundary of the UML.

One of the most important problems of the theory of the UML is the description of the wind-driven waves -- their generation, the distribution of the fluxes of momentum and kinetic energy coming from the atmosphere between the wind-driven and internal waves and the drift currents, the breaking of the surface waves and the generation of dynamic turbulence by them creating (together with the normal turbulence, that is, convection) mixing of the UML and at the same time determining the thickness of the UML and its synoptic and seasonal variations. All of these problems have been far from completely resolved. In particular, precision experiments have demonstrated that the elegant theories of wind-driven wave generation of O. Phillips and J. Miles are still inadequate, for they lower (by an order) the growth rates of the wind-driven waves; the proposals of M. M. Zaslavskiy and S. A. Kitaygorodskiy to define the theory more precisely considering the random nature of the turbulent wind velocity profiles in the layer of air next to the water are still not constructive. Among the new approaches, the numerical experiments of D. V. Chalikov in the generation of wind-driven waves deserve mentioning.

Summing with respect to areas and time, the effects of the local IAO lead to the formation of a number of global processes in the ocean and atmosphere. One of the most practically important (above all for agriculture) processes of global IAO are long-range weather anomalies. Here, above all, it is necessary to mention the anomalies studied in the series of papers by V. V. Shuleykin created by the processes of the type of thermobaric seiches in the atmosphere. Let us also note the arguments of the authors (1963) that the most important initial field for long-range weather forecasting

is the water surface temperature field in the world oceans; here even highly significant heat content anomlies of the upper layers of the ocean can correspond to the small anomalies of the water surface temperature field as was indicated by V. G. Kort according to the data of many years of observations in one of the sections through Kuroshio.

The El Niño phenomenon studied by J. Bjerknes (1966) can serve as a clear example of the large-scale IAO process. It consists in attenuation of the easterly winds of the eastern part of the equatorial zone of the Pacific Ocean (on the southeastern periphery of the Hawaiian anticyclone); a consequence of this turns out to be attenuation of the equatorial rise of cold water (upwelling), the heating of the upper layer of the ocean and then the atmosphere above it, intensification of the Trade Winds circulation, and after it the west-east transfer in the temperate latitudes and deepening of the Aleutian cyclone. This phenomenon is among the elemental disasters, for weakening of the upwelling leads to mass destruction of fish and a sharp reduction in the anchovy fishing. In the Atlantic at the same time the west-east transfer is attenuated in the temperate latitudes, the Iceland minimum is filled out, the easterly winds to the north of Iceland are attenuated, and the Arctic turns out to be under the effect of the anticyclone in the northern part of Alaska. Thus, this process encompasses the entire northern hemisphere.

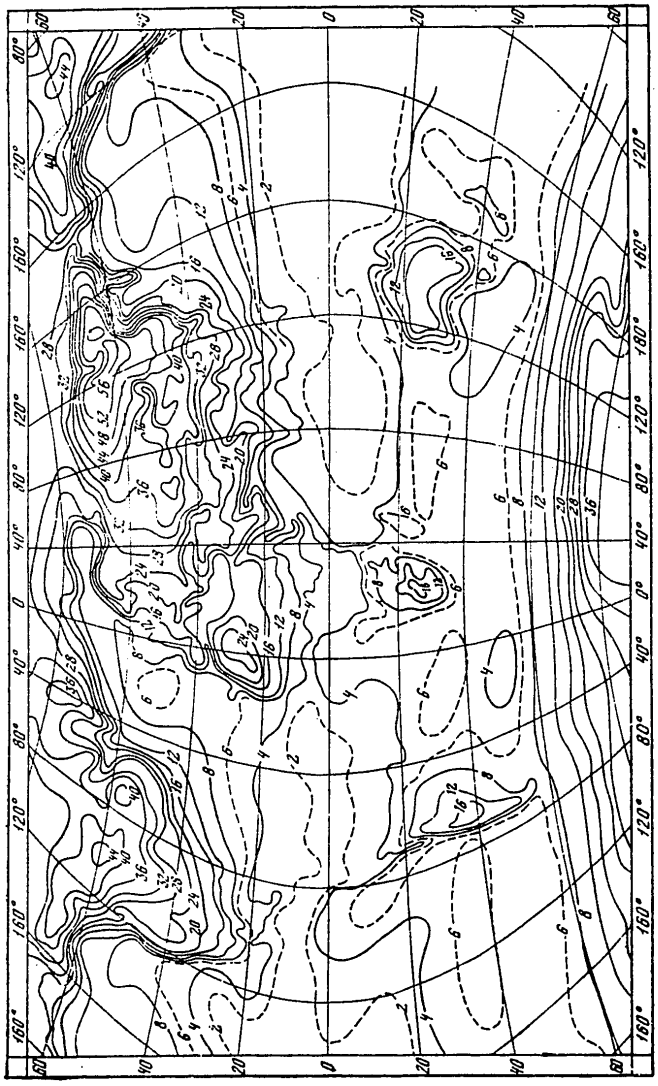
The global IAO is one of the most important factors of climate formation (defined as the statistical set of states which the atmosphere-ocean-dryland system goes through during time periods of several decades; until not so long ago the climate determination included the state of only the ground layer of the air; at the present time it has become clear that it is necessary to take the entire atmosphere and the ocean in their interaction and also the active layer of the underlying surface on the dryland). Let us note that the maps of climate types are not strictly zonal. On them,of course, differences are manifested between the continents and the oceans (the criterion of importance of these differences can be the rotational mach number $Ma=\omega R/C$, where ω is the angular velocity of rotation of the planet, R is its radius and C is the speed of sound in its atmosphere; for large Ma, the effect of latitudinal zonality predominates; for small Ma, the difference between the day and night sides of the planet predominates; on the earth $Ma\sim1.4$, and the nonzonal effects of the differences between the continents and the oceans are comparable to the effects of latitudinal zonality).

From the point of view of the effect on the atmosphere, the oceans differ from the continents primarily by their thermal properties -- much greater thermal conductivity (in the oceans this is turbulent thermal conductivity) and heat capacity, and therefore also thermal inertia, which smooths out the short-period and temperature fluctuations (including diurnal and seasonal). For this reason, by comparison with the oceans, the continents are cooled much more in the winter and are heated more in the summer and, consequently, in the winter they turn out to be colder than the oceans,

and in the summer, warmer than the oceans. Thus, in addition to the average annual temperature contrasts between the equator and the poles and the atmospheric and ocean circulation in the lower atmosphere created by them (trying to smooth them), seasonal (changing sign from winter to summer) temperature contrasts between the continents and oceans and the seasonal circulations created by them (trying to smooth them) which are called monsoons also arise. In the seasonal fluctuations the most sharply manifested is the difference between the continents where the amplitudes and seasonal temperature fluctuations of the ground layer and the air are very large, and the oceans where these amplitudes are small so that on the map of these amplitudes (see the figure) the distribution of the dryland and the sea is obvious even without indicating the shorelines.

In addition to the differences in the thermal conductivity and the heat capacity, on the average there is some difference between the oceans and the continents also with respect to their capacity to reflect the short wave solar radiation. Satellite maps of the albedo indicate that along with the general increase in albedo from the equator to the poles, an increase in albedo from the oceans to the continents is also noticeable on the same latitude so that for this reason the continents must be somewhat colder than the oceans on the average for the year. Let us note that some interyear variability of the planetary albedo map is observed; this is one of the sources of the long range weather fluctuations and, possibly, climate variations.

The seasonal temperature differences between the oceans and the continents are demonstrated by the maps of the average monthly temperatures at sea level; the regions of greatest cold in Antarctica, Yakutia, Northern Canada and Greenland attract attention on the winter maps, and on the summer maps, the regions of greatest heat in the subtropical deserts of Africa, Southern Asia and Mexico. The monsoon effects are clearly seen on the average monthly atmospheric pressure maps at sea level; quasipermanent subtropical high pressure regions are visible on the oceans of these maps, intensifying from winter to summer (in the northern hemisphere, the Azores and Honolulu, and the southern hemisphere, St. Helena, Mauritius and the South Pacific Ocean high pressure regions), and low pressure regions located closer to the poles and intensifying from summer to winter (in the northern hemisphere, Icelandic and Aleutian; in the summer hemisphere, Circumantarctic); winter high pressure regions are visible on the continents (in Siberia, Canada, South Africa and Australia) replaced in the summer by regions of reduced pressure. On the global map of the annual precipitation totals, the humid zone of the intertropical convergence zone and the arid zones of the subtropical deserts are well expressed, and it is possible to trace the trends toward an increase in precipitation from the subtropics to the temperature latitudes, from the continents to the oceans and also in the coastal areas of the monsoon regions and on the windward (primarily western) slopes of mountains.



Amplitude map of seasonal temperature variations

In the description of the climate of the ocean significant progress was made by V. N. Stepanov (1974). Let us present some of the zonal characteristics of ocean climate obtained by him. The thermal budget of the ocean is positive (the ocean is heated) in the tropical zone between 30° north latitude and 15° south latitude and it is negative (the ocean is cooled) outside this zone; the greatest positive budget -- to 80-100 kcal/cm^2-year -- is observed in the equatorial zone of the Pacific Ocean; the greatest negative budget -- to 75-100 kcal/cm^2-year -- in the Gulf Stream and Kuroshio zones. The average zonal surface temperatures of the ocean for the year in the tropical zone exceed 25°, reaching a maximum of 27.4° somewhat north of the equator, and at temperature latitudes they quickly decrease in the direction of the poles, passing through zero in the 60-65° south latitude zone and the 70-75° north latitude zone. The average temperature of the entire body of water of the World Ocean (without the Arctic basin) is 5.7°C.

The water budget of the ocean is positive (there is more precipitation than evaporation) in the equatorial zone between 10° north latitude and 5° south latitude and in the temperature latitudes; it is negative (evaporation exceeds precipitation) in the tropics and subtropics; the greatest positive budget — to 150-200 g/cm^2-year -- is observed in the western part of the equatorial zone of the Pacific Ocean; the greatest negative budget — to 150 g/cm^2-year -- is observed in the subtropics, especially in the Atlantic. The salinity of the surface water of the ocean is maximal in subtropics (35.75 parts per thousand in the 30-25° north latitude and 20-25° south latitude zones). It has a partial minimum in the equatorial zone (34.43 parts per thousand in the 10-5° north latitude zone) and decreases toward the poles in temperature latitudes, passing through 35 parts per thousand at latitudes of about $\pm$40° and dropping to 33.5 parts per thousand and lower in the Antarctic and to 31-30 parts per thousand in the Arctic. The average salinity of the entire body of water of the World Ocean is 34.71 parts per thousand.

The density of sea water which is conveniently measured in units of σ_t=1000 (ρ-1) on the ocean surface is minimal in the equatorial zone (22.18 in the 10-5° north latitude zone), and it increases toward the poles: to 27.30 in Antarctica, to 26.16 at 55-60° north latitude and then at higher latitudes of the Arctic it decreases to 24.55. The quasistationary currents on the surface of the ocean obviously have wind origin; their average velocities are 12-20 cm/sec. The tides created by them and also the thermochalinic expansion and compression of the water create deflections of the ocean surface from the equilibrium geoid level on the order of decimeters; the greatest deflections upward are noted on the western peripheries of the oceans, especially in the subtropics, and the downward, in the polar regions. A contribution to the movement of the ocean water comparable to the quasistationary currents is made by the synoptic eddies with horizontal scales on the order of 10^2 km and time scales on the order of months.

The global IAO makes a contribution both to climate formation and to generation of a number of processes of climate variations. This is most clearly obvious in the example of climate fluctuations with periods of tens and hundreds of years observed in historical time. Thus, the climatic warming of the first half of the 20th century according to the data of J. Mitchell in 1963 occurred in the oceans and on the continents; conversely, at that time there was a minor cooling. The "small ice age" of the 17th to 19th centuries, according to the propositions of J. Bjerknes (1965) can be explained by the positive feedback between the development of negative temperature anomalies of the Atlantic water in the vicinity of Iceland and the positive anomalies in the Sargasso Sea on the one hand, and weakening of the winter atmospheric circulation in the temperate latitudes of the Atlantic as a result of weakening of the IAO, on the other hand (the development of this process at some level is curtailed as a result of the appearance of negative feedback with meridional heat transfer by these ocean currents).

The alternations of glacial periods with grand continental glacial shields and interglacial periods when these shields in practice completely melted noted in the Pleistocene and having periods on the order of 20,000 to 100,000 years during this age (analogous interchange obviously occurred also in the Permian-Carboniferous and still earlier ice ages of the Wendian, the Upper Riphean and Lower Proterozoic) according to M. Milankovich can be explained as resonance intensified forced oscillations created by astronomical oscillations of the elements of the earth's orbit and inclination of the equator to ecliptic. Direct evidence in favor of this explanation (astronomical periods in the climatic indicator spectra) not available in the paper by J. Hayes, J. Imbry and N. Shackleton, 1976.

During the warmgeological ages the resonance intensification of astronomically forced climate variations did not occur, and these variations remained negligibly small, for at their minima the climatic background still remained so warm that the continental glacial shields did not form.

In this system the variations (cooling and warming) of the climatic background of the geological ages with time scales on the order of 10^8 years still require explanation. The qualitative variations of the global IAO with variations of the configurations of the oceans and continents (and the poles) as a result of movement of the continent can serve as such an explanation.

The quantitative theories of global IAO can be constructed on the basis of certain physical-mathematical models of the atmosphere and ocean in their interaction (or, more completely, the entire atmosphere-ocean-dryland system). Among the various possible classifications of such models, here we shall indicate their division into small-parametric (nonhydrodynamic, models with lumped parameters) and multiparametric (hydrodynamic).

The first of them cannot pretend to quantitative detail, but before creating the superpowerful computers (which permit statement of statistical-hydrodynamic numerical experiments with multiparametric models) they can offer a number of constructive results although, of course, a genuine theory having approving power is provided only by the multiparametric models.

The minimum number of parameters in the models of the first type must include the average global temperature of the air layer next to the water and the standard temperature difference between the equator and the poles. Such models can be constructed by the example of similarity theory for planetary atmospheric circulation developed by G. S. Golitsyn (1973) with the addition of parameters characterizing the role of the oceans and the continents. As an example we have the model constructed in the paper by S. S. Zilitinkevich and the author of this article in 1976. Let us also indicate the model with lumped parameters of V. Ya. and S. Ya. Sergin designed for the description of the interchangeability of the glacial periods.

Now in various countries of the world several tens of multiparametric models of the atmosphere have been constructed, but there are still only two genuine multiparametric models of the atmosphere-ocean-dryland system. The first of them constructed by S. Manabe and K. Bryan in 1969 offered a number of hopeful results. Its deficiencies include the assignment of prescribed cloudiness (according to the climatic data) and artificial splicing of large time intervals in the ocean to small intervals in the atmosphere. These deficiencies have been corrected in the model, the development of which was completed in 1976 at the Leningrad Division of the Institute of Oceanology of the USSR Academy of Sciences by D. V. Chalikov with the participation of V. G. Turikov, S. S. Zilitinkevich and the author of this article. A further development of the models of this type must create a basis both for long-range weather forecasting and climate theory.

SYNOPTIC EDDIES IN THE OCEAN (A SURVEY OF EXPERIMENTAL RESEARCH)

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 35-49

[Article by M. N. Koshlyakov, L. M. Fomin]

[Text] By the "synoptic ocean eddies" we mean the nonstationary disturbances of the ocean circulation with horizontal scale on the order of the Rossby scale [Rossby, 1937-1938] $R=Nh\cdot f^{-1}$, where f is the Coriolis parameter, h is the thickness of the baroclinic layer in the ocean and N is the average Vaisälä frequency with respect to the baroclinic layer; in middle latitudes $R\sim 50$ km. The inclined experimental data permit rough separation of the synoptic ocean eddies into two classes:

a) Frontal eddies formed as a result of splitting off of the meandering streams of the frontal currents of the Gulf Stream or Kuroshio type;

b) Open-sea eddies which are more like two-dimensional quasihorizontal waves of a synoptic scale.

The most fundamental contribution to the investigation of the synoptic eddies of the open sea has been made at the present time by the Soviet expedition "Poligon-70" [Brekhovskikh, et al., 1971] and the American-English expedition "MODE-1" [U.S. POLYMODE Organizing Committee, 1976]. Both were a logical continuation of the studies of the nonstationary ocean currents performed by the oceanologists of various countries before. Thus, the "Poligon-70" program was the next in a series of Soviet experiments especially aimed at studying the time and space variability of ocean currents. The basis for all of these experiments was the long-term measurements of the currents on buoy stations. These "test area" studies were performed in the USSR by the initiative of V. B. Shtokman, who in 1935 performed a series of current measurements in the Caspian Sea [Shtokman, Ivanovskiy, 1937]. Then came the test area in the Black Sea in 1956 [Ozmidov, 1962], the test area in the North Atlantic in 1958 [Ozmidov, Yampol'skiy, 1965] and the test area in the Arabian Sea in 1967 [Shtokman, et al., 1969]. Of the enumerated expeditions the test area in the

Arabian Sea ("Poligon-67") was the first in which synoptic ocean eddies were detected by a predominantly indirect method [Koshlyakov, Galerkin, Chyong Din' Khiyen, 1970].

The results of measuring the currents at depths of 2 and 4 km performed using the Swallow floats in the vicinity of the Bermuda Islands in 1959-1960 [Swallow, 1971] and indicating the presence of very powerful (up to 40 $cm\text{-}sec^{-1}$ at a depth of 4 km!) nonstationary currents with approximate scales of 50 days and 100 km experienced great resonance among the oceanographers. The spectral analysis of the density fluctuations in the pycnocline layer at the "Tango" station (24° north latitude, 135° east longitude) in the Pacific Ocean (Yasui, 1964), the temperature fluctuations in the thermocline in the vicinity of the Bermuda Islands [Wunsch, 1972] and the fluctuations of the current velocity in the entire body of the ocean at a point located directly to the north of the Gulf Stream (39° north latitude, 70° west longitude) [Thompson, 1971] revealed very clear energy density peaks at periods of 100 (the first two cases) and 40 days.

The basic observations were not the only ones (but they were the most important); by the end of the 1960's to the beginning of the 1970's they demonstrated the existence of powerful nonstationary long-period movements of the water in the depths of the ocean. However, a number of important problems remained unclear.

1. Are these currents universal for the ocean? Do they exist to great distances from the frontal currents of the Gulf Stream or Kuroshio type?

2. What is their nature? This is turbulence or waves, and if waves, then which -- plane or two-dimensional? Do they saturate the space continuously or are they individual disturbances?

3. What are the true scales of the current field? How are the space and time scales related to each other? Is this relation included in the known models of the nonstationary ocean movements?

4. What is the energy of these currents by comparison with the energy of other components of the spectrum of movements of ocean water? What is the most probable mechanism of their generation?

The necessity was obvious for an expedition in which answers to the formulated questions would be obtained at least in part and on a preliminary level by primarily direct current measurements. The "Poligon-70" became such an expedition.

The "Poligon-70" experiment was performed in the spring and summer of 1970 in the tropical zone of the North Atlantic, in the eastern part of the Northern Trade Winds Current [Brekhovskikh, and so on, 1971]. The basis for the observations was measurements of the currents at 17 buoy stations located along the rays of a rectangular cross with its center at 16°30' north latitude, 33°30' west longitude (Fig 1); the least length of

each ray was 100 km. The measurements were performed on ten horizons from 25 to 1500 meters; this system was maintained continuously from the end of February to the beginning of September 1970. The analysis of numerous current patterns on a synoptic scale constructed by the data from "Poligon-70" for various horizons and dates (some of these patterns are shown in Fig 1 for the 300 meter level) led to the following basic conclusions (Koshlyakov, Grachev, 1974; Grachev, Koshlyakov, 1977; Koshlyakov, 1977].

1. Several cyclonic and anticyclonic eddy type velocity disturbances were recorded on "Poligon-70." One anticyclonic eddy, the center of which ran near the center of the test area in the second half of May was measured especially well.

2. The "tight packing" of the eddies predominated explicitly. The periods of the weak currents in the center of the test area are interpreted as periods of passage of the saddle type regions between the four eddies through the test area.

3. The transverse scale of the eddies (the distance from the center of the eddy to the point with maximum velocity) was very stable, decreasing from 110-120 km at a depth of 300 meters to 100 km at 1000 meters.

4. The eddies moved to the west (with a small component to the south) with a mean velocity of 5-6 cm-sec^{-1}. This value was especially stable for the main anticyclone.

5. The slope of the axis of the main anticyclone in the direction approximately opposite to its displacement was recorded reliably. This slope led to a 60 km shift between the positions of the center of the eddy at depths of 300 and 600 meters in the second half of May which for a disturbance "wave length" of 440 km corresponds to a phase shift of the velocity oscillations by 50°.

6. Compiling on the average a value on the order of 10 cm-sec^{-1} at depths of 200-1000 meters, the current velocity in the eddy field at individual times and individual points reached 25 cm-sec^{-1} at 200-300 meters, 35 cm-sec^{-1} at 400-600 meters, 20 cm-sec^{-1} at 1000 meters and 10 cm-sec^{-1} at 1500 meters. The increase in velocity in the rear of the main anticyclone during May-June from 10 to approximately 17 cm-sec^{-1} at the 300-meter level and even to a greater degree at the 600-meter level was obtained quite reliably.

In a number of papers [Koshlyakov, Grachev, 1973; Koshlyakov, Grachev, 1974; McWilliams, Robinson, 1974; Fomin, Yampol'skiy, 1977; Brekhovskikh, et al., 1977] it was demonstrated that the drift of the "Poligon-70" eddies to the west is very well described by the linear models of the baroclinic Rossby waves -- quasihorizontal and quasigeostrophic wave movements on the synoptic scale, the local dynamics of which are determined by the effects of the latitudinal variation of the Coriolis parameter

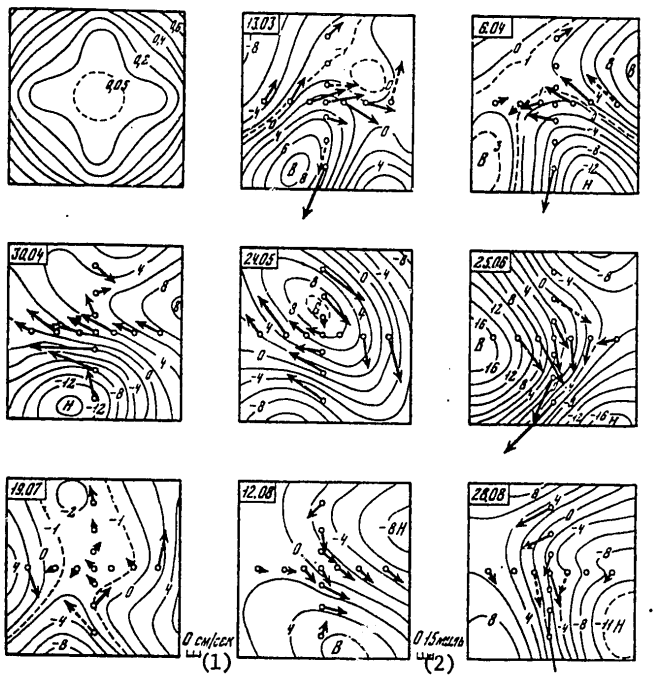


Figure 1. Evolution of currents of a synoptic scale on the 300-meter level according to the "Poligon-70" data (Grachev, Koshlyakov, 1977].
The dates are indicated in the lefthand upper corners of the figures. The arrows are the velocity vectors at the observation points obtained as a result of low-frequency (with a period of 3.5 days) filtration of the initial time series of the velocity; the dotted arrows are the result of interpolation with respect to depth or time. The absence of an arrow at the observation point means the absence of measurement data. The isolines are current lines calculated using the optimal Gandin interpolation [196]; the numbers on the isolines indicate the values of the current function at 10^7 cm^2-sec^{-1}.
B is high pressure; H is low pressure. The distance and velocity scales are given at the bottom. The centers of the squares at the point 16°30' north latitude, 33°30' west longitude, and the side of the square is 280 km. In the upper lefthand corner the distribution of the measure of the interpolation error of the current function is presented for the presence of initial data for all 30 of the measurement points used.

Key:
1. cm/sec
2. miles

and divergence of the horizontal curve [see, for example, Monin, Kamenkovich, Kort, 1974; Kamenkovich, Reznik, 1977]. This makes it possible to state that the baroclinic Rossby ocean waves were measured for the first time by the "Poligon-70" expedition. Let us then note that the properties of the main "Poligon-70" eddy noted above in items 5 and 6 (inclination of the axis and intensification in time) can be considered altogether as evidence of intensification of the eddy as a result of baroclinic instability of the large-scale current [Koshlyakov, Yenikeyev, 1977], that is, the process (see, for example, Kamenkovich, Reznik, 1977], for which the eddy scoops up energy from the available potential energy of the large-scale current connected with the slope of the isopycnic surfaces in its field. The last conclusion is of great interest from the point of view of the cardinal problem of the generation of synoptic ocean eddies.

The vertical structure of the synoptic currents on "Poligon-70" was studied by Vasilenko and Mirabel' [1977] by expansion of the current measurement data with respect to a system of vertical natural orthogonal functions [Obukhov, 1960]. It was demonstrated that the first three modes of this expansion in practice exhaust the vertical variability of the currents.

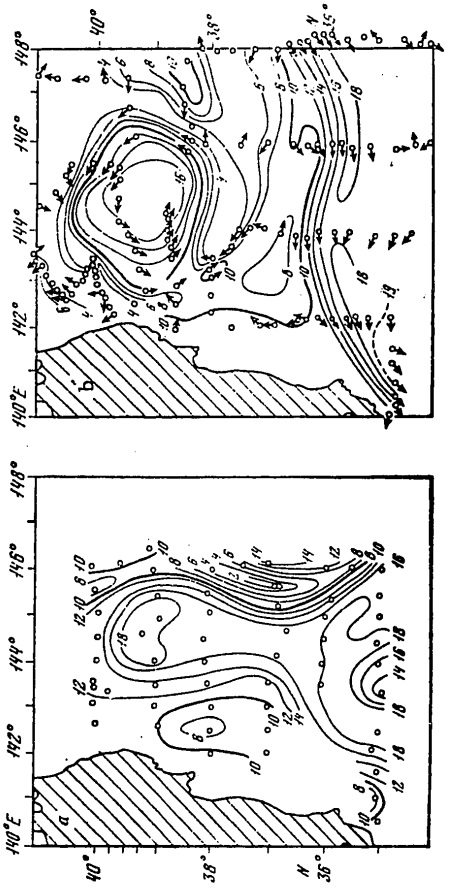
"MODE-1" [Mid Ocean Dynamics Experiment] was the second experiment after "Poligon-70" specially aimed at studying the ocean currents of a synoptic scale [U. S. POLYMODE Organizing Committee, 1976]. Its intensive phase was carried out by oceanologists of the United States and Great Britain in March-June 1973 in the vicinity of the Sargasso Sea with the center at 28° north latitude, 69°40' west longitude and a radius of approximately 200 km. A broad set of methods and means of oceanographic observations were used in MODE-1 of which the main ones were measurements of the currents and temperature on more than 20 buoy stations in the layer from 500 meters to the bottom of the ocean, measurements of the currents by SOFAR floats at a depth of 1500 meters and density surveys of the region predominantly to the ocean floor. The basic result of MODE-1 and "Poligon-70" must be considered to be the detection of several predominantly "tightly packed" synoptic eddies [McWilliams, 1976a; U.S. POLYMODE Organizing Committee, 1976]; one anticyclonic eddy was measured especially well which with respect to a number of parameters greatly resembled the main anticyclone of "Poligon-70" and propagated to the depths of the ocean to its floor. The average drift of the "MODE-1" eddies to the west (with a velocity of about 2 $cm\text{-}sec^{-1}$) was well placed within the framework of the linear theory of Rossby waves [McWilliams, Flierl, 1976; McWilliams, 1976b]. At the same time the observations by the SOFAR floats indicated a noticeable proportion of the transferred ("turbulent") form of the motion in the eddy field in the depths of the ocean [Rossby, Voorhis, Webb, 1975]; the corresponding effective coefficient of horizontal turbulent diffusion turned out to be $8 \cdot 10^6$ $cm^2\text{-}sec^{-1}$ [Freeland, Rhines, Rossby, 1975].

At the present time a large quantity of experimental data has been accumulated demonstrating the presence of synoptic eddies in the most

parts of the World Ocean. It is of interest that in many cases the traces of the eddies are reliably detected in old data (predominantly in the results of the density surveys) accumulated before the 1970's, but not attracting special attention until the "Poligon-70" expedition and "MODE-1." Accordingly, first of all let us mention the detection of very powerful (current velocity in the eddy field to 70-100 cm-sec^{-1}!) synoptic eddies in the western part of the Intertradewind Countercurrent in the Pacific Ocean in 1958 [Burkov, Ovchinnikov, 1960], in the Eastern Australian Current in 1964 [Hamon, 1965], in the region to the southwest of the Cape of Good Hope in 1967 [Duncan, 1968]. The disturbances of the oceanographic fields connected with the baroclinic synoptic eddies were reliably detected in the Northern Trade Wind Current in the Pacific Ocean [Bernstein, White, 1974], in the southwestern part of the Sargasso Sea [Beckerle, La Casce, 1973], in the regions to the south and directly to the north of the central part of the North Atlantic Current [Gill, 1975] and in many other parts of the World Ocean. In addition to the eddies of a synoptic scale, in the upper layer of the ocean eddies of essentially smaller scales -- from 5 to 50 km -- were observed in the upper layer of the ocean many times. Their presence was reliably recorded in the Northern Tradewind Current in the Atlantic [Kort, Byshev, Tarasenko, 1974], in the California Current [McEwen, 1948], under the ice (!) in the Arctic Basin [Hunkins, 1974] and in other parts of the ocean.

Even the far from complete presented list indicates the standard nature of the phenomenon of synoptic eddy formation for the World Ocean, which forces the proposition of a universal mechanism of this formation. Before we touch on this problem again at the end of the survey, let us briefly consider the frontal eddies, considering above all the discovery of their basic differences from the above-described eddies of the open sea.

The classical example of the separation of the cyclonic meander of the Gulf Stream and conversion of it to a cold cyclonic eddy south of this current which remains the best in oceanographic literature even today was described by Fuglister and Worthington [1951]. The formation, movement and evolution of the thermal anticyclonic eddy to the north from the Gulf Stream were described by Saunders [1971]; analogous processes for cyclonic and anticyclonic eddies of Kuroshio were described respectively by Masuzawa [1957] and Kawai [1972]. From Fig 2 it is obvious how quickly the separation of the frontal eddy takes place accompanied in the given case by intensive arrival of cold water from the northeast in the separation zone. The size, power and lifetime of the intercyclonic eddy are expressed in Fig 2. The velocity of the surface current in the eddy field immediately after separation reached 2 m-sec^{-1}. It must be noted that in contrast to the frontal eddies of the Gulf Stream and the Kuroshio cyclones, the Kuroshio anticyclones do not bear the nature of individual eddies drifting among the surrounding relatively quiet ocean after their separation. On the contrary, a broad part of the Pacific Ocean to the east of Japan approximately to 180° east longitude is a uniquely complex region in hydrologic and hydrodynamic respects, solidly saturated by pulsating streams and branches of the Kuroshio, Oyashio and Northern Pacific Ocean



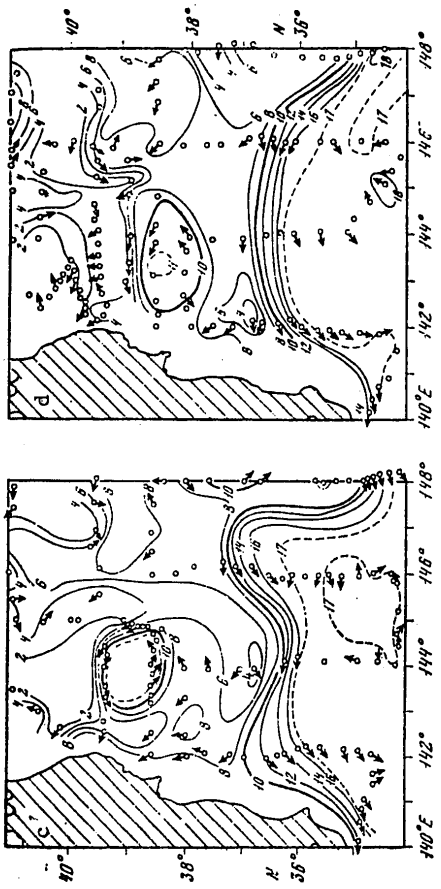


Figure 2. Temperature Distribution (°C) at a depth of 200 meters and current directions on the surface of the ocean in the region east of Honshu Island [Kawai, 1972]
a -- 1-21 July 1960; b -- 21 August 1960; c -- 15 February to 14 March 1961; d -- 3-27 August 1961. The circles are the positions of the bathometric stations; the direction of the currents was measured by geoelectromagnetic kinetograph from a ship

Currents moving and continuously deforming eddies of both signs formed predominantly as a result of separation of meanders of the above-mentioned currents but partially as a result of the simple recirculation effect on the insides of the wave like bends in their streams. The results of the studies of the structure and the dynamics of the mentioned region of the ocean are described in papers by Masuzawa [1955], Ichiye [1956], Bulgakov [1967], Barkley [1968], Kawai [1972], Byshev, Grachev and Ivanov [1976], Pavlychev [1975], Kitano [1975] and other researchers.

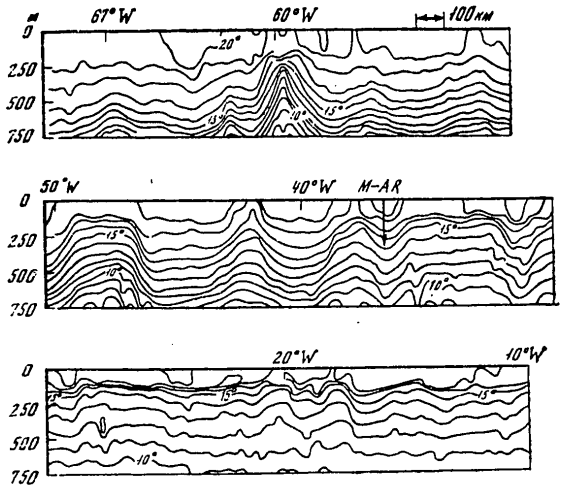


Figure 3. Temperature distribution (°C) in the section through 34°30' north latitude in the Atlantic on 22 January to 2 February 1975 according to G. Seaver [U.S. POLYMODE Organizing Committee, 1976].
The distance between the bathythermographic stations was 20 km. M-AR -- position of the North Atlantic Ridge axis.

The transverse cross section of the standard cyclone ("ring") of the Gulf Stream is investigated in the western (at 60° west longitude) part of the section in Fig 3. The individual nature of the formation is clearly visible. The young Gulf Stream rings are characterized by the following parameters [Fuglister, 1972; Cheney, et al., 1976]. The "diameter" of the ring defined as the transverse of the region of the cold anomaly is equal approximately to 200 km. The horizontal temperature gradient in the layer of the main thermocline can reach 10-12°C, which corresponds to an altitude gradient of the isothermal surfaces at 600-700 meters. Correspondingly, the speed of the rotational motion of the water in the upper part of the ring often reaches 2 meters/sec and even more. The young rings "are marked" on the surface of the ocean by a spot of reduced temperature, which makes it possible to detect them from satellites [Vukovich, 1976]. As the ring occurring basically in the process of layer by layer turbulent mixing of its water with the surrounding water of the Sargasso Sea ages [for example, Lambert, 1974], a slow decrease in the ring diameter, the horizontal temperature gradient and the rotation rate of the water in its field occurs [Fuglister, 1972; Cheney, Richardson, 1976].

After their formation, the Gulf Stream rings drift, as a rule, to the west and the southwest in the Sargasso Sea with an average velocity of about 3 km/day. [Lai, Richardson, 1977]. It is possible to assume that this drift is caused both by the natural dynamics of the rings [Warren, 1967] and by the effect of the large-scale current. The observations of the hydrophysical and hydrochemical properties of the ring [Lambert, 1974] and the measurements by the central buoyancy float [Cheney, et al., 1976] certainly demonstrated that the upper part of the rings approximately to a depth of 700-1000 meters is occupied predominantly by water moving together with the ring. On the contrary, in the depths, the "wave" form of the motion predominates in which the trajectories of the particles intersect the ring region [Cheney, et al., 1976]. The rings finish their existence either by absorption of them by the Florida Current or final extinguishing in the Sargasso Sea. The average lifetime of one ring is estimated at 2 or 3 years [Lai, Richardson, 1977]. Combining this estimate with the estimate of the number of rings formed during a year (5 or somewhat more) [Fuglister, 1972], we find that in the Sargasso Sea about 15 rings must be observed simultaneously. The latter conclusion agrees well with the experimental result giving 11 rings for November 1971 [Lai, Richardson, 1977].

The general properties of the frontal ocean eddies and the above-investigated eddies in the open sea permitting combination of them to a single type of synoptic ocean eddies are obvious: this is the horizontal scale, quasigeostrophicity and the defining role of the latitudinal variation of the Coriolis parameter and divergence of the horizontal current in their local dynamics. From what has been stated above, however, the following peculiarities of the frontal eddies obviously distinguishing them, let us say, from the "Poligon-70" or "MODE-1" eddies are clear.

1. The frontal eddies are formed in the regions of frontal ocean jet streams as a result of separation of the meanders of these currents; accordingly, immediately after formation the frontal eddies contain water inside themselves of different origin by comparison with the surrounding water.

2. The frontal eddies are quasiindividual formations (this conclusion does not pertain, strictly speaking, to the Kuroshio anticyclones). Only anticyclones are formed to the left of the frontal current and cyclones, to the right.

3. The advective form of the movement plays a significant role in the displacement of the frontal eddies; in any case it predominates in the upper parts of the frontal eddies.

4. The frontal eddies are extraordinarily concentrated formations. Their specific kinetic energy exceeds by two orders the specific kinetic energy of the standard eddies in the open sea.

It would be naive, however, to assume that there are no formations in the ocean which are intermediate with respect to their properties between, let us say, the rings of the Gulf Stream and the eddies of the "Poligon-70" eddy type. From what has been stated above it follows that the eddies of the frontal region of Kuroshio-Oyashio are in a defined sense such intermediate formations. Another example of such formations is the central part of the section in Fig 3. Whereas the standard Gulf Stream ring is visible in the western part of the section, and a continuous symmetric field of wave disturbances is present in the eastern part (for example, in the vicinity of 20° west longitude) similar to those observed during the "Poligon-70" and "MODE-1" expeditions, the entire central part of the section is occupied by disturbances of an intermediate type; these are not the single formations of the ring type, but also not the symmetric field of rises and falls of the isothermal surfaces; the regions of rise corresponding to the cyclonic sign of the eddy are more localized here and more clearly expressed than the regions of fall of the isotherms. Let us give attention to the fact that the increase in the degree of "self-containment" of the disturbances from the east to the west in Fig 3 follows the increase in their energy; the latter necessarily find its explanation in the modern theory of nonlinear Rossby waves [Larichev, Reznik, 1976].

In conclusion let us discuss some of the energy estimates. The results of measurements of the ocean currents by the navigational method were used as the basis for constructing the density distribution maps of the kinetic energy of the large-scale currents (K_m) and the mean density of the kinetic energy of the synoptic eddies (K_e) in the surface layer of the North Atlantic [Wyrtki, Magaard, Hager, 1976]. Both maps turned out to be surprisingly similar. With the exception of the Gulf Stream section up to 60° west longitude, a significant (on the average by an order) rise in K_e over K_m was obtained. The distribution of the average density of the admissible potential energy of the synoptic eddies P_e (the reserve of potential energy

connected with the deviation of the isopycnic surfaces from the horizontal position in the eddy field) in the principal thermocline in the North Atlantic was studied by Dantzler [1978] by the bathythermographic data. A very strong maximum in the Gulf Stream region, weak maxima in the region southeast of the Azores Islands and in the vicinity of the Northern Trade-wind Current ("Poligon-70"!) and the clearly expressed minimum approximately along 25° north latitude, that is, in the zone of practical absence of large-scale currents, were obtained. By analyzing the temperature sections from the atlas of F. Fuglister [1960], Gill, Green and Simmons [1974] obtained $P_m/P_e \sim 10$ (P_m) is the density of the admissible potential energy of the large-scale currents for the layer of the main thermocline in the central part of the basic anticyclonal circulation of the North Atlantic. The results of "Poligon-70" and "MODE-1" giving $(K_e/K_m) \sim 100$ for depths corresponding to the thermocline agree well with this estimate.[1] The analysis of the results of long-range measurements of the currents at depths from 2000 to 5000 meters in the Gulf Stream region from 70 to 55° west longitude and to the south of it again demonstrated a good decrease in the value of K_e in the direction from the Gulf Stream to the south [Schmitz, 1977]. The ratio (K_e/K_m) at these depths at 34° north latitude turned out to be on the order of 10.

All of these results can be reduced to two items:

1. The eddies are stronger where the large-scale currents are stronger.

2. The kinetic energy (and the admissible potential energy approximately equal to it) of the eddies is essentially higher, as a rule, than the kinetic energy of the large-scale currents and at the same time essentially lower than their admissible potential energy. These conclusions are highly significant experimental evidence in favor of the theory of eddy generation as a result of baroclinic instability of the large-scale ocean currents.

The authors express their appreciation to Academician L. M. Brekhovskikh and corresponding member of the USSR Academy of Sciences A. S. Monin for helpful discussion of the problems of the synoptic eddies and the specific content of this article.

---

[1] It is necessary to consider that on the average throughout the ocean P_m exceeds K_m by approximately three orders [Stommel, 1966; Gill, Green, Simmons, 1974;[Bulis, Monin, 1975]; at the same time P_e and K_e are values of the same order [for example, Kamenkovich, Reznik, 1977].

BIBLIOGRAPHY

1. Brekhovskikh, L. M.; Grachev, Yu. M.; Koshlyakov, M. N.; Fomin, L. M. "Some Results of Studying Synoptic Eddies in the Ocean," METEOROLOGIYA I GIDROLOGIYA [Meteorology and Hydrology], No 2, 1978, pp 5-14.

2. Brekhovskikh, L. M.; Koshlyakov, M. N.; Fedorov, K. N.; Fomin, L. M.; Yampol'skiy, A. D. "Test Area Hydrophysics Experiment in the Atlantic Tropical Zone," DOKL. AN SSSR [Reports of the USSR Academy of Sciences], No 6, 1971, p 198.

3. Bulgakov, N. P. "Basic Characteristics of the Structure and the Position of the Subarctic Front in the Northwestern Part of the Pacific Ocean," OKEANOLOGIYA [Oceanology], Vol 7, No 5, 1967, pp 879-888.

4. Burkov, V. A.; Ovchinnikov, I. M. "Study of the Equatorial Currents to the North of New Guinea," TRUDY IN-TA OKEANOL, AN SSSR [Works of the Oceanology Institute of the USSR Academy of Sciences], No 40, 1960, pp 121-134.

5. Byshev, V. I.; Grachev, Yu. M.; Ivanov, Yu. A. "Study of the Meso-structure of the Velocity Field in the Northern Pacific Ocean Current," OKEANOLOGIYA, No 16, 1976, pp 216-221.

6. Vasilenko, V. M.; Mirabel', A. P. "Vertical Structure of Currents in the Ocean in Different Frequency Ranges," IZV. AN SSSR. FIZIKA ATMOSFERY I OKEANA [News of the USSR Academy of Sciences. Physics of the Atmosphere and Ocean], No 13, 1977, pp 328-331.

7. Vulis, I. A.; Monin, A. S. "Admissible Potential Energy of the Ocean," DOKL. AN SSSR, No 221, 1975, pp 597-600.

8. Gandin, L. S. "Optimal Interpolation of Vector Fields," TRUDY GLAVN. GEOFIZ. OBSERVATORII [Works of the Main Geophysics Observatory], No 165, 1964, pp 47-59.

9. Kamenkovich, V. M.; Reznik, G. M. "Rossby Waves," GIDRODINAMIKA OKEANA [Hydrodynamics of the Ocean], Moscow, Nauka, 1978.

10. Korg, V. G.; Byshev, V. I.; Tarasenko, V. M. "Synoptic Variability of Currents in the Atlantic Test Area," ATLANTICHESKIY GIDROFIZICHESKIY POLIGON-70 [Atlantic Hydrophysics Poligon-70 [Test Area 70]], edited by V. G. Kort and V. S. Samoylenko, Moscow, Nauka, 1974, pp 181-188.

11. Koshayakov, M. N. "Synoptic Eddies in the Ocean," GIDROFIZIKA OKEANA [Hydrophysics of the Ocean], edited by V. M. Kamenkovich and A. S. Monin, Moscow, Nauka, 1977.

12. Koshlyakov, M. N.; Galerkin, L. I.; Chyong, Din' Khiyen. "Mesostructure of the Geostrophic Currents of the Open Sea," OKEANOLOGIYA, No 10, 1970, pp 805-814.

13. Koshlyakov, M. N.; Grachev, Yu. M. "Medium-Scale Currents in the Hydrophysical Test Area in the Tropical Atlantic," ATLANTICHESKIY GIDROFIZICHESKIY "POLIGON-70", edited by V. G. Kort and V. S. Samoylenko, Moscow, Nauka, 1974.

14. Larichev, V. D.; Reznik, G. M. "Two-Dimensional Isolated Rossby Waves," DOKL. AN SSSR, No 231, 1976, pp 1077-79.

15. Monin, A. S.; Kamenkovich, V. M.; Kort, V. G. IZMENCHIVOST' MIROVOGO OKEANA, Leningrad, Gidrometeoizdat, 1974.

16. Obukhov, A. M. "Statistically Orthogonal Expansions of Empirical Functions," IZV. AN SSSR. SER. GEOFIZ. [News of the USSR Academy of Sciences. Geophysics Series], No 3, 1960, pp 432-440.

17. Ozmidov, R. V. "Statistical Characteristics of Horizontal Macroturbulence in the Black Sea," TRUDY IN-TA OKEANOL. AN SSSR [Works of the Institute of Oceanology of the USSR Academy of Sciences], No 60, 1962, pp 114-129.

18. Ozmidov, R. V.; Yampol'skiy, A. D. "Some Statistical Characteristics of Velocity and Density Fluctuations in the Ocean," IZV. AN SSSR. FIZIKA ATMOSFERY I OKEANA [News of the USSR Academy of Sciences. Physics of the Atmosphere and Ocean], No 1, 1965, pp 615-622.

19. Pavlychev, V. P. "Water Conditions and Position of the Subarctic Front in the Northwestern Part of the Pacific Ocean," IZV. TIKHOOKEANSKOGO NAUCH.-ISSLED. IN-TA RYBNOGO KHOZYAYSTVA I OKEANOGRAFII [News of the Pacific Ocean Scientific Research Institute of the Fishing Industry and Oceanography], No 96, 1975, pp 3-18.

20. Fomin, L. M.; Yampol'skiy, A. D. "Local Kinematics of Synoptic Eddy Disturbances in the Velocity Field of Ocean Currents," DOKL. AN SSSR, No 232, 1977, pp 50-53.

21. Shtokman, V. B.; Ivanovskiy, I. I. "Results of a Stationary Study of Currents off the West Coast of the Central Caspian," METEOROLOGIYA I GIDROLOGIYA, No 3-5, 1937, pp 154-160.

22. Shtokman, V. B.; Koshlyakov, M. N.; Ozmidov, R. V.; Fomin, L. M.; Yampol'skiy, A. D. "Long-Term Measurements of the Space and Time Variability of the Physical Fields in the Ocean Test Area as a New Phase in Ocean Research," DOKL. AN SSSR, No 186, 1969, pp 1070-1073.

23. Yasui, M. "Internal Waves in the Open Sea," VNUTRENNIYE VOLNY [Internal Waves], translated from the English, Moscow, Mir, 1964, pp 237-262.

24. Barkley, R. A. "The Kuroshio-Oyashio Front as a Compound Vortex Street," J. MAR. RES., No 26, 1968, pp 83-104.

25. Beckerle, J. C.; La Casce, E. O. "Eddy Patterns from Horizontal Sound VElocity Variations in the Main Thermocline Between Bermuda and Bahamas," DEEP-SEA RES., No 20, 1973, pp 673-675.

26. Bernstein, R. L.; White, W. B. "Time and Length Scales of Baroclinic Eddies of the Central North Pacific Ocean," J. PHYS. OCEANOGR., No 4, 1974, pp 613-624.

27. Crease, J. "Velocity Measurements in the Deep Water of the Western North Atlantic. Summary," J. GEOPHYS. RES., No 67, 1962, pp 3173-3176.

28. Cheney, R. E.; Gemmill, W. H.; Shank, M. K.; Richardson, P. L.; Webb, D. "Tracking a Gulf Stream Ring with SOFAR Floats," J. PHYS. OCEANOGR., No 6, 1976, pp 741-749.

29. Cheney, R. E.; Richardson, P. L. "Observed Decay of a Cyclonic Gulf Stream Ring," DEEP-SEA RES., No 23, 1976, pp 143-155.

30. Dantzler, H. "Potential Energy Maxima in the Tropical and Subtropical North Atlantic," J. PHYS. OCEANOGR., No 8, 1978.

31. Duncan, C. P. "A Eddy in the Subtropical Convergence Southwest of South Africa," J. GEOPHYS. RES., No 73, 1968, pp 531-534.

32. Freeland, H.; Rhines, P.; Rossby, H. T. "Statistical Observations of the Trajectories of Neutrally Buoyant Floats in the North Atlantic," J. MAR. RES., No 33, 1975, pp 383-404.

33. Fuglister, F. C. "Atlantic Ocean Atlas of Temperature and Salinity Profiles and Data from the International Geophysical Year of 1957-58," Woods Hole Oceanogr. Inst., Woods Hole, Mass., 1960, 209 pp.

34. Fuglister, F. C. "Cyclonic Rings Formed by the Gulf Stream, 1965-66," STUDIES IN PHYSICAL OCEANOGRAPHY, edited by A. Gordon, Gordon and Breach, No 1, 1972, pp 137-167.

35. Fuglister, F. C.; Worthington, L. V. "Some Results of a Multiple Ship Survey of the Gulf Stream," TELLUS, No 3, 1951, pp 1-14.

36. Gill, A. E. "Evidence for Mid-Ocean Eddies in Weather Ship Records," DEEP-SEA RES., No 22, 1975, pp 647-652.

37. Gill, A. E.; Green, J. S. A.; Simmons, A. J. "Energy Partition in the Large-Scale Ocean Circulation and the Production of Mid-Oceanic Eddies," DEEP-SEA RES., No 21, 1974, pp 499-528.

38. Grachev, Yu. M.; Koshlyakov, M. N. "Objective Analysis of Synoptic Eddies in POLYGON-70," POLYMODE NEWS, No 23, 1977, Woods Hole Oceanogr. Inst.

39. Hamon, B. V. "The East Australian Current, 1960-64," DEEP-SEA RES., No 12, 1965, pp 899-921.

40. Hunkins, K. L. "Subsurface Eddies in the Arctic Ocean," DEEP-SEA RES., No 21, 1974, pp 1017-1033.

41. Ichiye, T. "On the Behavior of the Vortex in the Polar Front Region," OCEANOGR. MAG., No 7, 1956, pp 115-132.

42. Kawai, H. "Hydrography of Kuroshio Extension," KUROSHIO: PHYSICAL ASPECTS OF THE JAPAN CURRENT, edited by H. Stommel, K. Yoshida, Seattle, Univ. Washington Press, 1972, pp 235-252.

43. Kitano, K. "Some Properties of the Warm Eddies Generated in the Confluence Zone of the Kuroshio and Oyashio Currents," J. PHYS. OCEANOGR., No 5, 1975, pp 245-252.

44. Koshlyakov, M. N.; Grachev, Yu. M. "Meso-scale Currents at a Hydrophysical Polygon in the Tropical Atlantic," DEEP-SEA RES., No 20, 1973, Pp 507-526.

45. Koshlyakov, M. N.; Yenikeyev, V. Kh. "Synoptic-Statistical Analysis of the Current Field in POLYGON-70," POLYMODE NEWS, No 23, 1977, Woods Hole Oceanogr. Inst.

46. Lai, D. Y.; Richardson, P. L. "Distribution and Movement of Gulf Stream Rings," J. PHYS. OCEANOGR., No 7, 1977, pp 670-683.

47. Lambert, R. B. "Small-Scale Dissolved Oxygen Variations and the Dynamics of Gulf Stream Eddies," DEEP-SEA RES., No 21, 1974, pp 529-546.

48. Masuzawa, J. "An Outline of the Kuroshio in the Eastern Sea of Japan (Currents and Water Masses of the Kuroshio System, IV)," OCEANOGR. MAG., No 7, 1955, pp 29-47.

49. Masuzawa, J. "An Example of Cold Eddies South of the Kuroshio," REC. OCEANOGR. WORKS JAP., No 3, 1957, pp 1-7.

50. McEwen, G. F. "The Dynamics of Large Horizontal Eddies (Axes Vertical) in the Ocean Off Southern California," J. MAR. RES., No 7, 1948, pp 188-216.

51. McWilliams, J. C. "Maps from the Mid-Ocean Dynamics Experiment: Pt I -- Geostrophic Stream Function," J. PHYS. OCEANOGR., No 6, 1976a, pp 810-827.

52. McWilliams, J. C. "Maps from the Mid-Ocean Dynamics Experiment: Pt II. Potential Vorticity and Its Conservation," J. PHYS. OCEANOGR., No 6, 1976b, pp 828-846.

53. McWilliams, J.; Flierl, G. "Optimal Quasi-Geostrophic Wave Analysis of MODE Array Data," DEEP-SE_ RES., No 23, 1976, pp 285-300.

54. McWilliams, J.; Robinson, A. R. "A Wave Analysis of the POLYGON Array in the Tropical Atlantic," DEEP-SEA RES., No 21, 1974, pp 359-368.

55. Rossby, C. G. "On the Mutual Adjustment of Pressure and Velocity Distributions in Certain Simple Current Systems, II," J. MAR. RES., No 1, 1937-1938, pp 239-263.

56. Rossby, H. T.; Voorhis, A.; Webb, D. "A Quasi-Langrangian Study of Mid-Oceanic Variability Using Long Range SOFAR Floats," J. MAR. RES., No 33, 1975, pp 355-582.

57. Saunders, P. M. "Anticyclonic Eddies Formed from Shoreward Meanders of the Gulf Stream," DEEP-SEA RES., No 18, 1971, pp 1207-1219.

58. Schmitz, W. J. "On the Deep General Circulation in the Western North Atlantic," J. MAR. RES., No 35, 1977, pp 21-28.

59. Stommel, H. THE GULF STREAM. A PHYSICAL AND DYNAMICAL DESCRIPTION. 2d edition, Univ. California: Cambridge Univ. Press, 1966, 248 pp.

60. Swallow, J. C. "The 'Aries' Current Measurements in the Western North Atlantic," PHIL. TRANS., No 270, 1971, pp 451-460.

61. Thompson, R. "Topographic Rossby Waves at a Site North of the Gulf Stream," DEEP-SEA RES., No 18, 1971, pp 1-19.

62. U.S. POLYMODE Organizing Committee. U.S. POLYMODE Program and Plan, Cambridge, Mass. Inst. Technol., 1976, 98 pp.

63. Vukovich, F. M. "An Investigation of a Cold Eddy on the Eastern Side of the Gulf Stream Using NOAA 2 and NOAA 3 Satellite Data and Ship Data," J. PHYS. OCEANOGR., No 6, 1976, pp 605-612.

64. Warren, B. A. "Notes on Translatery Movement of Rings of Current in the Sargasso Sea," DEEP-SEA RES., No 14, 1967, pp 505-524.

65. Wunsch, C. "The Spectrum from Two Years to Two Minutes of Temperature Fluctuations in the Main Thermocline at Bermuda," DEEP-SEA RES., No 19, 1972, pp 577-594.

66. Wyrtki, K.; Magaard, L.; Hager, J. "Eddy Energy in the Oceans," J. GEOPHYS. RES., No 81, 1976, pp 2641-2646.

VARIABILITY OF THE DISTRIBUTION OF CHEMICAL ELEMENTS IN OCEAN WATER

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 87-98

[Article by V. N. Ivanenkov, O. K. Bordovskiy]

[Text] The chemistry of the ocean involves the study of the chemical properties and chemical composition of sea and ocean water, the layer of the atmosphere next to the water and liquid phase of the bottom sediments -- this is the so-called chemical statics. However, the heart of chemical oceanology is chemical dynamics -- the study of the variability of the distribution of the chemical elements -- and by the chemical dynamics, the study of the direction and speed of the chemical processes [Bruyevich, 1945].

Definite progress has been made in the study of the chemical statics of the seas and oceans. The chemical composition of the sea and ocean water, the general laws of salinity distribution, the pH, alkalinity, dissolved oxygen, forms of phosphorus, nitrogen and silicon basically have been well investigated. The trace elements and organic materials have been studied to the necessary extent. This is indicated by the large surveys, monographs and atlases with respect to entire oceans appearing in the 1960's to 1970's discussing a large complex of chemical elements. There is a monograph on the Pacific Ocean by the coworkers of the chemical division of the Institute of Oceanology directed by S. V. Bruyevich, "Chemistry of the Pacific Ocean" [1966], on the Indian Ocean, a survey by V. N. Ivanenkov and F. A. Gubin [1960], the collections "Oceanological Research" [No 4, 1964], "Indian Ocean Research" [1964], "Oceanographic Atlas of the Indian Ocean" [Wyrtki, Bennett, Rochford, 1971], the Atlantic Ocean, the survey by V. A. Bubnov [1966, 1970], B. V. Volostnykh [1973], Yu. I. Lyakhin and V. N. Ivanenkov [1975], and V. N. Ivanenkov [1977a].

The classification and circulation of the ocean water, the laws of the distribution of salinity and dissolved oxygen in them are reflected in the monographs by A. M. Muromtsev [1958, 1959, 196] and V. N. Stepanov [1974].

From the works summing up the results of chemical research in the World Ocean, first of all it is necessary to note the monographs "Chemical Oceanography" [1965, 1975], "Chemistry of the Ocean" by O. A. Alekin [1966], "Introduction to the Geochemistry of the Ocean" by A. P. Vinogradov [1967], "Marine Chemistry" by R. Horn [197] and the monograph from the series "Oceanology" "Chemistry of Ocean Water" published in 1979.

The general laws of the distribution of dissolved oxygen, pH, alkali chloride ratio, phosphates, nitrites, silicates and chemical-oceanographic division of the oceans into districts in the "Hydrochemistry" Division of the "Atlas of the Oceans," Part I -- Pacific Ocean (1974) -- and Part II -- Atlantic and Indian Oceans (1977) were demonstrated most completely and purely. This division contains more than 150 maps, sections and graphs. It was created by V. N. Vinogradov, B. V. Volostnykh, A. N. Gusarova, V. N. Ivanenkov, M. E. Istomina, V. A. Konnov, Yu. I. Lyakhin, A. N. Osipova, V. V. Sapozhnikov and A. M. Chernyakova under the scientific direction of V. N. Ivanenkov. When creating the "Atlas of the Oceans" the doubtful and indirect data were excluded, and when selecting the values of the isolines on the maps and sections, the diurnal variability caused by the biochemical processes was considered in the sections. Any of the atlases constructed by the data averaged over many years reflect a somewhat idealized picture of the distribution of one parameter or another, correctly reflecting only the main laws. In order to know what the distribution of the chemical parameters will be at any point in time, in addition to their average values, an idea is needed about the different-period chemical variability caused by the physical, biological and chemical processes.

The problem of chemical variability acquired primary significance long ago, for it is by the variability of the distribution of the chemical characteristics that it is possible to determine the rates of the chemical processes in situ and also the exchange rates of the chemical elements inside the body of water and at its interfaces with the atmosphere and the bottom.

The study of the variability of the distribution of the chemical elements must be performed simultaneously with an investigation of the variability of the physical, biological and anthropogenic factors causing chemical variability in order to learn how to forecast it. Forecasting the variability of the chemical regime is the theoretical basis for forecasting the variability of the biological productivity and also the scientific basis for the element of measures to preserve the natural conditions in the seas and oceans. The urgency of the problem of studying the variability of the distribution of the chemical elements in the oceans and seas among other problems of chemical oceanology is obvious.

A. S. Monin [Monin, Kamenkovich, Kort, 1974] isolates seven types of oscillations of the distribution of the physical parameters and the chemical parameters that depend on them. These fluctuations are created by physical processes for which specific time and space scales are characteristic.

Beginning with the time scales, this variability is called small-scale, mesoscale, synoptic, seasonal, interannual, intracentury and intercentury.

The materials from the hydrochemical observations accumulated at the present time can characterize only the interyear seasonal and mesoscale variability and that very approximately and for a small number of regions of the ocean. Sufficient data have still not been accumulated to characterize the synoptic including the intracentury and intercentury fluctuations of the hydrochemical regime. With the development of the test area method of research with the introduction of oceanological studies of new equipment into practice for continuous measurement of physical and chemical parameters, the possibility appears for broad study of the small-scale, mesoscale, and synoptic variability of the distribution of the physical and chemical characteristics.

The interyear variability in the distribution of the chemical parameters of the ocean water with the period from one to several years is manifested accordingly with respect to all chemical characteristics over large spaces measured in hundreds of miles with respect to the meridian and thousands of miles with respect to the parallel. It is caused by variability of the intensity of the global circulation of water and atmosphere. In the regions of the ocean where the meeting of water of different origin differing significantly with respect to chemical characteristics takes place, the interyear chemical variability can be manifested at all depths of the ocean to ultraabyssal.

The water of the surface structural zone in all three oceans at the interface between the Subarctic and Northern Subtropical Zones, between the Subantarctic and Southern Subtropical regions, especially in the western and eastern peripheries of these zones have the greatest differences of chemical and physical characteristics.

During the years with severe winters and heavy icing, the cold and oxygen-enriched surface subarctic water of the Labrador Current (in the Atlantic Ocean) and the Oyashio Current (in the Pacific Ocean) penetrate far to the south, lowering the temperature and salinity and increasing the oxygen concentration and the concentration of biogenic elements of the upper 200-meter layer.

Off the coast of Peru and Chile in individual years warm tropical waters impoverished with respect to biogenic elements penetrate hundreds of miles to the south, which leads to lowering of the productivity of the coastal water.

In the Atlantic Ocean between 10 and 30° north latitude the intermediate, deep and bottom water of North Atlantic Ocean meets with the intermediate and bottom Antarctic water. The former differs from the latter by the high degree of salinity (0.1 to 0.3 parts per thousand), the greater oxygen content (by 0.5 to 0.8 ml/liter), the larger values of the pH (by 0.10-0.15), lower alkalinity (by 0.02 to 0.03 mg-equiv/liter) and significantly lower content of biogenic elements (phosphates -- by

0.2-0.4 μg-at/ℓ, nitrates by 2-10 and silicates by 10-30 μg-at/ℓ). In individual years on intensification of the northern component of the water circulation, the Antarctic water penetrates to the north farther than usual and, on the contrary, with intensification of the southern component the North Atlantic water penetrates farther to the south. With respect to chemical characteristics this phenomenon is clearly obvious.

In the Indian Ocean between 10° south latitude and 10° north latitude the intermediate, deep and bottom Northern Indian water meets with the intermediate and bottom Antarctic water. The water of the Northern Indian origin is distinguished from the Antarctic water by greater salinity (by 0.1-0.02 parts per thousand), greater content of biogenic elements (phosphates by 0.2-0.5 μg-at/ℓ, nitrates by 5-10 and silicates by 10-30 μg-at/ℓ), lower oxygen concentration (by 0.5-1.0 ml/liter), smaller pH (by 0.1-0.2) and greater alkalinity (by 0.02-0.03 mg-equiv/liter). Therefore with respect to chemical indexes it is possible uniquely to determine the intensification or weakening of advection to the north of the waters of Antarctic origin. The meridional sections through the Indian Ocean along 65 and 90° east longitude were made in the last 20 years by expeditions of various countries no less than 10 times.

The variability from year to year matched with respect to all parameters in the intermediate, deep and bottom layers was noted. However, it turned out to be especially large by the observations in May-June 1976 on the 22d trip of the scientific research ship "Akademik Kurchatov" [Bordovskiy, 1976].

In the large straits between oceans, large interyear variability of chemical and physical characteristics was detected, for the transfer of surface, intermediate, deep and bottom water formed in different oceans through them is realized. In the body of water between Africa and Antarctica water of the Northern Indian, North Atlantic, Subantarctic and Antarctic origin is carried, differing significantly with respect to salinity, pH and oxygen and especially with respect to concentration of biogenic elements. The deep and bottom water of the North Atlantic origin differs from the corresponding water of the Northern Indian and Antarctic origin by the greater salinity, the larger oxygen content and higher pH, smaller values of alkali-chloride ratio and the main thing, significantly smaller concentrations of phosphates, nitrates and especially silicates. If we construct graphs of the vertical distribution of the chemical characteristics for points of the section through 20° east longitude 60 miles from each other with respect to individual years, in the northern part of the section we shall see the matched interyear variations with respect to oxygen by several tenths of ml/liter, with respect to phosphate by several tenths of μg-at P/ℓ, with respect to nitrates by several μg-at N/ℓ, with respect to silicate, by several tenths of μg-at Si/ℓ, and with respect to salinity, from 0.02 to 0.10 parts per thousand. All of this indicates the intensification (or attenuation) of the flow of water from the Atlantic to the Indian Ocean or, vice versa, from the Indian Ocean to the Atlantic Ocean.

In the southern part of the section it is possible to see the increase (or decrease) in cross sectional of the ocean occupied by water of Subantarctic and Antarctic origin.

In Drake Passage it is possible to expect interyear variations of the salinity, oxygen, pH, alkali and biogenic elements, for in the southern parts of the oceans the Atlantic and Pacific Ocean water differs noticeably with respect to the indicated parameters. The Pacific Ocean water has lower salinity, greater magnitude and pH and oxygen and greater concentration of phosphates, nitrates and silicates by comparison with the Atlantic water. If there is two-way transfer of water in Drake Passage, it will be noticeable with respect to the chemical index. It was previously considered [Kort, 1962, 1963; Treshnikov, Maksimov, Gindysh, 1966] that in practice one-way transfer of Pacific Ocean water to the Atlantic Ocean is realized through Drake Passage. V. A. Burkov [1972] demonstrated that deeper than 2000 meters the transfer of water through Drake Passage goes from the Atlantic Ocean to the Pacific Ocean. V. N. Ivanenkov and A. N. Gusarova [1973] estimated the transfer of bottom Antarctic water from the Atlantic Ocean to the Pacific Ocean at $0.1 \cdot 10^6$ km^3 per year. The studies performed in the vicinity of Drake Passage at the end of the 1960's and continuing at the present time (see the article by A. F. Treshnikov in this collection), demonstrated that the water transfer from the Atlantic Ocean to the Pacific was a widespread phenomenon. It is noticeable not only with respect to oxygen as was first noted by A. N. Bogoyavlenskiy [1963], but also with respect to all the chemical parameters. Depending on the interyear variabilityof the intensity of the transfer of Pacific Ocean and Atlantic waters through Drake Passage, the distribution of the chemical characteristics in this region also varies.

At the ultraabyssal depths, the following law is in effect. If the deep water trough is filled with bottom water of one origin, the intrayear variations of the chemical characteristics will not exceed the errors in the chemical analysis [Ivanenkov, 1970]. These include all the deep water troughs of the Pacific Ocean and the southern sandwich trough in the Atlantic Ocean. If the deep water trough can be filled with bottom water of different origin differing significantly with respect to chemical characteristics, great intrayear variability of the chemical parameters and the presence of maxima and minima of the chemical parameters with respect to the vertical of the trough is unavoidable [Ivanenkov, 1977b]. The latter include the deep water troughs of Puerto Rico and Romanche in the Atlantic Ocean, the Java Trench in the Indian Ocean. The distribution of the chemical characteristics in the deep water trenches of Kurilo-Kamchatka and Puerto Rico is demonstrated in the table.

The Puerto Rico trench can be filled with bottom water of North Atlantic or Antarctic origin or a mixture of them. In the table a case is presented with respect to observations on the 14th trip of the scientific research vessel "Akademik Kurchatov" where bottom North Atlantic water is present in the upper part of the trench (with high salinity, high

oxygen content and low phosphate and silicate concentration). Deeper down is the layer with a large portion of bottom Antarctic water (reduced salinity, reduced oxygen content and increased phosphate and silicate concentration). At the bottom of the trench, below 8200 meters, there is a layer of bottom North Atlantic water with increased salinity and increased oxygen content and relatively lowered concentrations of phosphate and silicate. In the Kuril trench similar maxima and minima of the chemical parameters are absent for it is filled with bottom water of one origin -- Antarctic water -- which has experienced great transformation along the path of its propagation.

Distribution of the mean values of the salinity (parts per thousand), the dissolved oxygen (ml/liter), phosphates (µg-at P/ℓ) and silicates (µg-at Si/ℓ) in the deep water Puerto Rico trench (the Atlantic Ocean) and the Kuril trench (the Pacific Ocean)

Depth, meters	Puerto Rico				Kuril Trench			
	S	O_2	P	Si	S	O_2	P	Si
5000	34.94	5.8	1.5	33	34.69	3.7	2.4	145
6000	34.90	5.6	1.7	55	34.69	3.8	2.4	145
7000	34.86	5.4	1.8	55	34.69	3.8	2.4	145
8000	34.90	5.5	1.8	54	34.69	3.8	2.4	145
8200	34.92	5.8	1.6	50	34.69	3.8	2.4	145
Deviation from the mean	±0.01	±0.1	±0.1	±2	±0.01	±0.1	±0.1	±5

The seasonal variability of the distribution of the chemical characteristics was studied more purposely than the interyear variability. A large quantity of materials which have not been completely processed have been accumulated on it. The information about the seasonal variability of the temperature, the salinity, the dissolved oxygen and the biogenic elements has found reflection in the "Atlas of the Oceans" and in the above-mentioned monograph, surveys, and also in a number of articles. In the "Atlas of Oceans" for the 0 and 50 meter levels, maps are presented for two seasons -- summer and winter -- and in the monographs, surveys and articles, the limits of seasonal variability of the distribution of the chemical characteristics and the physical and biological factors causing them are given in the form of tables and graphs.

The seasonal variability of the chemical parameters reaches the largest values in the regions of polar and temperate latitudes in the photosynthesis layer up to 50-100 meters thick. The oxygen content in the photosynthesis layer from winter to summer in the coastal highly productive regions increases from 6-8 to 9-10 ml/liter and more, and the concentration of biogenic elements in inorganic form decreases in the northern parts of the

ocean to values close to the analytical zero, and in the southern parts of the ocean, by 30-50% or more (the content of the biogenic elements increases by several times in organic form). In the open parts of the ocean with smaller intensity of photosynthesis, the seasonal variability of the chemical parameters in the photosynthesis layer is appreciably less than the indicated dimensions.

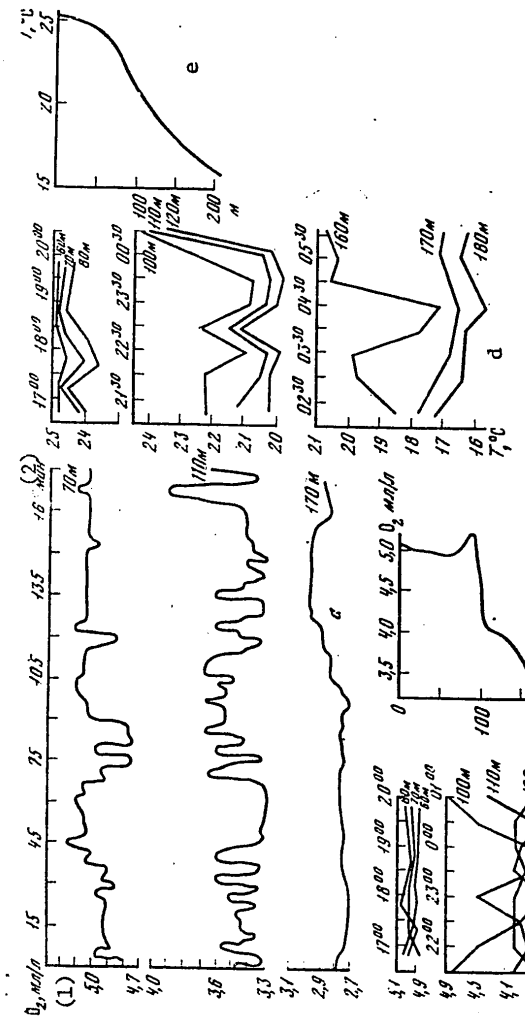
The seasonal variations in the polar and temperate latitudes penetrate by convection in the winter to depths of 200-300-400 meters or more. At these depths the seasonal variability of the values of the chemical parameters is relatively small, but several times greater than the measurement error.

In the subtropics and tropics the seasonal chemical variability is also detected, but it (on the average for the region) is appreciably less than in the polar and temperate latitudes. It is manifested in the regions where the water circulation conditions leading to a different degree of enrichment of the photosynthesis layer with biogenic elements vary. These include first of all the regions where the monsoon shift takes place and also the regions of the intensification or decrease in intensity of the cyclonic or intercyclonic circulations.

From the mesoscale variability a study was made to the highest degree of the variability caused by the tidal phenomena and the diurnal behavior of polar radiation on changes between day and night. The variability as a result of tidal fluctuations is manifested at all depths and depending on the degree of stratification of the water can reach 0.1-0.5 ml/liter with respect to oxygen, 0.02 to 0.10 with respect to pH, 0.1-0.5 µg-at P/ℓ with respect to phosphates, 0.2-2 µg-at N/ℓ with respect to nitrates, 2-20 µg-at Si/ℓ with respect to silicate.

The chemical variability as a result of changes between day and night is felt only in the photosynthesis layer. It is maximal in the highly productive regions and minimal in the oligotrophic regions. In the highly productive regions it can reach 1 ml/liter with respect to oxygen, 0.3 µg-at P/ℓ with respect to phosphates, 5 µg-at N/ℓ and 10 µg-at Si/ℓ with respect to silicon. In the low-productive regions it is an order less, and in the oligotrophic regions, two orders less.

With the development of the new equipment -- the appearance of temperature gauges, salinity gauges, gauges of dissolved oxygen, pH, transparency and others -- it became possible to introduce measurements of these parameters that are continuous with respect to the vertical. This equipment can be used not only in the sounding regime, but also for measurements that are continuous in time at the selected horizons from a drifting ship or anchored buoy. It is possible also to use them on the path of a ship, towing them behind the stern in a container at defined depth or on a towed "bar."



Short-period variability of the oxygen content and temperature in the discontinuity layer of physical and chemical parameters in the center of the test area

a -- variation of oxygen content at the 70, 110 and 170 meter levels measured by a dissolved oxygen probe; b -- variation of the oxygen content at the 60, 70, 80 meter levels; 100, 110, 120 meters; 160, 170, 180 meters (the water samples were taken by bathometers every 30 minutes, the oxygen was determined by the Winkler method); c -- vertical distribution of oxygen for the period from 1600 hours on 27 July to 0600 hours on 28 July (according to average data); d -- temperature variation at the 60, 70, 80 meter level; 100, 110, 120 meters; 160, 170, 180 meters (the measurement was taken every 30 minutes by deep-water dumping thermometers); e -- vertical temperature distribution for the period from 1600 hours on 27 July to 0600 hours on 28 July (according to average data)

Key: 1 -- ml/liter; 2 -- min

The first use of the new equipment led to the discovery of the fine structure of the water with respect to the physical parameters and also with respect to chemical and biological indexes, the discovery of the fine-scale variability as a result of micropulsation of the water with a period of several minutes [Fedorov, 1972, 1976; Ivanenkov, 1973]. The latter was traced most clearly during continuous operation of the oxygen sensors and temperature gauges during a prolonged time at the previously selected horizons. In the Atlantic "Poligon-70" the oxygen probe (having a mixing device and temperature compensation) and the thermochalinic probe AIST joined together operated 3.5 hours each at the 70, 110 and 170 meter levels, that is, in the upper, middle and lower parts of the density discontinuity layer. Water samples were taken in parallel by bathometers from the 60, 70, and 80 meter; 100, 110 and 120 meter; 160, 170 and 180 meter levels, and they were analyzed by the ordinary chemical methods. Part of the results are shown in the figure. The maximum chemical variability with a period of 10±5 minutes was noted in the middle of the density discontinuity layer at the 110 meter level. With respect to salinity it reached 0.30 parts per thousand; with respect to oxygen 0.5 ml/liter, with respect to phosphates 0.5 µg-at P/ℓ, with respect to nitrates and silicates 2-3 µg-at/ℓ, and with respect to temperature it reached 3-4°C [Ivanenkov, 1973].

The studies in the test area led to the following conclusions. It is inexpedient to construct the distribution maps for the physical, chemical, and biological parameters for the levels located in their discontinuity layer with respect to one time, random measurements. In order to isolate the variability of the chemical parameters as a result of the chemical processes, it is necessary to consider this variability not on the horizontal surfaces, but on the isopycnic surfaces, that is, the conclusion drawn earlier is confirmed experimentally [Ivanenkov, 1961].

The study of the chemical process rate in situ can be carried out in test areas over very long periods of time not measured in days, but in weeks. The hydrochemical observations over many days performed in the Atlantic "Poligon-70" and in the test areas of the Tropex-72 and Tropex-74 expeditions provided material for estimating the oxygen production and the extraction of phosphorus, nitrogen, silicon during photosynthesis and also for estimating the biochemical oxygen demand and the regeneration of nitrogen and phosphorus in the photosynthesis layer.

It turned out that in the tropical and equatorial zones of the Atlantic Ocean the oxygen production determined by its diurnal variability in situ is 3 to 4 times greater than was considered earlier beginning with the data obtained by the hour-glass radio carbon method. In the tropics 95% of the organic material created during the daylight is oxidized in the photo-synthesis layer in 24 hours, and the phosphates and the nitrates released are again used for photosynthesis [Ivanenkov, et al., 1972].

In the tropics half of the produced organic material and oxygen is created during photosynthesis in the lower part of the photosynthesis layer,

near the biogenic element and density discontinuity. The mechanism of this phenomenon consists in the mutual effect of the inertial, tidal and short-period fluctuations [Ivanenkov, 1977c]. The inertial fluctuations during the halfperiod lasting from a halfday at 30° north latitude and south latitude to 5 days at 3° north latitude and south latitude in the tropics raise the water of the density discontinuity layer by 20-30 meters together with biogenic elements and phytoplankton to the well-illuminated layers, creating optimal conditions for photosynthesis. The other half-period, unfavorable conditions for photosynthesis are created. Thus, tidal fluctuations are operative only with the period of 6 to 12 hours. As a result of short-period fluctuations, the water together with the dissolved and suspended materials, including with live phytoplankton undergoes undulating oscillatory movements with an amplitude of 5-15 meters in the density discontinuity layer. As a result of the short-period oscillations, the phytoplankton can be found under good illumination conditions for almost half of the daylight hours.

Taking into account the above-discussed mechanism, M. Ye. Vinogradov, et al. [1975] introduced a correction in the model of the ecosystem of the tropical zone of the ocean as a result of increasing the primary production every 5 days as a result of inertial oscillations.

The limits of chemical variability under the effect of climatic and physical processes of different periodicity were indicated above. By comparison with the biochemical processes at all depths their influence has predominant significance. For example, the variation rate of the oxygen concentration on any level under the effect of short-period oscillations is within the limits of 0.01 to 0.10 ml/liter per minute, and as a result of photosynthesis and destruction processes, 3-4 orders less.

In conclusion, it is possible to state that at the present time we more or less know the average picture of the distribution of the salinity, the oxygen, the pH, the CO_2, Alk, phosphates, silicic acid, nitrates, nitrites, ammonia, organic phorphorus and nitrogen in the oceans. The study of the chemical variability under the effect of physical and biological processes is only beginning. In order to learn how to predict chemical variability, complex physical, biological and chemical studies are needed.

BIBLIOGRAPHY

1. Alekin, O. A. KHIMIYA OKEANA [Ocean Chemistry], Leningrad, Gidrometeoizdat, 1966.

2. ATLAS OKEANOV. CH. I. TIKHIY OKEAN. [Ocean Atlas, Part I, Pacific Ocean], Leningrad, Izd-vo Glav. upr. navigatsii i okeanografii MO SSSR, 1974.

3. ATLAS OKEANOV, CH. II. ATLANTICHESKIY I INDIYSKIY OKEANY [Ocean Atlast, Part II. Atlantic and Indian Oceans], Leningrad: Izd-vo Glav. upr. navigatsii i okeanografii MO SSSR, 1977.

4. Bogoyavlenskiy, A. N. "Oxygen Distribution in the Waters of the Antarctic Ocean," OKEANOLOGIYA [Oceanology], Vol III, No 2, 1963.

5. Bordovskiy, O. K. OTCHET GIDROKHIMICHESKOGO OTRYADA. OTCHET 22-GO REYSA NIS "AKADEMIK KURCHATOV" [Report of the Hydrochemical Detachment -- Report of the 22nd Trip of the Scientific Research Ship "Akademik Kurchatov"], Moscow, 1976, fondy In-ta okeanologii im. I. P. SHIRSHOVA AN SSSR.

6. Bruyevich, S. V. "Some Problems of Chemical Oceanography of the Arctic, " DOKLADY NA YUBILEYNOY SESSII - 25 LET ARKTICH. N.-I. IN-TA [Reports at the Meeting and Celebration of the 25th Anniversary of the Arctic Scientific Research Institute], Leningrad, Moscow, Izd-vo Glavsevmorputi, 1945.

7. Bubnov, V. A. "Distribution Laws of the Minimum Oxygen Concentrations in the Atlantic Ocean," OKEANOLOGIYA [Oceanology], Vol VI, No 2, 1966.

8. Bubnov, V. A. "Formation of the Oxygen Minimum in the Ocean," TRUDY ATLANT. NIRO [Works of the Atlantic Scientific Research Institute of Oceanology], No 27, 1970.

9. Burkov, V. A. "General Circulation of Pacific Ocean Water," TIKHIY OKEAN [Pacific Ocean], Vol X, Moscow, Nauka, 1972.

10. Vinogradov, A. P. VVEDENIYE V GEOKHIMIYU OKEANA [Introduction to the Geochemistry of the Ocean], Moscow, Nauka, 1967.

11. Vinogradov, M. Ye.; Krapivin, V. F.; Oleyshman, B. S.; Shushkina, E. A. "Use of the Mathematical Model for Analysis of the Behavior of the Ecosystem of the Ocean Pelagic Zone," OKEANOLOGIYA, Vol XV, No 2, 1975.

12. Volostnykh B. V. "Basic Distribution Laws of Phosphates in the Waters of the Atlantic Ocean," KHIMIYA MOREY I OKEANOV [Chemistry of the Seas and Oceans], Moscow, Nauka, 1973.

13. Ivanenkov, V. N. "Primary Production of the Bering Sea," TRUDY IN-TA OKEANOL. AN SSSR [Works of the Institute of Oceanology of the USSR Academy of Sciences], Vol 51, 1961.

14. Ivanenkov, V. N. "Chemical Characteristics of the Deep Water of the Kuril Trench," TRUDY IN-TA OKEANOL. AN SSSR, Vol. 86, 1970.

15. Ivanenkov, V. N. "Basic Scientific Results of Hydrochemical Operations in the Test Area in the Atlantic Ocean in March-September 1970," KHIMIYA MOREY I OKEANOV. [Chemistry of the Seas and Oceans], Moscow, Nauka, 1973.

16. Ivanenkov, V. N. "Chemistry of the Atlantic Ocean Water," ATLANTICHESKIY OKEAN. [Atlantic Ocean], Moscow, Mysl', 1977a.

17. Ivanenkov, V. N. "Chemical Characteristics of Water Filling the Deep-Water Trenches of the World Ocean," KHIMIKO-OKEANOLOGICHESKIYE ISSLEDOVANIYA [Chemical-Oceanological Research], Moscow, Nauka, 1977b.

18. Ivanenkov, V. N. "Oxygen and Photosynthesis in the Ocean," PRIRODA [Nature], No 2, 1977c.

19. Ivanenkov, V. N.; Gubin, F. A. "Water Masses and Hydrochemistry of the Southern and Western Parts of the Indian Ocean," TRUDY MORSKOGO GIDROFIZ. IN-TA AN SSSR [Works of the Marine Hydrophysics Institute of the USSR Academy of Sciences], Vol 22, 1960,

20. Ivanenkov, V. N.; Gusarova, A. N. "Annual Exchange of Dissolved Oxygen, Silicic Acid and Inorganic Dissolved Phosphorus Between the Oceans," KHIMIYA MOREY I OKEANOV [Chemistry of the Seas and Oceans], Moscow, Nauka, 1973.

21. Ivanenkov, V. N.; Sapozhnikov, V. V.; Chernyakova, M. A.; Gusarova, A. M. "Chemical Process Rate in the Photosynthesis Layer of the Tropical Atlantic," OKEANOLOGIYA, Vol XII, No 2, 1972.

22. "Studies of the Indian Ocean," TRUDY IN-TA OKEANOL. AN SSSR [Works of the Oceanology Institute of the USSR Academy of Sciences], Vol 64, 1964.

23. Kort, V. G. "Water Exchange Between the Oceans," OKEANOLOGIYA, Vol II, No 4, 1962.

24. Kort, V. G. "Water Ex change of the Antarctic Ocean," OKEANOLOGICHESKIYE ISSLEDOVANIYA [Oceanological Research], No 8, 1963.

25. Lyakhin, Yu. I.; Ivanenkov, V. N. "Elements of the Carbonate System in the Waters of the Atlantic Ocean," KHIMIKO-OKEANOGRAFICHESKIYE ISSLEDOVANIYA MOREY I OKEANOV. [Chemical-Oceanographic Studies of the Seas and Oceans], Moscow, Nauka, 1975.

26. Monin, A. S.; Kamenkovich, V. M.; Kort, V. G. IZMENCHIVOST' MIROVOGO OKEANA [Variability of the World Ocean], Leningrad, Gidrometeoizdat, 1974.

27. Muromtsev, A. M. OSNOVNYYE CHERTY GIDROLOGII TIKHOGO OKEANA [Basic Characteristics of the Hydrology of the Pacific Ocean], Leningrad, Gidrometeoizdat, 1958.

28. Muromtsev, A. M. OSNOVNYYE CHERTY GIDROLOGII INDIYSKOGO OKEANA. [Basic Characteristics of Hydrology of the Indian Ocean], Leningrad, Gidrometeoizdat, 1959.

29. Muromtsev, A. M. OSNOVNYYE CHERTY GIDROLOGII ATLANTICHESKOGO OKEANA. [Basic Characteristics of Hydrology of the Atlantic Ocean], Leningrad, Gidrometeoizdat, 1963.

30. OKEANOLOGICHESKIYE ISSLEDOVANIYA [Oceanological Research], No 4, 1964.

31. Stepanov, V. N. MIROVOY OKEAN (DINAMIKA I SVOYSTVA VOD) [World Ocean (Dynamics and Properties of Water)], Moscow, Znaniye, 1974.

32. Treshnikov, A. F.; Maksimov, I. V.; Gindysh, B. V. "Great Eastern Drift of the Antarctic Ocean," PROBLEMY ARKTIKI I ANTARKTIKI [Problems of the Arctic and Antarctic], No 22, 1966.

33. Fedorov, K. N. "Internal Waves and Vertical Thermochalinic Microstructure of the Ocean," VNUTRENNIYE VOLNY V OKEANE [Interal Waves in the Ocean], Novosibirsk, Izd-vo SO AN SSSR, 1972.

34. Fedorov, K. N. TONKAYA TERMOKHALINNAYA STRUKTURA VOD OKEANA [Fine Thermochalinic Structure of the Ocean Water], Leningrad, Gidrometeoizdat, 1976.

35. KHIMIYA TIKHOGO OKEANA. SERIYA "TIKHIY OKEAN" [Chemistry of the Pacific Ocean. Pacific Ocean Series], Vol 3, Moscow, Nauka, 1966.

36. Horn, R. MORSKAYA KHIMIYA [Marine Chemistry], Moscow, Mir, 1972.

37. CHEMICAL OCEANOGRAPHY, edited by I. P. Riley, J. Skirrow, London, New York, Acad. Press, 1965.

38. CHEMICAL OCEANOGRAPHY, edited by I. P. Riley, J. Skirrow, London, New York, Acad. Press, 1975.

39. Wyrtki, K.; Bennett, E.; Rochford, D. OCEANOGRAPHIC ATLAS OF THE INTERNATIONAL INDIAN OCEAN EXPEDITION, Univ. Hawaii, 1971.

STATE OF THE ART AND PROBLEMS OF THE GEOLOGY OF THE OCEAN

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 99-106

[Article by A. V. Peyve, Yu. M. Pushcharovskiy]

[Text] The development of modern geology depends to a great extent on our knowledge of the geology of the oceans and seas. It is hardly necessary to talk about what enormous practical significance this knowledge has. In a brief report it is difficult to give a complete survey of the available data on the geology of the ocean lithosphere, and there is a great deal of it at the present time; therefore we shall try to discuss only the primary achievements and facts in generalized form with respect to the basic divisions of geological science. The most urgent problems of future research and geology, geophysics and geochemistry of the ocean crust will also be touched on.

The works with respect to the stratigraphic-lithologic studies of the sedimentary layer of the ocean crust constitute a large division of geological research.

Deep-sea drilling from the "Glomar Challenger" led to qualitative changes in the stratigraphy of the Cretaceous and the Cenozoic. For deposits of this age in the tropical, subtropical and temperate regions of the ocean detailed zonal scales have been developed with respect to plankton foraminifers, nannoplankton and radiolaria precisely comparable to each other. Zonal scales have been successfully created with respect to diatoms and silicoflagellates, which is especially important for the temperate and polar regions. The zonal scales with respect to plankton used for breakdown of the Cretaceous and Cenozoic of the oceans turned out to be identical to those on the continent. Thus, the necessity has arisen for creating a genuinely global stratigraphic scale of the Late Mesozoic and Cenozoic (with respect to plankton) used for the oceans and continents, for the tropical and polar regions.

It is only by using such a zonal stratigraphic scale that it is possible to solve one of the main problems of modern geology -- the problem of

synchrony (or asynchrony) of the geological processes and phenomena in the ocean basins and on the continents.

The application of the indicated scales during the course of deep water drilling makes it possible to make a detailed breakdown of the meso-cenozoic sediment of the first wave of the oceans, establish the age of the basal layers of the sedimentary mantle in many wells, discover the theoretical relation of the first and second layers of the ocean crust, obtain important data on the arrangement of the facies in space and time, and the distribution of the thickness of the sediments, and to estimate the nature of the stratigraphic series.

The combination of stratigraphic and lithologic data serves as a basis for analyzing the evolution of the paleoenvironment of the oceans over the extent of deep Mesozoic and Cenozoic time. In addition, the deep knowledge of the structure of the first layer is one of the components in the theory of the occurrence of ocean depressions and their development in the meso-cenozoic time.

In the future study of the geological sections of the ocean floor the problem of the age of the basal horizons of the first layer have exceptional significance. There is still clearly insufficient data for compiling geological maps of the propagation of these horizons with respect to the ocean floor. Such maps (with respect to fractional subdivisions) would open our eyes to a number of complex problems of the dynamics of the ocean floor.

Another problem is the analysis of the propagation and discovery of the geological meaning of the discontinuities detected in many wells and encompassing time intervals sometimes of tens of millions of years. In the overwhelming majority of cases these probably are erosions connected with variations in circulation of the water masses which, in turn, can depend on the rearrangement of the structural plan of the oceans. However, to what degree this is so, what the rate of such erosions is, what is the situation with redeposition of microorganisms -- all of these are unsolved problems.

The data with respect to the lithologic study of the sedimentary deposits of the oceans often have forced reevaluation of some of the concepts of the origin of sedimentary material developed when studying the continents, the laws of its spatial arrangement, the sedimentation rate, the discontinuities in the sediment accumulation, the depths of the ancient sedimentary basins, and so on. As a result of a comparative study of the sedimentogenesis of the continents and oceans, many new discussion problems have come up. In particular, this pertains to the problem of types of sediment accumulation in the oceans.

The discovery of the clastic deposits in the oceans formed as a result of destruction of the rock on the ocean floor is entirely new. Their study has only still just begun, but it, as is already now obvious, is of great interest both for recognition of the sedimentary process in the ocean and for investigation of the movement of the deep water masses and also tectonic reconstructions. Serious scientific conclusions can be drawn from the detection of such deposits on the continents.

In order to estimate the oil and gas bearing nature of the oceans and the bordering seas, the discovery of the composition, thickness and general laws of the structure of the first layer of the ocean crust by the deep water drilling data had special significance.

The discoveries of sedimentary horizons in the oceans over broad spaces enriched with ore components, the detailed study of the iron-manganese concretions have great scientific and practical significance.

I should also like to emphasize that the study of the volcanic rock in the oceans reveals the important role of the processes occurring at the vulcanite and ocean water interface.

At the present time we have at our disposal broad petrologic-geochemical data on the magmatic rock of the ocean crust. In the lower part of the ocean crust -- the Atlantic, Indian and Pacific Oceans -- the entire varied set of ultrabasic rock and also gabbroids, basalts and a lesser number of plagiogranite have been detected. As has now been discovered, it is this rock that makes up the solid ocean crust. This rock is found not only in the mid-ocean ridges, but also in the trenches, troughs, bounding seas, island archipelagos and in the faults of the abyssal depressions. Thus, it is now clear that over the majority of the expanse of the oceans rock has developed which is comparable to the blocks of rock of the ophiolithic association on the continents. A more detailed study performed in recent times indicates that in geochemical respects the rock does not have theoretical differences. Hence, the concept has developed which is shared by all mobilist-geologists that the ophiolites of the continents are blocks of ocean crust of the geological past.

The findings in all the oceans of quite strongly metamorphosed rock -- various amphibolites, including granatoamphibolites -- are a great discovery. The still more metamorphsed melanocratic rock is found in the inclusions of the ocean basalts.

All of this rock, with the exception of the basalts of the second layer, is strongly dislocated, but we shall discuss this later.

At the beginning of realizing the plan for deep sea ocean drilling in August 1968 from the American ship "Glomar Challenger," scientists of different countries established the basic peculiarities of the geophysical structure of the ocean crust which turned out to be 4 to 5 times thinner than the continental crust, and in the composition of which there is no

granite layer so characteristic of the continent. V. I. Vernadskiy wrote about this for the first time. Although by the end of the 1960's there was a great deal of information about the composition of the geophysical layers of the ocean crust, nevertheless, from the dredging data a geological concept was developed according to which the first layer of the ocean crust at the top is made up of sedimentary rock, and the second, basically basalts, and the third, metamorphic rock, gabbroids and partially ultrabasites. Below, as was proposed, there are ultrabasic rock of the earth's mantle. The idea was already then stated of the similarity of the sections of the ophiolites of the continents and oceans.

At the present time the geophysical and geological data completely substantiate the ideas of the composition and theoretical geological section of the ocean crust, its similarity to the ophiolites of the continents, which now does not leave any grounds for further development of the fixistic concepts.

We must note the fruitful results of studying the relief of the ocean floor. The discovery of the system of mid-ocean ridges is a great contribution to earth sciences. This discovery was the initial starting point for the concepts of plate tectonics. At the present time there are good maps in the relief horizontals of the ocean floor without which any research would be impossible. In the United States, for example, theoretically new technical means have been created for continuous detailed topographic surveying of the sea floor, which will have enormous significance.

The classical area of tectonic analysis -- the tectonic division of the earth's crust into districts in the final analysis finding expression in the tectonic maps -- has also yielded significant results in the geological study of the bottom of the oceans and seas. It is demonstrated that the oceans and large parts of them are essentially structural nonuniform, which sharpens the attention on the differentiated analysis of their geological history and geodynamics.

Two contradictory geological concepts -- fixism and mobilism -- have coexisted in geological science for the last century. Many different models explaining geological phenomenona have been advanced by representatives of one concept or another. We have already emphasized that fixism has at the present time lost its significance, being in no position to explain the results of studying the earth's crust of modern and ancient oceans. Fixism, as has been pointed out by many scientists, is also incompatible with the new geosynclinal theory, the essence of which consists in the conversion of the ocean crust to continental. Fixism, on the contrary, is forced to recognize the working of the continental crust into an ocean crust without shifting of the plates, that is, so-called oceanization.

At the present time the model of "plate tectonics" is the most widely recognized in the theory of mobilism. In this generally known model, in contrast to the mobilistic model of Begener, attention is given to two

principal groups of phenomena: 1) spreading with the formation of a new ocean crust in the mid-ocean ridges and 2) subduction of the ocean crust with respect to the Beniof surfaces with the formation of andesite vulcanism in the archipelagos.

The Geological Institute of the USSR Academy of Sciences has already for many years been developing and modifying the model of mobilism in general similar to the Vegenerov model based on a new understanding of the geosynclinal process leading to the formation of the continental earth's crust by lateral differential displacement of large and small, thick and thin plates of the continental and ocean crust with respect to different surfaces inside the lithosphere. By tectonic displacement and packing of the plates in the oceans and on the continents crustal nonuniformities arise, and conditions are created for deformations, metamorphism and magmatism. Accordingly, it is especially necessary to emphasize that, as has now been explained, the ocean crust has complex and prolonged development, multiphase metamorphism and multiple deformations which must be taken into account by the model of plate tectonics. Indeed, spreading in its initial sense is, it is possible to say, "threatened," for there is no entirely new earth's crust anywhere, there isa crust which is renewed as a result of introduction of metal material into it.

Attention is attracted by the ubiquitous tectonic processing -- schist formation, breccia formation, milonitization of the dunite-hartzburgnite complex of the lower crust of the modern oceans. If we consider the ubiquitousness of these phenomena also in ophiolitic alloctons and protrusions on the continents, it is possible to propose not only the tectonic nature of the Mohorovichich surface in the oceans, but also to think that in petrographic respects it is represented by tectonized restite. There are other zones of lateral tectonic flow of the rock masses in the lithosphere.

For understanding of the essence of geosynclinal process, detailed geological and geophysical studies of the systems made up of the deep water trench, archipelago, and bounding sea have very important significance. In these systems, in the final analysis, conversion of the ocean crust to continental takes place and they correspond to the so-called transition stage of development of the earth's crust. These are the modern geosynclinal systems. The cardinal problem in the given area is the origin of the deep water trenches and depressions of the bounding seas. The latest experiments have shown that the bounding seas can have different origin, but in many cases it has been established that to one degree or another these are strain structures. They represent an element of the tectonically unstable zones next to the ocean where along with the creative process there are destructive processes. Therefore the cause of formation of certain seas (the Sea of Japan, the Coral Sea, the Tasman Sea and a number of others) is parting of blocks of the earth's crust.

However, there are forms, for example, the deep water depressions of the Barents Sea -- the Aleutian and Bowers -- cut off from the ocean bed by the archipelagos that do exist. From the point of view of evolution of the earth's crust such a phenomenon is entirely legal.

The origin of the deep water trenches (geosynclinal trenches) still cannot be considered explained. As is known, there is the point of view that they represent the structural expression of subduction zones. Accordingly, it is necessary to mention the seismic profiles through the Kuril deep water trench obtained by the expedition of the Yuzhmorgeo Association and demonstrated at the Conference of the Interdepartmental Tectonic Committee in February 1977. A system of reflecting surfaces of the outer slope of the trench submerged under the inner slope is visible on them. Analogous profiles are obtained also by the SakhKNII Institute expedition. However, in the first case the "pleutectonic" interpretation is given, and in the second case, that the trench is a tension structure and that the second layer of the outer slope is facially replaced by the rock of the inner slope.

Geologists have been able to write more than once in the past that the deep water trenches are tension structures usually coupled to chain type of volcanic uplifts. It is worthwhile to note that the deep water trenches or, better stated, the slit type troughs, also exist outside the archipelago systems, being found within the limits of the central regions of the ocean floor. They include, for example, the Diamantina or Obi trench in the Indian Ocean. In the central part of the Philippine Sea we have the Yap trench. This confirms the idea of the nature of the trenches being that of a fault in which displacement is perpendicular to the breakage surface, but it is possible that the trenches have different origin.

Then let us touch on the problems of the shelf and continental slope geology. A great deal of attention is now fixed on the shelves. For more than 10 years the United Nations has had a Committee on Coordination of Research and Joint Development of the Mineral Resources on the Shelf of Asia. On this committee many countries are represented: Malaysia, Indonesia, Thailand, the Philippines, Japan and a number of others. The United States, the Federal Republic of Germany, Australia, Great Britain, The Netherlands and Canada are intensely interested in the work of the committee and participate in it. The committee has given special attention to finding and exploring oil and gas deposits and also to the sea coast placers. At the present time the studies have assumed a very broad scale, and several international geological and oceanological organizations have become involved in them. Moreover, a trend has been noted toward encompassing not only the shelf but also the slopes to the abyssal regions and to some degree, even these regions themselves, in the research. Additional technical means and qualified personnel and money are being found for the organization of this research. The developed capitalist countries are participating greatly in all of this work.

This is only one example of the increased interest in the study of the shelves.

From the literature on shelf geology, however, it is obvious that the required clarity is not to be found in the tectonic interpretation of the "shelf" concept.

The new ideas of the geosynclinal process, as has already been stated, offer the possibility of an entirely new approach to the understanding of the process of the formation of the continental earth's crust. It can either be mature or not mature (where the granite-metamorphic layer is still continuing to be formed) or decaying (undergoing destruction).

The shelves are formed in all of these cases, but they have significant characteristic features respectively. The general geological definition of the term "shelf" can be proposed in the following form. The shelves are the edges of the ocean or sea floor bounded by the continental slopes or sides of the deep water sea basins. Here the emphasis is placed on the edges of the bottom and not the continents as is usually assumed. This is more precise. The shelves are divided into passive and mobile.[1] The passive shelves have a plate structure and are a continuation of the structural zones of the dry land with a mature continental crust. The moving shelves are characterized by a more complex tectonic relief and they are associated with the mobile zones where the granite-metamorphic layer is in different stages of formation, and the continental crust as a whole is still not mature. The passive shelves are characteristic, for example, of the Atlantic, and moving shelves, for many regions of the western part of the Pacific Ocean.

By definition it is established that the shelves extend to the continental slope or the sides of the deep water basins. Of course, with respect to structural role this is not the same thing as is usually considered in geomorphological literature. For example, the scarps separating the continents from the oceans cannot be made parallel with the slopes of the deep water basins of the inland seas, and so on. However, they are characterized by one common characteristic: in both cases there is thinning and wedging out or breaking off of the granite-metamorphic layer. The tectonic essence of such scarps consists in this. Now we must discuss the program for future research, the results of which will depend entirely on the technical means which we shall have.

The geological-geophysical and geochemical studies are being conducted in order to discover the laws of the composition, the structure and development of the ocean earth's crust and to estimate the mineral resources in its depths.

---

[1] For more details see M. S. Markov, Yu. M. Pushcharovskiy, S. M. Til'man, "Tectonics of the Shelf Zones of the Eastern Arctic and Far Eastern Seas," SOVETSKAYA GEOLOGIYA [Soviet Geology], No 1, 1978.

As is known, in the shelf regions of the ocean and seas great quantities of oil and gas have been extracted for a long time, but it does not appear possible to estimate the mineral prospects of the oil and gas-bearing nature of the oceans themselves without deep sea drilling. The latter fact along with the primary scientific significance has stimulated the development of a plan for deep sea drilling and the construction of a special drilling ship, the "Glomar Challenger" in the United States. In the next 10 years it will be necessary to direct research toward the development of the principles of earth sciences -- stratigraphy, lithology, tectonics, geophysics, geomorphology, petrology, geochemistry and the studies of minerals using the materials from the national and international scientific programs for ocean studies.

Two divisions form the core of these programs:

1. The geological structure and history of development of the upper part of the ocean crust predominantly by the deep sea drilling data, partially with respect to dredging and geophysical data.

The leadership in compiling the deep sea drilling program and in performing these studies goes to the United States. Our goal is maximum use of the core material from the wells for the development of a national scientific program. In addition, it appears expedient to extend Soviet participation in the IPOD project. In addition to the direct participation in drilling stipulated by the agreement, the Soviet Union could develop the comprehensive study of the core material more broadly than at the present time and resolve the scientific problems of stratigraphy, lithology, petrology, geochemistry and geophysics of the oceans. The scientific research institutions of the USSR Academy of Sciences, the USSR Ministry of Geology and the Ministry of Higher Education of the USSR must be involved in this. In the future the scientists of the Soviet Union could participate in compiling general surveys of scientific data with respect to geology and geophysics of the oceans by the drilling materials.

2. The composition, age and nature of the deformations under the condition of occurrence of the rock in the lower part of the ocean crust and comparative study of the lithosphere of the oceans and continents.

Above all, these studies are connected with the study of rock corresponding with respect to its physical properties to the third and frequently the second layers of the ocean crust. We have in mind the ultrabasic rock (lherzolites, dunites, hartzburgites, and so on), metamorphic rock (green shales, amphibolites, granatoamphibolites, and so on) and also basic rock (gabbro, diabase, basalts, and so on) known in the various structures of the ocean crust of all oceans. All of the institutes of the geology, geophysics and geochemistry division of the USSR Academy of Sciences, the Institutes of the Scientific Centers of the USSR Academy of Sciences, the Republic Academies of Sciences and the USSR Ministry of Geology could unite their efforts around these experiments.

The solution of the problem is possible by using purposeful detailed multistage dredging (and in the future even by using special submarines) accompanied by auxiliary geophysical studies in the various tectonic structures of the oceans. The study of rock obtained from natural denudations will be large contribution to understanding the geology of the lower part of the ocean crust which, as is proposed, will not be studied so quickly by drilling. It is also necessary to consider that the proposed superdeep drilling cannot because of the great expense provide the abundant rock material which can be obtained when performing specialized, comparatively cheap studies of natural denudations on the steep slopes of the ocean floor.

The comparative study of the lithosphere of the oceans and continents includes not only the stratigraphic-lithologic, petrologic-geochemical and tectonic studies performed on a comparative level, but also special geophysical studies to compare the lithosphere of the oceans and continents and to solve the general problems of geodynamics.

GEOLOGICAL PROSPECTS FOR THE MASTERY OF SOLID MINERALS OF THE OCEAN FLOOR

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 107-117

[Article by P. L. Bevrukov]

[Text] The interest in the study of the mineral resources of the deep sea regions of the World Ocean has increased sharply in many countries in the last 20 years. This is connected with the ever-increasing demands for new sources of mineral raw products, the development of technical means, the expansion of knowledge about the geological structure of the ocean floor.

In this article a study is being made of the geological prospects for the mastery of solid minerals at great ocean depths beyond the boundaries of the shelves. This restriction is not at all connected with the fact that the minerals of the shallow water regions have secondary significance. On the contrary, in the near future they will be the primary object of development of the mineral wealth of the sea floor. The scientific aspects of the search for minerals on the shelves, above all, the placers of valuable heavy minerals, are discussed every year at various conferences. At the same time the problem of the exploitation of the mineral resources of the deep sea parts of the ocean still is given less attention inasmuch as it appears to be a matter of the remote future. In reality, there is still no country that is exploiting the minerals of the deep sea regions on an industrial scale. However, the preparation for it in the form of various research and experimental projects is proceeding at growing rates. Therefore it is expedient to look ahead, into the depths of the ocean and consider the modern state of the art of the knowledge with respect to this new problem.

At the present time, as a result of the work of numerous oceanographic expeditions of various countries and also deep sea drilling it is possible to state with certainty that there are various forms of potentially useful minerals or sediments and rock with increased concentrations of valuable metals in the sedimentary series of the oceans and that some of them, above all, the multicomponent iron-manganese ore concretions, are already acquiring industrial significance.

In addition, it is necessary to note that both abroad and in the Soviet popular scientific literature exceptionally optimistic conclusions are being drawn regarding the possible practical value of certain mineral formations of the ocean floor. However, the concept of the ocean floor as an inexhaustible storehouse of various types of mineral raw materials still needs prolonged, serious geological and technical-economic substantiation. Here it is necessary to consider the significant difference in structure of the continental and ocean crust, the great uniformity of the composition of the latter and the low accessibility of its deep regions. On the other hand, it must not be forgotten that the degree to which geologists have studied the oceans still remains thousands of times less than the geology of dryland.

In addition to the sedimentary series, ore mineralization shows are encountered on the ocean floor and in magmatic rock predominantly in the active volcanic ridges, in the fracture zones. However, the prospects for finding industrial deposits in these rocks at great depths still are highly indeterminant. Something will be said about the known shows of sulfide mineralization in magmatic rock of the ocean floor below. In the deep sea regions of the ocean at the present time primary attention can be attracted to the minerals not of the magmatic rock, but the sedimentary series and, above all, that occurring on the surface of the floor.

Among them, above all, it is necessary to mention the iron-manganese concretions covering enormous expanses of the Pacific, Indian and Atlantic Ocean floors. In postwar years they were studied in detail by expeditions of a number of countries, including the Soviet expeditions on the "Vityaz" and other scientific research vessels. In the last 10 to 15 years the United States and certain other countries have intensified their studies of the iron-manganese concretions in connection with proposed industrial use of them.

The most important characteristic feature of ocean iron-manganese concretions is the increased, and in places, quite high content of such valuable metals as Cu, Ni and Co in them, by which they differ from the shallow water concretions similar to those exploited in the Baltic Sea. The average content of each of these elements in the Pacific Ocean is about 0.5%, and the maximum reaches 1-2%. In addition to the mentioned metals, the concretions contain increased concentrations (by comparison with the country sediments) of Zn, Mo, Pb and a number of other metals (a total of more than 40 elements).

The iron-manganese concretions are widespread in the oceans under various tectonic and facial conditions and in a large range of depths. They occupy the greatest areas on the floor of the ocean troughs at depths from 4 to 6.5 km, that is, below the critical depth of carbonate accumulation, in regions with minimum sedimentation rate (<1 mm per 1000 years). In addition, the concretions often form accumulations on the slopes and peaks of various types of uplifts, at depths from 4 to 1 km and less where increased velocities of the bottom currents permit accumulation of sediment.

Within the limits of all, even the main, ore-bearing fields the degree of coverage of the bottom with concretions (or their concentration) varies within the broad limits -- from 0 to 90-100%. For high concentrations (approximately more than 50% they form characteristic "bridges" on the bottom. The gravimetric amounts of them fluctuate from <1 to 50-70 kg/m^2. Over many broad areas there are more than 5 to 10 kg/m^2. These values are now taken as minimal from the point of view of possible profitability of the exploitation of concretion ores (with correspondingly high quality of them).

At places where volcanic rock has been denuded on the ocean floor, this rock usually is covered with ore crusts from 1 mm to 10-15 cm thick which, as a rule, is similar with respect to composition to the iron-manganese concretions. Under the conditions of strongly dismembered relief and spotty occurrence of sediments sections of the bottom covered with concretions and ore crusts and free of both often alternate at short distances. In the axial parts of the mid-ocean ridges with especially complex relief and numerous shows of basalts, the ore crusts are encountered more rarely than the conretions.

The chemical composition of the iron-manganese concretions undergoes significant variations both on transition from certain regions of the oceans to others and in comparatively smal sections of the floor. As the most general laws let us note the following.

In the peripheral regions of the oceans where the concretions occur in the upper oxidized layer of the terrigenic sediments having a high content of organic material and were formed by purely diagenetic means, sharp fluctuations in the Mn content and its ratio to the Fe and low values of the Cu, Ni and Co, as a rule, less than 0.15% of each of them, are characteristic.

In the pelagic zones, far from the continents, a significant factor in the formation of the concretions and ore crusts becomes slow precipitation of Fe and Mn hydroxides from the bottom water. In the areas of increased biological productivity in the equatorial zones where the organic material content in the sediment increases somewhat, the concretions have a sedimentary-diagenetic origin.

The highest concentrations of Mn (20-30%) and also the Cu and Ni sorption processes connected with them in the pelagic parts of the oceans are observed predominantly at the bottom of the deep troughs. The Fe contents in the concretions present the opposite picture: in the regions of high Mn content the Fe concentrations are low (5-10%). On the underwater mountains and high abyssal hills, the Fe content in the concretions increases (to 20-25%), and the Mn, Cu and Ni content decreases. The Co content correlates to a higher degree with the Fe content than with the Mn, as a rule, also increasing on the bottom uplifts in the more oxidizing situation. The distribution laws of the metals in the concretions on the various forms of the relief were studied in detail on the expeditions on the "Vityaz" during operations in the test areas ["Iron-manganese concretions..." 1976].

In what regions of the oceans are the occurrences of concretion ores especially prospective at this time from the point of the possibility of using them and what factors give rise to this situation?

If the high Cu and Ni content in the concretions (with an abundance of concretions and relative sustained nature of the ore shows) is the main index, then in the Pacific Ocean the broad belt of propagation of copper-nickel manganese concretions extending in the northern tropical part of the ocean along the periphery of the equatorial zone of high biological productivity is of the greatest interest. Within the limits of this belt, which has a total extent of more than 4000 km, with a width of several hundreds of kilometers, the concretions most enriched with Mn, Cu and Ni, occur usually on the argillaceous-siliceous radiolaria silts. At this time abroad the greatest attention has been fixed on this belt which, for brevity, can be called the radiolaria belt, and primarily its eastern half located southeast of the Hawaiian Islands between the Clarion and Clippert fracture zones.

It must be pointed out that the first experimental work with respect to extraction of concretions on a comparatively large scale was performed by one of the American companies in 1970 on the Blake Plateau east of Florida at a depth of about 800 meters, and by a Japanese company in the same year -- in the region north of Tahiti at a depth of about 3800 meters. In the first case the hydraulic system was used, and in the second case, a continuous cable conveyor system with suspended dredges. The operating experience using these methods was used for further improvement of them. In the 1970's detailed studies and mass collections of concretions were made on the ships of the United States and the Federal Republic of Germany, primarily within the limits of the idicated radiolaria belt southeast of the Hawaiian Islands at depths from 4000 to 6000 meters; sections for primary exploitation of the concretions were noted here.

At the present time abroad preparatory work is being done to build technical means for the exploration of extraction and processing of concretion ores by more than 20 large companies (United States, Federal Republic of Germany, Japan, Canada, France and certain other countries) combined into several consortiums. According to the latest published data, the United States proposes to begin industrial exploitation of concretions in the Pacific Ocean in 1980-1981.

However, it must be emphasized that the international legal problems of exploitation of ocean concretion ores still remain unsolved. The problems of possible pollution of the ocean when extracting the concretions have still not been answered.

Within the limits of the radiolaria belt of the Pacific Ocean on the gently sloping hilly bottom of the trough at depths from 4500 to 5600 meters, the concretions contain on the average about 25% Mn, 1.2% Cu, 1.3% Ni and 0.2% Co. The total Cu+Ni+Co content reaches a maximum of 3.5%, and on the

average, about 2 to 2.5%. Although the sections with high concentrations of concretions alternately complexly with the sections of the bottom free of them, according to the data of American researchers, there are zones here with quite stable quantitative indexes, and the geological reserves of the concretions are reckoned approximately in billions of tons.

Comparing the radiolaria belt of the Pacific Ocean with other regions of it and also with the regions richest in concretions in the Indian and Atlantic Oceans, it is possible to state that in none of them do the concretions have such high Cu and Ni content over significant areas.

The regular association in the pelagic zone of the Pacific Ocean of the manganese concretions with the maximum Cu and Ni content with the broad belt of siliceous ooze around the periphery of the equatorial zone of high biological productivity permits the proposal of indirect relations of this phenomenon to the processes of biogenic sediment accumulation. This relation can be of a dual nature. First, in the zones of high biological productivity of surface water these metals obviously are transported additionally to the bottom with biogenic detritus; it is known that in the equatorial zone the absolute masses of Cu and Ni in the biogenic sediments are increasing. Secondly it is known that more significantly the radiolaria silts have the greatest porosity and somewhat increase the organic materials content; during the diagenetic processes this promotes migration upward of the Mn and the Cu and Ni together with it and accumulation of them in the concretions. Thus, the broad zonality of the biogenic sediment accumulation in the ocean obviously is also reflected in the chemical composition of the manganese concretions.

In the Indian Ocean increased concentrations of Cu and Ni in the concretions are also noted around the periphery of the zones of high biological productivity -- in the central trough, in the Western Australian and Southern Australian trenches.

If the highest Co content in the concretion ores is taken as the main index for prospective evaluation of them in the Pacific Ocean, then some interest can be attracted to the submarine mountains located in the northwestern part of the Pacific Ocean and around the periphery of the southern trench, in the vicinity of the Cooke Islands where the Co content in the concretions reaches 1.5 to 2% in places with high qualitative indexes. However, in such forms of the relief the concretions are very nonuniformly distributed.

In any part of the ocean the industrial value of the occurrences of the concretions and discovery of their actual reserves must be preceded by specialized scientific research and geological exploration work, including detailed bathymetric, geophysical, geological and lithologic surveys, underwater photography, systematic sample taking and express analysis of them on board ships. Such operations must be widely developed on the Soviet expeditions.

In addition to the iron-manganese concretions in the deep sea parts of the oceans, the so-called metal-bearing sediments are attracting great interest. They are widespread along the system of active mid-ocean ridges, especially widely in the southeastern part of the Pacific Ocean, on the eastern Pacific Ocean rise and in the sections of the deep troughs adjacent to them. These are limestone and at depths of more than 4-4.5 km, argillaceous carbonate-free sediments having increased content of Fe, Mn and many other metals. Their thickness in this part of the ocean fluctuates from several tens of centimeters to 10 meters, and the area occupied by them is measured in many millions of square kilometers. Their age is from Quaternary to Middle Miocene. A broad literature is devoted to the metal-bearing precipitates first detected on the third trip of the diesel electric "Ob'" in 1958, in the USSR and abroad. In recent years they were studied in the greatest detail on the 8th and 14th trips of the "Dmitriy Mendeleyev" scientific research ship [Lisitsyn, and so on, 1976].

The formation of the metal-bearing sediments in the vicinity of the eastern Pacific Ocean rise, more precise enrichment of them by comparison with the normal pelagic silts with Fe and Mn (on the average by approximately 2-4 times) and certain other metals is connected by all researchers with the additional inflow of endogenic ore material in the form of exhalations or hydrotherms. In favor of this is the association with the zones of high permeability of the earth's crust and increased thermal flux located in the regions of its extent and young basaltic vulcanism and also the geochemical calculations of the absolute masses of the ore materials in the sediments, primarily Fe and Mn and their ratio to the terrigenic components -- Al and Ti. This is also indirectly indicated by finding various signs of hydrothermal alteration of the sediments, in particular, manifestations of sulfide mineralization, in the regions of propagation of metal-bearing sediments in the fracture zones, for example, in the Hess basin. The enrichment of the metal-bearing silts with Cu, Ni, Zn, Co and certain other elements in some degree is caused by the processes of sorption and coprecipitation with Mn and Fe hydroxides.

By comparison with the iron-manganese concretions, the metal-bearing sediments are characterized by lower contents of all of the main metals. Thus, in the argillaceous differences of metal-bearing sediments enriched with them in the Bower basin directly to the east of the eastern Pacific Ocean rise, the Mn content reaches a maximum of 3-4%; in individual samples it reaches 7%, and the Cu and Ni are about 0.1% each, that is, approximately an order lower than in the iron-manganese concretions.

The metal-bearing sediments are present also in the regions of the mid-Indian and mid-Atlantic ridges, but the increased metal concentrations there are frequently associated with the limestone sediments and they are only discovered after recalculation for carbonate-free material. In the deep rift valleys and in the fracture zones carbonate-free sediments enriched with Fe and Mn are frequently encountered, but they have insignificant thickness.

It must be noted that in the zones of active mid-ocean ridges and rises in a number of places hydrothermal mineralization shows were detected in the form of manganese crusts. They are distinguished from the standard ocean manganese crust formed by precipitation of metals from sea water by the anomalously high Mn content (to 40-60%) and its ratio to the Fe and also by the higher (by 1-2 orders) deposition rate. During the work under the FAMOUS Franco-American project in the rift zone of the mid-Atlantic ridge direct observations from submarines and bathyscaphs established the seepage here of hydrotherms with the precipitation of Mn and Fe hydroxides on the surface of the basalts. The analogous crusts were detected by dredging within the boundaries of the same ridge and also in the fault zone in which displacement was perpendicular to the breakage surface on the axis of the Galapagos Rise [Rona, 1976; Moore, Vogt, 1976; Scott, et al., 1974].

In addition to the active mid-ocean ridges and parts of the troughs adjacent to them, the metal-bearing sediments of exhalation-hydrothermal origin in the Pacific Ocean were found at significant distance from them, near individual underwater volcanoes, in the fracture zones, for example, in the form of interlayers in pelagic clays south of the Roratonga Island where test area geological studies were performed on the "Vityaz'" scientific research ship. The metal-bearing sediments were also encountered in the cores of some of the wells from deep sea drilling in the Pacific and Atlantic Oceans in the more ancient deposits of the sedimentary series and in its base above the basalts. Their thickness in individual holds reaches many tens of meters, and the age varies from Neogenic to Cretaceous.

In all of the enumerated cases the content of such metals as Cu, Ni, Co, Zn and others in the metal-bearing sediments is below the level for which they could be considered as ore occurrences. This does not exclude the necessity for further investigation of the laws of their propagation, composition and genesis, the more so in that it is impossible to deny the possibility of finding even higher concentrations of certain valuable metals in the exhalation-sedimentary formations of the oceans.

Indirect evidence of this is the discovery about 15 years ago, it is true, in another facial situation, of a more intense modern hydrothermal-sedimentary process in the rift zone of the Red Sea located on the continuation of the system of active central ridges of the Indian Ocean. In several closed depressions in the Red Sea at depths of about 2000 meters hot (to +60°) brines were detected with increased metal content and polymetal ore sediments closely connected with these brines. These sediments were investigated by the expeditions of Great Britain, the United States and the Federal Republic of Germany (beginning in 1964) and by Soviet expeditions on the ships "Vityaz'" (1960, 1977), "Akademik Vavilov" (1967) and "Akademik Kurchatov" (1976). In 1972 deep drilling was also performed here ["Initial Reports...," 1974].

In the sections of ore sediments of the Red Sea iron-montmorillonite layers occur at the top, and iron (amorphous-hetite), sulfide and manganite, lower down. The ore sediments of the Red Sea have variable, but on the whole Fe content (maximum calculated for salt-free material about 50%), Mn content (in individual interlayers more than 30%), Zn content (more than 5%) and Cu content (to 2.5%) and also increased content in a number of other metals, including, according to the data of the American scientists, silver and gold (the latter from 0.5 to 5.6 grams/ton). The highest Fe content is characteristic for hetite sediments, and Zn and Cu, for sulfides containing sphalerite and chalcopyrite [Baturin, 1971; "Hot Brines...," 1969].

The Red Sea ore sediments are the clearest example -- natural model -- of modern marine hydrothermal post-volcanic sedimentary ore formation which began here about 10 to 20,000 years ago and is taking place with a rate approximately two orders higher by comparison with the ocean sediment accumulation.

Over the extent of the last 10 years in the United States and the Federal Republic of Germany the problem has been discussed of the industrial use of ore deposits of the Red Sea which, according to the approximate calculations, will contain in one of the basins of this sea alone in a layer 10 meters thick reserves of nonferrous and global metals estimated at several billions of dollars ["Hot Brines..," 1969].

In 1973 at the International Symposium "Oceanexpo-73" in Dusseldorf reports of several scientists of the Federal Republic of Germany were devoted to the problems of the technology of processing the Red Sea ores. It must be noted that the layers richest in nonferrous metals are located several meters below the surface of the floor. Nevertheless, the possibility of industrial development of the Red Sea ore sediments has not been removed from the agenda.

As was pointed out above, various shows of hydrothermal mineralization have been noted more than once on the bottom of the ocean not only in the sedimentary, but also in the magmatic and metamorphic rock, primarily in the fracture zones associated with the system of mid-ocean ridges and rises.

Thus, from the rift zones of the mid-Indian ridges on the 36th trip of the "Vityaz'" (1965) and on the second trip of the "Akademik Kurchatov" (1967) fragments of hydrothermally altered ultrabasic rock and amphibolites with quartz streaks with thin (to 1-2 mm) interstitial sulfide mineralization were raised. Among the ore minerals in the streaks are pyrite, chalcopyrite, ilmenite, hematite, malachite, kovellin [Rozanova, Baturin, 1971]. The spectral analyses in the streaks revealed, in addition to Fe and Cu, increased concentrations of Zn, Mo, Co, V and certain other metals. The fragments of hydrothermally altered ultrabasites with contents of the same metals and also Hg, Sn and Be which are high as opposed to the Clarke contents were collected also in the vicinity of the mid-Atlantic ridge [Dmitriyev, et al., 1970].

The most significant shows of sulfide mineralization were discovered in the fracture zones in the southeastern part of the Pacific Ocean at depths of 4-5 km by the expedition on the scientific research ship "Dmitriy Mendeleyev." Three varieties of sulfide mineralization were established here -- magmatic, late magmatic and post-magmatic [Smirnov, et al., 1975]. The magmatic sulfides were detected in the dolerite blocks in the transform fracture zone intersecting the eastern Pacific Ocean rise in the vicinity of 34° south latitude. The dolerites contain accumulations of titano-magnetite crystals with which sulfide impregnation represented by the finest pyrrotine crystals is associated. The postmagmatic sulfides were discovered in the basalt clastics, and they are represented by phenocrysts and thin streaks of chalcopyrite, bornite and covellite. The post-magmatic sulfides were detected in blocks of serpentinized gabbro-norites, dolerites and basalts in the Hess basin in the axial part of the Galapagos Ridge near its articulation with the eastern Pacific Ocean rise. This basin is considered as the young center of separation of the lithospheric plates. Here the rock is dismembered by fine streaks of quartz and calcite with fine pyrite and chalcopyrite grains.

The presented data indicate that the rift zones of the mid-oceanic ridges, the fault zones where the movement is perpendicular to the breaking surfaces and the transform fractures mark the channels conducting the hydrotherms and exhalation from the depths of the crust and the upper mantle. The scales of the detected ore mineralization shows in the magmatic and metamorphic rock of the ocean floor are not large, but considering the low degree to which it has been studied, it is still impossible to refute the possibility of finding more significant ore shows on the ocean floor. At the same time it must be considered that in contrast to the iron-manganese concretions which can be scraped or sucked from the floor surface, the exploitation of ore deposits in magmatic rock would require drifting of mines. Under the conditions of the great ocean depths, this appears to be hardly possible in the foreseeable future. Nevertheless, it must be emphasized that further study of the endogenic ore shows in the oceans is extraordinarily important for recognition of the geological processes occurring in the ocean crust and the peculiarities of the formation of ore deposits on the continents.

Among the nonmetallic mineral resources of the ocean floor the phosphorites developed on the shelves and on the submarine mountains are of defined interest.

On the shelves the phosphorites are represented predominantly by concretions and grains, and they are located on the coasts of West Africa, the eastern states of the United States, California, Peru and Chile and on the Chatham Plateau and also in certain other regions. Phosphorites are absent on the shelves of the Soviet seas.

Modern and late Quaternary phosphorites [Baturin, 1969] have developed on shelves of Namibia, Peru and Chile; on other shelves the phosphorites have prequaternary age -- from Neogenic to Late Cretaceous (off the coast of Morocco), that is, they are relict formations [Bezrukov, Baturin, 1976]. As was proven by G. N. Baturin, the phosphorites on the shelves were formed in the zones of upwelling and high biological productivity, and they have biogenic-diagenetic origin. The P_2O_5 content in them fluctuates from 20 to 30%. The geological reserves are significant in places; for example, off the coast of California they are reckoned at several billion tons.

In the remaining shelf regions test extraction of phosphorites was tried, but then the work was halted. In each of the regions of propagation of shelf phosphorites, the prospects for their use depend on many factors: the quantity per unit area (as a rule, low), the conditions of occurrence, quality, total reserves, the development of the deep-sea equipment and growth rates of the demands for phosphate raw material. On the whole the widespread practical use of shelf phosphorites is obviously a matter of the remote future, the more so in that on the dryland in recent years new large phosphorus-bearing basins have been discovered, and many long-known basins have still been far from used up.

On the submarine mountains the phosphorites are the most widespread in the northern part of the Pacific Ocean at depths from several hundreds of meters to 3-3.5 km. They are represented by white and brown dense rocks coated with iron-manganese crusts. The phosphorites of the submarine mountains are of the metasomatic phosphorite type; the phosphate in them usually replaces the calcium carbonate of bentogenic and pelagic limestones. The P_2O_5 content in the purest differences in locations reaches 25-32%, but on the basis of the extremely nonuniform occurrence at the tops and on the slopes of the mountains. At great depths the phosphorites of this type at the present time do not appear to have any practical value.

In concluding this brief survey of mineral resources (both already discovered and proposed) and individual shows of ore mineralization, it must be emphasized that they do not exhaust the list of possible sources of mineral raw material on the surface and in the depths of the ocean floor. For scientific prediction of mineral resources over the broad expansions of the oceans it is necessary to have further development of the theoretical studies aimed at discovery of the basic laws of sedimentogenesis, geological structure and geological history of the oceans in their various tectonic regions. It is necessary in a planned way to study the processes of sediment and ore formation, underwater vulcanism, the tectonics of the nodal regions of the ocean. Along with improvement of the lithologic, geochemical and tectonic maps compiled long ago it is necessary to compile geological maps of the oceans (with removal of the Quaternary cover where it has insignificant thickness) [Bezrukov, 1971]. All this requires significant expansion of the geological and geophysical studies in the oceans.

The systematic studies in the geological test areas with purposeful dredging of the magmatic and sedimentary rock of the bottom used on the expedition of the Oceanology Institute of the USSR Academy of Sciences over a period of many years are especially prospective. The fastest organization of ocean drilling on Soviet ships is needed to solve many of the fundamental and practical problems of geology.

BIBLIOGRAPHY

1. Baturin, G. N. "Autigenic Phosphorite Concretions in the Modern Sediments of the Shelf of Southwest Africa," DOKL. AN SSSR [Reports of the USSR Academy of Sciences], Vol 189, No 4, 1969.

2. Baturin, G. N. "Deep Sea Ore Sediments of Hydrothermal Genesis," ISTORIYA MIROVOGO OKEANA [History of the World Ocean], Moscow, Nauka, 1971.

3. Bezrukov, P. L. "Problems of the Theoretical Investigation of Ocean Minerals," OKEANOLOGIYA [Oceanology], Vol XI, No 6, 1971.

4. Bezrukov, P. L.; Baturin, G. N. "Lithology and Age of Ocean Phosphorites," LITOLOGIYA FOSFORITONOSNYKH OTLOZHENIY [Lithology of Phosphorite-Bearing Deposits], Moscow, Nauka, 1976.

5. Dmitriyev, L. V.; Barsukov, V. L.; Udintsev, G. B. "Rift Zones of the Ocean and the Problem of Ore Formation," GEOKHIMIYA [Geochemistry], No 8, 1970.

6. "Iron-Manganese Concretions of the Pacific Ocean," TRUDY IN-TA OKEANOL. [Works of the Oceanology Institute], Vol 109, 1976.

7. Lisitsyn, A. P.; Bogdanov, Yu. A.; Murdmaa, I. O., et al. "Metal-Bearing Sediments and their Genesis," OKEANOLOGICHESKIYE ISSLEDOVANIYA [Oceanological Research], No 29, 1976.

8. Rozanova, T. V.; Baturin, G. N. "Ore Hydrothermal Shows at the Bottom of the Indian Ocean," OKEANOLOGIYA, Vol XI, No 6, 1971.

9. Smirnov, V. I.; Bogdanov, Yu. A.; Borodayev, Yu. S., et al. "Sulfide Mineralization in the Basic Rock of the Bottom of the Pacific Ocean," DOKL. AN SSSR, Vol 223, No 3, 1975.

10. HOT BRINES AND RECENT HEAVY METAL DEPOSITS IN THE RED SEA, New York, Springer Verl., 1969.

11. INITIAL REPORTS OF THE DEEP-SEA DRILLING PROJECT, Washington, Vol XXIII, 1974.

12. Moore, W. S.; Vogt, P. R. "Hydrothermal Manganese Crusts from the Two Sites near the Galapagos Spreading Axis," EARTH AND PLANET. SCI. LETT, No 29, 1976, pp 349-356.

13. Rona, P. A. "Pattern of Hydrothermal Mineral Deposition. Mid-Atlantic Ridge Crest of Latitude 26°N, 1976," MAR. GEOL., Vol 21, No 4, 1976.

14. Scott, M. A.; Scott, B. B.; Rona, P. A., et al. "Rapidly Accumulating Manganese Deposit from the Median Valley of the Mid-Atlantic Ridge," GEOPHYS. RES LETT., No 1, 1974, pp 355-358.

GEOPHYSICAL STUDIES OF THE OCEAN AND SEA FLOOR IN CONNECTION WITH THE PROBLEM OF UTILIZING THE MINERAL RESOURCES OF THE CONTINENTAL SHELF OF THE USSR AND THE WORLD OCEAN

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 136-145

[Article by V. V. Fedynskiy, B. A. Bondarenko, A. N. Volkoye, I. A. Garkalenko, I. S. Gramberg, R. M. Demenitskaya, M. R. Nustil'nikov]

[Text] In the "Basic Areas of Development of the National Economy of the USSR in 1976-1980" approved by the 25th Congress of the CPSU, the goals of the scientists and the geological explorers with respect to solving the problem of investigating the World Ocean are clearly defined.

In this article a brief discussion is presented of the state of the art and the goals of geophysical research to study the geological structure and mineral resources of the seas and oceans performed by the USSR Ministry of Geology and other ministries and departments.

It must be noted that the bodies of water of the World Ocean were the first areas of the earth where geophysical research began to be performed in practice in the complete absence of reliable geological information. Moreover, modern concentrations of the geological structure of the bottom of the seas and especially the oceans developed primarily on the basis of marine geophysics data.

The World Ocean is a complex, varied subject of geophysical research. As is known, the following large-scale morphological elements have been isolated in it: the continental boundary, the deep-sea bed and the mid-ocean ridges.

In the total area of the World Ocean of 361 million km^2, the continental shelf makes up 42 million km^2, the continental slope is 31 million km^2, the deep-sea part is 288 million km^2, including the middle ridges of about 20 million km^2.

The geological structure of the bottom of the ocean can be represented by four theoretically different models: the continental shelf, the continental slope, abyssals and mid-ocean ridges.

The presence of a basement made up of folded rock of different age and different degree of metamorphosis under the sediments of any thickness and degree of lithification is characteristic of the shelf. The crust is 35-20 km thick and is underlain by normal mantle. The model of the continental slope and foot has a similar, but more complex nature inasmuch as it is a continent-ocean joining structure. In it two subtypes are isolated -- the Atlantic and Pacific Ocean subtypes distinguished by the fact that the Pacific Ocean subtype includes modern troughs and archipelagos, and the Atlantic subtype includes submerged ridges and quiet troughs. These two subtypes indicate that the regions represented by them are in a different geodynamic condition.

The model of the abyssal part of the ocean includes layers of sediments, vulcanites and foundation of undiscovered origin underlain by the normal mantle. The total thickness of the crust here is about 5 km.

The discontinuously minimum amount of sediment on the thick lens of vulcanites which is underlain by the anomalous mantle is characteristic for the model of the mid-ocean ridges.

The surface layers of the bottom of the World Ocean are essentially distinguished with respect to their structure from the dryland, and they are represented by a total of two geological formations: the modern nonlithified sediments and the shows of vulcanites no older than the Jurassic. The areas of the shelves and the submarine promontories which are the drowned remains of continents constitute an exception.

Here we shall not discuss the theoretical ideas of the tectonics of the ocean floor which at the present time are a subject of scientific discussion. The main concepts are based either on the hypothesis of working of the earth's crust of the continents into the ocean crust or the hypothesis of continuous creation of a new crust on the planet as a result of building up of the ocean floor and movement of the lithospheric plates.

Independently of the concepts adopted, it is entirely obvious that the oceans have not been constant in their position on the surface of the earth. Along with gradual, evolutionary, slow or even sporadic changes in the floor occurring during fading ages, there were two (or more) large evolutionary ages when the entire appearance of the surfacesof the continents and the ocean floor underwent basic change.

The laws of distribution of minerals in the earth's crust of the World Ocean have enormous practical significance. It has been established that a significant part of the shelf area turns out to be prospective for prospecting for industrial occurrences of oil and gas although the degree of prospectiveness and the forecasted reserves in each case are different. Oil and gas are detected both on the shelf and on the continental slope. The oil and gas bearing nature of the abyssal zones of the ocean still has been little studied.

The solid minerals in the World Ocean have different manifestations. Placer deposits are connected with the shelf. In the abyssal zones, the basic object of exploration is iron-manganese and phosphate concretions and also ore-bearing ooze and brines.

With respect to the overall estimate of the Soviet and foreign specialists these concretions are a complex ore which can be used to extract iron, manganese, copper, nickel, cobalt, phosphate and certain transuranium elements. The oozes and brines are characterized by a large complex of useful components (including gold, lead, silver, tin, thallium, zinc) and a favorable form of occurrence along the narrow and deep tectonic zones. The technology of their extraction appears to be theoretically simple.

The continental shelf of the USSR is one of the largest in the world. In practice all of the types of large geotectonic elements known in the territory of the USSR are encountered within the limits of the shelf: ancient and young platforms, Paleozoic, Mesozoic and Cenozoic folded regions.

The main goal of regional geological-geophysical studies on the shelf is the study of the thickness of the sedimentary mantle, the boundaries of the oil and gas-bearing basins and their structural levels.

Considering the economic aspects of mastery of the shelf, the prospecting and preparation of large structures with the proposed multilevel nature of the productive complexes in the most favorable areas for exploitation are urgent.

The work with respect to prospecting for solid minerals was done up to the present time in the eastern seas of the Arctic Ocean and also in the Baltic Sea, the Sea of Okhotsk and the Sea of Japan. It is necessary to expand the range of prospecting operations, to give a regional estimate of the presence of solid minerals and then concentrate work in the areas, the minerals of which are of the greatest economic interest.

The geophysical methods and technical means which the Soviet specialists and organizations have at their disposal are highly varied. They made it possible to organize studies to solve the enumerated geological problems on a large scale. It is necessary to note that the marine geophysics research in the USSR began to be performed long ago: electrical explorations since 1933, gravimetric work since 1935, seismic exploration by reflected waves 1941, and complex geophysical research, 1948.

At the present time in order to solve the geological problems, complexes are being used with automatic recording of measurements and processing of them on a computer. The composition of the complexes of marine geophysical operations is as follows: for regional studies, deep seismic sounding, geoacoustical investigation, on-board gravimetry, hydromagnetometry, geothermal measurements; during exploration and preparation for exploration of oil and gas prospective structures, a reflected wave seismic exploration,

geoacoustics, on-board and bottom gravimetric surveying, magnetic surveying, sometimes electrical exploration; when studying the deposits of solid minerals, electrical exploration, geoacoustics and magnetic exploration. The experimental-procedural work with the application of all geophysical methods have significance, for there are still many insufficiently resolved problems in marine exploratory geophysics.

The seismic techniques have been mastered in modifications that are harmless to marine fauna and with nonexplosive sources of elastic vibrations.

The USSR Ministry of Geology has specialized expeditionary ships of basically two types available for performing geophysics research: small ones of up to 500 tons with limited navigational range and autonomy up to 10 days and medium ships up to 500-1500 tons with unlimited range and autonomy to 30 days. The ships of the second type permit complex geophysical studies on the shelves of the seas of the USSR and in the World Ocean.

The broad bodies of water in the World Ocean of the Arctic, the Antarctic and certain other regions are covered by aeromagnetic and aerogravimetric surveys. The aerogravimetric survey for studying gravitational anomalies of the World Ocean is especially prospective, for the accuracy of the gravimetric measurements obtained here is only slightly inferior with respect to accuracy to the marine on-board gravimetric survey.

In the Arctic and Antarctic, airborne landing activities are carried out in which the geophysical measurements are performed on ice.

The navigational support of the marine geophysics operations has the most important significance. Various navigational systems are used for this purpose. The USSR Ministry of Geology jointly with a number of other organizations is involved in creating a navigational complex, including a navigational information gathering and storage system, calculation of the coordinates and control of both the ship and marine geophysics operations.

A distinguishing feature of the geophysics operations on the sea is simultaneousness of obtaining information -- seismic, gravimetric, magnetometric, navigational, and so on. For gathering and recording the geophysics and navigational data on carriers and in the Minsk-32 computer format at the present time the semiautomatic Grad system is used. In 1975 an on-board analog-to-digital complex for proce-ssing seismic data on the basis of the Minsk-32 computer was developed and introduced into production. It performs express processing of seismic explanation data by the common depth point method. Work is being done to create an on-board, fully automated complex for recording and primary processing of geophysical data and insuring quality control of material.

For processing the marine geophysics information at the shore computer centers, the Minsk-32 computers are used which are also equipped with

devices for coupling the nonstandard, peripheral equipment to the computer, input of geophysical data and output of the processing results to the plotters. The software is sufficient for executing highly varied versions of data processing for a complex of geophysical methods.

The shore centers process the entire set of navigational-geophysical data in which the primary role both with respect to volume and with respect to complexity of processing is played by seismic exploration. The closest problem is improvement of the power and output capacity of the existing shore computer centers.

The production organizations of the Ministries of Geology of the RSFSR and the Ukrainian SSR, the Soyuzgeofizika Association, the VNIGRI, NILZarubezhgeologiya institutes, and so on are participating broadly in the resolution of the problems of marine geophysics and performing marine research.

These organizations in cooperation with the organizations of the other departments are developing and manufacturing marine geophysics equipment in individual models (the digital equipment for gathering geophysics data on board the "Grad" ship, the shore computer complex based on the Minsk-32 computer, the on-board gravimetric complex, the Poisk-ATM geodetic system, and so on).

Let us proceed with a brief survey of the results of the geophysical operations on the continental shelf of the USSR.

Caspian Sea. It is possible to consider the Caspian Sea the cradle and school of Soviet marine geophysics. At the present time the greater part of the geophysics operations in the Caspian are carried out by the Ministry of the Petroleum Industry.

The regional studies have demonstrated that the Caspian Sea in the north belongs to the epihercine and precambrian platforms, and in the south, to the alpine geosynclinals. The platform part consists of heterogeneous blocks of different age, and the thickness of the sedimentary rock fluctuates from 2-3 to 10-15 km.

In the southern part of the Caspian Sea seismic exploration has been used to map a large number of structures in the body of the tertiary sediments. Especially large and prospective structures are located within the boundaries of the Apsheron threshold and the Baku Archipelago. A number of structures have been explored by the deep drilling, and industrial oil and gas deposits well known to everyone have been discovered in them.

The Azov-Black Sea Basin. Until 1968, primarily regional geophysical studies were performed in the Azov and Black Seas.

The last 5-year period has been characterized by a sharp increase in volume of the seismic exploration work, the introduction of multiple seismic profiling with respect to the common depth point method.

In 1978 within the limits of the Azov and Black Sea Basins about 100,000 running km of seismic profiles have been made; of them about half were made by the common depth point method. The planned gravimagnetic surveys are being performed at the present time basically in the deep sea regions of the Black Sea.

By the results of regional investigations at the present time a quite detailed study has been made of the structure of the first structural stage of the northwestern shelf of the Black Sea. The thickness of the sedimentary deposits in the depressios reaches 7 to 10 km. In the deep sea trench primarily in the Crimean-Caucasus sector of the sea, the thickness of the sedimentary series reaches 12-14 km; a number of large uplifts have been isolated. Within the boundaries of the Azov-Black Sea basin, geophysical research has revealed more than 90 local structures.

Exploratory drilling was carried out in the Golitsyn structure in the Black Sea and in the structures of the Azov Sea.

A deficiency of the geophysical operations in the Azov-Black Sea Basin is their shallow depth, as a result of which at the present time the structural plan of only the Cenozoic deposits is relatively well known. In addition, up to now the problem of the nature of the joining of the Crimean and Caucasus folded systems has still not been solved, and this makes it impossible uniquely to define the region of development of the productive complexes here.

Far Eastern Seas of the USSR. The geophysical methods in the Far Eastern bodies of water have received intensive development, beginning in 1966. Since 1973 seismic exploration has been carried out by the common depth point method. The multiplicity of the observations increased from 6 to 24. The greater part of the seismic work is done on the Sakhalin shelf. Along with seismic methods, bottom and on-board gravimetric surveys, magnetic, electrical exploration and geochemical studies are used.

The exploratory and detailed geophysical work has encompassed the northeastern and southwestern Sakhalin shelves. Other sections of the Sakhalin shelf have been basically studied to the regional and exploratory stages. In all the remaining areas of the Far Eastern seas the regional stage of study has still not been completed.

Within the boundaries of the Sakhalin shelf and adjacent bodies of water zones of development of maximum thicknesses of the sedimentary formations have been isolated. In the coastal bodies of water of Sakhalin, the presence of downwarps and depressions has been established in the Tatar Strait, Sakhalin Gulf and along the east coast of the island where the

thickness of the Meso-Cenozoic formations reaches 5 to 8 km. Within the boundaries of the troughs on the shelf a number of anticlinal zones have been discovered which are prospective for oil and gas; the majority of them continue from the dryland regions with established oil and gas-bearing nature.

The insufficient depth of regional geophysical studies and slow rates of performing them beyond the boundaries of the Sakhalin shelf must be noted.

Along the coast in the Far East there have also been explorations of the coastal deposits of solid minerals.

Arctic Sea. The planned complex geophysics research in the Arctic Seas of the USSR began in 1963. Considering the specific nature of the work on the Arctic shelf, an efficient complex of regional studies was developed and introduced. The basic forms of research are the leading aeromagnetic survey, the airborne landing gravimetric observations and spot seismic soundings by the reflected wave method. By 1972 systematic studies had encompassed the entire Arctic shelf and a significant part of the polar ocean basin.

The beginning of the second phase of geophysics studies came during the years of the Ninth Five-Year Plan. In the complex of geophysics methods, the seismic profile studies by the reflected wave method and also in small volume, by the refracted wave method are acquiring leading significance. They are combined with the bottom gravimetric observations and a hydro-magnetic survey. For the second phase, enlargement of the scale of the studies to 1:500 000 and even 1:200 000 is characteristic.

By the results of the studies survey geophysical maps, structural-tectonic diagrams and geological-geophysical sections were compiled.

Both a series of fragments of the platforms located on the dryland (Russian, Western Siberian, Siberian) and intrashelf platform formations (Bering-Kara and Hyperbora platforms) have been established over this enormous area. In the region of development of platform type structures the Arctic shelf is characterized by block structure.

Another part of the shelves of the Arctic Basin (the southern parts of the Eastern Siberian and Chukhotsk Seas) complicated by the folded structures of Mesozoic Age is the region of predominant development of plicate dislocations and it is significantly less disturbed by block adjustments. The boundary between these two regions runs across the shelf of the Sea of Laptev, representing a centriclinal of the deep-sea European sedimentary subbasin of the Arctic Ocean.

During the process of regional studies of the USSR Arctic shelf, large sedimentation basins were discovered which are characterized by the duration of the development and significant thickness of the sedimentary mantle.

The explorations of the solid minerals on the Arctic shelf were started in 1973. The forecasting-estimating and exploration work still performed in small volume, has demonstrated that the shelves of the Eastern Arctic region where the principal metallogenic provinces of the northern part of Asia are traced have the greatest prospects for the discovery of submerged and modern placers in the coastal zones of the seas.

Baltic Sea. In the last 10 years in the Baltic Sea bottom gravimetric, hydromagnetic and aeromagnetic surveys were made. The regional seismo-exploratory studies by the reflected wave method were completed, and seismic exploratory operations by the refracted wave method have been completed.

According to the regional geophysical materials for the Baltic Sea, the boundaries of the Baltic syneclise have been drawn off, its sedimentary origin is proved by the stratigraphic subdivisions from the upper Proterozoic to the Neogene-Quaternary system.

For regional operations, more than 20 local uplifts have been detected.

The extrapolation of the predicted petroleum criteria from the coast to the water permits consideration of the greater part of the central Baltic prospective for oil in the lower Paleozoic, basically the middle to upper Cambrian deposits.

As a result of the geophysical operations in the central part of the sea, accumulations of iron and manganese concretions were discovered; significant reserves of building materials have been detected in the Finnish and Riga Gulfs. The underwater slope of the Sambiyskiy Peninsula is prospective for amber and phosphorites. Possibly the argillaceous silts occupying the central part of the deep sea depressions of the Baltic Sea are prospective for claydite raw material. Small accumulations of ilmenite-zirconium placers have been detected in the coastal region.

The investigation of the shelves provided much new data on the geological structure and the laws of distribution of minerals in the shallow parts of the World Ocean closest to our country. However, the interest in the deep sea bed which is exhibited by all countries of the world is caused not only by the fact that the ocean floor is an enormous additional area where minerals can be found but also by the fact that the ocean itself is an arena where the geodynamic situation of the Meso-Cenozoic period of the life of the earth can be most completely understood. Therefore in parallel with the broad development of marine geological-geophysical operations on the USSR continental shelf, Soviet geophysics research is being done in the World Ocean, including by the efforts of the USSR Ministry of Geology. The procedure being followed consists in traveling regional transoceanic complex routes. Individual parts of the ocean are subject to test area surveys. As a result of this work enormous amounts of material

are gathered with respect to the deep structure of the oceans. It is especially necessary to note the complex study of the Arctic Ocean. How paradoxical that this ocean is the most systematically and fully studied as a result of the fact that when performing geophysical work the drift ice was used as a type of "ice land."

The materials with respect to investigation of the oceans were an important basis for compiling both tectonic maps with respect to individual regions and tectonic map of the world. As for minerals directly, for the deep sea part of the World Ocean today obviously the solid varieties are emerging in first place with respect to significance.

According to the estimates of the United Nations, the exploitation of such ocean formations as the iron-manganese concretion, in spite of the tedious and expensive introduction of the ocean mining and extracting industry into operation, in the final analysis it can lead to cutting the price of certain metals in half.

In the complex program for further strengthening and improving the cooperation and development of socialist economic integration of the member countries of the CEMA adopted at the 25th meeting of the CEMA in 1971, the problem of "investigation of the seas and oceans for purposes of utilizing their mineral resources" will be among the most important scientific and technical problems which are the objects of joint development on a multisided basis. In 1972 an agreement was signed for scientific and technical cooperation with respect to the problem, the participants in which are the geological departments of the member countries of the CEMA.

The implementing of the programs for scientific and technical research and planning and design work in the field of marine geology and geophysics are being participated in by 32 organizations of the cooperating countries.

The programs define the specific assignments forming the following three basic areas:

1) Complex geological-geophysical studies in individual parts of the World Ocean to determine the prospects for the use of mineral raw resources of the sea floor;

2) Geological-geophysical studies of the national shelves of the cooperating countries to utilize mineral raw materials of the national economy;

3) The development and the creation of highly effective technical means for insuring geological-geophysical studies and geological exploration work on the shelves and in the World Ocean.

When developing assignments, various forms of cooperation are used: on the basis of the coordination plans, by creating temporary working collectives, on the basis of multisided agreements with partial or complete financial mutual calculations; for example, for performing the geological exploration work in the Baltic Sea, a joint organization of three countries has been created (German Democratic Republic, Polish People's Republic and the USSR).

On the whole the programs for scientific and technical research and design work are being successfully implemented.

The forecasting reports with respect to the main areas of the problem have been developed: 1) theoretical prerequisites and general geological study of the World Ocean as the basis for exploring for minerals; 2) geological-geophysical studies in the seas and oceans for purposes of exploring the oil and gas deposits and also solid minerals; 3) geophysical methods and technical means of exploring oil, gas and solid mineral deposits.

In 1972-1976 studies were made by 17 joint expeditions in the Black and Baltic Seas, in the Atlantic and Pacific Oceans on the ships of the People's Republic of Bulgaria, the German Democratic Republic, the Polish People's Republic and the USSR for regional investigation of the geological structure and complex studies of the prospective forms of mineral raw material. As a result, a preliminary estimate is presented for the metal-bearing placers at the southern part of the shelf of the People's Republic of Bulgaria and the boundary regions of the shelf of the German Democratic Republic and the Polish People's Republic. A preliminary forecasting estimate was made of the construction materials reserves in the sectors of the German Democratic Republic, the Polish People's Republic and the USSR in the Baltics. New data have been obtained on the distribution of the accumulations of the iron-manganese concretions.

In the field of creating technical means, the on-board system for express processing of geophysical data using the YeS-1010 computer in the marine execution has been developed and undergoing sea trials, and the software for it has been developed (Hungarian People's Republic and the USSR). On the basis of the cooperation of the German Democratic Republic, the Polish People's Republic and the USSR, a set of marine magnetometric equipment has been developed (a magnetometer, gradiometer, magnetic variation station). The first marine tests have been set up and run on the model of the nuclear-analytical complex for express analysis of the formations of the sea floor (Hungarian People's Republic and the USSR).

An assignment has been realized for the creation of a digital receiver for marine electrical exploration (the USSR and the Hungarian People's Republic).

Another form of international cooperation with respect to study of the ocean is the participation of the Soviet Union in the program for deep-sea ocean drilling on the American ship "Glomar Challenger."

In the next 10 to 15 years the marine geophysics research to study the geological structure and mineral resources of the continental shelf of the USSR and the World Ocean performed by Soviet scientific and production organizations undoubtedly will receive further intensive development. There is no doubt that the volume of this work will increase much more rapidly than on the dryland. The geophysical operations in the sea will receive especially powerful qualitative stimulus with assimilation of deep-sea drilling equipment in our country.

The theoretical significance of the development of marine geophysics research appears no less important. The broad study of the laws of the physical fields and various parameters of the sea floor on the basis of new material and by means of new procedures has aroused economic interest in the structure of the lithosphere. The modern structure of the ocean floor undoubtedly is a consequence of the fundamental processes of the geological development of our planet. Therefore, from the theoretical point of view the problem number one in studying the ocean floor is understanding the genesis of the ocean which can serve as the key to reproducing the history of the development of the earth as a whole and to the discovery of the mechanism of the processes of self-regulation of the planet as a developing system.

BASIC RESULTS OF RESEARCH IN THE OCEAN REGIONS OF POLAR LATITUDES (POLEX PROGRAM)

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 146-156

[Article by A. F. Treshnikov]

[Text] Soviet oceanological research in the polar regions encompasses a period which at the present time is reckoned in decades. The basic stages of this period reflect the development of studies from the first natural observations on the "North Pole" drift stations to the large-scale hydrologic surveys of the Arctic Ocean by the high-latitude "Sever [North]" expeditions, from formulations of the principles of the study of the hydrometeorologic regime of the Arctic Ocean to the establishment of the basic laws of the geographic distribution of the main hydrologic elements, from the efforts of the scientifically based prediction of weather and ice conditions on the North Sea Lane to the creation of the system for scientific-operative support of navigation.

By the 1970's, important scientific results were obtained, the basic content of which reduces to the following.

1. The structure of the water masses and three-dimension circulation of the water of the Artic Basin was established, and the role of the inflow of Atlantic and Pacific Ocean water in the formation of the hydrologic regime of the Arctic Ocean was discovered.

2. A study was made of the basic laws of the ice drifts in the Arctic Basin. The Mesoscale effects were discovered which arise in the ice cover. A theoretical analysis was made of the tidal rarefications and compressions of the ice.

3. A study was made of the nature of the flows in the bordering Arctic Seas and the laws of the thermal conditions of the Arctic Seas.

4. A study was made of the basic laws of formation, the dynamics and the rupture of the ice cover of the Arctic Seas. A procedure was created for long-range forecasting of the ice conditions in the Arctic Seas during the navigation period on the basis of the statistical analysis of their cause and effect relations to the atmospheric processes.

5. The basic laws of the tidal and nonperiodic fluctuations in the level of the Arctic seas have been established, and statistical methods of forecasting them have been developed.

Thus, as a result of the studies made, the basic features of the hydrologic regime of the Arctic Ocean and bordering seas were not only discovered, but the principles of scientific-operative support of navigation were created on the basis of the qualitative description of the laws of formation of the ice hydrologic conditions.

The holding of the International Geophysics Year was the beginning of planned studies by the Soviet scientists in the Antarctic Ocean. The oceanographic trips of the diesel electric "Ob'" and other ships of the Soviet Antarctic Expedition begun in 1956 and continuing in subsequent years were a major contribution to the oceanography of the Antarctic Ocean.

New circulation systems of the surface waters in the Antarctic Ocean and coastal seas were constructed; the basic types of water masses were discovered; the first estimates were made of the water exchange through Drake Passage and in a section along 20° east longitude; the basic features of the ice conditions of the Antarctic were established; the first information was obtained about the formation of the hydrologic conditions of the shelf seas.

The analysis of the indicated results of the oceanological research demonstrated that in spite of defined achievements in studying the oceanological conditions of the polar regions, it was necessary to raise these studies to a qualitatively new level, to formulate the theoretically different problematics of the studies. The fact is that the performed studies made it possible to study in sufficient detail the behavior of the individual physical processes and phenomena in the ocean and to formulate the hypotheses regarding their nature and variability. However, for further development of the constants of the evolution of these processes and especially for the development of numerical methods of their forecasting, on the basis of the complex study of the processes in both media it was necessary also to find and qualitatively estimate the mechanisms responsible for the large-scale interaction of the atmosphere and ocean. The search for these mechanisms is impossible without the clear idea of the quantitative relations in the large-scale energy exchange of the atmosphere and ocean and estimation of the role of the ocean in the overall energy balance of the system. The specifics of this problem for the polar regions consists in their basic role as energy drain zones. It was necessary to estimate the energy

role of the polar regions in the global energy balance also in the Global Atmospheric Research Program (GARP) developed by the WMO in 1968.

The necessity for the resolution of the indicated problems also gave rise to the creation of long-term programs for the study of large-scale interaction of the ocean and atmosphere in the polar regions such as the "natural experiment in the interaction of the ocean and atmosphere," POLEX-North and POLEX-South. The basis for these programs was large-scale natural experiments in two regions of the earth located north of 50° north latitude and south of 50° south latitude.

At the present time, in spite of the large number of studies with respect to the large-scale heat exchange of the atmosphere and ocean two problems of cardinal significance for the entire program as a whole remain unexplained:

1) The ratio of the heat transfers in the atmosphere and ocean (or the contribution of advection in the ocean to heat budget of the ocean-atmosphere system), especially within the high latitudes;

2) The relative role of heat transfers by the currents and changes in the content of the ocean in the heat exchange ocean with an atmosphere.

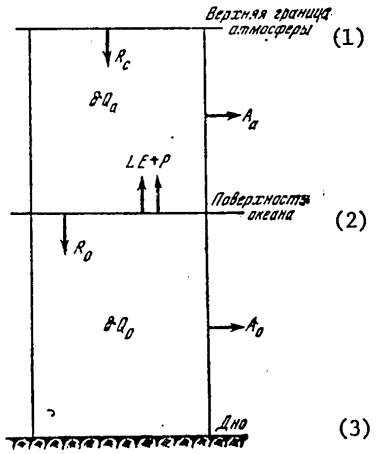


Figure 1. Diagram of the heat budget of the atmosphere-ocean system.
R_c -- radiation balance at the upper boundary of the atmosphere; R_0 -- radiation balance at the surface of the ocean; LE+P -- fluxes of "latent" and "explicit" heat from the ocean; A_a -- advection of heat in the atmosphere; A_0 -- advection of heat in the ocean; δQ_a -- variation of the heat content of the atmosphere as a result of the inflow of heat from condensation of water vapor; δQ_0 -- variation of the heat content of the ocean

Key:
1 -- upper boundary of the atmosphere; 2 — ocean surface; 3 -- ocean floor

To answer these questions it is necessary to obtain significantly more accurate estimate of all the components of the energy budget of the atmosphere-ocean system (Fig 1) in the high latitudes of the northern hemisphere. This problem is one of the basic goals of the large-scale natural experiment in the northern polar region (POLEX-North).

Its urgency is emphasized by the fact that, as the studies of V. V. Shuleykin demonstrated [1953], the thermal state of the high latitude regions of the North Atlantic and the heat loss from the ocean to the atmosphere in these regions has great significance not only for weather conditions of the adjacent region, but the influence of these factors is also propagated through the territory of Europe, including the European territory of the USSR.

The structure, the basic means of the natural experiment, the data control system are presented in POLEX-North [1976]. The experiment with the participation of 10 scientific research vessels, the high-latitude "North" expedition, two IL-18 flying aircraft laboratories and about 90 ground aerological stations, was performed by institutions of the Main Administration of the Hydrometeorological Service with the primary role played by the Arctic and Antarctic Scientific Research Institute in April to August 1976 in the body of water encompassing the Northern European Basin, the Arctic Basin and the northern part of the Pacific Ocean (Fig 2).

At the present time observation material is in the scientific analysis phase, but definite conclusions can be drawn with respect to the Northern European Basin [Treshnikov, et al., 1977].

The calculations have demonstrated that according to the data of two hydrologic surveys of the Northern European Basin, the average times of which lag behind each other by 2 months, the variation of the heat content of the ocean in the 0 to 2000 meter layer during this period was 20 kcal/cm^2. For the same period the heat content of the atmosphere varied by 2 kcal/cm^2.

According to the calculations of the heat advection in the atmosphere, by the data of the aerological observations, at the stations along the outline of the test area from the surface to the 100 mb level during the experimental period about 15 kcal/cm^2 of heat were taken out of the test area. Thus, considering the variation in heat content of the ocean and the atmosphere, the total energy consumption in the test area was 37 kcal/cm^2.

This consumption must be compensated for at the expense of the influx of solar radiation and heat advection by currents in the ocean.

The radiation budget of the system calculated in advance by the actinometric sounding data on the 100 millibar level of the surface turned out to be equal to 12 kcal/cm^2, which was only 1/3 of the magnitude of the energy consumption. Hence, the heat advection in the ocean defined as the remainder term will be 25 kcal/cm^2. Even considering the possible errors in determining the indicated components of the heat balance the value of the heat advection in the ocean turned out to be quite high.

Efforts were made to calculate also the radiation balance at the ocean surface by the data from ship actinometric observations and satellite data on clouds. It turned out that in May and June the radiation balance on the ocean surface was on the average about 18 kcal/cm^2. Considering this value the total heat flux from the ocean to the atmosphere which turned out to be 23 kcal/cm^2 was defined as the remainder term.

The presented estimates unconditionally are approximate, but they, in our opinion, permit a number of conclusions to be drawn as applied to the indicated region:

1) In the spring (May-June), that is, even during the period of maximum inflow of solar radiation, the heat transfer in the ocean turns out to be a more important factor in the formation of the thermal conditions of the atmosphere;

2) Advection of heat by the currents is one of the main sources of heat transferred by the currents in the atmosphere to the east and the northeast, including the boundaries of the European territory of the USSR;

3) Heat accumulation in the ocean turns out to be of the same order with the radiation budget and advection of heat by the currents, and this means that in the fall and winter months the role of the ocean heat delivered by the currents can exceed by several times the amount of heat going into the atmosphere from other sources, including from the sun.

As the final conclusion it is possible to point out the necessity when developing long-range meteorological forecasts for considering the ocean inflow of heat into the investigated region as one of the factors forming the weather conditions for the given region and northwestern Europe.

Everything that has been discussed makes it possible to consider that the experiment was successful as a whole. However, in order to obtain final conclusions repetition of such an experiment in other seasons of the year is required.

An important problem that was solved by the Arctic and Antarctic Scientific Research Institute in recent years within the framework of the POLEX program is the study of the dynamics of the large-scale anticyclonic circulation of the water in the Arctic Basin and its relations to the atmospheric processes and ice conditions of the Arctic Seas. In the plan for its solution by the high-latitude "North" expedition, five yearly hydrologic surveys were made in April of the Arctic Ocean with respect to the network numbering more than 150 points. Unique data analyzed in combination with the previously obtained materials and using data on the atmosphere and ice conditions of the Arctic Seas made it possible to establish that the primary factors shaping the density field of the Arctic Basin are the preceding summer atmospheric processes and fluctuations of the water exchange of the Arctic Ocean with adjacent parts of the Atlanti and Pacific Oceans [Treshnikov, Baranov, et al., 1976].

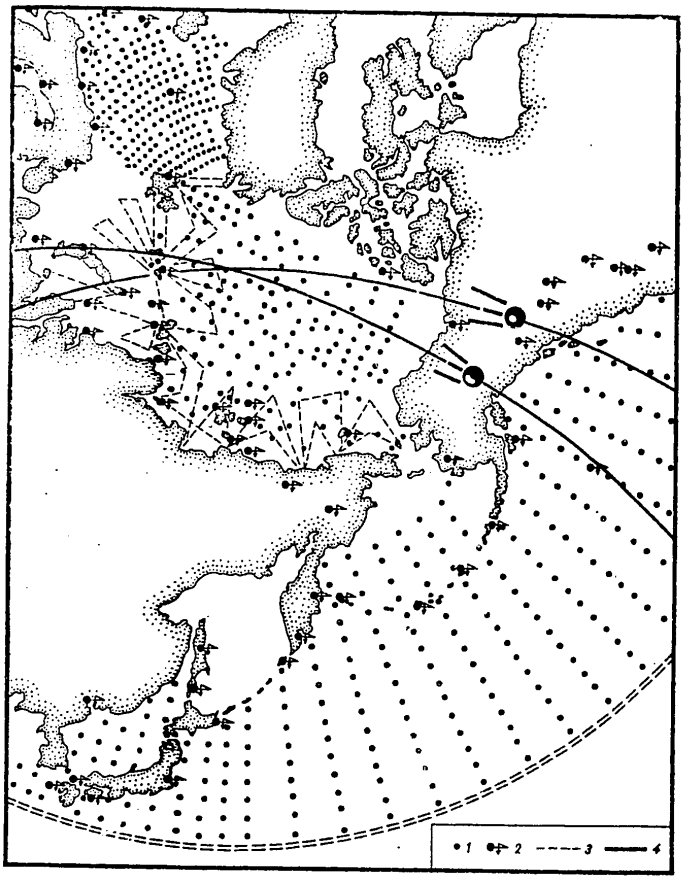


Figure 2. Schematic of the operations of the national natural experiment POLEX-North-76
1 -- hydrologic stations; 2 -- agrometeorological stations; 3 -- flying observatory routes; 4 -- trajectories of artificial earth satellites

The detected cyclicity in the interyear variability of the intensity of the anticyclonic circulation which essentially influences the ice conditions of the seas of the eastern sector is an interesting factor. Previously the relation of the ice conditions of the Arctic Seas to the variations in area encompassed by the anticyclonic circulation has already been noted. The data of recent years will permit a clear representation of this process. During the years of intense anticyclonic circulation of the water in the Arctic Basin (L973-1975), the periphery of the anticyclonic circulation encompasses the zone of the seas of the eastern sector which gives rise to the removal of the perennial ice and shift of the edges to the north.

A decrease in intensity and corresponding reduction in area encompassed by the circulation will lead to the development of the cyclonic type circulation especially in the Chukotka Sea, and the edges of the perennial ice are located on the average 5-6° south with respect to latitude. Here the cyclicity of the process approximately estimated at 6 to 7 years will permit use of the indexes of the dynamic altitude field of the Arctic Basin (in the form of the main component).

As a result of regular hydrologic surveys of the Arctic Ocean, the understanding of the role of the Atlantic water in the heat budget of the Arctic region has been significantly expanded. The fluctuations of the heat content of the Atlantic water from year to year turned out to be quite significant, and, therefore, the opinion previously existing about the small changes with respect to magnitude in the thermal state of the deep water in the Arctic Basin and the concept of conservatism of the hydrologic conditions of the Arctic Basin based on it are in need of reexamination.

The discussed results are only part of the conclusions obtained as a result of performing a detailed analysis of the natural experimental data. It is natural that such results are of interest not only in revealing the mechanisms of the large-scale interaction between the ocean and atmosphere, but they are also necessary initial data for simulation of the hydrometeorological processes in the polar regions.

Just as during research in the northern polar region, setting up natural experiments in the Antarctic Ocean under the POLEX-South program pursues the study of the thermodynamic interaction between the ocean and atmosphere as the main goal, which will promote the formation of an Antarctic circumpolar current system. The formation of the Antarctic intermediate and Antarctic bottom water and the study of this large-scale phenomenon is the most important element in the creation of a theory of global climate variation.

As a result of realization of these natural experiments performed in 1975-1977 in various parts of the Antarctic Ocean both within the framework of the national program and during joint Soviet-American studies (the expeditions in Drake Passage and in the section through 132° east longitude), highly valuable materials were obtained. The analysis of these materials will permit concentration of the efforts of the researchers on the solution of several large problems of the dynamics of the water of the Antarctic Ocean which have extraordinarily important significance for the entire problem of global circulation of the ocean and climate dynamics. The first problem is to study the structure and dynamics of the Antarctic circumpolar current (ACC) system.

At the present time it is quite well known that the ACC is a multistream, well developed system. Until recently it was considered that the water transfer in the ACC zone is realized from the surface and to the bottom in a general easterly direction. In recent years the hypothesis has been advanced of the existence of the powerful circumpolar countercurrent

underlying the ACC below the 1500-2000 meter level and equal to it with respect to flow rate. This problem was studied by the natural data obtained in three parts of the Antarctic Ocean. The data from the instrument observations from anchored buoy stations in Drake Passage lasting up to a month made it possible to detect the bottom countercurrent in a westerly direction with speeds of 5 to 10 cm/sec, but only at levels below 3000 meters. Above this level the water flow was in the general easterly direction which was indicated, in particular, by the annual series data from the 1000, 1500, 2500 meter levels obtained on the American submerged buoy station installed in 1975 in the center of Drake Passage [Program Summary..., 1977]. The results of the current velocity vector on all levels are directly predominantly to the north, the northeast and the east.

The data of the instrument measurements in the section through 20° east longitude (it is true, short-term) obtained by coworkers of the Oceanology Institute of the USSR Academy of Sciences [Ganson, et al., 1977] also indicate that even at the 4000 meter level the current velocity had a stable easterly direction and reached 16 cm/sec.

At the same time, the last observations from the Soviet submerged buoy stations in the current for 16 days in the Australian sector in the vicinity of 51° south latitude and 132° east longitude indicated the existence of the countercurrent at the 2800 meter level with speeds from 5 to 16 cm/sec.

Thus, the existence of the countercurrent in the bottom layers of the ACC has been instrumentally established, but its power with respect to depth and volume of water carried by it do not correspond to those proposed in the mentioned hypothesis, and the problem of whether it is permanent or of an intermittent nature, as the American researchers propose, still requires resolution.

There are reasons for proposing that the bottom countercurrents are of a local nature and are connected with the discharge of cold bottom water accumulated on the west slopes of the underwater and above-water ridges. They are characterized by weak velocities and carry water masses distinguished with respect to their properties from the water lying above.

The problem of the presence of jet countercurrents which quite frequently have been recorded when performing single sections and calculations by these data of the geostrophic currents is a subject of discussion. The countercurrents of this type appear in the form of streams of westerly flows developed from the surface to great depths with comparatively uniform speeds along the vertical which carry water masses, as a rule, not differing with respect to their properties from the water of the basic ACC flow. The results of the studies in the vicinity of Drake Passage permit consideration that this type of countercurrent is the result of the presence of developed meanders and eddies, the occurrence of which along with the dynamic instability of the ACC flow is connected with the bottom relief.

The estimates performed by us and American researchers of the flow of water through Drake Passage by instrument observations or with the use of them demonstrated that the flow rate of the ACC in the summer in 1975 and 1976 in the given region was 105 to 125 and up. This value is at the present time the most reliable and can be used as the estimate in the global circulation models.

The instrument observations performed in recent years also made it possible to estimate the mesoscale and synoptic fluctuations of the speed of the ACC currents.

It was established that the maximum variability of the current occurs in the upper layer of 0-1000 meters. The maximum variability on both sides of the front is at depths of 0-200 meters, and in the vicinity of the front, at depths of 500 meters. In the velocity spectra of the current, semi-diurnal and diurnal tidal variations, inertial fluctuations and long-period components have been isolated. The latter make a basic contribution to the variability of the currents in the month scales. According to the preliminary estimates themselves, the long-period variability of the current is felt from the oscillations with periods of 5-6 and 13-14 days. The study of the causes of the occurrence of the indicated oscillations and also obtaining estimates of seasonal and perennial fluctuations of the ACC flow rates is one of the problems of future research.

Until recently the opinion existed that the ACC is with respect to its origin a wind-driven current. However, the results of the latest theoretical and natural studies indicate [Treshnikov, et al., 1977] that the nature of the ACC is closely connected with the zonal thermal nonuniformity of the southern hemisphere intensified by the temperature contrast between the Antarctic and the oceans surrounding it. This is also indicated by comparing the axes of the ACC and the Antarctic polar front (APF) which is explained by the common thermodynamic cause of their occurrence, and it is maintained by the dynamic interaction of the meridional and zonal circulation in the vicinity of the ACC velocity maximum promoting mutual intensification of both phenomena. Hence, it follows that the structures and dynamics of the ACC and the APF are closely connected with the dynamics of the APF, and the study of the Antarctic polar front presents another important problem in studies of the Antarctic Ocean.

The structure of the APF zone at the present time has been investigated in detail in the vicinity of Drake Passage [Alekseyev, et al., 1977] and in the Australian sector with the application of thermochalinnic probes and bathythermographs. An interesting characteristic in the variation of the temperature distribution on intersection of the frontal zone from south to north is thickening of the cold layer before the front, which can be explained by accumulation of cold Antarctic water here as a result of constant discharge from the south. In the vicinity of the front cold Antarctic water goes down, simultaneously actively being displaced with the surface subantarctic water, which, obviously, leads to the formation of Antarctic intermediate water.

A very important characteristic of the APF zone is the presence of eddies in it. It is known that the eddies in the ocean were first detected in the hydrophysical test areas in the North Atlantic [Brekhovskikh, et al., 1971].

At the present time two types of eddies are known: the eddies in the open sea, the origin of which, as is proposed, is connected with the Rossby waves and the eddies formed as a result of meandering of the frontal zones and called rings. These types of rings were detected both in Drake Passage and when studying the bodies of water between Australia and Antarctica [Emergy, 1977]. The dimensions of such eddies are about 60 miles in diameter. They were observed to the north of the frontal zone and were propagated from the surface to the bottom. In the upper layer, to the zero surface, the direction of movement of the water in them was cyclonic, and in the lower, below the zero surface, anticyclonic.

When studying the water masses of the Antarctic Ocean, the most urgent problem is the problem of the formation and propagation of the bottom Antarctic water, which has extraordinarily important significance for the problems of the general circulation of the ocean and climate variations; on this basis, the given problem can be considered among the most important along with the mentioned problems.

It is possible to propose that one of the paths of solving the given problem in the Antarctic Ocean is the study of shelf water. This water is located on the continental shoal, in regions directly adjacent to the coast of Antarctica. With respect to origin, the shelf water is various forms of surface Antarctic water of winter period with still lower temperatures and higher salinity.

The shelf water, mixing with the relatively warm deep water, forms the bottom Antarctic water. The mixing mechanism for this water, as has been pointed out, is not completely explained, but the fact is indisputably established that this water is formed not only in the Waddell Sea, as was proposed over a long period of time, but also in the Ross and Davis Seas, in Prydz Bay and ina number of other coastal regions.

One of the possible mechanisms of the mixing of the water on the continental shoal, as our latest research has demonstrated, can be breaking of internal waves on the gently sloping shelf. The data from the American studies performed since 1976 in the Waddell Sea indicate the correctness of our assumptions.

Finally, the study of the processes of large-scale energy exchange between the ocean and atmosphere and obtaining quantitative estimates of the role of the ocean in the energy balance of the southern polar region constitute an important problem. For this purpose it is necessary to have the most accurate possible determination of all components of the heat budget of the atmosphere-ocean system according to natural data obtained in large-scale

energy test areas as was done in the natural POLEX-North-76 experiment. The performance of such experiments during the PGEP period, as we have planned, has great significance for the goals of GARP. The results and problems discussed above constitute the basis for the Soviet proposals for the International Program to Study the Antarctic Ocean.

Summing up what has been discussed above, let us emphasize that the oceanological studies in the polar regions are at the present time a broad program in search of mechanisms responsible for the large-scale interaction of the ocean and atmosphere, the detection of which is possible only with broad complex natural studies planned and realized for special scientific problems.

The results obtained when realizing this type of experiment are excellent test materials for checking the existing numerical models of atmosphere and ocean circulation and, what is more important, they will permit the formulation and establishment of the actual mechanisms for the basis of the developed models, absence of which is essentially felt in the progress in the field of developing numerical methods of long-range weather forecasting.

BIBLIOGRAPHY

1. Alekseyev, G. V.; Afanas'yev, B. V.; Smirnov, N. P. "Antarctic Polar Front in Drake Passage," TRUDY AANII [Works of the Arctic and Antarctic Scientific Research Institute], Vol 365, 1977.

2. Brekhovskikh, L. M., et al. "Some Results of the Hydrophysical Experiment in the Test Area in the Tropical Atlantic," IZV. AN SSSR. SER. FIZIKA ATMOSFERY I OKEANA [News of the USSR Academy of Sciences, Physics of the Atmosphere and Ocean Series], vyp 7, No 5, 1971.

3. Ganson, P. P.; Krivosheya, V. G.; Neydman, V. G.; Tarasenko, V. M. "New Data on the Antarctic Circumpolar Current," DOKL. AN SSSR [Reports of the USSR Academy of Sciences], Vol 233, No 3, 1977.

4. PROGRAMMA NATSIONAL'NOGO NATURNOGO POLYARNOGO EKSPERIMENTA 1976 GODA ("POLEKS-SEVER-76") [Program for National Natural Polar Experiment of 1976 (POLEX-North-76)], 1976, rotaprint of the Arctic and Antarctic Scientific Research Institute.

5. Treshnikov, A. F.; Alekseyev, G. V.; Sarukhanyan, E. I. "Problems of Border Circulation of the Antarctic Ocean," TRUDY AANII, No 365, 1977.

6. Treshnikov, A. F.; Baranov, G. I.; Gudkovich, E. M.; Sarukhanyan, E. I. "Climatic Trends in the Circulation of Water and Ice," PROBLEMY ARKTIKI I ANTARKTIKI [Problems of the Arctic and Antarctic], No 47, 1976.

7. Treshnikov, A. F.; Karelin, B. D.; Sarukhanyan, E. I. "Spatial Structure of the Currents in the Central and Southern Parts of Drake Passage," TRUDY AANII, No 344, 1976.

8. Shuleykin, V. V. FIZIKA MORYA [Physics of the Sea], Moscow, Izd-vo AN SSSR, 1953.

9. Aagaard, K.; Coachman, L. K. "Toward an Ice-Free Arctic Ocean," TRANS. AMER. GEOPHYS. UNION, No 56, 1975.

10. Emergy, W.; Savchenko, V. "A Cyclonic Ring South of Australia," POLYMODE NEWS, No 25, 1977.

11. PROGRAM SUMMARY AND LONG-RANGE PLANS -- ISOS, NSF, 1977.

12. Treshnikov, A. F.; Nikiforov, E. G.; Sarukhanyan, E. I.; Smirnov, N. P. "Evaluation of Heat Balance Components of the Atmosphere Ocean System (Review of Major Results of POLEX-North-76 Field Experiment in the North European Arctic)," REPT JOINT IAGA-IAMAP ASSEMBLY, Seattle, Washington, 22 August-3 September 1977.

EFFECT OF GOVERNMENT POLICIES ON THE DEVELOPMENT OF MARINE ACTIVITY

Moscow USPEKHI SOVETSKOY OKEANOLOGII in Russian 1979 signed to press 13 Apr 79 pp 157-164

[Article by L. L. Lyubimov, G. K. Voytolovskiy]

[Text] The Soviet Union is conducting an active maritime policy. When evaluating the significance and the necessity for strengthening the maritime potential of the USSR as one of the areas of economic strategy of the CPSU, it is necessary to begin with the fact that the economic strategy includes definition and statement of the long-term goal which under the conditions of socialism is unswerving raising of the standard of living of the people. It is obvious that the inclusion of the wealth of the ocean in the economic turnover for satisfaction of the growing demands of both personal and production consumption corresponds to this goal and will promote its achievement.

More and more complete use of the resources of the ocean in the process of production consumption will favor an increase in strength of the national economy, which will mean acceleration of scientific and technical progress, growth of the productivity of labor, balance of the national economy as a result of the possibility of improved maneuvering of resources.

The development of a maritime economy which is taking place as a result of the combined effect of natural resources, scientific-technical and ecologic possibilities of their exploitation, social-economic demands of society, is complicated by a variety of effects of modern international relations on it.

The production process in the ocean for a long time has been realized predominantly outside the limits of the territorial waters or other zones of national jurisdiction, that is, in the open sea. A characteristic feature of this process is that the objects of labor before extraction of them from the sea were "nothing." Over the long-term historical period, the economic activity in the ocean in practice has not been regulated and is based on the principle of international maritime law called the free

open sea. The logic of this principle begins with the fact that the open sea was difficult of access for continuous and effective occupation, that the resources of the World Ocean were inexhaustible, and various forms of exploitation of the resources and expanses of the ocean were not related to each other. With the development of production relations and production forces of society, these traditional views have changed, and as a result of events occurring in world maritime policy, the amount of water considered in the open sea has been almost cut in half.

On the basis of its specific nature, marine activity has always been coupled with international relations. The effectiveness of a maritime economy as a whole and its individual branches is directly connected with the fact that unity of the World Ocean as a geographic environment and object of labor corresponds to unity of international legal standards and rules for its use. This condition was met to a greater degree by the age where the freedom of the open sea as a form of international legal regime extended in practice to all or almost all the World Ocean. In that era the effectiveness of marine activity depended exclusively on the traditional technical-economic factors: the volume of capital investments, the presence of professional personnel, the development of scientific research and experimental-design developments, the technical level of production in the marine branches, and so on. The principle of freedom of the open seas defined the possibility of complex, comprehensive and unimpeded realization of scientific research in the World Ocean. It opened up unlimited access to the use of its resources, including space.

After World War II an active effort of many countries toward unilateral limitation of the spatial sphere of the open sea was noted in the area of international maritime relations. The initiative, as is known, began with the United States, which in the first postwar months declared its claims to the "wealth of the depths and the floor of the continental shelf under the open sea, but contiguous with the shores of the United States..." Having in mind the possibility of so-called "effective occupation of the shelf by the coastal government."[1] This initiative was actively supported by many Latin American countries, who made analogous claims to the level of territorial appropriations. Many countries protested the unilateral, illegal acts of these countries. Collective efforts were made to prevent this, but neither the first (1958) nor the second (1960) Geneva Conference on Maritime Law succeeded in achieving an agreement with respect to a common standard establishing the maximum limit of the width of territorial waters and the outer boundary of the continental shelf zone. As a result, the principle of freedom of the open sea began to be violated, cases of discrimination of sovereign governments were noted, losses were imposed on world fishing and shipping and also other forms of marine activity.

---

[1]Kolombos, D., MEZHDUNARODNOYE MORSKOYE PRAVO [International Maritime Law], Moscow, Progress, 1975, p 64.

The age of assault on the open sea began, invariably leading to the claiming of larger and larger areas as zones of national jurisdiction.

Until quite recently the width of the territorial waters and other coastal zones did not exceed 3 to 12 miles. During the postwar period about 80 countries expanded them. By 1 June 1977 out of 100 countries having sea boundaries, 62 countries had announced the establishment of territorial and fishing (economic) zones, the width of which significantly exceeded 12 miles. The process of expansion of the boundaries in the bodies of water to which the sovereignty of the coastal countries extends, which began more than 300 years ago, has been especially intensified in recent years and has begun to have a negative influence on the possibility of the placement of productive forces in the open sea.

Simultaneously with this, the increase in significance of ocean reserves in the world economy has stimulated various forms of regulation of marine activity on all levels -- national, regional and international. The process of this regulation has occurred quite elementally and has led to aggravation of the contradictions between the various countries with respect to the problems of the condition of marine spaces and the use of the ocean resources under conditions where on the part of a number of governments and reactionary imperialist circles a clear effort has been made to divide up the World Ocean, place broad expanses of the open sea, the resources of the maritime waters and the ocean floor under their control, transforming the problems of marine activity into an object of strained political and diplomatic struggle.

The imperfection of a number of items of modern international maritime law codified at the Geneva Conferences in 1958 led to elasticity of the outer boundaries of the continental shelf established by the coastal governments and to indeterminacy of the outer boundary of the territorial sea. As a result of the fact that at the Geneva Conferences of 1958 and 1960 it was not possible to reach agreement with respect to the boundaries of the territorial waters, the process of unilateral expansion of sovereignty by the maritime countries over the zones in the open sea continued. The status of such zones included both territorial and resource sovereignty. Essentially in a number of countries these forms of sovereignty and the principle of the freedom of the open sea began to be considered as mutually exclusive concepts.

National sovereignty touched on many parts of the World Ocean where its most important and technically accessible resources are concentrated. At the same time the access of other countries to these resources was converted to a subject of the policy of the maritime countries. This began to paralyze marine activity and led to the fact that about 30 intracontinental countries turn out to be completely without marine resources; more than 20 geographically unfavorably located countries received access to a negligible part of them.

At the present time it is possible to note two basic trends in world maritime policy:

1) Expansion of the zones of national jurisdiction over the spaces and resources in the ocean;

2) Application of the concept of the "common inheritance of mankind" to the remaining part of the ocean spaces and resources.

The expansion of the jurisdiction of the maritime countries by claiming significant parts of the World Ocean as economic zones is connected first of all with an effort to acquire the resources and space previously not belonging to any country. The effort by the capitalist countries to expand the sphere of application of capital, their "struggle for economic territory"[1], for division of the World Ocean finds concentrated expression in the maritime policy of these countries, and it influences modern international relations.

The foreign interpreters of the concept of "common inheritance of mankind" as applied to the open sea propose the following:

1) The resources of the open sea cannot be annexed, but can be used under the control of a universal international organization acting as manager of these resources;

2) It is necessary to create a control system in which all of the users will be represented;

3) The distribution of economic advantages among the members of the world community must be made considering the initial interests of the developing countries.

At the present time both trends complement each other, but as each of them develops they will become more and more contradictory. In the future this can become a serious source of situations of conflict in the marine activity, the history of which is already spotted with them.

At the present time the legal practice of governments has been converted to the most important factor of marine activity in the coastal regions of the World Ocean, a sharp contradiction has arisen between unity of the World Ocean as a geographic environment and pluralism of the standards and rules for its use. The necessity for overcoming this contradiction must be considered the most important cause of the convening and the basic goal of the work of the Third Conference of the United Nations on Maritime Law. It is difficult to overestimate the significance of the successful realization of

---

[1]V. I. Lenin, POLN. SOBR. SOCH. [Complete Collected Works], Vol 27, pp 372-373.

this goal for strengthening world peace and international security. Its solution is one of the most important problems of international relations directly connected with the strengthening of cooperation among the countries, development of the process of detente, and more and more intense use of the resources and spaces of the World Ocean to the advantage of all countries and peoples. The sharpest political struggle will take place at the Third Conference, the outcome of which will determine the future international legal status of the World Ocean. The essence of this struggle basically consists in the collision of two political approaches. A number of countries, including the Soviet Union, are for using the World Ocean in the interests of peace and for the good of all countries and people. This approach is based on considering existing realities, the proper expectations of the people, their present and long-term interests. It is permeated with a sense of historical responsibility for the fate of the World Ocean, the wealth of which must serve the present and future generations. The proponents of this approac h are coming out for a complex, interrelated solution of the basic problems of maritime law in the context of a comprehensive convention which will be developed by the Conference.

Another approach is manifested in the unilateral acts of some of the maritime countries who have arbitrarily extended their jurisdiction to large parts of the open sea. The policy of arbitrariness and usurpation of the maritime spaces is being actively popularized by the People's Republic of China, which is trying to aggravate the disputes and fire conflicts around the discussed problems. "Not a day passes that, for example, provocations do not come from Peking, aimed at breaking down international regulation, encouraging the efforts of certain governments to take over broad expanses of the sea."[1] The first meeting of the Third Conference of the United Nations on Maritime Law took place under the conditions where the process of unilateral decisions by the maritime countries not desiring to wait for the development of the mutually acceptable convention had intensified noticeably.

The unilateral acts connected with expanding their jurisdiction of some of the maritime countries forced others to take corresponding measures to protect their national interests.

The USSR, "...in order to some degree to compensate for the losses of our fishing occurring as a result of the limiting measures undertaken by other countries,"[2] established temporary measures on 1 March 1977 to preserve animate resources and regulate fishing in the marine areas adjacent to the

---

[1]Gorin, I. "World Ocean — Common Property," NOVOYE VREMYA [New Time], 1977, 2 June, No 23, p 18.

[2]Brezhnev, L. P. "Answers of the Secretary General of the Central Committee of the CPSU to Questions by the Editor in Chief of the Newspaper ASAKHI S. Khata," PRAVDA, 7 June, 1977.

coast of our country. The order of the Presidium of the Supreme Council of the USSR as of 10 December 1976 and the measures provided for in it are of a temporary nature and by this fact differ theoretically, for example, from the American law adopted in April 1976 which established a 200-mile zone with exclusive rights in it of the United States to the animate resources of the sea. The temporary measures adopted by the USSR will remain in force only until adoption of another law defining the status in Soviet coastal regions considering the results of the work of the Third Conference of the United Nations on Maritime Law. The Soviet Union has subsequently come out for international regulation of the problems discussed at the Conference, for the conclusion of a convention in which the problems of utilizing the biological resources of adjacent waters will be solved complexly, and their interrelation, considering the interests of all countries. This consistent principle of maritime policy of our socialist government was emphasized at the Sixth Meeting of the Supreme Council of the Ninth Convening.[1] In the unofficial draft of the future convention, the basic outlines of the future international legal status of the World Ocean are planned as a package considering the interests, the rights and the obligations of the countries of the world independently of their social structure, economic and geographic position. The positive solution of the key unregulated problems of maritime law will permit limitation and diminishing of the contradiction between unity of the ocean and the applied international legal standards of use of its resources and spaces, that is, it will to a significant degree "reconstruct" the most important international political condition of effective marine activity.

However, this contradiction can hardly be completely eliminated only on the basis of the work of the Third Conference. The standardization of the norms depends not on one convention solution. After adopting the convention it will be necessary to have a number of practical steps with respect to delimitation of the boundaries between the maritime countries, between the latter and the international zones, reexamination of national laws, resolution of disputes in connection with interpretation and application of the convention.

The basic problems are the prospects for establishing the conditions of use of the completely open sea or those ocean spaces which are beyond the limits of national jurisdiction. As is known, more than 10 years ago the Americans advanced the idea of internationalization of the monitoring of the use of the mineral resources of the sea bed under the international waters now called the international zone. Obviously, they expected exclusively political laurels from the realization of this idea. However, the international political situation during these years has changed significantly. The idea of internationalization of monitoring has been implemented

---

[1]Georgadze, M. N. "Approval of the Orders of the Supreme Council of the USSR," PRAVDA, 18 June 1977.

to a significant degree in the 11th part of the draft of the future convention, and its specific implementation gradually will begin to contradict American interests. Therefore the United States has prepared a reserve position which in case of its realization can have far-reaching consequences. We are talking about the Murphy-Bro Law introduced into the U.S. Congress in February 1977 and providing (in case of adoption) for the possibility of American companies beginning to monopolize the resources of the international zone of the sea bed. Private American companies are lobbying for the adoption of this law which would allow them to proceed with the extraction of bottom minerals before the conference reaches an agreement. It is clear that these acts are contrary to the goals of the Third Conference. Their purpose is to accelerate the issuance of licenses to private American companies for industrial exploitation of deep sea minerals although in accordance with the resolution of the General Assembly of the United Nations as of 15 December 1969, before establishment of the international status of the sea bed beyond the boundaries of the continental shelf of a government the physical and juridical aspects are obligated to refrain from any activity with respect to exploitation of its surface and depths. Such actions and claims cannot be regarded as acceptable, and they disrupt the efforts of the conference. They are fraught with the most serious consequences for the prospects of regulating the most important international problems based on a united convention. Appearing at the 31st Meeting of the General Assembly of the United Nations on 28 September 1976, Politburo Member of the Central Committee of the CPSU, USSR Foreign Minister A. A. Gromyko emphasized: "The Soviet Union considers that the problems facing this conference must be solved by its participants on a mutually acceptable basis. No one must try to press arbitrary and one-sided decisions on the conference which do not have anything in common with the interests of justice and fruitful cooperation of the governments in such an important area as the use of the World Ocean."[1]

The Soviet delegation to the Third United Nations Conference on Maritime Law agreed to the use in the draft of the future convention in its part pertaining to the resources of the sea bed and its depths beyond the active limits of national jurisdiction, the convention of "common inheritance of mankind." However, our country has not agreed to conversion of it in one form or another to the inheritance of monopolies. Nevertheless, with respect to the open sea in some countries an effort is beginning to deal with a broader class of problems than regulation of exploration and exploitation of the mineral resources of the international zone of the sea bed. It is not excluded that in the future they will try to extend the concept of "common inheritance of mankind" to the international zone as a whole and conduct affairs so that the system of universal international organizations of the type of the International Agency on the Sea Bed will place all of the activity in this area under international control. This

[1]PRAVDA, 29 September 1976.

essentially will lead to complete elimination of both the principal and the spatial sphere of the open sea. At the same time the proponents of this approach are trying to place under their own control access to the greater part of the World Ocean, including the international zone and their zones of national jurisdiction.

At the same time in 1976 international legal practice provided the first example of a somewhat different practical use (application and interpretation) of the concept of "common inheritance" -- the INMARSAT convention (International Organization on Marine Satellite Communications). In essence this convention set a precedent for agreement on the use of an international resource (in the given case, outer space), setting up the participation of the governments in the decision making system depending on their actual technical-economic contribution.

Thus, in the future there will be the problem of selecting among different approaches for individual types of activity to establishing the international legal status of the use of the World Ocean. On the other hand, the adoption of a universal approach that is identical for all types of activity is not excluded. Therefore studies are already needed now to determine the priorities of various types of marine activity of the USSR in the ocean. The complex estimates of the consequences of possible versions of their international legal regulation for purposes insuring our political and economic interests in the ocean against the background of developing marine activity are also needed.

All forms of marine activity are interrelated, mutually conditioned, and the political-legal regulation of one of them is felt immediately in the others. This also determines the complexity of selecting the most acceptable approach, the arrangement of priorities, the more so in that as all branches of the marine economy develop, the economic significance of their interdependence and commonness will grow, which cannot be considered when organizing production in the ocean. The first condition of validity of choice, the growth of effectiveness of all forms of marine activity and success in the world competition with capitalist countries is constant improvement of the level of scientific substantiation of the development and placement of production forces in the World Ocean. This is the initial position which can be won only by the collective efforts of the representatives of various areas of the study of the sea. Here it is especially important to carry out the missions stated by the 25th Congress of the CPSU in the "Basic Areas of Development of the National Economy of the USSR for 1976-1980": "Strengthen the interrelation of social, natural and technical sciences."

10845
CSO: 8144/0574

- END -

[1] "Materials of the 25th Congress of the CPSU," Moscow, Politizdat, 1976, p 213.