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Translation

WORLD OCEAN EXPLORATION AND ENGINEERING PROBLEMS

ed. by

A.I. Voznesenskiy

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WORLD OCEAN EXPLORATION AND ENGINEERING PROBLEMS

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CONTENTS

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[Annotation]

[Text] A study is made of the modern strategy of ocean research, the problems of international cooperation in its exploitation and protection against pollution. The state of the art with respect to above-water, underwater and aerospace methods of oceanological research and also the means of exploiting biological and mineral resources of the ocean is analyzed.

The book is intended for a broad class of readers, primarily the specialists engaged in this field of science.

FROM THE PUBLISHING HOUSE

The exploitation of the World Ocean, just as the exploitation of outer space, is one of the most important and extremely complex problems of modern times. This problem can be solved only by developing a clear-cut strategy and determining the forms of international cooperation in the matter of exploitation of the ocean and preservation of it as an integral ecological system.

This collection is devoted to these problems and also the analysis of the state of the art and prospects for the development of above-water, underwater and aerospace methods of oceanographic research, the investigation of means of exploiting the mineral and biological resources of the World Ocean, the prospects of human inhabitation of the depths of the sea. The most important Soviet scientists have contributed to the collection: Academician of the USSR Academy of Sciences L. M. Brekhovskikh, Academician of the Ukrainian SSR Academy of Sciences B. A. Nelepo, Corresponding Members of the USSR Academy of Sciences A. S. Monin, Ye. P. Popov, and so on.

The collection is designed for a broad mass of readers, primarily the specialists connected with the investigation and exploitation of the World Ocean, the intensity of which is building every day. Accordingly, the publishing house also plans further discussion of the main areas of these processes and also publication of the most interesting results, giving special attention to the engineering problems of ocean exploitation.

It is requested that all comments and suggestions be sent to the following address: 191065, Leningrad, ul. Gogolya, 8.

PART I. GENERAL PROBLEMS OF OCEAN EXPLORATION AND EXPLOITATION

MODERN STRATEGY IN OCEAN EXPLORATION AND EXPLOITATION

[Article by L. M. Brekhovskikh]

Leonid Maksimovich Brekhovskikh: academician, member of the Presidium of the USSR Academy of Sciences, Secretary Academician of the Department of Oceanology, Atmospheric Physics and Geography of the USSR Academy of Sciences, editor-in-chief of the journal OKEANOLOGIYA [Oceanology] is a specialist in the field of ocean acoustics and one of the participants in discovering the underwater sound channels (1946). He has been leader of numerous ocean expeditions, including the Polygon-70 experiment. He is a Lenin and State Prize Laureate, and a winner of the Gold Medal of the Royal Acoustics Society of Great Britain.

The resources of the ocean are far from as unlimited as was thought until recently, but they are, nevertheless, quite large. They are acquiring more and more significance as the earth's population increases, and the biological, mineral and other resources of the continents are consumed at a more and more intense rate. Now on the average there are about 15 kg of extractable biomass from the ocean and the seas adjacent to it for each resident of our planet. This figure can be increased significantly in the future with the proper approach to the use of the biological resources of the ocean. About 1/5 of the world extraction of oil and gas is at the present time from the continental shelves. The mineral wealth of the open sea floor is great and still almost entirely untouched. More than 70 different elements of the Periodic Table, including uranium and gold, are dissolved in the seawater itself. It is at the present time still economically inefficient to extract, let us say, gold from seawater, but other elements, for example, magnesium, potassium and bromine are already being extracted in large quantities in the oceans and seas.

The energy resources of the ocean are also enormous, and they are still little used.

About half of the oxygen which the population of our planet breathes is produced in the process of photosynthesis in the upper layer of the ocean.

The ocean is an important transport artery. The cargo of the many tens of thousands of transport ships sailing the oceans is reckoned in many billions of rubles annually.

It is possible to say without exaggeration that the ocean determines the weather on our planet. Over the greater part of our country, for example, the weather is determined by processes occurring in the Atlantic and Arctic Oceans.

Hundreds of scientific research ships belonging to various countries are continuously at sea. From these ships and also from research submarines which submerge to the depths of the ocean, from satellites and manned space laboratories, tens of thousands of scientific coworkers are continuously following what is going on in the ocean and learning its secrets. For the solution of the most complex problems it has become a tradition to combine the efforts of many countries in the performance of joint experiments. Sometimes several dozen research vessels are engaged in them simultaneously.

The Soviet oceanologists have joint research programs with the scientists of Poland, the German Democratic Republic, Bulgaria, England, France and the United States. In spite of all of this, we must recognize that the ocean still remains for the most part unknown. It has still been investigated entirely inadequately. Gradually ever-newer aspects of its life are unfolding before us. However, the presently available concepts of the ocean -- movement of its waters, the bottom structure, the peculiarities of the biological system, and so on -- can still be considered knowledge "in the first approximation."

The ocean is being studied by physicists, geologists, biologists, chemists and scientists of many other specialties. The goal of the physicists is investigation of the dynamic processes in the ocean, that is, movements of the water masses of all scales, from the ocean currents on a planetary scale to the fine ripple on the surface of the water; the study of the interaction of the atmosphere and ocean and also various physical fields in the ocean -- gravitational, magnetic, sonic, and so on. Geologists are studying the structure of the ocean floor both in the coastal zones and in the open sea. This is necessary to establish the distribution laws of the minerals in the bottom of the ocean and also to understand the history of our planet, the structure of the continents and the oceans in the geological past.

Biologists study the laws of development of life in the ocean on all levels. They determine the interaction of various elements of the biological structure of the ocean in order to determine the most efficient methods of exploitation of the biological resources.

Chemists together with biologists study the chemical composition of the ocean water, especially to prevent pollution of it.

Now let us discuss the basic areas of investigation of the World Ocean, the modern strategy and modern methods of studying it.

1. Synoptic Variability of the Ocean. Ocean Eddies

The study of the dynamics of the ocean, that is, the movements of its water masses, is bringing ever-newer discoveries. About 15 years ago Soviet scientists discovered the equatorial subsurface countercurrent in the Atlantic Ocean. It turned out that a powerful river several hundreds of kilometers wide flows along the equator from west to east at a depth of 300 to 500 meters. On the surface the current is in the opposite direction. A year later an analogous countercurrent called the Tareyev Current was discovered in the Indian Ocean also by Soviet scientists. It was established that the equatorial countercurrent also exists in the Pacific Ocean. It was discovered for the first time by American scientists and is called the Cromwell Current.

An outstanding discovery was made by Soviet scientists during the "Polygon-70" experiment in the Atlantic Ocean in 1970. The purpose of the experiment was to discover the stability of the sea currents in the zone where, as proposed, they are the most stable. For this purpose the northern trade current zone and an area with a comparatively smooth bottom was selected. The test area method of investigation (for more detail about this method see Section 9) was used for the first time on a large scale. The scientists broke down the large research area into bodies of water 200x200 km^2 in size, and they set up an enormous cross ocean "antenna" in it made up of 17 buoy stations. Current and temperature gauges were located at different levels at each buoy station. The experiment lasted for 6 months. During the first few weeks it was discovered that the nature of the current does not have anything in common with what was imagined earlier and what was depicted on all of the ocean charts. It was established that gigantic eddies several hundreds of kilometers in size passed through the test area. These eddies are to a known degree analogous to cyclones and anticyclones in the atmosphere. The speed of the water masses participating in the rotation of the eddy is 15 to 20 cm/sec. The rate of advancement of the eddy to the west with a small southerly component was about 4 cm/sec. The eddy movement encompassed in practice the entire body of the ocean.[1]

Several years ago, in 1973 the American scientists performed an analogous experiment in the Sargasso Sea. The currents were investigated in depths from 500 meters to the bottom. The experiment was called MODE-I (Mid Ocean Dynamical Experiment). The same methods were used in this experiment as the "Polygon-70" experiment, but sound buoys with neutral buoyancy were also used. These buoys (for more details see Section 9) move at given depths together with the water masses and communicate their locations by sound signals.

The results of this and other experiments demonstrated that the eddy movement of one force or another exists in the ocean in practice everywhere, even under the ice of the Arctic Ocean. It is true that their dimensions are somewhat less here (about 50 km). They are also found in the Antarctic waters. It turned out that in a number of areas the kinetic energy of the eddy movement is tens and sometimes even hundreds of times greater than the kinetic energy of the known currents.

The most effective program for studying eddies in the ocean was implemented during the process of the international POLYMODE experiment. The name of this experiment came from combining the first half of the word "Polygon" and the name of the American experiment MODE, and it reflects the essence of the matter quite precisely. Basically this was a Soviet-American experiment, the purpose of which was to discover how ocean eddies arise and how they interact with each other and also with the mean ocean currents, and what their final fate is. It has already been discovered that there are a minimum of two types of eddies. The eddies of the first type, the so-called rings, occur in the Atlantic Ocean as a result of "gemmation" of the Gulf Stream meanders. These rings travel farther in the ocean independently, they live about 2 or 3 years, and then they are again encompassed by the Gulf Stream. About five rings occur annually, and, consequently, at each point in time there are about 15 rings "roaming" the Atlantic Ocean. The second type eddies -- open-sea eddies -- occur as a result of instability of movement of the water masses or, as oceanologists say, baroclinic instability. These eddies are of somewhat different structure than the rings. The temperature contrasts and eddy velocities are less expressed in them.

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[1] L. M. Brekhovskikh, M. N. Koshlyakov, K. N. Fedorov, L. M. Fomin, A. D. Yampol'skiy. "Hydrophysics Test Area Experiment in the Atlantic Tropical Zone," DOKL. AN SSSR [Reports of the USSR Academy of Sciences], Vol 198, No 6, 1971, pp 1434-1437.

2. Wave Movements in the Ocean

Researchers are giving a great deal of attention to the study of various wave processes in the ocean. Let us consider the processes of a mechanical nature, that is, let us discuss, let us say,electromagnetic waves propagated in the sea. Sound waves have the widest frequency range and the highest propagation rate among the waves of a mechanical nature. They are propagated at a rate of about 5400 km/hr. The sounds of lower frequencies have very little damping and can cross even the Pacific Ocean itself. It is true that more than 2 hours are required for this. The lowest frequency sound waves with a period of about 1 second (such sounds are no longer distinguishable by man and are called infrasounds) are generated by underwater volcano eruptions and underwater earthquakes. It is possible to determine the approach of tsunamis by them. (The problem of sound waves is investigated in more detail below.)

A tsunami occurs in the case of underwater earthquake or underwater volcanic eruption. Harmless in the open sea, it becomes steeper and steeper as it approaches the shore and reaches the shoals. Hitting the shore in the form of a wall many meters high, it carries enormous destructive force. Scientists have worked hard on studying both the tsunami itself and methods of warning the coastal populations of the approach of a tsunami. There are two services to predict tsunamis in dangerous areas: continuous recording of seismic waves which occur simultaneously with the tsunami during the earthquake, and tracking the level of the water surface in the sea. However, during an underwater earthquake or volcanic eruption, as has already been stated, a low-frequency sound wave occurs which moves many times faster than the tsunami. As it approaches the shore, special instruments -- hydrophones -- can warn the population of the approaching wave.

The tsunami propagation laws in the open sea are of interest. Academician M. A. Lavrent'yev has established that underwater ridges can serve as waveguides for it, along which it is propagated to great distances without attenuating noticeably.

When talking about waves in the ocean, we primarily mean its undulating surface. The study of surface waves began long ago, for it is very important to know the laws controlling them for navigation and shipbuilding.

However, until recently far from all of the secrets of surface waves have been unraveled. In particular, there is still no theory which sufficiently exactly describes the occurrence and the buildup of waves under the effect of wind. Difficulties arise as a result of the fact that the wave itself changes the wind field characteristics. There have still been few experimental studies of the space-time spectra of surface waves.

The surface waves of the most diverse periods are of practical interest, from fractions of a second (capillary waves) to tens of seconds. The complexity of studying surface waves in the open sea is connected also with the fact that it is difficult to find a stationary base for measuring their parameters. Frequently the instruments are located on the ship which itself fluctuates in the wave, and as a result of the measurements, the total effect of the movement of the wave itself and the ship on the wave is recorded. The remote instruments -- wave meters -- located at a distance from the ship still provide little information about the spatial characteristics of the waves.

In recent times methods have begun to be developed for studying the wave action from artificial earth satellites. These methods can turn out to be highly prospective.

The ocean surface can be entirely smooth and quiet, but this does not mean that there is no movement over its entire depth. In the ocean body, internal waves can "rage," the amplitude of which reaches hundreds of meters. It is true that the word "rage" is not entirely appropriate in the given case inasmuch as the internal waves are very slow, with periods measured in tens of minutes and even many hours, but this does not keep them from manifesting a raging form. It is proposed that the American submarine "Thresher" sank after getting into such a wave.

Internal waves are analogous to surface waves to a known degree. Actually, the water surface is the water-air interface, that is, the interface of two media with different density. Inside the ocean there are also layers of different density, although the gradient of the latter is small between them. Now let us represent the boundary between two such layers. At rest, it, just as the surface of the water, is horizontal. Let us assume that for some reason the heavy layer is forced upward, and it bends into a hump. Under the effect of gravity it then drops downward. The disturbance formed will be propagated in all directions. These will be internal waves. With respect to their nature, they are richer than surface waves. The internal waves can move not only in the horizontal plane as surface waves, but in the vertical plane and also at any other angle of inclination to the surface. It turned out that in the ocean these waves exist in practice everywhere and at all times. However, what are the primary sources of internal waves, how do these waves interact with each other, with the surface waves and turbulence, where, in the final analysis, is their energy damped -- all of these questions still remain unexplained.

Another form of ocean wave -- the Rossby waves -- has the longest period. It is 1.5 to 2 months. These waves, the lengths of which vary from tens to hundreds of kilometers, move slowly, with a speed of several centimeters per second, from east to west and encompass the entire thickness of the ocean. It is interesting that in this case the energy transport takes place in the opposite direction, from west to east. The waves of this type were first discovered in the atmosphere and are frequently called Rossby-Blinova waves.[1]

There is a proposition that the system of ocean eddies detected during the "Polygon-70" experiment is a system of Rossby waves. The movements of the water particles in the Rossby waves are almost strictly horizontally directed. In the so-called barotropic Rossby waves, the entire mass of water, from the surface to the bottom, moves at the same speed. However, there is a great variety of "baroclinic" Rossby waves, the characteristics of which vary with depth.

3. Small-Scale Structure of the Ocean Water

The ocean continuously absorbs the energy of the sun and the wind, converting it to the energy of the currents, the eddies, the internal and surface waves. However, the question arises of what the energy of these movements is expended on? Where, as the scientists say, is its source? It turned out that the energy influx from the sun and the wind takes place basically on large scales, and its discharge, that is, the conversion of this energy, in the final analysis, to heat, in nonuniformities of the water, on very small scales. These are primarily sections of small-scale turbulence (the characteristic scales are fractions of a millimeter). In addition, the small-scale structure of the ocean water influences many other processes, in particular, the propagation of sound and optical waves. Therefore a great deal of attention is given to the study of it.

The study of the structure of the small-scale or fine structure of the ocean water has become possible only in recent times when scientists and engineers have created the so-called sondes -- very sensitive probes with resolution to fractions of a millimeter. Such probes permit us to study in detail, for example, the temperature and salinity of the water as a function of depth. It was considered earlier that this relation is smooth, and the deviations obtained in the experiments have simply been ascribed to imperfection of the instruments. However, the instruments have become improved and it has turned out that on variation of depth, the temperature and the salinity vary in a highly characteristic manner: they remain constant in certain thin layers (the thicknesses of these layers vary from tens of centimeters to tens of meters), and they change quickly, almost discontinuously on going from one layer to another.

Thus, the ocean is a type of large layered pie.

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[1] Corresponding member of the USSR Academy of Sciences Ye. N. Blinova first developed the most complete theory of such waves.

Later, researchers learned how to make instruments which with the same high resolution led tothe vertical structure of the horizontal currents in the ocean. It turned out that the same thing occurs with the currents. By using such instruments it was discovered that the currents inside certain layers are almost constant and vary quickly on transition of the boundary between the layers. This is the so-called fine structure of the ocean current.

The horizontal extent of such thin layers can be tens of kilometers. At the given point the fine structure can be kept almost invariant for several days. This means that the researcher can sound the ocean a multiple number of times for several days, and the curve,let us say, for the temperature as a function of depth, in all details, will repeat from time to time.

How does this extraordinarily characteristic fine structure of the ocean water arise? No one knows exactly up to now. One thing is clear: it plays a highly significant role in the overall power engineering of the ocean. In addition, the fine structure generates a number of extraordinarily interesting phenomena. For example, at the boundaries of these almost uniform layers, relatively high-frequency internal waves are propagated with periods equal to tens of seconds and even minutes. No one has proposed before this that the internal waves of such high frequencies can be propagated in the ocean.

The fine structure unconditionally influences the development of the lower stages of life in the ocean. Various types of plankton and bacteria can be held at the boundaries of the layers where a density discontinuity exists, and not one, as previously proposed (the so-called liquid bottom) but hundreds.

4. Interaction of the Ocean and Atmosphere. Weather and Climate of the Planet

The greater part of the solar energy heating our planet basically comes to the tropical regions of the ocean. There it is absorbed by the upper layer of the water 10 to 20 meters thick, and then in the form of heat it is frequently carried away with the currents, and partially goes from the ocean into the atmosphere. The mechanism of this transition is as follows: the water evaporates from the surface of the ocean, it rises upward in the form of vapor, and it condenses there in the colder layers of the atmosphere. Here the latent heat of condensation is released which also warms the atmosphere. As a result of different heating of it at different geographic latitudes, winds arise which, in turn, accelerate the surface waters of the ocean, and so on. Thus, there is a continuous energy relation between the atmosphere and the ocean. In addition, the atmosphere and the ocean exchange matter and momentum.

It is generally known that the state of the ocean cardinally determines the weather on the dry land. However, no one still exactly knows how to predict the weather for a month or several months in advance, considering the effect of the ocean. In order to solve this important problem for all mankind, the scientists of different countries have combined their efforts and created a large international scientific research program called GARP (Global Atmospheric Research Program).

It is appropriate that the first large experiment by this program was performed in tropical regions of the Atlantic. About 40 ships of different countries (13 from the Soviet Union) and also aircraft and artificial earth satellites participated in this experiment in 1974.

A large quantity of information has been obtained about the state of the ocean depths and the entire body of the atmosphere in these regions which has still not been completely processed. However, the preliminary results are extraordinarily interesting; they indicate the relation of the atmosphere and the ocean and also the role of the ocean in weather formation.[1] The quasitwoyear cyclicity of phenomena in the upper layers of the atmosphere and the effect of this cyclicity on the weather have been discovered and investigated in detail. It has been established that the subsurface Lomonosov current is not stationary. Waves travel along its core, with a length of about 1500 kilometers similarly to how waves travel along a string that we have held. However, it is impossible to limit ourselves to the investigation of only tropical regions. Intensive transmission of energy from the ocean to the atmosphere takes place in the polar regions. This process also has a great deal of effect on the weather formation. Therefore Soviet scientists have realized two subprojects POLEKS-Sever [POLEX-North] and POLEKS-Yug [POLEX-South] within the framework of the GARP program.[2]

Within the framework of these plans, it was necessary to discover in what way heat gets from the equatorial regions to the polar regions? It was previously considered that this energy is transferred by the atmosphere. Now it has been discovered that a significant part of it, perhaps about half, is transported by the ocean currents.

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[1] It is interesting that when putting together the GARP program the meteorologists did not initially call for the participation of oceanologists in it, but after several years it was discovered that without detailed tracing of the behavior of the ocean the stated problems could not be solved.

[2] Treshnikov, A. F. "Basic Results of Studies in Ocean Parts of the Polar Latitudes (POLEX Program)," DOKL. NA I S"YEZDE OKEANOLOGOV SSSR [Reports of the First Congress of USSR Oceanologists], 1977, June.

In the experiment performed in 1976 primarily by the institutions of the State Committee of Hydrometeorology and monitoring of the natural environment of the USSR, there were 10 scientific research vessels, two laboratory aircraft and 90 ground aerological stations. The experiment encompassed the northern European basin and the northern part of the Pacific Ocean. After it was determined that a significant part of the energy goes to the northern regions with the ocean currents, it was necessary to determine whether or not the heat content of these currents changes from year to year. Previously it was considered that the situation is more or less stable, and the heat content of these currents almost does not change. The experiments demonstrated that these currents are invariable to a significant degree, and this complicates the long-term weather forecasting.

In the southern polar region, the investigation of the most powerful circumpolar Antarctic current in the World Ocean belting Antarctica has the greatest significance. It has a width of about 2,000 km and transports ten times more water than the Gulf Stream. In the joint experiments in 1975/1976, the Soviet and American scientists more precisely defined the power of this current: it transports about 3 million km^3 of water per year.[1]

In spite of the broad experiments performed in the polar and the tropical regions, the processes determining the weather on our planet, and the role in this of the ocean still remain far from discovered. Great hopes in this respect are placed on the first global international experiment which will begin in February 1979. The studies encompass all of the oceans and also the continents. It is necessary to mention that the latter have somewhat greater reflectivity with respect to the sunlight and the ocean. Therefore they absorb less solar heat and are heated less in the summer than the ocean. In the winter, on the contrary, the continents cool more sharply than the oceans. The temperature contrast between the oceans and the continents creates winds in the latitudinal direction. This problem must also be studied in detail in the first global experiment.[2]

Along with the performance of the large-scale experiments, the scientists are constructing mathematical models of the circulation of the atmosphere and ocean. One such model was developed in the Leningrad Department of

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[1] The total annual runoff of all rivers of the northern hemisphere is about 40,000 km^3.

[2] The concept of the interaction of the atmosphere, the ocean and the continents was developed in the report by Academician V. V. Shuleykin "Large-Scale Interaction Between the Ocean, the Atmosphere and the Continents," at the First Congress of Oceanologists of the USSR, 1977, June.

the Institute of Oceanology of the USSR Academy of Sciences. It takes into account the state (temperature, wind, current) of the atmosphere and the ocean on many levels at a large number of points (squares) of the oceans and continents. The model has provided much of interest. Thus, if we imagine the ocean to be uniform and initially quiet, and then we include the atmospheric winds and heat, mass and momentum exchange between the atmosphere and the ocean, then, as it turns out, about 200 years are required for the latter to reach a state of movement and stratification which is now observed. This indicates how much inertia the ocean system has.

Another mathematical model of the circulation of the atmosphere and the ocean has been developed at the Computer Center of the Siberian Department of the USSR Academy of Sciences under the direction of Academician G. I. Marchuk. Results were obtained on the basis of it which are important for long-range weather forecasting.

During the course of the implementation of the GARP program, it is also necessary to discover the mechanisms which determine the climate of the earth and the trend of its variation at the present time.[1] It is known that in the northern hemisphere the years of 1945-1946 were comparatively warm. Since that time continuous cooling of the climate of the northern hemisphere was observed until 1970. Then obviously again there was some systematic warming. Possibly it is caused by the anthropogenic effect, that is, the effect of man on nature, in particular, the increase in carbon dioxide discharged into the atmosphere and the so-called greenhouse effect. If this is so, then the warming will continue for many more years and the consequences of it can turn out to be unfavorable for our planet as an environment for man to inhabit. However, it is entirely possible that this warming is caused by natural climatic fluctuations which have been noted in the past of our planet, and that after some time it will shift to cooling.

It is impossible without detailed knowledge of the properties and state of the ocean to solve these genuinely important problems for all mankind. At this time approximately a thousand times less data reaches the world centers for gathering hydrometeorological information about the ocean than about the atmosphere. This indicates how much the ocean studies must be expanded in order to achieve the required level.

5. Ocean Acoustics

Sound waves are a natural form of waves which can be propagated in seawater without great attenuation to significant distances (several thousands of kilometers for low sound frequencies). Electromagnetic waves

[1] Climate is weather averaged over 10 to 30 years.

and even a powerful laser beam can penetrate seawater no more than a kilometer. In marine experiments the sound from small explosions has been picked up at a distance of 22,000 km, and monochromatic sound, at a distance to 28,000 km. Sound waves in the ocean have already been mentioned above, but they are worth discussion in more detail.

Not one science of the ocean can get along without the use of sound. As a result of a very simple, but important sonic instrument -- the sonic depth finder -- we now know the bottom relief of the World Ocean and the seas adjacent to it well. It was used to discover powerful systems of mid-ocean ridges. This discovery has been the basis for a new theory of the earth's crust (which will be discussed below). By using special sonic devices called side-scanning sonar, it is possible to examine the relief of the sea floor in much more detail and much faster than with the sonic depth finder and to detect even comparatively small objects lying on the floor. In other words, it is possible to compile a type of photograph of the sea floor.

The sound waves are also used to "transilluminate" the sea floor and, consequently, to detect minerals in it. The lower the frequency of the sound, the deeper into the sea floor it can penetrate. Considering the scattering of the sound in the water, it is possible to discover the so-called sound-dispersing layers of a biological nature. Here it is possible to determine the size of small fish and the concentration of their accumulations characteristic for this layer. The method is so sensitive that it permits detection of the presence of a small fish, let us say, several centimeters long in 100 m^3 of water.

Sound is widely used for controlling autonomous instruments operating under water and delivering information about the numerous properties of the ocean (for more detail see Section 9).

A prominent event in the development of underwater acoustics was the discovery in the 1940's of the underwater sound channel by American and Soviet scientists independently of each other. It turned out that in the depths of the ocean there were layers of water in which the speed of sound is less than in the surrounding layers, and therefore they serve as waveguides for the propagation of sound. On being propagated in such a waveguide, the sound does not touch the surface of the water or the bottom where it could be scattered and absorbed. In the water itself the low-frequency sound is absorbed insignificantly (for example, sound 50 hertz in frequency can travel a distance of up to 10,000 km, and its energy will decrease a total of only 10 times in so doing). This property is used, in particular, for information transmission under water.

The scientists dealing with the acoustics of the ocean must study the multifaceted interaction of sound waves, the wave action on the surface of the water and the bottom considering its complex relief and the complex inside structure, the sound-dissipating waves of a biological nature in the ocean, the turbulence of the ocean water, internal waves, the fine vertical structure of the water, and so on. The so-called synoptic eddies which we discussed also have a significant effect on the propagation of sound. The eddies with a cold nucleus focus the sound waves under defined conditions, and the eddies with a warm nucleus, defocus them. The paths of the sound waves are significantly distorted by the ocean fronts which are encountered in the currents such as the Gulf Stream, the Kuroshio, and so on. An important goal of underwater acoustics at the present time is the study of the stability of the sound fields against a background of very great variability of the ocean. When solving it, the acoustics experts must work side by side with oceanologists. The latter must study the oceanological situation in the finest detail against a background of which the sound is propagated.

The most interesting phenomenon in underwater acoustics is the natural noise of the ocean. The ocean makes noise. Its voice can continuously be heard in the air. However, the ocean is far from noiseless also at depths. The nature of underwater noise can be quite varied. In the low-frequency range (from 1 to 20 hertz) the basic cause of it is the seismic activity of the earth. On our planet hundreds and thousands of small earthquakes take place daily which create a continuous background of vibrations of the earth's crust -- the so-called microseisms. They also generate underwater noise. The noise of somewhat higher frequencies is produced by the undulating surface of the water. It turned out that the two surface waves interacting with each other can generate sound waves which emit into the atmosphere and into the depths of the ocean.

The sound waves in the ocean can occur also from storms which play in the atmosphere over the ocean, and so on. Noise with frequencies of 100 to 300 hertz are caused by the noise generated during the navigation of ships. At every given point in time, let us say, there are many hundreds and sometimes thousands of ships in the Atlantic Ocean, the engines and propellers of which continuously emit noise.

The noise of still higher frequencies originates from the popping of air bubbles occurring during the breaking of waves. This is cavitation noise analogous to the whistle of a tea kettle before it boils. The noise of the same nature is created by the propellers of high-speed ships when they turn at high speed.

Biological noise, although as a rule it is not very strong, is of great interest. Marine animals and fish, it turns out, are highly talkative. Actually, their communication with each other under water is by sound waves, and many, for example, dolphins, can detect their prey only with the help of underwater sound location.

Thus, when researchers submerge sound-receiving instruments -- hydrophones -- under water, they receive rich information about the state of the ocean, the activity of remote volcanoes, approaching tsunamis, biological life in the ocean, processes occurring on the surface of the ocean, and so on. Therefore, an important problem in underwater acoustics is the further study of underwater noise in the ocean. It is also necessary to remember that the underwater noise is natural interference for the operation of various underwater sonic instruments.

6. Exploration of the Sea Floor

All the most significant information about the structure of the sea floor has been obtained in the last 20 to 30 years. The age of great discoveries in this region began with the detection of the mid-ocean ridges. It turned out that on the bottom of the World Ocean there is a united system of such ridges with a total extent of more than 60,000 km. Each ridge is a swell from 200 to 3,000 km wide with a rift valley in the middle developed by transverse and longitudinal joints. In the vicinity of the ridges, increased seismic activity, thermal flux and also characteristic gravitational and magnetic anomalies are observed.

No less important discoveries have been connected with deep drilling of the earth's crust under the ocean in accordance with the international program on the American drilling ship "Glomar Challenger" which for ocean depths to 6 km permits drilling more than 1-1/2 kilometers of ocean sediment (the record drilling depth at the present time is about 2 km). It turned out that the age of all the sediments drilled to the consolidated rock reaches no more than 160 to 170 million years anywhere. However, it is known that the ocean has existed about 3 billion years. The question is what happened to the older sediments? The solution of this problem has led to the generation of the Wegener hypothesis of the movement of the continent. When all of the data about the structure of the sediments on the ocean floor and its relief and the magnetic anomalies on the bottom were put together, scientists arrived at the conclusion that molten material is continuously reaching the vicinity of the mid-ocean ridges from the internal layers of the earth. This leads to continuous parting of the sea floor, and this means that, for example, Europe and America are moving away from each other at a speed of approximately 3 cm/year.

Thus, a comparatively structured concept of the tectonics of lithospheric plates was created. In accordance with this concept, the entire earth's crust (continental and oceanic) consists of enormous plates which float on a softer layer (the asthenosphere) at a depth of about 100 km. Theories explaining this movement have been developed.[1]

In our country there have been especially acute discussions among the so-called "fixists" and "mobilists," that is, the scientists who have refuted large horizontal displacements of the earth's crust and the scientists who, on the basis of all tectonics of our planet, have

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[1]A. S. Monin, ISTORIYA ZEMLI [History of the Earth], Leningrad, Nauka, 1977.

considered this movement. At the present time it is finally recognized that mobilism is the only valid concept explaining the tectonic processes of the planet. Of course, there is still much unexplained in this problem, but that is always the case in science -- the more we discover, the more questions arise.

It is of interest that without acoustic engineering the deep drilling of the ocean floor would be impossible. In order to drill, the ship must stay over the well with an accuracy to 10-15 meters at depths to 6 km. It is clear that this problem cannot be solved by putting the ship on anchor. This problem, just as the problem of repeated entry of the drilling tool into the drilling hole, is solved using sound waves.[1]

Soviet scientists have done a great deal of work with respect to the international "Correlation" program, the goal of which was to explain the geological structure of our planet considering the achievements of the geology of the continents and the World Ocean.[2]

The geology of the shelf zones of the oceans and seas has been developed intensely, which is explained by their prospectiveness for oil and gas. According to the forecast data, in 1980 as much oil and gas will be extracted from the shelf zone as was extracted from the dry land a few years ago.

The shelf regions are no less rich in tin, gold, titanium magnetites, phosphates and their minerals.[3]

The mineral wealth of the open ocean, in particular, the iron-manganese nodules which are particularly widespread at great depths in the ocean (from 4 to 6 km) is large and comparatively little studied. These nodules contain about 35 different elements. Sometimes the weight of the iron-manganese nodules per m^2 of bottom area gives 50 to 70 kg.[4]

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[1]"Deep drilling will be discussed in more detail in the article by V. N. Samarskiy and K. G. Suvorov in the present collection.

[2]A. V. Peyve, Yu. M. Pushcharovskiy, "State of the Art and Problems of the Geology of Oceans," DOKL. NA I S"YEZDE OKEANOLOGOV SSSR [Reports of the 1st Congress of USSR Oceanologists], 1977, June.

[3]V. V. Fedynskiy, et al., "Geophysical Studies of the Sea and Ocean Floor in Connection with the Problem of Using Mineral Raw Materials of the Continental Shelf of the USSR and the World Ocean," DOKL. NA I S"YEZDE GEOLOGOV SSSR [Reports of the 1st Congress of Geologists of the USSR].

[4]P. L. Bezrukov, "Geological Prospects for the Exploitation of Solid Minerals of the Ocean Floor," DOKL. NA I S"YEZDE OKEANOLOGOV SSSR, 1977, June.

The iron-manganese nodules contain in a number of cases up to 20-25% iron, 20-30% manganese and also copper, cobalt, nickel, and other elements although the latter exist in comparatively small amounts (a maximum of up to 1%). However, they are of interest for industry. In the Pacific Ocean in northern tropical latitudes, a belt about 4000 km long and several hundreds of kilometers wide runs approximately along the parallel, in which in practice the nodules are widespread everywhere.

The metal-bearing sediments on the bottom of the ocean with increased metal content have practical significance. They were first detected in 1958 during the third trip of the diesel-electric ship "Ob'." The scientists of the Institute of Oceanology of the USSR Academy of Sciences have recently studied the metal-bearing precipitates on the bottom in detail in the vicinity of eastern Pacific Ocean uplifts. The increased metals content is also noted in the regions of the mid-ocean ridges. The reserves of valuable minerals are contained in hot brines and metal-bearing sediments in the Red Sea, in a region which is a continuation of the Indian Ocean Ridge. According to some foreign data, in one of the basins of the Red Sea alone in a layer of sediments up to 10 meters thick there are nonferrous and noble metals amounting to several billions of dollars.

7. Biological Resources of the Ocean[1]

At the present time basically fish are extracted from the ocean. In recent years the catching of fish has stabilized at the level of approximately 70 million tons a year. The estimates of the fish reserves made by scientists of the various countries indicate that the annual maximum take of fish in the World Ocean must not exceed 100 to 150 million tons. Thus, the fish take is close to the limit. In spite of this fact, the biological resources of the ocean remain in reality untouched. Actually, the area of the ocean exceeds by many tens of times the area of the cultivated dry land and, in addition, in the ocean it is possible to use the entire upper layer on the order of 10-15 meters which is penetrated by sun rays and where, consequently photosynthesis can occur, for the production of food products. However, the ocean still provides only approximately 1% of the food products (this is about 18% proteins). The potential possibilities of the ocean are enormous. In particular, in the ocean 500 billion tons of phytoplankton are produced annually, from which the entire biological chain of the ocean begins. It is true that at each

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[1]In this section materials are used from the report by M. Ye. Vinogradov and N. M. Voronina "Development of the Communities of Oceanic Pelagic Zone" at the First Congress of Oceanologists of the USSR, 1977, June.

For more details on the biological research of the ocean see the article by P. A. Moiseyev in this collection.

given point in time the ocean contains a total of about 2 billion tons of phytoplankton which arises from the life cycle of more highly developed organisms. It is quickly eaten up by them, but it also grows quickly, supported by the water. It is surrounded on all sides by nutrients; it does not need to create a root and stem system as plants on the dry land do.

The mass of plankton is enormous, but nevertheless it is a total of only 1/20 of the entire biomass of the ocean. The total amount is estimated at about 35 million tons.

What are the possible paths of utilization of these ocean resources? There are three such paths. The first path: man can extract not only fish but also zooplankton which is available in large quantities in Antarctic waters. Zooplankton is in the form of small crustaceans or the so-called krill; previously it was eaten by whales, but now as a result of human slaughter their number has decreased significantly, and the krill is multiplying in large quantities. The protein obtained from krill is highly nutritious, it contains many valuable amino acids and is to a known degree therapeutic. The mass of krill caught can exceed by several times the mass of fish caught at the present time. In the given case basically technical problems arise. It is necessary to create special fishing gear and develop a process for removing the hard chitinous shell from the small delicate crustaceans.

The second path is the use of the biological resources of the open ocean. It is well known that the biological productivity of the ocean is especially great in the vicinity of the upwelling of deep water rich in nutrients -- the so-called upwellings. For example, the upwelling off the coast of Peru makes up a total of only 0.02% of the area of the World Ocean, but it yields 15% of the world catch of fish. The existence of upwellings, although, probably not with the same characteristics, is possible in the open ocean. In particular, in the synoptic eddies with a cold nucleus which we have discussed above, upwelling of the water and carrying away of nutrients occur. These regions are distinguished by increased biological productivity. It is entirely possible that in some parts of the ocean it is possible to construct artificial upwellings. In other regions it is necessary to fertilize the sea water to increase the bioproductivity of various forms of life, from algae to fish.

The third path is breeding of animate organisms in the ocean. With respect to the ocean we are essentially in the position of primitive man and we are engaged only in hunting. The time has come to begin to breed fish, grow mussels, algae, and so on. In this respect the shoals, bays and gulfs are prospective. The cultivation of new fish for the given regions, the offspring of which are imported from other seas, even oceans, frequently is highly effective.

However, whatever path we select, it is first of all necessary to know the biological structure of the ocean, that is, how the biomass is distributed in the ocean, how the various organisms interact with each other, how energy is transported through the food chain from the simpler to the more complex organisms, what conditions are needed for faster breeding of certain elements of the biological chain, and so on.

The role of the physical conditions is illustrated most clearly by the upwelling phenomenon, but in practice in all other cases they play a highly significant role. Let us consider, for example, the breeding of phytoplankton in the vicinity of Antarctica. Its greatest productivity is noted approximately 2 months after the maximum sunlight. The question is why? It would appear that the presence of nutrients and sunlight is entirely sufficient for rapid breeding of it, but the situation is not that simple. The phytoplankton multiply the fastest when appropriate stratification takes place in the upper layers of the ocean, when a discontinuity layer exists, the water in the upper layers of the ocean ceases to mix with the deeper water. These conditions come approximately 2 months after maximum sunlight, that is, after the upper layers of the ocean are well heated.

This example convincingly indicates that it is necessary to create a theory of the biological community of the ocean as a whole or at least in individual regions considering the physical, chemical and other conditions. It must be developed as the theories of large systems are developed -- using modern mathematical methods and electronic computers. Only after carefully studying the interrelations of various chains of the biological system of the ocean can we most effectively utilize its resources without disrupting its principles. Scientists throughout the world are now working on this problem, including the scientists of the USSR Academy of Sciences and many other departments.

8. Pollution of the World Ocean

One of the many functions of the World Ocean having decisive significance for the existence of mankind is the processing and neutralization of numerous waste products coming into it from the rivers or directly, for example, emergency oil spills during marine extraction, disasters with tankers, and so on. Much harmful industrial waste comes into the ocean, including the heavy metals -- lead, mercury, and so on. For example, the North Atlantic is strongly contaminated by such waste. Finally, numerous poisons, pesticides, part of which in the final analysis we consume together with fish, come into the rivers and then to the seas and oceans from the fields.

Until recently the ocean dealt with its own purifier function. However, the danger has now arisen that the load on it in the form of pollution is becoming extraordinary, and this can have irreversible consequences.

For example, let us consider the question of pollution with oil and petroleum products. A very thin (about 1 mm) surface layer of the water in the ocean to a significant degree regulates the heat and moisture exchange between the atmosphere and the ocean. On the appearance of an oil slick the characteristics of this layer also change, as a result of which the processes of the interaction of the atmosphere and the ocean take place differently. This can have a significant effect on weather and climate, on the underwater life in the ocean, on the influx of solar energy to its waters, and so on.

Another example is still clearer. The role of nuclear power engineering is growing continuously and will grow in the future. Here the question arises of how to deal with the harmful radioactive waste from nuclear power plants? Among them are elements with a halflife of millions of years. Thus, burial must be exceptionally reliable. Even the smallest fraction of this waste must not get into the natural circulation for millions of years.

Approximately 10 years ago plans were developed abroad for dumping containers with radioactive waste in the deepest parts of the World Ocean. Soviet scientists raised sharp objections to these plans (in this respect a great deal of credit goes to Corresponding Member of the USSR Academy of Sciences V. G. Bogorov). They demonstrated that even in the deepest ocean basins there are currents, and water from these depressions will gradually mix with the water of the entire ocean. As a result, these plans were not implemented. In subsequent years additional facts were discovered indicating that deep-water basins are regions of the greatest seismicity. In these regions located on the edges of the oceans, the oceanic earth's crust creeps under the continental crust. Therefore cataclysms of one sort or another are frequent there: eruption of volcanoes, earthquakes and so on, and danger of the most extraordinary mechanical rupture of the containers is great.

In recent years new plans have arisen in which it is proposed that the containers with radioactive waste be placed in the center of the tectonic plates. It is considered that at these points the seismic situation is the quietest. A discussion of this plan has been the subject of an entire issue of the OCEANUS journal of Woods Hole Oceanographic Institute in the United States.[1]

Thus, there are many dangers threatening the ocean. The role of the scientists is to discover them in time, find the solutions to the problems facing mankind on the path of exploitation of the ocean.

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[1] OCEANUS, Vol 20, No 1, 1977.

9. New Methods and Means of Studying the Ocean

With time, both the methods and means of studying the ocean have been improved. In the last 5 to 8 years the so-called test area method of investigation which was first widely used in the "Polygon-70" experiment in the Atlantic tropical zone, has become widespread. The essence of the method consists in the fact that in the comparatively large body of water of the ocean there are ships or autonomous buoys from which prolonged synchronous observations are made of the state of the ocean (on the surface and at various depths) and also of the atmosphere. These experiments make it possible to obtain sufficiently reliable answers to the questions of the nature of the processes occurring in the depths of the ocean and also the interaction of the ocean and the atmosphere. The previously practiced method of investigation in sections or at defined points of the ocean from one ship or the performance of multiple-day stations turns out to be less effective. Actually, it is possible to obtain data at various points of the ocean at different times. Here frequently it is impossible to determine what causes the change in state of the ocean on going from one point to another -- is it the result of a change in the geographic coordinates or simply the result of the fact that some time has passed. Of course, a great deat of data is now obtained from individual ships, but the trend is toward planning large test area experiments.

Another presently developing, highly prospective method of investigating the ocean is connected with the use of the space media -- orbital stations or artificial earth satellites. It is possible that only this will permit us to obtain a sufficient quantity of information about the condition of the ocean equal to the amount of data on the state of the atmosphere.

Now let us discuss the means of investigating the ocean. The basic instrument used until recently by the Soviet researchers to measure ocean currents was the Alekseyev alphabetic printing current meter. It has performed a great service and has been used, in particular, in "Polygon-70." However, this instrument has a number of significant deficiencies. One of them consists in the fact that the measurement results are recorded on paper tapes; then they must be manually copied onto the punch tape for subsequent processing by computer. Now the autonomous instruments are beginning to be widespread which record data on magnetic tape or photographic film with mechanized transmission of the data to a computer for processing. The instruments which give not an instantaneous value of the current velocity vector, but one averaged over a defined time interval have an important advantage here. The analogous instruments are also available for measuring the temperature and salinity of the water. This type of instrument, just as the current meters are suspended at the buoy installations at various levels on a cable running from an anchor to the surface or submerged buoy.

However, the continuous dependence of the current feed on the depth can be obtained only using continuous-sounding instruments, one of which is the instrument with cross ultrasonic beams (Gross beam). Here the current velocity is determined by the Doppler effect for ultrasonic waves. The instrument is lowered into the water on a cable until it reaches a sufficiently great depth from the drifting ship. The data obtained are continuously recorded on board the ships. By using such an instrument, the Soviet scientists first detected the thin interlayering of the currents in the ocean.

Free-falling current sondes exist. As a rule, they are based on the phenomenon of electromagnetic induction. The water particles flowing between two electrodes in the earth's magnetic field create a difference in electric voltages on these electrodes.

A great deal of interesting data on the ocean current has been obtained by using drifting buoys with underwater sail or buoys with neutral buoyancy. In the former case the surface buoy is connected by a cable to a sail located at the depth where the current is measured. The current, acting on the sail, moves the surface buoy along. Either a ship or an artificial earth satellite tracks the movement of the buoy.

In contrast to these buoys, the neutral-buoyancy buoys are autonomous. After being dropped in the water they sink to a previously defined depth, they reach equilibrium, and then they move together with the water masses. The location of the buoys is periodically determined using sound signals transmitted by them and received by a number (no less than three) of the sound receiving stations. Thus, the American researchers obtained a great deal of interesting data on the currents in the eddies of synoptic scale in the Sargasso Sea.

The temperature and salinity of different depths were almost always measured until recently by tipping thermometers and bathometers. All the basic data are received using continuously submerged sondes, which simultaneously measure the temperature, the electrical conductivity (and by them the salinity is calculated) at depth. This is a significantly more operative method than the construction of hydrologic stations using tipping thermometers.

Operative measurements of the temperature in the upper layers of the ocean (to approximately 700 meters) is possible from a ship or aircraft using expendable bathythermographs. In this case the instrument dropped from the ship or from the aircraft, makes sounds and transmits information about the vertical temperature profile through a thin wire to the ship or by radio to the aircraft. After each experiment the instrument is lost, but it is inexpensive and, in any case, cheaper than the information obtained.

In addition, there are sondes which also record many components of the chemical composition of the water: oxygen, phosphorus, carbon dioxide, pH, and so on.

There are highly complex multifunctional buoys which are installed on anchor at defined points in the ocean. They transmit information on the condition of ocean depths (current, temperature, salinity), and also the layer of the atmosphere next to the water on the artificial earth satellites. These are reliable, but quite expensive systems. There is an international project IGOSS (Integrated Global Ocean Station System) which provides for the installation of several hundreds of such buoys throughout the entire World Ocean. However, unfortunately, this project will be very expensive.

It must be noted that at a small number of points in the ocean there have been "weather ships" from a number of countries, including the Soviet Union, standing continuous watch for a long time. The information about the characteristics of the ocean and atmosphere measured from these ships are transmitted to the International Data Centers. These measurements over many years have great scientific value.

The station platforms on the bottom and on the shoals are also used for research purposes. From them it is possible continuously to measure the characteristics of the wave and any other parameters of the water and air masses in the given region. One such platform is located in the Caspian Sea, 30 km from Baku. The scientists of the Azerbaydzhan SSR Academy of Sciences and also the Institute of Oceanology and the Institute of Atmospheric Physics of the USSR Academy of Sciences have obtained many interesting data pertaining to the dynamics of the wave action, the characteristics of internal waves and also the thin interlayering of the water masses.

However, it is impossible to install such platforms in a deep place. In these cases stabilized anchored buoys are used. One such buoy is the "Flip" of the Scripps Oceanographic Institute in the United States. This structure can be towed any distance like a ship. At the given point it is tipped, assuming a vertical position and is put on anchor. As a result of its elongated shape it stays almost stationary even in high waves. The scientists are located in a special laboratory with their equipment in the upper part of the buoy above water, and they can perform observations of the wave action, currents, and the underwater ocean noise, and so on.

The current fluctuations caused by comparatively fine-scale turbulence (scales from several centimeters to tens of meters) are measured from stabilized buoys, platforms or ships using the instruments turbulimeters. These are low-inertia instruments which continuous record three components of the current velocity as functions of time.

The problem of investigating the internal waves in the ocean is very complex. In the American MODE experiment, a complex three-legged structure was used from the bottom to the surface (the spacing between the supports was about 5 km). In the "legs" of the structure there were a large number of current and temperature gauges. Ideally this permits determination of all of the necessary space and time characteristics of the internal waves, but it is very complicated and expensive. More frequently the studies of the internal waves are performed by the method of small polygons on which chains of temperature gauges are towed behind the ship. The ship makes a so-called asterisk -- a system of tacks in different directions. This procedure is not acceptable if the waves are highly unstationary and their characteristics vary during the process of the experiment itself, usually lasting about 15 to 20 hours.

By the initiative of the Soviet scientists, the studies of the internal waves have begun to be performed, applying the so-called distributed temperature gauges. In order to measure the temperature at one point, the average temperature is measured with their help in a defined depth range. With such temperature averaging with respect to depth (usually within the limits of 10 to 20 meters) interfering multifrequency noise is picked up from the recordings which permits more exact isolation of the internal waves themselves. However, the experimental study of the internal waves still presents great complexities.

For investigation of the parts of the bottom relief of the ocean, a side scanning sonar is widely used, which we discussed previously, and for investigation of the internal structure of the bottom, a seismoprofilograph. In this instrument there is a low-frequency sound emitter -- "air gun," which periodically ejects a defined volume of air into water under increased pressure. The latter, expanding, generates a side wave which passes through the entire body of the ocean, then it penetrates the bottom and is propagated downward into it, subsequently being reflected from the various nonuniformities. The reflected waves are picked up by sound receivers located in the hydroacoustic gear towed behind the ship. This method permits continuous determination of the bottom structured depths of several kilometers as the ship moves.

Of course, when studying the structures of several upper kilometers of sedimentary series of the bottom the most productive, although most expensive method is the method of direct drilling of the bottom.

Important results about the surface structure and the body of the ocean floor can be obtained from research submarines. Recently such studies were performed on the "Paysis" [Pisces] submarines by Soviet scientists in Lake Baykal. American, French and English scientists used the "Alvin" research submarine capable of descending to depths of up to 6 km to investigate the structure of the mid-Atlantic ridge. Lava eruptions indicating continuous inflow of molten material from the depths of the earth in the given region were recorded.

It is necessary also to recognize the autonomous unmanned means of exploring the ocean floor and the body of it as prospective. They can be controlled by a cable or operate independently by a given program.

The sea floor has been investigated more than once by manned underwater craft in which aquanauts have spent prolonged periods of time. They went into the ocean, conducted continuous observations of the state of the environment, took samples, and so on. These craft are prospective for servicing underwater industrial installations.

Ocean exploration spacecraft are developed. By scattering electromagnetic waves on the ocean surface from space it is possible to determine the spatial and frequency spectra of the ocean waves. Knowing the latter, it is possible to calculate the speed of the surface wind and also the flow velocity of the surface layers of the water. By infrared emission of the surface, the surface temperature of the water is determined, by the reflection coefficient of the electromagnetic wave from the air-water interface it is possible to determine the electrical conductivity, which also means the salinity of the water. By its color, it is possible to establish the degree of pollution and also a degree of development of biological life in the given region.

From space it is possible to detect schools of fish and also to study the peculiarities of the bottom relief in shallow regions and even observe the internal waves. By using the hydrodynamic and thermodynamic models of the ocean, by the data on the surface and upper layers of the ocean it is possible to draw some conclusions about the state of its internal layers.

10. Organization of Research in the Ocean

A number of organizations are engaged in the coordination of scientific research on an international scale, the largest of which is the international oceanographic commission under UNESCO. Under the aegis of this commission a number of large scale studies have already been realized, in particular, studies of the Indian Ocean, zones of the Caribbean Sea, the Kuroshio Current, and so on. The most important scientific problems of an international nature pertaining to the study of the ocean have been worked out within the framework of the International Council for Ocean Studies (the national member of this council in the USSR is the Commission on World Ocean Problems of the USSR Academy of Sciences).

The cooperation of these scientists in the USSR, Poland, the German Democratic Republic, Bulgaria, Romania and Cuba in studying the ocean is being coordinated within the framework of the CEMA by a special coordinating center existing under the Oceanology Institute of the USSR Academy of Sciences. Under the Committee on Science and Engineering of the USSR Council of Ministers there is a scientific council for the study of the World Ocean and the use of its resources.

The 25th Congress of the Communist Party of the Soviet Union has stated the problem of investigating the World Ocean and using its resources for a number of the main goals of Soviet science. The organization and coordination of these studies in which thousands of scientific coworkers are participating on hundreds of research vessels and many scientific research organizations is becoming extremely important. The plan for complex use of the ocean approved by the USSR State Committee on Science and Engineering for the Tenth Five-Year Plan was compiled by the Commission on World Ocean Problems ofthe USSR Academy of Sciences jointly with other departments in accordance with a new principle. It consists basically of the scientific programs providing for studies in clearly defined areas. The participation in the plans of the different departments under the direction of the main department has been provided for. This will permit not only concentration of the efforts of the scientists of different institutes on the most important problems but also it will permit the studies to be made more effective. It is sufficient to remember that not long ago the expeditions of various departments went into the same ocean, in the same year, and each ship worked by its own plan.

Let us discuss the most significant plans for ocean studies. Some of them, such as, for example, the international programs GARP and POLYMODE, and also the international deep drilling project in the ocean have been discussed above.

Work will be continued in the framework of the international "Geodynamics" project, the goal of which is to study the spatial nonuniformities of the earth's crust and the mantle in the ocean, the transition zones of the crust of the ocean type to the crust of the continental type, improvement of the hypothesis of the origin and the development of the ocean floor.

National projects also have great significance in which the efforts of Soviet scientists are concentrated. One of them is the "Biotalassa" project. Its goal is to study the principles of the formation of bioproductivity of regions of the open ocean which are prospective in fishing respects.

The work with respect to the interdepartmental project "Geos" is arousing interest. Its goal is to study the geological structure of the sedimentary layer in the oceans and seas, comparison of the geological sections in various parts of the World Ocean, discovery of the laws of sediment accumulation and also the features of the geological structure based on the continuous seismic profiling data.

The "Volna" [Wave] project is also important. Its goal is to study surface and internal waves in the ocean.

INTERNATIONAL COOPERATION IN THE STUDY OF THE WORLD OCEAN

[Article by A. S. Monin, Ye. A. Tsvetkova]

Andrey Sergeyevich Monin, corresponding member of the USSR Academy of Sciences, director of the Oceanology Institute of the USSR Academy of Sciences imeni P. P. Shirshov is involved with the problems of geophysical hydrodynamics. He is actively working on the implementation of the programs of international scientific cooperation in the area of investigation of the World Ocean, in particular, Soviet-American studies of ocean currents and ocean dynamics (the POLYMODE program).

Elena Alekseyevna Tsvetkova, scientific coworker, scientific secretary of the Commission on International Scientific Relations of the Oceanology Institute of the USSR Academy of Sciences imeni P. P. Shirshov, is working on the problems of international scientific cooperation in the field of World Ocean exploration.

The effort to obtain the greatest cost benefit from marine studies in the shortest time, to exclude duplication to the maximum degree, and to achieve more efficient use of the scientific forces and material resources expended on the projects, has led to the fact that a number of countries have already developed, are developing or are planning in the near future to develop long-range national programs for oceanological research. This effort has given rise to the creation in a number of countries of coordinating agencies with respect to oceanological research in the form of national committees and councils or other institutions endowed with great powers.

However, the comprehensive independent study of the World Ocean is a problem which is beyond the means of any one country. Thus, no one country can allocate the required number of special research ships and scientific personnel for studying ocean processes which sometimes vary in a few hours over a significant body of water. It is only as a result of the close cooperation of scientists and specialists of different countries working on the same oceanological problems that in the final analysis it is possible to obtain exact scientific representation of the ocean as a whole and the processes originating in it and the most effective paths of the use of its resources can be found. Such cooperation is possible only on efficient organization and coordination of it on an international scale.

1. Goals and Forms of International Cooperation in the Study of the World Ocean

In what way does international cooperation promote the solution of the problems facing the oceanologists of different countries, in what areas of oceanological research is it most necessary, and what are its most efficient forms?

The experience of recent years indicates that not only is the exchange of scientific information and mutual standardization of the instruments and measurement techniques needed, but also joint expeditionary studies of the ocean, cooperation in the field of monitoring the state and protection of the marine environment, and use of navigational means.

The exchange of scientific information permitting specialists of different areas of oceanology to obtain the required data on the oceans on the scale of the entire planet quickly and without great material expenditures is possible only on the basis of international cooperation.

The publication of scientific results obtained by the oceanologists of various countries, in the special scientific journals, many of which are widely circulated and the total number of which increases from year to year, the participation in the international meetings on the most urgent problems of oceanology, exchange of scientists among the institutions of the country interested in the development of marine science, the strengthening of contacts between them and, finally, obtaining the required information through the world data centers -- all of these are tested means of exchange of scientific information on an international basis.

The existing system of world data centers includes the data centers A and B (oceanography) in the United States (Washington) and the USSR (Moscow), respectively, and also permanent centers (disciplinary, regional and national). The system, which was completed during the period of the International Geophysical Year (1957-1958) has completely justified itself. The results of the studies performed by the published national programs obtained during the course of joint international measures; voluntary contributions of the governments and individual scientists come into the data centers. Then after recording and maximum possible standardization this information is processed and disseminated among the interested sides. Thus, it becomes possible to study ocean phenomena on a world scale and study the interdisciplinary interrelations among the various phenomena.

Mutual calibration and standardization of instruments and measurement techniques is a required condition for comparing the observation results in the ocean by the various countries. Here the reliability of the measurements increases without which correct description and recognition of the investigated processes is impossible. Now it is obvious that the differences in the results obtained in the past by various countries were primarily connected with differences in the instruments and measurement techniques. The experiments with respect to mutual calibration and international standardization organized and performed under the aegis of international organizations will permit achievement of a united degree of accuracy and complete comparableness of measurements.

As is known, at the present time the oceanologists of the various countries are making wide use in their research of certain basic standards, for example, standard seawater and carbon-14 solution, standard plankton networks, certain constants and functions, including the coefficients entering into the equation of state of seawater, and so on. For international studies of the ocean performed on broad scales, the standardization of the methods of recording the obtained data is acquiring special significance. The volume of scientific and accompanying materials which must be exchanged is exceptionally high, and their effective processing by modern automated systems within the framework of one country can be achieved primarily by standardization of the form of representation of all of the primary data for putting them in the computers on an international basis.

Joint expeditionary studies of the World Ocean, as has been pointed out, are necessary on the basis of the nature and the scales of the processes occurring in it. These ocean studies on an international basis will permit us to study large-scale interaction of the ocean and atmosphere and to develop the scientific principles of ocean forecasting; to create a global network of ocean stations which receive broad timely and synchronous information about the state of the World Ocean as a whole and the processes occurring in it, to investigate the number and the distribution of the fish populations and their interrelation for purposes of increasing and maintaining the world catch of fish; to study the ocean floor using the methods of modern geophysics and deep-sea drilling to discover the geological history of the oceans.

The monitoring of the state of the marine environment and preservation of it can be realized only on the basis of international cooperation.

At the present time the joint efforts of the oceanologists of different countries have been aimed at creating scientific principles of the prediction and the prevention of destructive natural phenomena originating in the ocean. It is possible to include hurricanes and typhoons, storm waves and tsunami, catastrophic death of commerical species of fish caused by meteorological factors, eruption of underwater volcanoes, and so on among them.

The international cooperation in the study of these phenomena will promote the fastest recognition of the nature of their occurrence and the development of protective measures or measures to decrease their destructive consequences.

International cooperation in the matter of controlling the pollution of the ocean is no less important, the absence of which can lead to consequences that are fatal to mankind. The joint study of undesirable consequences of human activity in the ocean -- pollution of its water, in particular, the coastal water -- with domestic and industrial waste water, petroleum products, radioactive waste, and so on will permit the creation of an effective system for monitoring the state of the marine environment, the development of effective complexes of organizational-technical measures for the control of pollution and maintenance of purity of the oceans and seas in which everyone living on our planet is interested.

Use of Navigational Means. It is well known that the results of any operations in the ocean carried out from on board scientific research ships depend to a high degree on the precision of navigation. Recently the methods of precision navigation even at great distances from the dry land based on using low-frequency radio equipment or artificial earth satellites have become widely developed. The realization of these methods is possible only on the basis of international cooperation in various forms. They include the granting of plots in the various countries for ground installations, the dissemination on a world scale of the required equipment or specifications for radio receivers that use satellite signals, and so on.

2. International Oceanological Organizations

The history of the creation of international organizations in the field of oceanology goes back to 1902 when the International Council for the Exploration of the Sea (ICES) was created. Its goals were limited to the problems of fishing oceanography in the North Sea and the northeastern parts of the Atlantic Ocean. In subsequent years the growth of international activity in the field of ocean studies led to the creation of an entire series of special international organizations.

Today the world has more than 30 such organizations. They are divided into basic groups: nongovernmental and intergovernmental. The members of the former usually are academies of sciences, national scientific councils, and so on. The intergovernmental organizations are divided into those connected with the UNO system and those not connected with it.

The International Council of Scientific Unions (ICSU) is an important nongovernmental organization. It is the largest association of national scientific institutions and international unions, committees and commissions created in 1931 to establish scientific relations between the countries and for coordination of the activity of the international scientific unions in all areas of natural sciences, including the area of oceanology.

At the present time the members of the ICES are scientific institutions of 64 countries of the world; the council includes 16 scientific unions of which the International Geodetic and Geophysics Unions (with the International Association of Physical Sciences of the Ocean and the International Association of Meteorology and Atmospheric Physics), the International Union of Geological Sciences (with the International Association of Sedimentologists and the Commission on Marine Geology), and the International Union of Biological Sciences (with the International Association of Biological Oceanography) study the problems of oceanology to one degree or another.

For concentration of the efforts of the scientists in the most urgent problems of oceanology the ICES has created a number of special committees under its direct subordination and having representatives of several unions in it. Among such committees the problems of oceanology are directly dealt with by the Scientific Committee on Oceanic Research (SCOR).

The Scientific Committee on Oceanic Research created in 1957 is in essence the main international scientific organization in the field of oceanology. The SCOR is the basic scientific-consultative agency of the International Oceanographic Commission of UNESCO which gives its assistance in the solution of many purely scientific problems which arise in the organization of oceanographic cooperation among an intergovernmental level. The primary goal of SCOR is to promote the development of the international scientific activity in all fields of oceanological research by organizing discussions with respect to the most important problems and cooperation with the other interested international organizations.

At the present time the SCOR members are 34 representatives of national academies of sciences or the organizations corresponding to them and 6 representatives of the various ICES unions.

The greater part of the work of SCOR is performed through its groups created for the solution of individual scientific problems of oceanology. At the present time there are 20 working groups coordinating the studies of the internal dynamics of the ocean, the influence of the ocean on climate, the possibilities of mathematical simulation of oceanic processes and also biological oceanography, the biological effects of the variability of the ocean, the processes of equatorial upwellings of the water, paleooceanography, and so on. Through its working groups the SCOR is the initiator of the holding and the organizer of the international scientific symposia and conferences with subsequent publication of the scientific works. With the active participation of the SCOR, the oceanologists of the various countries perform joint projects at sea, including for the calibration of instruments and procedures.

The International Association for the Physical Sciences of the Ocean (IAPSO), one of seven associations of the International Geodetics and Geophysics Union (IGGU) of the ICSU created in 1922 and receiving its present-day name in 1967, has a direct bearing on oceanology. However, in contrast to the SCOR, the class of problems of which encompasses all areas of oceanology, the IAPSO, as the name itself indicates, deals with the problems of physical oceanography, that is, the study of the physical processes in the ocean and at its boundaries calling on the achievements of mathematics, physics and chemistry. This association plays the role of the international coordinating agency in the indicated region. There is naturally a close relation between the SCOR and the IAPSO. The greater part of the work is performed by these organizations through the working groups of the SCOR and the IAPSO (working groups, commissions and committees). With respect to many of the most important problems of oceanology joint working groups have been created among which, for example, are WG No 10 "Oceanographic Tables and Standards"; WG No 34 "Internal Dynamics of the Ocean"; WG No 42 "Pollution of the Baltic Sea"; WG No 46 "Contribution of Rivers to the Oceanic System"; WG No 47 "Oceanographic Programs During the Period of the First GARP Global Experiment"; WG No 48 "Effect of the Ocean on Climate"; WG No 49 "Mathematical Simulation of Oceanic Processes"; WG No 55 "Predictions of the El Ninõ Phenomenon"; WG No 56 "Processes of the Equatorial Upwelling of Water."

The activity of the majority of these joint groups, the work of which is participated in by representatives of other international agencies also turns out to be highly fruitful, for example, in determining the most urgent scientific problems of studying the ocean, the development of joint research programs and rendering aid to the corresponding international and national organizations and their implementation.

The SCOR and the IAPSO are large organizations of oceanologists playing the role of international scientific consultative agencies. The practical organization of the studies in the ocean by coordination of the studies of various countries are performed by the international organizations connected with the UNO.

The basic one among them is the Intergovernmental Oceanographic Commission (IOC) created in 1960 within the framework of the United Nations for the problems of education, science and culture (UNESCO) in order "to promote the development of scientific studies of the oceans to understand the nature and exploit the resources by joint activities of its members." The members of the IOC of UNESCO include 64 governments at the present time.

The IOC investigates the international programs of oceanological research and also undertakes the necessary steps for implementation of them, it analyzes the results of the scientific research and defines the basic problems requiring international cooperation, and it also offers recommendations regarding the nature, the forms and methods of exchange of oceanological data through the international and specialized data gathering centers.

For implementation of special plans connected with ocean studies, the IOC of UNESCO creates working groups, groups of experts and committees from the interested members. Under the Presidium of the IOC of UNESCO (the chairman and two vice chairmen) is the Consultative Council of Representatives of the Member Countries of the Commission which helps in decision making with respect to all important problems between IOC sessions.

The international programs of oceanographic research recommended by the IOC of UNESCO to its members for specific execution are carried out by the means of the participating governments by agreement with them and also partially by the means of other international organizations of the United Nations system (such as, for example, the Produce and Agricultural Organizations of the United Nations -- FAO) which are not members of the Commission, but agree to finance such programs.

The IOC of UNESCO also deals with such problems as the marking of the oceanographic buoy stations, finding radio frequencies for use by their oceanologists, the standardization of the methods of oceanological research, the creation of tsunami warning systems, the development of means of preventing ocean pollution, and so on. The commission has stimulated the preparation of the "long range and expanded program for research and exploitation of the World Ocean" (1970), the development of which has been actively participated in by SCOR. Under the guidance of the IOC of UNESCO, a series of atlases of the Indian Ocean has been prepared and published; the geological-geophysical atlases of the Atlantic and Pacific Oceans are also being prepared for publication.

In dealing with the problems of international coordination of oceanological research, the IOC maintains contacts with other oceanological organizations. The closest relation exists between the IOC of UNESCO and the SCOR of the ICSU.

The IOC of UNESCO also cooperates with the nonoceanological organizations, it comes to their aid when solving the most important problems connected with studies of the World Ocean, for example, with the WMO (World Meteorological Organization) entering into the United Nations system, although such is not recognized as participating in the investigation in the majority of oceanological problems. Thus, in close cooperation with the WMO and with the support of other interested organizations the IOC of UNESCO is coordinating the work of the Integrated Global Ocean Station System (IGOSS) and working in contact with the World Weather Service under the conditions developed by the WMO and the IOC. The purpose of IGOSS is to provide the broadest, timely and systematic information about the state of the ocean required for observation of phenomena on a global scale which in the final analysis will help to develop reliable methods of predicting the state of the oceanic environment and weather.

The IOC of UNESCO has a great deal of experience in the organization and the performance of large-scale international studies in various parts of the World Ocean based on cooperation with certain regional organizations, primarily with the already-mentioned ICES. The value of the joint regional studies consists in the fact that the results obtained supplement the materials of the large scale international research programs realized under the aegis of the IOC of UNESCO.

3. Examples of Studies of the World Ocean Based on International Cooperation

For proper understanding of the set of physical, chemical and biological processes occurring in one region or another of the World Ocean, their interrelations and mutual dependence, regular synoptic surveys are required which are performed by several ships over the entire area of this region.

In the last two decades the IOC of UNESCO in cooperation with other organizations of the United Nations system and the ICSU, based on the scientific consultation of SCOR, has organized and performed a number of large-scale international expeditions in the Indian, Atlantic and Pacific Oceans and also in Antarctic waters, the Mediterranean and the Caribbean Seas.

The International Indian Ocean Expedition (IIOE) in 1959-1965 was participated in by 23 countries (14 of which provided their own ships), 40 scientific research vessels, 180 scientific research trips of different duration and complexity were made. The results obtained were published with the direct participation of the IOC of UNESCO. In particular, the collections of expedition materials (5 volumes) and also a series of IIOE atlases on various divisions of the research were widely disseminated.

The International Joint Studies of the Tropical Regions of the Atlantic Ocean were performed in 1963-1964 in three phases (EKVALANT I-III) with the participation of 8 countries. Thirty ships completed 36 scientific research trips. On the basis of the results of these studies in accordance with the UNESCO IOC line, an Tropical Atlantic Ocean Atlas was published.

The studies of the Kuroshio Current and a number of regions of the Pacific Ocean (STK) were performed in 1965-1967 by representatives of 11 countries. Thirty-six scientific research vessels completed 36 scientific expeditions to study the variability of Kuroshio and also discover the geological and geophysical peculiarities of the region and establish its biological resources. The latter has special significance for the population of the area which obtains its protein food basically from products of the sea.

From 1970 to 1975 a broad program of joint scientific studies was implemented under the aegis of the UNESCO IOC in the Caribbean-Mexican Basin which was called SIKAR. The joint efforts of 20 participating countries in the program were directed toward the accelerated and broadened understanding of the nature of the region, its physical-chemical regime, hydrography, geology, exploration and subsequent development of mineral, energy and biological resources and also rendering of aid to the developing countries of the region in the assimilation of modern methods of maritime research and the training of national oceanological personnel.

The Soviet Union participated in all of these IOC research programs.

A good example of the cooperation of intergovernmental and nongovernmental international organizations for science is the Global Atmospheric Research Program (GARP). It was undertaken jointly by the ICSU and WMO. Its purpose was to improve the understanding of the general atmospheric circulation and, consequently, to develop more exact methods of long-range weather forecasting. The implementation of this, one of the most important, program was participated in by scientists in the field of atmospheric physics, oceanology and adjacent disciplines directing their efforts at the study of atmospheric processes on a global scale. The studies by this program are coordinated by the United Organizational Committee (UOC) created by the ICSU and the WMO in 1967. The UOC, which includes the scientists of 12 countries, is a scientific agency which investigates all of the proposals and generates recommendations.

Under the experimental subprograms of GARP known as the Atlantic Tropical Experiment (GATE from GARP Atlantic Tropical Experiment) was executed in the tropical part of the Atlantic Ocean in June-September 1974. During the course of GATE-74 which was participated in by 25 ships and 12 aircraft, valuable scientific data were obtained for checking models of different atmospheric processes to include them in the final description of the general atmospheric circulation and also in the forecasting systems based on this description. On the basis of the data obtained, an international GATE oceanographic atlas has been created.

At this time the First GARP Global Experiment (FGGE) for the study of general atmospheric circulation is being carried out with the participation of a large number of scientific research vessels and meteorological satellites of many countries of the world. The experiment will be carried out in 1979.

During the process of FGGE, a study will be made of the structure of the current field and the fields in the equatorial parts of the ocean and the reaction of these fields to the effect of the atmosphere which is variable in time. An important part of the program is the study of the time-space structure of the equatorial subsurface countercurrents, in particular, the phenomena of meandering of the equatorial countercurrents predicted by theory and established experimentally during the GATE.

The Soviet Union is participating in FGGE, the preparation for which, including the numerical experiments with respect to the problems of general atmospheric and ocean circulation, the study of the boundary layer of the ocean and atmosphere, oceanic currents, and so on, and it has been successfully performed by Soviet scientists for a number of years.

Experience shows that the effect of the collective efforts of several countries is felt not only purely mathematically, but also scientifically, for it permits investigation of large-scale phenomena.

4. Participation of the USSR in the Work of the International Oceanological Organizations

In the USSR the oceanological studies on the national level are coordinated by the Commission of the USSR Academy of Sciences on Problems of the World Ocean and the Oceanographic Committee of the Soviet Union under the State Committee of the USSR on Science and Engineering, and with respect to certain problems, also the USSR Ministry of Fishing and the State Committee of Hydrometeorology and Monitoring of the Natural Environment of the USSR. Soviet representation in the principal international oceanological organizations is accomplished through these organizations.

Soviet scientists are participating especially actively in the SCOR activities. The membership of the USSR in SCOR is maintained by the USSR Academy of Sciences through its Commission on World Ocean Problems, which plays the role of the national committee of oceanologists.

For many years Soviet researchers have participated in the activity of the SCOR Working Group No 10 "Oceanographic Tables and Standards." For compiling the international tables for calculating salinity by the measured electrical conductivity the WG No 10 has analyzed several hundreds of seawater samples gathered in all parts of the World Ocean from the ships of different countries. A result of this work is the publication of the "International Oceanological Tables" which at the present time are widely used by the oceanologists of various countries, including the Soviet Union. For the compilation of such tables by the efforts of one government it would be necessary to perform several large-scale oceanographic expeditions, and the work of a number of experts for at least 2 or 3 years would be needed.

It is necessary to consider the performance of the international comparative tests of current meters from on board the scientific research vessel "Akademik Kurchatov" in accordance with the SCOR line in 1970 with the participation of representatives of 6 countries no less fruitful. The USSR Academy of Sciences received the thanks of the SCOR leadership for the successful performance of these tests. During the course of the operations, current meters were calibrated, which permitted estimation of the degree of accuracy of the data obtained over the course of almost 20 years by the BPV type meter of the Alekseyev system. In addition, the advantages and disadvantages of the various instruments being calibrated were discovered, which will be taken into account when designing new types of current meters.

The many years of participation of Soviet scientists in the SCOR work offers convincing evidence that further activity within the framework of this organization is unconditionally expedient.

As has been noted above, a number of scientific problems solved by the Scientific Committee on Oceanological Research are similar to the problems within the scope of the IAPSO as a result of which a quite significant part of the work is performed by the SCOR and the IAPSO in close cooperation. On the national level it would be natural to expect just as close coordination of the work of the organizations representing the USSR within these international agencies. However, it is necessary to mention with regrets the poor coordination of the activity of the Interdepartmental Geophysics Committee under the Presidium of the USSR Academy of Sciences dealing with the entry of the USSR into the IAPSO and the Commission of the USSR Academy of Sciences on Problems of the World Ocean through which our country is represented in the SCOR. As a result of this, in recent years there has been noticeable weakening of the activity of Soviet scientists in the work of the IAPSO.

Probably for this reason the scientists of the USSR Academy of Sciences are not participating in the activity of one of the important international oceanological organizations, the ICES, which includes only the

USSR Fishing Ministry. This situation obviously cannot be recognized as satisfactory, for the ICES is an organization which deals not only with fishing problems, but also scientific problems. Thus, the ICES participated in the International Geophysical Year and also the "Overflow" expedition (1960), during the course of which the Faero-Iceland Ridge region was investigated.

Thus, the necessity for participation by Soviet oceanologists in the ICES, and, above all, the scientists of the USSR Academy of Sciences, along with the fishing specialists is obvious. It is expedient to involve specialists from the USSR Fishing Ministry in the participation, for example, in some of the SCOR working groups dealing with the problems of marine biology (WG No 52 "Estimating the Quantities of Micronekton," WG No 54 "Live Resources of the Antarctic Ocean," WG No 55 "Prediction of the El Ninõ Phenomenon," WG No 56 "Processes of Equatorial Upwelling" and so on). This would promote the making of more competent decisions with respect to the specific problems of marine hydrobiological research. At the present time the necessity has also arisen for a closer relation between Soviet organizations which represent the USSR in the SCOR and the WMO, that is, the Commission of the USSR Academy of Sciences of Problems of the World Ocean and the institutions of the State Committee of Hydrometeorology. The permanent working contacts between Soviet specialists working in the SCOR and the WMO, mutual information about the studies performed or planned by these organizations and mutual involvement of specialists in the solution of individual important problems -- all of these are acquiring special significance today, during the active phase of the first GARP Global Experiment.

As an active participant in all of the significant international programs to study the World Ocean, the Soviet Union has always taken its proper place in the UNESCO IOC, which solves important scientific problems on an international level that are not within the power of one institution or one country. The IOC renders a great deal of aid to the developing countries in the development of national oceanological programs, in the creation of national oceanological institutes. For almost two decades of its existence the IOC has proved its usefulness as a powerful international coordinating organization in the field of oceanology which bases its activity on the scientific consultations of respected international organizations, and above all, the Scientific Committee on Oceanic Studies -- ICSU -- the active organization in which scientific international cooperation is effectively developed.

It is still more distressing that recently a trend has been noted toward withdrawal of the UNESCO IOC from the solution of problems of a scientific-organizational nature to the solution of problems on a political and administrative level. In the commission activity a transition has been noted toward the analysis of the claims of individual countries reflecting their political interests, the investigation of which is the prerogative of the United Nations. Accordingly, the number of requests for scientific recommendations on the part of the IOC to the SCOR has diminished sharply. Moreover, the IOC has created its own scientific-consultative office which essentially duplicates the SCOR functions and on the scientific level is neither sufficiently representative nor sufficiently competent.

It is our firm conviction that the UNESCO IOC must rid itself of bureaucratic tendencies noted in recent years and dedicate its work to a united goal -- the development of scientific studies in the World Ocean.

The existence of a large number of international organizations in the field of oceanology can create the impression of "organizational overload." However, if we consider the variety of problems involved in the exploration and exploitation of the World Ocean, the number of oceanological organizations existing at this time in the world does not yet appear too large.

The most effective solution of these problems can be achieved as a result of the joint efforts of the countries interested in the further development of ocean studies with their coordination by the competent international oceanological organizations.

INTERNATIONAL REGULATION OF THE EXPLOITATION OF THE WORLD OCEAN

[Article by L. L. Lyubimov]

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1. Pluralism and Its Negative Consequences

The international regulation of marine activity has been realized to one degree or another since the standards and principles of the international law of the sea arose and began to be developed. However, after World War II, especially in recent years, this process has developed at an avalanche pace. All forms of activity of governments in the World Ocean have been subject to regulation in a short period of time.

Until recently the basic principle regulating the maritime activity was freedom of the open sea. It meant that the oceans and their resources are available for use by any country. The scope of this principle encompassed the entire World Ocean with the exception, as a rule, of a three-mile zone of coastal waters. Today the situation is a different one.

The sharp exacerbation of the raw materials problem has increased universal interest in the marine reserves of mineral raw materials. Scientific and technical progress has provided for the possibility of effective industrial development of them. However, such possibilities have developed only among a very limited group of highly developed countries. They would have one-sided advantages in this area. Of course, some form of international regulation of the given problem is possible, but many maritime countries have taken another route, announcing their sovereignty over the resources of the continental shelf.

This process started in 1945 by a declaration of President H. Truman "U.S. Policy with Respect to Natural Resources of the Sea Floor and Continental Shelf." Responsibility lies with the United States for the first steps in the strangulation of the principle of freedom of the open seas and unimpeded access of governments to the marine resources [4, 5]. Obviously the United States considered that the announcement of sovereignty over the resources is impossible on the greater part of the continental shelves adjacent to the continents, the political maps of which in 1945 were colored predominantly the color of the mother country. At the same time it was proposed that the access of the developed capitalist countries to the shelves would remain open. Subsequent events upset these calculations.

At the end of the 1940's a number of Latin American countries announced their rights not only to the resources, but also to the coastal areas themselves. The concept of "territorialism" arose indicating mastery of the coastal governments over the broad expanses of the sea adjacent to their territory containing these resources. This led to further destruction of the principle of freedom of the open sea, to the situation where governments capable of developing coastal maritime resources have lost the possibility to do so. However, the given process has not been supported by the majority of maritime countries, and "territorialism" has remained a relatively local phenomenon.

Nevertheless, the principle of sovereignty over the resources of the coastal regions has been further developed, and today it is in fact supported by all countries having an outlet to the sea. It has been extended not only to mineral resources, but also to the biological resources. This has led to the formation first of fishing and then economic zones of various extent (as a rule, a 200-mile strip off shore). By the end of 1977, more than 70 countries announced the introduction of such zones. On completion of this process the resources of almost 40% of the World Ocean will fall under the jurisdiction of maritime countries [6].

The width of the territorial waters has also been subjected to more precise definition. In accordance with age-old tradition there was a 3-mile limit for such territories (the maximum range of a shore gun). Today, with the exception of the followers of "territorialism," the majority of maritime countries agree on the 12-mile limit. In order to insure the security of these countries such a limit can be considered optimal. Nevertheless, within defined parts of the World Ocean it covers the entire body of water. We are talking about so-called narrows (the entrances to and the exits from the oceans, international straits, archipelago waters, and so on). The overlapping of such expanses with territorial waters has been for some countries adjacent to them the reason for efforts to extend the regulating rules that are applicable in territorial waters to these waters. If this trend received universal support and was reinforced, there would be significant loss to the interests of international shipping [1].

Thus, recently a trend has appeared in the policies of the maritime countries for more intense regulation of marine activity in the seas adjacent to them. This has been expressed in expansion of the territorial sovereignty, in adopting a set of standards and rules regulating in practice all forms of maritime activity in the coastal regions. Customs, sanitary, environmental protection, resources and other laws of the maritime countries, which differ significantly from each other, have begun to be extended to them. The unity of the World Ocean as a geographic environment has been juxtaposed with the pluralism of forms and types of government regulation over a significant part of the ocean.

All of this has a negative effect on maritime activities.

Above all, the exploration and prospecting operations preceding the extraction of mineral resources on the shelves have been greatly complicated. The declaration by maritime countries of sovereign laws on these shelves has been accompanied in many cases by the introduction of the mechanism of permission to perform scientific research connected with the resources. However, since in practice it is impossible to delimit "resource" investigations and "nonresource" investigations, in many of the coastal areas all research in general has begun to be forbidden, which has greatly complicated the procedure of making agreements between foreign companies and the maritime country for permission to perform research work. In addition, the prospecting and exploration without preliminary agreement for subsequent stages (including extraction) are accompanied with great risk and can turn out to be a net loss. Therefore over a significant part of the continental shelves exploration work, in particular, for oil and gas, is developing at a slow pace, whereas the developed countries have given enormous attention to it. As a result, there is a serious disproportion in the operations with respect to exploration and extraction of natural minerals on the shelves, although nonuniformity in the geographic location of the marine oil and gas resources is significantly less than on land.

The set of forms and methods of regulation is felt still more negatively in the fishing industry. The access of foreign ships to the biological resources of the fishing and economic zones is conditioned by a significant number of obligations which can be arbitrarily changed over the course of the year. With respect to the investment process, ocean fishing does not differ from any other form of production activity. Of course, unjustified fluctuations in the raw material base and assessment rates are holding up the development of this branch, they are leading to a sharp reduction in its cost effectiveness, and the outflow of capital from it. In the zones of a number of countries which do not engage in intense fishing, foreign fishing vessels are not permitted in general.

The establishment of fishing and economic zones has already led to the reduction in the role, and in a number of cases, the actual elimination of regional international fishing organizations. Nevertheless, their activity had great significance for the concentration of international effort in the field of fishing reconnaissance, the discovery of potential resources, constant improvement of their study and accumulation of the necessary information.

The changes in the regulation of the conditions of marine activity have to a significant extent touched on their commericial shipping which depends on the regime of the economic zones, the straits used for international shipping, archipelago and territorial waters, and so on [2].

In recent years a number of maritime countries have tried arbitrarily to establish a regime for the stopping of ships in ports and the use of it to refuse permission to ships sailing under a defined flag. In addition to direct losses which these measures impose on young commercial fleets, they naturally can cause a response reaction leading to a "port war." Some countries are also raising the question of collecting fees "for the right of passage of ships" through their waters. Such a measure has an analog only in the early Middle Ages, and it is economically unjustified. In the case of its application, serious material losses will be imposed primarily on the fleets of the developing countries. For the first time in the history of navigation, the problem has arisen of the possibility of closure of one region or another to shipping. In particular, Canada has already reserved commercial shipping in some areas adjacent to it as its exclusive right.

Lack of united regulation of measures to protect the sea is promoting expansion of discriminatory rights of the maritime countries. Individual maritime countries have begun to introduce their own laws with respect to protection of the marine environment, containing more rigid standards than those adopted internationally.

In a number of cases the maritime government, for example, is trying to get the right to control the structural design, the equipment and composition of the crews on ships passing through its territorial waters or economic zones. Although theoretically the purpose of this is to protect the cleanness of the marine environment, in practice such measures frequently lead to discrimination against ships of certain countries. Simultaneously, the economic zone regime is being replaced without substantiation by the territorial water regimes, the invisible process of "creeping jurisdiction" is being realized which will lead to new territorial claims.

The principles of responsibility for pollution of the marine environment contain an enormous amount of confusion and ambiguities, in particular, with regard to such problems as establishment of the individual bearing such responsibility, the pollution criteria, the determination of the required volume of proofs, the trial procedure, and so on. The absence of a united international mechanism with respect to the regulation of disputes among governments is increasing the negative consequences of the application of sanctions by the maritime countries for commercial shipping. Up to now there is no united opinion even with respect to the grounds on which the maritime countries can generate national laws to protect the marine environment in territorial waters adjacent to economic zones, international straits, and so on. The regime of marine environment protection against pollution from ships has turned out to be the most differentiated. As a result, the basic weight of the environmental protection measures has in practice been transferred to the maritime sphere, although 80% of the blame for the pollution of the sea rests with land activity, as a result of which the pollutants get into the ocean through river runoff and atmospheric precipitation. The expenditures on prevention of contamination from ships amount to a significant part of the overall expense of building, operating and maintaining them. It is natural that they are oriented toward the observation of the international standards with respect to structural design and equipment of the ships; deviations of the national requirements from such standards impose losses both in the activity of commercial shipping and in many cases, to the marine environment itself.

The disparity of national standards regulating navigation also touches on the problems of navigational-hydrographic support; as a result there are areas with significantly worse conditions for safe navigation.

Commercial shipping annually performs a volume of services estimated at 100 million dollars. If the process of random national "standards creation" were to continue and acquire the nature of an exclusive regulating force, then this could lead to forced changes in the usual shipping lanes, unjustified delays of ships and disruption of cargo delivery schedules, the disturbance of the operation of the most important and largest world transport link, providing for international economic relations.

These are some, perhaps, the most significant consequences of disparity in the national measures regulating maritime activity. They lead clearly to the conclusion of the necessity for adapting regulating measures having a universal nature and not permitting discrimination against any country. More and more effective technical-economic prerequisites for efficient use of marine resources and expanses have been created in the world and are continuing to be created. Nevertheless, the chaotic regulation of the exploitation of the World Ocean is threatening to undermine its economic base, to destroy the productive forces of maritime affairs.

2. Principles of Standardization of Regulating Standards

The Third International Conference of the United Nations on the Law of the Sea which was participated in by almost 150 countries was to standardize the regulating standards. It was held in 1973 and received a mandate from the United Nations to prepare a united universal convention of the sea providing for standardized and nondiscriminatory regulation of all aspects of the maritime activity of countries considering their interests [3].

The elements of such standardization include optimal parameters of the navigational regime, including unobstructed passage of such ships through territorial waters and straits used for international shipping, freedom of navigation in the open sea, in particular, in economic zones. The necessity has arisen for the creation of a united system of standards regulating the activity of commercial fleets on a mutually acceptable basis in various parts of the World Ocean in order to insure equal economic conditions for such activity, the cessation of unfounded economic claims to commercial vessels.

In the exploitation of the biological resources of the World Ocean the problem of access of foreign fishing ships to them in the economic zones has special significance. There are two primary aspects of this question: political guarantees and economic conditions. The first aspect is today, as was noted above, the prerogative of the maritime countries. The absence of international legal guarantees is inflicting losses on world fishing as a whole. It is necessary to consider that the development of a modern fishing industry is inconceivable without a stable raw material base.

The more and more approved practice of short-term fishing agreements already is having a destructive effect on the volume of construction of the latest fishing vessels. At the same time their tonnage is increasing as before as a result of the small ships to which the shore fishing base is beginning to be oriented.

The question arises of how it is possible to fill the vacuum formed as a result of the weakening or elimination of the international fishing organizations. First of all, this pertains to the area of fishing research and reconnaissance. The determination of the level of the admissible, maximum stable catches will permit discovery of the excesses unused by the maritime country and distribution of it among the interested countries considering their historic and other rights and also the necessity for the conclusion of the corresponding agreements with the country that controls the biological resources.

The concept of the maximum admissible levels of use of the animate resources of the economic zones was the basis for the talks at the Third Conference. In essence, it is shared today by the majority of governments, and in case of its adoption can serve as the basis for organizing international cooperation in the area of fishing with strict observation of the principle of nondiscrimination. In the summary draft of the convention it is emphasized that after determining the level of the admissible catch, the maritime country will grant other countries access to the excesses through the corresponding agreements and on the basis of mutual recognition of established rules and conditions.

Such rules include the issuance of fishing licenses using defined ships and equipment, the receipt of the required compensation by the maritime country in different forms (financial payments, deliveries of equipment for fishing and processing or any other forms agreed on by the interested countries); the establishment of catch quotas for defined times, including the given types of reserves; the issuance of permission to conduct the necessary volume of research, and so on.[1] All of these questions together make up the economic conditions of access to the biological resources. The class of such questions is clearly defined in the summary draft of the convention which is extraordinarily important, for it permits some degree of orientation of the "applicants" and a significant decrease in the possibility of the occurrence of situations of conflict.

In other words, the document promotes standardization of the regimes for the use of the biological resources of the economic zones in the interests of both the proprietor countries and the applicant countries. Simultaneously, it charges the maritime countries with defined obligations with respect to conservation of the animate resources and providing other countries with the required scientific information, statistical data on the catches and fishing conditions through the subregional, regional and international organizations. At the same time the known possibility will be created for preserving the role of the international fishing organizations, although in altered form.

The declaration by the maritime countries of rights to the animate resources of the economic zones has posed the problem of joint use of migrating species of fish whose life cycle takes place in the waters and economic zones of several countries. This "migrating proprietorship," if the problems of its exploitation are not regulated, will often become the instrument of political pressure. In particular, it is not excluded that some country can begin to kill off a certain species migrating through its zone not forming a reserve in it in order to inflict losses on an adjacent country. Therefore the development of international rules regulating the exploitation of such forms of biological resources,

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[1]Report of the United Nations Organization A/Conf. 62/WP.10 and Add.1, 1978, p 19.

determination of the special rights of the countries, in the waters of which the reserves of the "transient" species are formed, is extraordinarily important. Complex problems also arise in connection with the sovereign rights of the maritime countries over the mineral resources of the continental shelves. The Third Conference inherited the unsolved problem of the outer limit of the continental shelf from the first two conferences. More precisely, it was in some way solved, but in a more than indefinite form. The convention signed in 1958 by the First Conference of the United Nations on the Law of the Sea establishes the limit "to a depth of 200 meters or beyond this limit to the point to which the depth of the covering waters permits exploitation of the natural wealth." Such a formula essentially states the definition of the outer limit of the shelf as a function of the technical progress in the marine extractive industry. There can be hardly any doubt that in the future it will be possible to exploit mineral resources at any depth. The question of which countries have already achieved the level or will be the first to achieve the level giving unquestioned advantages is no secret.

Today the problem of establishing the outer limit of the continental shelf remains quite acute, it continues to cause serious disagreements among the participants in the Third Conference. The group of Arab states sets this limit to 200 miles from the shore. The countries having a wide shelf are trying to advance it as far as possible. They promote, in particular, the application of such criteria as depth of sedimentary rock which must constitute 1% of the total distance of the outer limit to the shore. In other words, if the depth of this rock is 1 km, then the outer limit must be at 100 km, and if its depth is 10 km, then 1000 km from shore. Such an approach is highly complicated, and this is obvious to many specialists. The fact is that at present only 16% of the ocean floor has been investigated, and that far from completely. In order to discover the depth of the sedimentary rock it is necessary to perform drilling operations which in practice no one is going to perform at great depths, for significant expenditures beyond the capacity of even the richest countries are required. Finally, the already established boundary can be advanced if deeper sediments are found. Thus, the indicated criterion leads both to propagation of the sovereign laws of the maritime country to the resources of enormous parts of the sea floor and to continued indeterminacy of the boundaries. The Soviet Union and other socialist countries have stood for the principle, in accordance with which the outer limit of the shelf must be determined by the 200-mile block, and in cases where the shelf extends beyond it, to the 500-meter isobath.[1] This approach is based on the generally accepted ideas in world science of the structure of the sea floor and corresponds, with very rare exception, to the actual spatial characteristics of the continental shelf. Several compromise versions were proposed at the Third Conference. All of them permitted the

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[1]The isobath is a line on a chart representing lines at the bottom of the ocean, every point of which is at the same depth.

possibility of determining the outer limit of the continental shelf in accordance with the criterion of depth of the sedimentary rock. In this case if the shelf extends beyond the 200-mile economic zone, then its outer limit must not extend farther than a precisely established number of miles from this distance. This would introduce a sort of clear distance criterion. However, such a solution mostly takes into account the interests of only the relatively few countries having a broad shelf. Even so, they do not agree with the proposal, and the conference reached another impasse.

The problem of the outer limit of the shelf at first glance is not connected with the regulation of maritime activity. Indeed, the establishment of the spatial sphere of various forms of such regulation depends on its solution. If the limit is within the 200-mile zone, then the total territory of the sea floor, the resources of which fall under the sovereignty of the maritime countries will turn out to be appreciably less than when using the criterion of depth of the sedimentary rock. This has important significance, for example, for scientific research in the World Ocean. Unfortunately, some countries not involved in maritime activity and not intending to become involved assume that absence of knowledge of the ocean does no harm to them. This can do damage to all countries and to all mankind as a whole. Therefore the use of the criterion of depth of the sedimentary rock, even combined with a clear-cut distance criterion does not exclude the possibility of considering where the shelf is located: within the limits of the 200-mile zone or beyond its limits.

The intracontinental and geographically unfavorably located countries are worried about the fact that the resource "occupation" of the shelves by the countries having an outlet to the sea relieves them of any hopes for the use of the given resources. Therefore they are raising the question of the obligation of the maritime countries to reckon part of the revenues from mining the mineral resources of the shelf for their use. There are now proposals to deduct up to 10% or more of the value of the mineral raw materials extracted on the shelf (beyond the 200-mile limit) for these countries.[1] Simultaneously there are proposals to use a differential scale of deductions depending on the level of economic development of the maritime country owning the shelf resources. In addition, an effort is being made to extend analogous requirements to the resources extracted on the shelf within the economic zones.

Such an approach is only one of the many versions of taking into account the interests of the intracontinental and geographically unfavorably located countries, hardly the most successful one. Obviously here we begin with the proposition that the shelf resources are somehow under the

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[1]Report of the United Nations Organization A/Conf. 62/65,8. V. 1978, p 11.

joint ownership of the maritime and nonmaritime countries. In any case it is otherwise impossible to understand the idea of sharing income (profits) under the condition that the nonmaritime country does not participate in the expenditures on developing the resources. However, the concept of joint ownership will hardly be adopted by the maritime countries. Therefore the interests of the other group of countries will begin to be considered only on the basis of political compromise in the text of the overall problem of the use of the mineral resources of the continental shelf, including the problem of its outer limit.

At the Third Conference 53 governments formed a special group which actually turned out to be completely dispossessed of the wealth of the World Ocean. The fact is that more than 95% of the presently utilized biological resources of the sea, a significant part of the marine oil and gas and other reserves have become the property of the maritime countries. The discrimination against the entire group of countries making up more than a third of the total number of members of the United Nations is absolutely unjustifiable. The Third Conference is developing methods of considering their interests in the exploitation of the marine resources and areas. The thrust of its efforts in this direction would be reflected in the possible marine activity of nonmaritime countries.

The attention of many countries in the last decade is being more and more attracted by the prospects for the development of the mineral resources of the sea floor beyond the limits of the continental shelf (the international region of the sea floor). These include oil and gas, glauconitic sand, deep-sea red clay, lime and siliceous muds, metal-bearing oozes, ferromanganese, concretions. The use of the majority of them is a matter of the very remote future. However, the development of the technology for their extraction and metallurgical conversion has advanced quite far.

During the course of discussions at the Third Conference, a mutually acceptable solution was found to the basic principles of the deep-water extraction regime such as the use of the international part of the sea floor and its resources exclusively for peaceful purposes, the nonappropriation of the resources and territory of the region, the inadmissibility of monopolizing the resources by any country or group of countries and private companies, environmental protection, and so on.[1]

It was not possible to reach a compromise with respect to the central question of access to the resources of the sea floor. The group of developed capitalist countries initially stood for automatic access of their private countries to these resources. It is natural that the realization of this requirement would lead to monopolizing their management

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[1] Report of the United Nations Organization A/Conf. 62/WP.10 and Add. 1, 1978, pp 33-37.

with respect to the resources of the international zone of the sea floor, considering the monopolistic position of these countries in the world capitalist economy in the field of extraction and processing technology for ferromanganese nodules. In turn, the developing countries ("Group 77") were for the development of the resources of the sea floor exclusively by an international enterprise which should be created as an economic unit of a future international agency. At the same time "Group 77" tried to take away the rights of the sovereign governments to exploit the resources.

The Soviet Union and other socialist countries advanced a compromise proposal that such development be carried out simultaneously both by the international enterprise and the governments, government enterprises and private companies by contract with the international agency. This proposal was called the "parallel system." On the basis of it, during the course of the 7th session of the conference, an approach was developed which is presently shared by the majority of countries. It provides for the possibility of the participation of governments in the development of the resources of the sea floor by contact with the international agency and, in addition, insures realistic viability of the future international enterprise inasmuch as it charges the governments of the obligation to give it technological and financial assistance in the first, most difficult phase of its activity.

Of course, not all of the problems pertaining to the international regime of the sea floor have been solved, but a good basis has been developed for completion of the talks. The outlines of a system for exploration and exploitation of the resources of the sea floor, many problems of the political structure of the functions of the international agency, the methods of mobilizing means to finance its administrative budget and the regulations for the future international enterprise have been defined. Certain problems, in particular, those pertaining to economic aspects of the regime of the activity of the governments by contracts still remain unregulated.

3. Dangers of Unilateral Actions

The unilateral actions with respect to mineral resources of the sea floor which some countries are planning to undertake who are not satisfied with the course of the talks and who are taking a hard line in them constitute the greatest threat to the future of the development of a mutually acceptable regime for the regulation of the deep-sea extraction of minerals. They consider it possible to draft the right to the private companies of several imperialist countries to begin the extraction of such resources independently in spite of the united universal convention on the law of the sea developed by the Third Conference. In essence, this would be a unilateral seizure of the resources declared by the United Nations to be the "common inheritance of mankind."

Such actions can not only do serious harm to the work of the Third Conference as a whole, but also destroy the entire process of the development of united universal norms for regulating maritime activity. Naturally this is holding up the process of exploitation of the World Ocean still more.

The governments striving on the basis of unilateral acts with respect to the resources of the international part of the sea floor to obtain advantages for themselves outside the framework of the mutually acceptable regulation mechanism are interested in breaking up the Third Conference which is devoted to adopting united regulating standards for maritime activity. Obviously, they are joined by the countries which, having solved for themselves the problem of sovereign rights to the resources and territories of their coastal regions, do not plan to develop their own branches of maritime business.

What are the consequences of holding up the regulation of economic activity with respect to exploitation of the World Ocean? First of all it leads to a reduction in its cost effectiveness. This process especially strongly involves countries where the maritime branches have begun to develop quite recently. The growth of expenditures on maritime activity in these countries and in particular, the increase in specific expenditures not only are increasing the capital consumption in the correspond-branches, but in a number of cases makes them noncompetitive.

Another serious consequence can be the worsening of the conditions of international economic cooperation in the maritime sphere. The development of commercial shipping, for example, is inconceivable without relatively simultaneous propagation of the scientific and technical achievements in the majority of maritime countries, especially in the area of equipment of the port complexes, navigational and other means providing for the safety and rhythmic delivery of cargo, and so. It is impossible to achieve noticeable progress in studying the World Ocean without constant growth of the joint efforts. In addition, as many oceanological specialists note, up to now the World Ocean has been studied to a lesser degree than space.

The exploitation of the ocean requires the application of the latest technology, large financial means and qualified personnel. The entire set of measures with respect to regulating the economic use of maritime resources and territories forms the basis for the international conditions of such activity. In recent years, however, such active international migration of fixed productive capital of maritime business has not been observed as before, which indicates that an alarming trend is arising toward maritime autarchy -- the antipode of international cooperation.

The unregulated nature of the activity in the World Ocean leads to the occurrence of newer and newer situations of conflict in the seas. For example, with respect to the problems of fishing alone in 1949 to 1972 more than 1,100 conflicts have been recorded.[1] The absence of uniformity in the norms multiplied by infinite divergences of national interest would unavoidably increase such encounters and disputes.

Among the various international legal mechanisms in the area of maritime activity the Third Conference is also developing a mechanism for regulation of disputes. The special features of it have already been agreed upon. The alternative to this mutually acceptable mechanism can only be the application of force, the insurance of selfish interests in the dispute arising through "patronage" of the more powerful country, the participation in blocs, the use of various pressures on the opponent, including military pressures not last of all. It is entirely obvious that all of this can do significant harm to the safety of maritime activity, peace on the seas, and in the final analysis the peace and the safety throughout the entire world. "We are beginning with the fact," the Chairman of the Council of Ministers of the USSR A. N. Kosygin emphasized, "that the future legal situation must promote the strengthening of peace and improvement of the standard of living of the people, and the practical problems of utilizing the World Ocean must take into account the reasonable interests of all governments. The efforts to solve these problems unilaterally, without necessary consideration of the demands and legal rights of other countries can convert the seas and oceans to another source of tension and conflict. We wish to avoid this."[2]

The absence of standardized norms for regulating the production activity in the World Ocean would have, in the final analysis, a negative effect on the solution of the problems of conservation of the marine environment. Its pollution has already reached the dangerous level for global natural and climatic processes on the earth. The area of the biologically dead bodies of water is continuously expanding. The necessity for the performance of effective measures with respect to protection of the seas by the joint efforts of all governments has matured long ago.

Thus, the problems of regulating the maritime activity have under modern conditions acquired the most important significance. The pluralism of international conditions of maritime activity is holding up the process of mankind's exploitation of the productive forces of the World Ocean, it is slowing the development of maritime affairs. Expressing concern for this reason, the head of the Soviet delegation at the conference, Deputy Minister of Foreign Affairs of the USSR S. P. Kozyrev noted that the situation in the World Ocean and around its problems is becoming more and more complicated on the basis of the known development of events in recent years. It is necessary to normalize the situation as quickly as possible,

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[1]E. Mann Borgese, DRAMA OF THE OCEANS, New York, 1975, p 208.

[2]PRAVDA, 1977, 22 September

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to create conditions for effective, well-ordered use of the World Ocean and its resources in the name of the strengthening of peace, the strengthening of international detente and insurance of progress and improved standard of living of the people. The alternative of broad, equal international cooperation for the good of man has been advanced to the division of the enormous expanses and wealth of the World Ocean. Its realization is to become one of the most important factors in the strengthening of peace and security on the seas, further promotion and detente, peaceful coexistence and cooperation of people. It is entirely attainable if, with respect to the World Ocean regime, just as all other "vitally important problems facing mankind as a whole at the present time," a "reasonable collective solution of these problems in the form of planned international cooperation" is found.[1]

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ECONOMIC-ECOLOGIC PROBLEMS OF THE EXPLOITATION OF THE WORLD OCEAN

[Article by M. T. Meleshkin]

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In the search for mineral and food resources required for the satisfaction of vital demands, mankind has reached the era of active exploitation of the ocean. There is one peculiarity in this process. The exploitation of the continental resources has occurred for thousands of years as the productive forces of society have grown and improved. The accumulation of the negative consequences of this activity has taken place slowly, although with progressing acceleration, and empirical experience with respect to eliminating the negative consequences has been accumulated. Now mankind has at his disposal the required sum of knowledge permitting theoretically correct planning of his activity to neutralize its negative consequences. This is being done in insufficient volume and far from always, but the presence of the knowledge of how to behave in the continental space so as not to cause irreversible ecologic changes is itself a positive thing.

There is still little such knowledge about the World Ocean, and it is difficult to hope that the process of accumulating this knowledge will correspond to the rates of economic exploitation of the ocean to which mankind has approached armed with unprecedented technical means. As a result of this intrusion into the ocean in a very short time the processes occurring in it can change radically.

The general planetary danger which such uncontrolled activity free of the necessary scientific bases in the ocean can bring with it is difficult to overestimate. Thus, the destruction of the processes of oceanic photosynthesis and evaporation as a result of film pollution with oil and increased turbidity of the ocean water can lead to significant changes in the heat, water and oxygen budgets of the earth with all of the disastrous consequences deriving from this, including a change in weather and climate of the planet. As a result of inefficient exploitation of the biological resources of the World Ocean, which are an important source and reserve of food protein, its biological productivity can be reduced significantly.

From what has been stated it is clear that when formulating the plans for economic development of the maritime regions and exploitation of the World Ocean it is necessary to consider all aspects of the possible short and long-term consequences of this activity. The difficulties in such planning are intensified by a number of objective facts, among which the most important are the following:

Significant lag in the rates at which the oceanosphere is being investigated behind the rates of its anthropogenic transformations. As a result of insufficiency and scattered nature of the operations with respect to studying the basic physical-mechanical and biological processes in the ocean, world research practice can at the present time propose only a limited set of environmental conservation recommendations for economic use of its resources;

The absence of international norms for regulating the exploitation of the ocean. Today about 100 countries have approached the exploitation of these resources, the conceptual principles of the ecologic policies of which are essentially different. Some of them, above all, the capitalist countries, are striving not to weight down their national budgets with expenditures on environmental protection measures.

The development of the united international strategy for exploitation of the ocean resources is complicated by the fact that the water is still not so much a region of cooperation as a region of economic competition of two systems. Conditions are being created for the preservation of modern trends toward elemental and conventionally unstandardized transport, fishing, industrial and military use of its resources [18]. There are, however, grounds for assuming that international detente, just as aggravation of the problems of ocean conservation, can promote intensification of the international cooperation in this area.

1. Peculiarities of the Modern Phase of Exploitation of the World Ocean

According to the United Nations data, the contribution of the maritime economy to the world economy in the last two decades has increased by 9 times and amounted to more than 110 billion dollars [26].

One of the most serious incentives to intensify the industrial use of the mineral resources of the ocean, primarily oil and gas, was a sharp increase in the proportion of the latter in the fuel and energy balance of the majority of the countries of the world. It is sufficient to point out that for the countries of Western Europe it increased from 8% in the prewar period to 70% at the beginning of the 1970's [30].

The exploration and exploitation of the marine deposits of liquid and gas hydrocarbons are at the present time becoming one of the leading areas of ocean exploitation. The exceptional activity of the investigated process is being maintained by high effectiveness of the capital investments in marine oil and gas extraction. According to the data of A. V. Kurov [15], the invested means with respect to net profit are returned in 2.5 to 6 months, which is connected both with the high world prices for petroleum and the comparatively low cost of its extraction within the shelf zones of the ocean.

The exploitation of other mineral resources takes place at slower rates, but already today the development, for example, of underwater places is providing the basic part of the rural extraction of zirconium and rutile, ilmenite, and so on [6, 16, 28]. It is possible to expect that with completion of the plans for the extraction of the ferromanganese nodules from the deep parts of the ocean, the process of their extraction will be intensified significantly. According to the estimates of the United Nations, the beginning of industrial mining of the nodules is expected at the end of the 1970's; by the middle of the 1980's it can satisfy up to 18% of the world demand for nickel, up to 50% for cobalt, and so on. On the whole the total cost of the extracted marine mineral resources, including oil and gas and also the products of marine chemistry in 1976 will be 60 to 70 billion dollars [18].

One of the most urgent problems of exploitation of the World Ocean is the active use of its bioproduction potentials.

Obviously on the modern level it is necessary to set down the scientific and practical principles of a new strategy for using the bioproduction capabilities of the marine environment. In our opinion they must consist in increasing the relative extraction of organisms located in the lower levels of the trophic chain than fish and producing appreciably greater biomass and also with respect to the comprehensive development of aquaculture (mariculture) [1]. The last-mentioned area of use of the marine environment for obtaining protein food appears to be especially prospective.

It is very important that the solution of the basic problems connected with an increase in the role of the biological resources of the World Ocean in the overall food budget of mankind will be concentrated within the boundaries of the shelf zones, in the inland and shelf seas. At the same time these most productive regions of the World Ocean are experiencing maximum negative effect from the continental economy, manifested primarily in chemical pollution of the marine environment and alteration of its material substrate properties as a result of reduction of the fresh water runoff.

The scale and the trends in the pollution of the seawater are causing substantiated concern not only with respect to degradation of their biological productivity and reduction of the nutritive qualities of the fishing products, but also with respect to the possible global destruction of the natural equilibrium of the processes and the "ocean-atmosphere" system.

At the present time there are more than 600,000 different chemicals in the waste ejected into the environment, a significant part of which are accumulated in the World Ocean [5, 27].

The ever-increasing inflow of polluting and eutrophizing materials (about 1/3 of the fertilizers and other agrotechnical materials used on the continents get into the ocean [5]) is significantly transforming the natural processes and relations in the ecologic systems of the ocean, and it is one of the primary causes of their conversion to the lower level of productivity which does not correspond to the economic efforts of the society. About half of the animate resources have been killed in the Mediterranean Sea as a result of pollution [12]; in the Baltic Sea there are more and more frequent cases of a bottom oxygen shortage, to complete disappearance of it, the death of bottom fauna and the formation of the so-called benthos desert. More than 3.6 million tons of oxygen are consumed annually here for the oxidation of domestic wastewater alone [24]. The mass deaths of fish in the estuaries of the rivers and on the shelf of the industrially highly developed countries have become a usual phenomenon, the scales of which are constantly growing. Thus, the losses as a result of mass death of the fish off the coast of Japan at the beginning of the 1960's was estimated at 5 million yen.

According to the estimates of S. A. Patin and N. P. Morozov [25], the possibility of decreasing the nekton production on the scale of the World Ocean under the effect of its pollution with global toxicants already now will be no less than 20 million tons per year.

The accumulation of toxic materials, above all, heavy metals, chlorinated hydrocarbons and radionucleides within the biological objects of the ocean is of serious danger. In addition to the direct toxic effect leading to a reduction in the productivity of the organisms of all trophic levels, the incorporation of these pollutants also makes use of the ocean fishing objects for food purposes impossible. Thus, the concentration of carcinogenic multiring hydrocarbons in the mussels off the coast of France reaches 3.4 mg/kg of dry material; the average residual DDT content in marine fish is 1 mg/kg, in oysters it is 5.4 mg/kg, and so on. The content of certain carcinogenic metals in the biological objects of the estuaries of the North Sea is such (for example, up to 5800 mg/kg with respect to zinc) that in the opinion of the foreign specialists [33], these bodies of water are ideal places for experimental studies of the problems of cancer etiology.

The ever-increasing economic removal of river runoff also is having a negative effect on the properties of the marine environment. About 4000 km^3 of river water [17] are used annually for irrigation, industry and power engineering by all the countries of the world, and of course, the scales of possible consequences of the conversion of river runoff appear to be quite significant. For the closed and semiclosed intracontinental seas they frequently have the nature of an "ecologic collapse." For example, as a result of the irreversible removal of more than 30% of the fresh water in the basin of the Azov Sea, the hydrologic conditions determining primarily the unique biological productivity of this body of water turned out to be deformed to a significant degree, and the total catches of valuable species of fish, in spite of intensive measures with respect to their industrial reproduction, have been reduced by more than 10 times [2]. The active water management construction and the basin of the Caspian Sea accompanied by the annual removal of up to 12% of the river runoff (35 km^3/year) has promoted a reduction in the biological productivity of the Northern Caspian from 30 to 10 centners/km^2. A number of populations, including the Caspian herring, have lost their fishing significance. By the end of the century the irreversible water consumption here will increase to 100-115 km^3 [6]. Under these conditions in the absence of discharging fresh water from the basins of the northern rivers, the level of the Caspian Sea will drop by 1.5 to 2.0 meters by the year 2000 by comparison with the present level. This alone is capable of leading to significant degradation of the biological productivity of the given body of water, which at the present time is the largest internal fishing region of the country. The predicted reduction in the runoff of the Danube, the Dnepr and the Dnestr is more than 140 km^3/year, which will have an unfavorable effect on the biological productivity of the northwestern shelf of the Black Sea, within the limits of which about 60% of all of its biomass is formed.

The presented fragmentary facts clearly indicate the exceptional urgency of the fastest scientific-practical solution of the complex and multiple problems aimed at bringing order into the interactions in the system made up of the economy and the marine environment. One of the knotty elements of this work is the creation of methods of objective economic-ecologic evaluation of the losses imposed by the anthropogenic alterations of the marine environment. Unfortunately, up to now detailed studies have only touched on the continental regions; the seawater was completely excluded from the sphere of analysis.

During the process of organizing analogous operations with respect to the marine environment undoubtedly it will be useful to assimilate a number of ideas which have justified themselves when developing the "continental" procedure. At the same time the specific nature of the marine environment and the peculiarities of its interaction with the productive and nonproductive activity of man unconditionally requires the formation of theoretically new approaches, part of which can be formulated already today.

First of all it is necessary to note the insufficiency of the modern studies aimed at estimating only the most obvious version of the losses which occur as a result of anthropogenic reduction of the biological and recreation resources of the sea. In accordance with the studies performed in the Odessa Department of the Economics Institute of the Ukrainian SSR Academy of Sciences [3], the estimates must take into account the losses imposed as a result of the following:

Impossibility of the use of one body of water or another for maricultural purposes or reduction of its potentially possible productivity;

Worsening of the technical qualities of the machines, mechanisms and structures in contact with the qualitatively altered marine environment;

Changes in the bottom relief and the intensity of the coastal abrasive processes under the effect of anthropogenic changes in the hydrodynamic regime of the coastal zone of the sea;

The use of masses of water for balneoological and recreational purposes and also in the chemical and other branches of industry;

Weather and climatic changes geodetically connected with the disturbance of the dynamic equilibrium in the "ocean-atmosphere" system;

Weakening of the processes of self-regulation of the marine ecologic systems and the necessity for compensation for the unfavorable consequences arising here as a result of specialized technogenic measures.

In the sphere of economic-ecologic analysis the last two items are new, and therefore they are in need of some comment.

It has already been stated that the solution of the ocean is capable of significantly disturbing its basic general-planetary functions and causing accompanying unfavorable changes in the oxygen and carbon dioxide budgets, the global hydrologic cycle, the thermal regime and atmospheric circulation. In the opinion of V. Kh. Buynitskiy [5], the symptoms of such changes are already observed today. They are manifested, in particular, in an increase in the recurrence rate of severe droughts or floods, destructive hurricanes or freezes where sometimes they have not been observed previously, which inflicts enormous material losses and has a destructive effect on the health and life of man. It does not appear possible even in the first approximation to estimate the dimensions of this loss and establish its direct dependence on the pollution of the ocean, but the objective difficulties of this type can hardly serve as a sufficiently weighty argument against the necessity for purposeful resolution of this problem in the future.

In its natural state, the marine and ocean environment corresponds to the greatest degree to a system of the homeostatic type retaining constant operating conditions in the face of random external fluctuations [29]. The return of this system to a state of equilibrium is possible as a result of self-regulation -- the "servomechanism" effect which fixes changes in the external environment and transmits the corresponding information to the system and the "regulator," insuring preservation of its constant regime under conditions of variable external effects [29]. These two mechanisms -- the servomechanism and regulator -- are similar in many respects, and they are identified in a united self-regulation mechanism which operates by the principle of negative feedback.

Until recently the mechanism of self-regulation of the marine ecologic systems was beyond the limits of any natural or cost estimates. At the same time the integral estimate of the losses inflicted on the marine environment by the economic activity of man must necessarily also include estimates connected with the attenuation of the self-regulating capacities of the ecologic systems. Here it is necessary primarily to accent the attention on the necessity of estimating the capacity of the marine environment for self-cleaning to remove pollution and estimation of the economic and extra-economic losses which are connected with degradation of it [3]. According to the formulation of A. I. Simonov, "by self-cleaning we must understand the set of physical, chemical, biological and hydrobiological processes causing decomposition, utilization of pollutants and leading to the restoration of the natural characteristics of the seawater" [27, pp 55-56].

The World Ocean and its individual bodies of water have a self-cleaning potential of enormous power, significantly exceeding the total power of the existing purification structures. For example, according to the low estimates of A. M. Bronfman [2], the self-cleaning potential of the Azov Sea with respect to petroleum products and detergents alone turns out to be equivalent to the operation of the purification structures costing more than 500 million rubles.

The self-cleaning system, just as any other finely balanced system for self-regulation of marine biogeocenoses, has a defined but far from unlimited stability with respect to external effects. Among the specific causes lowering the effectiveness of the self-cleaning it is necessary to mention the extraordinary pollution and salinization of the bodies of water, a reduction in the concentration of biogenic elements and oxygen, a decrease in the biological, including primary productivity, the hydrodynamic activity of the water, and so on. The signs of deterioration of the self-cleaning system of the sea are already today detected by a number of researchers [27, 32], and it is possible to predict that in the future this phenomenon will be manifested to an even greater degree.

It is logically understandable that the reduction in intensity of self-cleaning catalyzes the processes of pollution of the marine bodies of water with all of the negative consequences of an ecologic and economic level derived from it. The elimination of these consequences is possible only on investing significant social means insuring either restoration of the self-cleaning potential or reduction of the amount of toxic waste in accordance with the new, diminished capacity of the ecologic system of the sea with respect to their detoxification.

Both in the first and in the second case the dimensions of the required capital investments turn out to be highly significant. Thus, in the Azov Sea, as a result of the anthropogenic increase in salinity alone, the calculated annual self-cleaning potential with respect to petroleum products and detergents has been reduced on the average by 20,000 and 46,000 tons, respectively [2]. As the calculations show, the optimization of the salinity of the sea which would promote restoration of the self-cleaning potential is possible only as a result of the complex realization of large water management programs with an approximate cost of about 1 billion rubles. Another path providing for the elimination of the indicated quantity of the investigated pollutants requires additional concentration in the basin of purification structures costing no less than 150 million rubles. When performing analogous calculations and for other pollutants, the last figure undoubtedly will increase by several times.

Obviously the presented example is sufficient for illustration of the stated position of the necessity for objective economic estimation of the losses occurring as a result of anthropogenic disturbances of the natural mechanisms of self-regulation of the marine environment.

It is also necessary to point out another important fact requiring attention when forming the scientific principles of the exploitation of the marine environment. Until recently in practice any change in its quality was considered the consequence of anthropogenic effects. This procedural method has significantly satisfied the calculations of the losses, but it can hardly be recognized as sufficiently correct.

In reality, any anthropogenic transformations of the parameters of the marine environment take place against a complex background of their natural changes. Under these conditions the separation of the dynamics of the corresponding parameters of the marine environment into two components -- natural and anthropogenic -- becomes extremely important. The economic calculations of the losses must be based on the last of them.

2. Methodology and Problems of the Development of the Economic-Ecologic Studies of the Ocean

The approach existing until recently to the exploitation of the marine environment has not taken into account the interrelation between the defined branches of economic activity of man and the effect on the state of the marine environment as a whole. This approach has been based to a significant degree on the opinion of inexhaustibility of natural resources. The economic practice corresponding to it leads to intense pollution of the sea, has a negative effect on the ecologic characteristics of the marine environment, and leads to disturbance of its natural cycles and relations.

In this connection the lag is especially acutely felt, and more precisely speaking, the complete absence of complex studies relating the problems of the development of production and the dynamics of the state of the marine environment. It is for this reason that the demand arises for a new complex approach to the resolution of the problems of exploitation of the ocean taking into account the interaction of all spheres of economic activity and their influence on the environment. Only in this case will the development of integrated systems for the creation and placement of production complexes with optimal interrelation of them to the environment be possible.

The modern period of development of human society is distinguished by especially active expansion of the "economic space," transformed in one way or another as a result of human activity. The sphere of economic exploitation of the seas and oceans includes not only shelf regions, but also the spaces of the continental slope, the epipelagic zone and bottom. The modern annual cost benefit from the exploitation of the World Ocean reaching 110 to 120 billion dollars is felt from the products and services obtained when using the refraction, power engineering and chemical resources of the marine environment.

It is undoubtedly the case that the development of the basic and scientific-practical research in the mentioned directions requires joint investigation of the ecologic, technological and social-economic aspects of the problem of exploitation of the ocean. However, it is unfortunately necessary to note the significant interdisciplinary disconnection of this research.

Here we are completely in agreement with the opinion of Academician I. P. Gerasimov who considers that the objective difficulties of the structural development in the field of the purposeful conversion of the national environment are connected not only with insufficiently contemporary knowledge of the natural processes and the laws of their anthropogenic modifications, but they are also caused by the relative peculiarityof the presently existing economic, technical and ecologic approaches to the solution of the corresponding problems. "It is for this reason,"

I. P. Gerasimov writes, "that the complex development of scientific principles of the conversion of nature is especially closely felt at the present time to the problems of the synthesis of scientific knowledge... with the occurrence and development of new 'boundary' sciences or scientific areas that reflect the trend toward the integration of scientific knowledge" [7, pp 32-33]

The clear recognition of the sufficiency and imperfection of the traditionally isolated approaches to the study and solution of the contemporary problems of the World Ocean and also the effort to generalize as completely as possible the variety of data obtained during the course of its exploitation were the basic motivating causes of the development of the marine economic-ecologic research [22, 26] establishing the priority direction of the activity of the Odessa Department of the Economics Institute of the Ukrainian SSR Academy of Sciences.

This new direction of the economic science has arisen at the juncture of two sciences -- economics and ecology. In this respect it is similar to other boundary sciences, for example, biophysics or biochemistry. Although in all the enumerated cases there is synthesis of the various sciences, the nature of the synthesis of economics and ecology differs significantly from the synthesis of physics and biology or biology and chemistry. Recently we have primarily talked about the synthesis of the method of one science -- physics or chemistry -- with a subject of another -- biology. Biophysics is the study of life by physical methods, biochemistry, the study of the living by the methods of chemistry. However, it is impossible to study either economics by the methods of ecology or ecology by the methods of economics. We are not talking about a simple combination of subjects and methods of economics and ecology; such an association would have an eclectic nature and would not be successful. Therefore, we are talking about the synthesis of scientific fields. It consists in the fact that one science -- ecology -- defines a set of restrictions, the maximum admissible loads on the World Ocean, and the other, economics, imposes defined restrictions on its state. Here, ecology, which investigates the plasticity of the natural ecologic systems, analyzes the possibilities of the variation within defined limits by admissible loads. Beginning with the trends and the directions of the development of the national economy, economics permits discovery of the possible paths and means required for changing the anthropogenic loads to the marine environment. What has been stated above makes it possible to talk about the existence of a united "economy and World Ocean" system which is the subject of study of the so-called economology of the World Ocean.

Thus, the study of economic-ecologic problems of the World Ocean can be defined as the science of the laws of functioning, stability and development of the "economics and World Ocean" system including the subsystems of different levels, scales and complexity. The primary goal of this science is the control of the processes of the development of the system on the local (individual enterprises and biocenoses), regional (regions near the sea and individual bodies of water, the World Ocean itself) and global levels [21].

The theoretical and procedural bases for it are only beginning to be revealed at the present time. The latter circumstance is explained by the fact that the control of the "economic-World Ocean" system, just as any control, includes the following three mandatory elements: the object of control, the means of control and the purpose of control [3]. The theoretical principles and their synthesis -- cybernetics and systems analysis -- have been finally formulated only comparatively recently. As a result of the integration of these sciences, regional economics and the natural sciences of the ocean, at the present time the theoretical principles of the ecology of the World Ocean are being formulated.

By the object of control we mean the planetary cycle of matter and energy as a whole and its elements on the local and regional levels in the economic space of the earth, the leading role in which belongs to the World Ocean. Part of the elements of this cycle are first of all subordinate to the laws of development of productive forces, and another part, the laws of development of nonequilibrium dynamic systems.

The last elements of the cycle belonging to the environment, it is possible to state, have properties of inertia, delay, damping, adaptation, and so on which insure a defined level of stability of them with respect to the external disturbances and also:

The possibility of the existence of an entire spectrum of stable nonequilibrium states of the environment,part of which corresponds to the demands of society in all phases of its development;

The presence of "permissible" transitions from one equilibrium state to another, the achievement of which is connected with special economic and technological activity.

With correspondence of the level of development of productive forces to the production relations in society the means of controlling the "economy and World Ocean" system are such economic levers as:

The economic evaluation of resources from the national economic points of view;

The expenditures on elimination of the consequences (payment) of pollution and, in general, worsening of the state of the environment and individual resources, the exceeding of the consumption norms, and so on;

The cost and the profits from using the resources and the environment as a whole.

When investigating the economic levers as the basic ones in the control of the entire system, special significance is acquired by the compatibility of expenditures at the present time with the future effects from using the ocean resources. The goal of this comparison is not only efficient use of the means allocated for the storage and reproduction of the resources, but also the search for paths of rearrangement of production for which the cost benefit from the introduction of new technologies will pay for the expenditures on conservation of the natural resources [10]. It is for this reason that the integrated economic evaluation of the dynamic and self-recovering properties of the environment acquires special significance. This evaluation permits proper consideration of the problems of the distribution of the resources of the ocean among the branches and individual production facilities, and in the stage of prospective planning for the placement and development of production facilities significantly increases the national economic effectiveness of its assimilation. The cost estimate of the resources of the World Ocean will promote an increase in the material responsibility, the operative-economic independence of the enterprises of the marine economy as a whole, the fastest return on the expenditures, and the compensation for all expenditures by the revenues. The planned profitability of production becomes the most important means of implementing the regime of the economy insuring fulfillment of the plans with minimum expenditures of social labor.

At the same time the economic estimate of the resources of the World Ocean must be considered as the derivative of the economic estimates of the production obtained on the basis of them. Therefore it is necessary to have joint interrelated investigation of the entire system of economic estimates of the resources, the losses and the prices of the finished products. Here, the expenditures on production (considering the expanded reproduction) must be reflected in the price of each type of product and also a decrease in the losses attributed to other branches and the government and payment of the corresponding compensations for them.

Here the economic-ecologic science of the World Ocean begins with the fact that the maximum effectiveness of the economic means of controlling the system can be achieved only in the case of successive application of the program-purpose approach when implementing the economic-ecologic measures of any scale. This conviction is based on the fact that only the methods developed on the basis of systems analaysis and the program-purpose approach as its inseparable part will permit efficient combination of centralized and decentralized control of the interbranch national economic complexes which are formed from the achievement of the general national goals of economic development [14], and they are related by their structural-functional cycles [11, 13]. The goal of the control of the "economy and World Ocean" system is to increase the national economic effectiveness of the socialist method of production. The circulation of materials and energy between production and the World Ocean which is realized on the scale required for satisfaction of all demands of the society under the following conditions is considered optimal:

Minimization of the expenditures of social labor;

Efficient distribution and use of extracted resources;

Maintenance of quality of the environment on a level insuring normal conditions of vital activity and stability of the natural ecologic systems of the society at the present time and in the foreseeable future.

The methods of dialectics, systems analysis, optimization and simulation methods of cybernetic, economic and ecologic simulation are used for the solution of the stated problems, and methods are being developed for economic-ecologic simulation permitting determination of the most efficient methods of control input on the basis of the prospective analysis of the state of the system.

The systems approach based on the principles of Marxist-Leninist dialectics has made it possible to formulate a system of concepts, principles and categories making up the basis for the theoretical foundation of the econology of the World Ocean. Let us consider some of these concepts, principles and categories.

Concept of Unity of Economics and Ecology. Beginning with the existence of a united circulation of matter and energy and the "economy and World Ocean" system, let us isolate the direct (the disturbing effect of the economy on the environment, removal of resources, discharge of waste, and so on) and the inverse (variation of the production efficiency with variation in state of the environment) relations in it.

The indicated types of relations are averaged by the reaction of the environment to the external disturbance transforming the direct relations in accordance with the chain of natural interrelated processes. It is expedient to differentiate the processes with respect to energy levels. The processes of heat and moisture circulation have the highest energy; the energy of the dynamic processes, namely, the currents and waves, is of a lower order, and, finally, the energy of the biochemical conversions of the ocean is several orders lower. It is natural that the interaction in the "economy and World Ocean" system realized by the "disturbance-transformation of the disturbance-variation in efficiency of use of resources," chain proceeds only in the direction from the processes with higher energy and not vice versa. Therefore as a result, for example, of a change in the river runoff, the hydrologic and the hydrochemical regimes of the inland seas and the coastal waters of the ocean, their biological productivity, and so on change. At the same time an effect that is applied only to the biological processes, let us say, the removal of some species from the food chain of the ecologic system, disturbs this integralness, but has no influence on the hydrologic regime of the body of water.

In this concept it is postulated that along with control of the direct relations it is necessary also to control the inverse relations by active intervention in the intensity and direction of the processes of transformation of the disturbances and the environment.

Quality of the Marine Environment. The quality of the marine environment is a category permitting determination of the complex dynamic (considering the transformation of the disturbance in the environment) estimate of the difference of its real state from the desired or normative state, which characterizes the potential possibilities and the comparative effectiveness of the satisfaction of the demands of society.

The state of the environment can be determined by the set of parameters: physical-chemical (salinity, temperature, concentration of various compounds); dynamic (current, wave action); geomorphological (bottom relief and shore lines); biological (biomasses of the organisms of different trophic levels, their multiplication rate), and so on which vary in space and time. Let us call them the parameters of state of the marine environment $\zeta_1, \zeta_2, \ldots, \zeta_n$ and let us define the ranges of their variation; at the same time let us define the region G of the n-dimensional euclidian space called the region of state. In this region each point corresponds to the set of numbers defining the state of the environment. This set can be interpreted as the vector $\vec{S}(\zeta_1, \zeta_2, \ldots, \zeta_n)$ having n components and it is possible to identify it with the state of the environment [19].

Let as a result of the production activity certain components of the state vary, that is, its parameters. Here the vector $\vec{S}$ varies by some amount $\Delta\vec{S}=\vec{S}-\vec{S}_{init}$. The vector $\Delta\vec{S}$ reflects the variations (shifts) which have occurred in the state of the environment. Let us note that inasmuch as certain ζ_i and ζ_k are related to each other by the functional relations, the shift $\vec{S}$ always takes place over the surface of certain hypersurfaces $\phi_\ell(\zeta_1, \ldots, \zeta_k, \ldots, \zeta_r)=0$ describing the transformation of the disturbance in the marine environment.

Let us break down the region of states G into the subregions G_i defining the subset of the parameters $\{\eta\}_i$ connected with the requirements on the state of the environment of the i-th user. When an enterprise of this region uses the environment, it can be assigned an economic estimate defined as the effectiveness of the activity of the latter for the state of the environment $\vec{S}$.

Analogously, it is possible to define economic estimates of the shift of the state of the environment $\Delta\vec{S}$. For this purpose it is necessary to know the production function of the activity of the branch or the individual enterprise in which the subset of parameters of state of the environment $\{\zeta_j\}_i$ appears as a series of arguments. In the case of complete interchangeability of these arguments (additiveness of the production function [4] with respect to $\{\zeta_j\}_i$), it is expedient to introduce the vector $\vec{D}$, the components of which are the coefficients of the limiting effectiveness of the parameters of state. Inasmuch as the magnitude of the limiting effectiveness indicates an increase in the production efficiency on variation of the corresponding parameters of state of the environment by a small amount [9], the scalar product of the vector $\vec{D}$ with the vector $\Delta\vec{S}$ also will give a cost estimate (comparative effectiveness) of the use of the environment in various states.

Principle of Dual Unity of the Natural and Anthropogenic Effects on the Marine Environment. Any anthropogenic transformations of the marine environment are realized against a complex background of its natural rhythmic and arhythmic fluctuations and can be adequately understood only considering the latter. During the process of the interaction of natural and anthropogenic factors, both attenuation of the consequences of the economic activity of man and intensification of them can occur. These effects have a quasiperiodic nature caused by the natural rhythm of the natural processes. In particular, for the marine and oceanic bodies of water the most expressed are the intracentury rhythmic fluctuations of the parameters of state of the environment with periods of 2, 5, 7, 8, 11, 18 years or more [24]. Along with the problem of separation of the natural and anthropogenic components of the recorded state of the marine environment, problems arise in the objective selection of time, determination of the values of the components of the vector of state $\vec{S}$ and the reduction of the results obtained to the defined phase of the natural rhythmic development of the investigated body of water.

Principle of Staging of the Economic Exploitation of Renewable Resources of the Ocean. Among the various forms of trajectories of motion of the vector $\vec{S}$ over the hypersurface $\phi_\ell(\zeta_1 \ldots, \zeta_r)=0$ there are a number of closed ones corresponding to the stable states of the environment, and a number of open trajectories corresponding either to transition of the environment from one stable state to another or transition of it from stable to unstable state.

Inasmuch as the stability margin of the natural systems is finite, the following cases are possible.

If the effect of production on any parameter of state is much less than its natural variations, then the force of the effect on the passage of some time weakens or is localized.

For commensurableness of the anthropogenic effect and natural variations of the physical-chemical, biological and other parameters, stable cycles occur which contradict the effect of production.

Finally, if the disturbing effects are much more than the individual items of the natural balance, then restoration of it by natural means turns out to be impossible. Therefore the efficient use of the marine environment can be realized in several stages depending on the nature of the reaction of the environment to the effect of production [20].

In the first stage all of the production effects are extinguished as a result of the property of the environment for self-restoration and the exploitation of the resources takes place as if they were infinite. In the essence of the matter, until the present time the interaction with the sea of the basic branches of the national economy has been realized in this way.

The second stage comes when some quality level of the environment is maintained both as a result of self-restoration and purposeful activity of man. In this case, defined expenditures are required for the restoration of limited resources.

In the third stage the natural object in practice is not self-restored, the required level of quality of the environment is completely supported by technical means.

The use of the above-discussed principles and concepts is possible only as applied to the region. The basic problem occurring here is the problem of economic regionalization of the World Ocean. It has still been little studied and is simultaneously much more complex than the problem of economic regionalization of the continental sections as a result of continuity of the water environment and interrelation of the processes occurring in it and also the inertia of the ocean. Accordingly, changes in state of the ocean as a result of the irrational activity of man are manifested after a long period of time. When solving this problem it is impossible to use either administrative, natural or physical-geographic division or division by the branch attribute into fishing, transport and geological areas. A territorial economic regionalization appears to be expedient.

It is appropriate to isolate such regions on the basis of a new typology -- the typology of systems of the type of "demand for natural resources -- sources of the resources -- economic-ecologic possibilities of their exploitation."

The basic idea consists in the fact that the region of prospective exploitation must be determined using a number of indexes of the quality state of the resources and the environment (stable and periodically varying) and also those which characterize the demand of the economy and technical possibilities of satisfaction of them. This system of economic regionalization of the ocean has sufficient flexibility and can be successfully used when solving the problems of prospective planning and development and also the placement of the productive forces in the ocean.

In addition, this system permits determination of the sections in which the spatial interests of the various branches (extraction of petroleum and gas, fishing, the health resort industry, marine transportation) are encountered, and it also offers the possibility of determining the indexes which provide the basis for conflicts among these branches and finding compromise solutions by analysis of these indexes.

In order to solve the investigated problems of complex and branch economic regionalization, as it appears to us it is necessary:

1) To state the problem for a sufficiently prolonged time interval, for only stable long-term strategy of the development of economic activity will promote an increase in effectiveness of capital investments and a reduction in the production expenditures and, on the contrary, any reorientation in this sphere is connected with enormous capital expenditures and temporary reduction of the productivity of labor;

2) Functionally to determine the configuration of the region isolated for the solution of the goals stated for the investigated period, using the series of indexes (characteristics) which are discovered when analyzing the stated problems;

3) To determine the basic indexes of the development of economic regions [the level of concentration (power) and specialization (volumes of output of individual types of production), rates of development, production technology, the system of relations with respect to delivery of raw materials, materials and finished production] jointly and simultaneously, for all of the enumerated parameters are formulated by the natural, economic and social conditions which are different in different regions and, consequently, cannot be established until the limits of these regions are known. The dimensions of the exploited bodies of water, in turn, depend on the production capacity and a number of other characteristics of the productive forces and, consequently, cannot be found until the latter are known;

4) To realize regionalization of the exploited territory in such a way that the existing and the projected regions will form a united system, within the limits of which the solution of the stated problem is possible.

For realization of the formulated principles in the dynamic models of the branch and integral economic regionalization the expenditures on production and transportation of raw materials and finished products, in contrast to the existing models of optimal planning and the development and placement of the branches of industry, are considered as the given functions of the water in the regions, the concentration and specialization of the economy in them and also time.

This permits use of the investigated concepts and principles of economic-ecologic science of World Ocean for the solution of the primary problem -- the program-target planning of its economic exploitation.

3. Program-Purpose Planning of the Economic Exploitation of the Ocean

At the present time defined progress has been made in the solution of the special economic-ecologic problems. Thus, the hydroengineering structures have been created which favorably change the regime and the lithodynamics of the coastal zone of the sea, fishing is regulated for purposes of reproduction of ichthyofauna, the maximum admissible discharge of pollutants is standardized, individual bodies of water are enriched, their hydrologic cycle is defined, and so on. The indicated measures are forms of control of the inverse relations in the "economy and World Ocean" system, that is, the control of the reaction of the environment to the external disturbances.

The realization of larger and more complex measures is theoretically possible. In recent years the idea of the control of marine ecologic systems, including the entire World Ocean, is being more and more frequently advanced. In our opinion, this statement is premature, and under modern conditions the center of gravity of the solution of the problems of the control of the marine environment must be shifted to the region of regional transformations.

The most acceptable here is the target program approach which provides for primary solution of the problems of social development by planned use of resources and promotes deep manysided substantiation of the planning decisions made for the distant future.

The program must provide for a set of measures of scientific research, social-economic, production, organizational-management and other nature which are coordinated with respect to resources, executors and time of completion, the implementation of which will promote the realization of the stated goal or the set of interrelated goals [23].

The effective development of the set of measures included in the program (from scientific research operations to distribution, handling and consumption of the program production) can be achieved only with exact formulation of its final purpose.

The formulation of the purpose is the first most important step in compiling the program inasmuch as the formulation of the purpose determines the choice of restrictions on the means of achieving it, the criteria for selecting alternatives, and so on.

It is considered that the main purpose of the program expressing a defined social demand generalizes all of the nonmain program goals and appears at the same time in the form of the assigning element. Consequently, this main goal can decay into the subgoals subordinate to it and interrelated, the achievement of which provides for the realization of the primary initial goal. The set of such mutually ordered and subordinate subgoals forming the hierarchical structure usually is called the vertical goal tree.

It is considered that the lower level of the vertical goal tree is the level of appearance of alternatives. The subgoals themselves are always without alternatives, and the methods of achieving them, as a rule, are multivariant.

Therefore the majority of authors presuppose the construction not only of vertical goal trees with nodes of the "and" type, but also the trees of the versions of their attainment with the nodes of the type "or," and then they are matched with each other. Here the methods of matching are considered to the present time undeveloped, for it is done on different levels, with different degree of detail and is determined to a great extent by subjective factors.

The evaluations of the goals by levels and by significance are poorly developed.

It appears more procedurally valid to construct an integrated goal tree, the levels of which strictly correspond to the types and scales of activity aimed at implementation of the program. Usually the following eight levels are distinguished: scientific resources, technological resources, elementary technology, functional technological flow charts, applicability, social systems, environment, society at large [31].

It is obvious that the four upper levels of the versions correspond to the levels of development of the given problems, and the lower levels of goals, to the levels of the effect of the functioning system.

Inasmuch as depending on the scales the goals are located at different levels, for effectiveness of the analysis of such trees it is necessary to answer the following questions: Are the following possible:

Forcing of the research and development with respect to some programs requiring special concentration of different efforts;

The discovery of the technological difficulties, technical goals, and so on;

Estimation of the possible paths of achieving the primary goals.

In order to obtain answers to these questions, clear fixing of the purpose systems designed directly for the performance of the goal and located on the divide fifth level is required. For each isolated purpose system functional technological flow charts are found which provide for attainment of the goal (fourth level) and describe the specific technical-economic characteristics (third level).

If at the time of investigating the draft of the program there are technological flow charts available, the characteristics of which provide for the execution of the stated goal with external restrictions caused by the already existing purpose systems (for example, the predicted level of irreversible water consumption), then the construction of the goal tree ends with this. If the technical-economic characteristics of the existing structures do not provide for attainment of the goal, then the construction of the second level of the goal tree begins -- the search for the required experimental design operations (OKR).

Finally, in the absence of a sufficiently reliable version of the OKR, expansion of the goal tree takes place to the first level -- a search is made for the required scientific research operations (NIR) insuring the required version of the OKR.

The above-described five levels are entirely adequate if the external restrictions on the execution of the program are given which do not permit further examination of it. If during the course of execution of the program correction of the external restrictions is permitted, then advancement upward from the fifth level to the goals touching on the interests of the society as a whole takes place simultaneously.

When compiling the large-scale regional programs, inclusion of the goals of the sixth and seventh levels in the tree appears to be essentially necessary inasmuch as these levels correspond to the systems for maintaining the quality of the environment, insuring harmonic development of it.

As a result of the use of the proposed method in the process of developing the integrated goal tree, unique coordination of the primary goal and the subgoals of the program on the levels corresponding to the scales of their activity with the multiversion system of measures insuring achievement of the stated goal and encompassing the entire life cycle of the program production takes place.

As a result of strict fixing of the goal and subgoal levels, the measures aimed at achievement of the primary goal are uniquely isolated. The selection of the versions of their realization must be made within the framework of the developed program. Accordingly, the development of the measures required for achievement of the primary goal must be realized within the framework of the programs of the higher rank.

The purpose program for use of the reserves of the biological resources of the marine environment of the Black Sea and Azov Basin developed at the Odessa Department of the Economics Institute of the Ukrainian SSR Academy of Sciences is a specific realization of the discussed basic principles of program-goal planning of the economic control of the World Ocean. It is demonstrated in it that the biological and fishing productivity of the Black Sea and the Azov Sea, their limans and estuaries can be radically increased, but the implementation of measures subordinate to the following basic goals is required to do this:

1. The preservation and maintenance of high quality of the marine environment.

2. The shift of the center of gravity from fishing, the possibilities of the further expansion of which are limited, to aquaculture (mariculture) providing for the obtaining of high guaranteed volumes of fish and marine products with high profitability of production.

3. The orientation of a significant part of fishing and aquaculture toward the objects located on the lower trophic levels of the biological chain (algae and mollusks), the biomass of which is appreciably greater than the biomass of the plant-eating and especially predatory fish.

The selection of these goals predetermines the investigation of the following purpose systems:

Insurance of the required quality of the water environment, including the marine environment, the Black Sea and Azov Basin;

The insurance of the conditions for reproduction of the biological resources of the basin;

The extraction of biological resources;

Organization of agriculture;

The processing of biological resources into food and feed products and also into raw material for the technical branches of industry;

The sale and marketing of the finished product.

For each of the above-enumerated systems, the functional technological structures were defined providing for the obtainment of the stated goals.

The analysis of the modern state of the art and the desired state in the future to the year 2000 has made it possible to plan the set of ecologic, social-economic, production, experimental design, scientific research and organizational measures, the set of which is aimed at attainment of the stated goals and determines the volumes of the required resources.

As is known, the final step in the development of each program is the step of inclusion of it in the national economic plan (in its program and non-program divisions). As a result of the peculiarities of the development of the economic-ecologic programs for exploitation of the World Ocean, it is necessary to create a system of economic-ecologic planning and control. The schematic diagram of this system consists of four subsystems: observation (monitoring) 1, ecologic 2 and economic 3 forecasting and the economic-ecologic planning itself 4 (Fig 1).

The object of control considered as the united system is represented in the diagram in the form of two blocks: 5 -- "economy" and 6 -- "environment." Considering the nature of the relations among them, monitoring appears to be expedient which includes three types of observations required for control purposes:

A_{56} -- the nature of the anthropogenic disturbances;

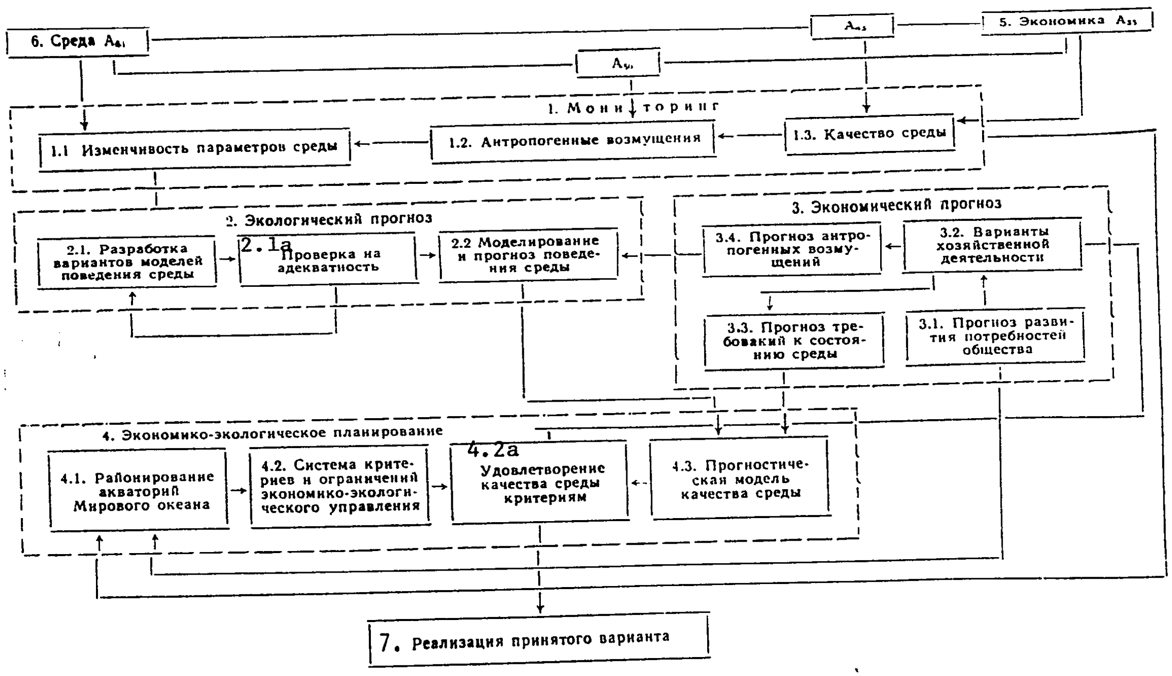

Figure 1. Schematic diagram of the system for economic-ecologic control of the process of the exploitation of resources of the marine environment

[See key on p 77]

[Key to Fig 1, p 76]

1. Monitoring
1.1. Variability of the parameters of the environment
1.2. Anthropogenic disturbances
1.3. Quality of the environment
2. Ecologic forecasting
2.1. Development of versions of the behavior models of the environment
2.1a Checking for accuracy
2.2. Simulation and forecasting of the behavior of the environment
3. Economic forecasting
3.1. Forecasting the development of the demands of society
3.2. Versions of economic activity
3.3. Forecasting the demands on the state of the environment
3.4. Forecasting the anthropogenic disturbances
4. Economic-ecologic planning
4.1. Regionalization of the bodies of water in the World Ocean
4.2. System of criteria and restrictions of economic-ecologic control
4.2a Satisfaction of the quality of environment criteria
4.3. Forecasting model of the quality of the environment
5. Economy A_{55}
6. Environment A_{66}
7. Implementation of the adopted version

A_{65} -- the values of the parameters of state of the environment entering into the production functions of the users;

A_{66} -- variability of the parameters of state of the environment entering into the transformation function of the anthropogenic disturbances.

The monitoring of the marine environment permits determination of the values of the ecologic parameters required for the construction of the production functions. However, for the construction of the same functions special information is required about the values and the dynamics of the economic factors which implies the supplementing of the monitoring also by the observation system A_{55}.

As is obvious from the presented system, the economic-ecologic monitoring, in addition to the above-enumerated four basic types of observations, include the following functional blocks:

1.1 and 1.2 -- processing of information A_{56} and A_{66} in order to discover the functional relations between the parameters of state and the environment subject to anthropogenic disturbances;

1.3 -- processing of the information A_{55} and A_{65} in order to determine the quality of the environment, that is, evaluate its state, performed by each user in accordance with his demands.

Various models of behavior of the environment (block 2), the checking of which for adequacy is done by the retrospective and modern data using the information of blocks 1.1 and 1.2 are formed in the ecologic forecasting system 2 on the basis of the information generated by block 1.1. The final result of the functioning of the subsystem 2 is the generation of models of the environment 2.2 permitting forecasting of the dynamics of the basic parameters of its state.

In the economic forecasting subsystem 3 on the basis of forecasting the development of the demands 3.2, versions of the economic activity are being generated.

The interaction of the blocks 5 and 6 takes place on the level of the individual enterprises in specific regions. Consequently, the work is done on two levels: microeconomic, represented by the production functions of the measures, and macroeconomic taking into account the intereffect of these enterprises through the environment.

On the basis of the production functions for each of the versions of economic activity, the demands on the parameters of state of the environment are formulated, the list of which must be included in the monitoring program pertaining to the system of observations A_{65}.

The information about the size and the nature of the anthropogenic disturbances placed in block 3.4 is determined by the technology and the volume of production output corresponding to the versions of the economic activity. This information is used in the model of the environment (block 2.2). In turn, the information of block 3.3 jointly with forecasting the state of the environment (the output of block 2.2) is the basis for simulation of its quality (block 4.3).

In the subsystem 4, the versions of economic activity are matched with the predicted state of the environment, that is, the economic-ecologic planning itself. For this purpose, block 4.2 is provided which generates the criteria and the restrictions for the bodies of water with different nature of use. The regionalization required for these purposes is carried out in block 4.1 on the basis of the information about the current state, quality of the marine environment (block 1.3) and prediction of the demands of society (block 3.1) with respect to the nature of the proposed use of the bodies of water.

In conclusion, it is now justifiable to draw the general conclusion that the further development of the economic-ecologic studies of the World Ocean will promote the creation of complex national and international programs for the exploitation of its resources under the condition of comprehensive conservation of the natural environment and the general planetary functions.

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MONITORING OF CHEMICAL POLLUTION OF SEAWATER

[Article by A. I. Simonov]

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1. Characteristics of Seawater Pollution

The first reconnaissance step in the studies of the chemical pollution of water performed in our country in the Atlantic Ocean was completed by 1975. As a result of these studies a number of general conclusions were drawn regarding the nature of the pollution of the marine environment which has to a great extent promoted the determination of the monitoring of the water pollution.

It has been established that pollution, especially with petroleum hydrocarbons, is acquiring a global nature. At the present time the pollution fields, as a rule, formed off shore, are propagated far beyond the boundaries of the coastal regions, they encompass many seas and regions of the oceans completely. These fields are stable in time and space [6].

The given conclusion is confirmed by numerous observations which were performed in the last 3 years by different countries within the framework of the Experimental Project of the International Oceanographic Commission (IOC) of UNESCO and the World Meteorological Organization (WMO) of the United Nations for monitoring the petroleum pollution of the World Ocean not only in the Atlantic, but also in the Pacific and Indian Oceans. The scientific research ships of the Soviet Union are participating actively in the implementation of this plan.

Observations in the North Atlantic have demonstrated that the shelf waters of the continental and island regions are the most polluted where the petroleum hydrocarbon content fluctuates within the limits of 0.05 to 0.68 mg/liter. On going away from the shelf, the concentration decreases. On the whole, the picture of the hydrocarbon distribution caused by the complex structure of the water and the peculiarities of the process of the solution of it in seawater appears to be quite complicated. Petroleum hydrocarbons are contained in the seawater basically in the form of lumps and films.

The lumps of petroleum hydrocarbons are formations of various shape and consistency from black to yellow-brown in color and from 1.0 to 30-45 mm in size.

During the taking of one sample, as a rule, by a sampler, lumps of different types and sizes are collected, which indicates the nonuniformity of the pollution field and the constant transformation of the latter under the effect of external factors.

It has been established that the lumps of petroleum in the surface layer of water of the North Atlantic are present in 89% of the cases of taking samples in the amounts from 0.1 to 456.50 mg per m^2.

The concentrations of the petroleum lumps per m^2 of sea surface are distributed as follows:

Lumps weighing <0.1 mg (traces of petroleum)	10.6%
Lumps weighing 0.1-1.0 (average pollution)	45.3%
Lumps weighing 1.0-5.0 (strong pollution)	36.7%
Lumps weighing >5.0 (very strong pollution)	7.4%

In 80.7% of the samples taken the lump concentration reaches 1.0 mg/m^2 and more.

Many lumps are carriers of nektonic periphyton, the basis for which is the goose barnacles, isopod-crustaceans and other mobile forms. Thus, a lump weighing 6.85 grams with a very developed surface was populated with a colony of 21 barnacles with head sizes of 3-4 mm.

An analysis of the number of lumps by the method of gas chromatography demonstrated the presence in them of organochlorine pesticides which were absorbed on their surface during migration in the marine environment. Thus, for example, an aggregate caught at a point with coordinates 36°01' north latitude and 15°02' west longitude weighing 72 mg contained 2.79 ng of γ-hexachlorocyclohexane (HCCH), 20.42 ng of DDT and 1.23 ng of DDE.

Enormous bodies of water are encompassed by the oil slicks. Thus, the visual observations performed within the framework of the IOC and the WMO projects [9] indicate that such a film completely covers the South China and Yellow Seas, zones 300,000 km^2 in area at the Panama Canal (the films were detected in 40 to 50% of the cases of all observations), the entire Kuroshio system (to 30%), the zone west of the Hawaiian Islands 600,000 km^2 in area (to 30%), the southeastern part of the Bering Sea, and almost continuous zone along the coast of North America to 500-600 km wide (to 20%).

These visual observations are completely confirmed by instrument observations of the propagation of the oil lumps in the surface 10-meter layer of the water which are the final product of the evolution of heavy fractions of the petroleum hydrocarbons in different stages of their mineralization. The oil lumps are detected in all of the above-enumerated regions and also in the largest body of water from the Hawaiian Islands north to Alaska and east to the shores of North America. The greatest content (to 100 mg per m^2) was noted in the regions south of Japan and between the Hawaiian Islands and San Francisco, that is, in the regions of most intense navigation in the northern part of the Pacific Ocean.

The data on petroleum pollution of the Pacific Ocean waters again confirmed the conclusion that it is acquiring a global nature.

The performed studies have made it possible to draw another important conclusion regarding the significant effect of chemical pollution on the primary production of ocean water [3]. Estimating the effect of chemical pollution on the primary productivity of the surface water, it is necessary first of all to note that in the regions where the concentrations of pollutants were low, maximum chlorophyll concentrations (0.1-1.0 micrograms/liter) were observed, and there was no product of its decomposition pheophytin which during the vegetative period probably can serve as an index of the degree of effect of the pollutants on the primary production of the phytoplankton.

Wherever the seawater turned out to be the most polluted with mercury and petroleum products, the chlorophyll content was appreciably lower (basically to 0.1 micrograms/liter), and the pheophytin content increased (to 2-3 micrograms/liter). The high concentrations of chemical pollutants do not have so much an inhibiting, suppressing effect on the process of photosynthesis of algae as they deeply affect the vital organic matter formed during the course of this process.

Thus, it is possible to consider the fact of the significant effect of pollution on the primary production of seawater established.

In addition, an important conclusion has been drawn regarding the role of the basic circulation systems and with respect to the stagnant zones of the oceans and seas in the transport and accumulation of pollutants, respectively.

The greatest concentrations of these materials are noted in the coastal zones where they come from the shore, and in the broad relatively low-mobile regions of the ocean where they are brought in by systems of currents. Thus, the currents of the Gulf Stream, the North Atlantic Current which are saturated with pollutants off the coast of North America and Europe are unnoted in the vicinity of the Sargasso Sea, the Norwegian Sea and the Barents Sea. Thus, the unloading zones, including the Arctic region are becoming accumulators of powerful materials. In the north-western part of the Pacific Ocean the basic Kuroshio Current breaks down the field of the polluted water into two parts: one is adjacent to the shores of Japan, and the other withdraws into the open sea. The transport of the pollutant takes place predominantly in the peripheral zones of the circulating systems, where they are concentrated on the effect of the transverse component of the current velocity.

Another conclusion has been drawn in recent years. Significant concentration of petroleum hydrocarbons, synthetic surface-active materials and chlorinated hydrocarbons in the surface microlayer of the water (to 3000 microns) coming into the World Ocean via various channels. It has been established that the concentration of the indicated materials in the surface microlayer is 1 to 2 orders higher than in the surface layer of the water and the water layer of the atmosphere. On going away from the continents and the shelf zones, their concentration as a whole diminishes, but it still remains comparatively high. The chlorinated hydrocarbons, the concentrations of which are reduced to "trace" values constitute an exception.

Simultaneously with removal from the continents, the quality composition of the pollutants changes: the suspended part increases absolutely and relatively, and the dissolved part of the petroleum hydrocarbons decreases, the absolute and relative proportions of the DDE and the DDD (metabolites of DDT) also rises, and the proportion of the DDT decreases.

Thus, it is possible to consider the nature of the phenomenon of persistently high concentrations of chemical pollutants in the surface microlayer of the World Ocean global, just as the nature of the destruction of the naturally developed physical-chemical parameters of this layer under the effect of pollution.

Part of the monitoring is the system for observations of water pollution, bottom deposits and the surface of the World Ocean which will permit changes to be isolated in the state of the oceanic and, to some degree, the land animate environment taking place under the effect of anthropogenic activity. In this respect the monitoring of the pollution of the World Ocean water has subordinate significance in the system for monitoring the natural environment.

Solving the problem of the pollution of the World Ocean water means to develop substantiated proposals with respect to reducing the discharge of waste into the oceanic environment in such a degree that the processes of natural utilization of the pollutants will constantly prevail over the processes of pollution and lead to the elimination of the disturbances or the possibilities of disturbances in the ecologic systems of the World Ocean and the earth as a whole.

This goal can be reached by solving the following problems:

Observation of the dynamic levelof pollution of the World Ocean water, generalization and determination of the developed trends in the variation in the pollution level;

Predicting the dynamics of the pollution levels of the ocean water and tendencies in their variation;

The development of proposals with respect to preventing discharge of pollutants into the ocean environment considering the results of the indicated forecast.

At the present time the balance method of forecasting the pollution levels and calculating the rates of reduction of the discharge of the pollutants has been developed and tested for individual seas [1].

The calculation of the dynamics of the pollution levels takes into account the inflow of pollutants into the sea, their decomposition, their loss to the bottom deposits, the atmosphere and in the case of the hydrologic cycle, to another sea simultaneously. Each of these processes is characterized by its own rate coefficient. The essence of it reduces to the following.

It is known that the flow rate of the pollutants per unit time is proportional to the mass and the velocity coefficients of the outflow. Each is assumed constant for the investigated time interval. Under these assumptions, the pollutant budget for the time dt is described by the equation

$$M_t = \frac{q_t}{\sum K} - \left(\frac{q_t}{\sum K} - M_0\right) e^{-\sum Kt},$$

where M_0 and M_t are the presence of pollutants in the sea respectively at the beginning of the calculation and during the period dt, thousands of tons; q_t is the rate of inflow of pollutants in the sea; ΣK is the sum of the rate constants of the outflow of the pollutants along various channels.

From the equation it is obvious that for the constants q_t and ΣK the mass of the pollutants in the sea M_t for $t\to\infty$ asmptotically approaches the value $q_t/\Sigma K$ with some delay which is characterized by the term $(q_t/\Sigma K-M_0)e^{-\Sigma Kt}$ and determines the dynamic properties of the processes occurring in the sea.

The presented formula is somewhat complicated for the calculations; therefore using the expansion of the value of $e^{-\Sigma Kt}$ in a series, we bring it to the operating form:

$$M_t=M_0+\frac{2q-2M_0\Sigma K}{2+\Sigma K\Delta t}\Delta t.$$

The empirical coefficients used in the formulas for calculating the rate constants of the outflow of pollutants and also the rate constant of the biochemical destruction K_1 as a function of temperature were obtained on the basis of the experimental data and natural observations [1].

However, the use of this method requires the presence of reliable data not only on the arrival of pollutants in the sea, but also level of pollution in the body of water, the surface and bottom layer of the water, the bottom deposits and the magnitudes of the hydrologic cycle both between the individual layers of water and with the adjacent sea.

2. Channels for the Inflow of Pollutants into the World Ocean

The scientific principles of the organization of monitoring of the pollution of the World Ocean waters taking into account the channels and the rates of inflow of the basic pollutants (petroleum hydrocarbons, chlorinated hydrocarbons, heavy metals, synthetic surface-active materials), the time they are in the marine environment, the rate of exchange and the phase interface (water and bottom deposits, water and the layer of the atmosphere next to the water, water and animate organisms), their evolution in the seawater, the capacity to be concentrated in the boundary zones (surface, bottom deposits, density discontinuity in the air) are discussed to a known degree in the "program for monitoring the background levels of individual pollutants in the open seas," the compilation of which was participated in by the author of this article by resolution of the UNEP, WMO and the IOC.

During the development it is necessary to consider many facts, primarily arising in nature which give rise to many of the most important features in the evolution of pollutants:

The high dynamicity of the ocean waters, which leads to quite fast spread of the pollutants over great expanses;

The different time nature of the exchange, the ventilation of the water, the age of the water masses over the shelf and in the open part of the ocean, in the upper and nearby layers;

Limited potential of the sea water for natural utilization of chemical pollutants, self-cleaning, especially at low water temperatures.

In addition, it is necessary to consider the nature of the sources in the channels of inflow of the pollutants, and their physical-chemical properties.

Obviously it is necessary to consider the problem of the pollution of the marine environment with each specific pollutant separately. How correct this is, can be judged by briefly analyzing the process of the pollution with petroleum hydrocarbons (NU) and chlorinated hydrocarbons.

At the present time about 6 million tons of petroleum hydrocarbons get into the seawater annually from various sources and along various channels. This makes up about 0.23% of the annual world petroleum extraction. In order to realistically represent this figure, it is sufficient to say that during all of World War II a total of about 4 million tons of oil got into the ocean as a result of the sinking and damaging of tankers [8].

The general idea of the sources and channels of inflow of petroleum hydrocarbons into the seawater can be obtained on the basis of the data presented below [10]:

Sources and channels of inflow of petroleum hydrocarbons	Volume, % of the total inflow of pollutants
Discharge from ships at sea, including discharge of washing and ballast water	23
Discharge from ships in ports, in the bodies of water next to the ports, including the losses when transferring petroleum from the tankers and to them, when loading the fuel	17
Discharges from shore, including industrial waste water	11
Inflow with the rain runoff from the cities	5
Inflow in the case of disasters between ships at sea	5
Inflow when drilling on the shelf	1
Inflow with river water	28
Inflow from the atmosphere	10

These data are noteworthy in two respects. First, they permit determination of the basic channels of inflow of the petroleum hydrocarbons into the World Ocean and estimation of the magnitude of each of them. Thus, the inflows directly into the sea amount to 29%; with river runoff 28; the discharge from the shore and from ships in ports and the bodies of water next to the ports, 33%.

Secondly, they indicate that 43% of the inflow of the petroleum hydrocarbons under the present conditions cannot in practice be regulated, for the river runoff, atmosphere and municipal rain runoff amount to their powerful collectors. This fact significantly complicates and postpones the time of solution of the problem as a whole.

The constant presence and increase in the content of petroleum hydrocarbons in seawater indicates the predominance of the rate of their inflow over the rate of natural reclaiming.

The studies performed in different countries indicate the influence of the petroleum hydrocarbons on the reduction in reproduction and the reduction in species composition of animate organisms and also the occurrence of cancerous diseases [2]. The threshold concentrations causing death of single-cell algae or retardation of their division lie within the range of 0.05 to 1.00 mg/liter. Accordingly, oil and gas are on the "black list" of dangerous pollutants, the discharge of which is totally forbidden by the London Convention on Prevention of the Pollution of Seawater of 1972.

In the Soviet Union the maximum admissible concentration of petroleum hydrocarbons in the marine bodies of water having fishing significance has been regulated -- it is 0.01 mg/liter. It must be noted that over the broad expanses of the seas, in the continental shelf zones, the actual concentrations of the petroleum hydrocarbons can be appreciably above the maximum admissible.

The pollution of seawater influences not only the animage organisms. The presence of petroleum hydrocarbons on the surface of the water in the form of films and high concentrations of them in the surface microlayer can significantly disturb the energy, gas and hydrologic cycle between the ocean and the atmosphere, for the surface tension of the oil film is several times less than the surface tension of pure water, the coefficient of thermal conductivity is two orders higher, the heat capacity is several times less than in water, the gas conductivity of the normal film of monomolecular layer is 50% of the gas conductivity of pure water. On the whole, the presence of petroleum hydrocarbons on the surface of the water can influence not only the hydrobiological conditions of the ocean but also the climate and the oxygen content of the earth's atmosphere inasmuch as the ocean is an important factor in the formation of their regime.

What has been stated above permits isolation of several of the most important aspects of the monitoring of the World Ocean pollution with petroleum and petroleum products.

The first aspect consists in tracing the dynamics of the levels of petroleum pollution of the open waters of the World Ocean in the regions sufficiently removed from the basic channels of their inflow.

The second aspect consists in estimating the accumulation of the petroleum hydrocarbons in the zones of the World Ocean in which the degree of natural reclaiming of these materials is low as a result of low water temperatures. These zones include the Baltic, Bering and Norwegian Seas, the Arctic Ocean and Antarctica.

Primarily the petroleum hydrocarbons get into the Arctic Ocean with the currents from other oceans and, above all, the water of the North Atlantic current [6]. The greater accumulation of petroleum hydrocarbons in the Arctic Ocean by comparison with other oceans can be promoted by certain of its physical-geographic peculiarities: namely, low water and air temperatures which inhibit the presence of chemical and biochemical oxidation of the petroleum hydrocarbons even in the summer.

The third aspect consists in estimating the accumulation of the petroleum hydrocarbons in the surface microlayer of the oceans and seas, their influence on the atmospheric pollution, variation of the heat, moisture and gas exchange of the ocean with the atmosphere. At the present time, as observations show, the average petroleum hydrocarbon concentration exceeds 1 mg/liter over the entire North Atlantic in the surface microlayer of the water. The approximation calculation shows that the total petroleum hydrocarbon content in the surface microlayer of the entire World Ocean can be 1.5 to 2 million tons, which is a third of the annual inflows of the petroleum hydrocarbons into the ocean water. It is obvious that the volume of concentration of the petroleum hydrocarbons in the surface microlayer is enormous. This fact indicates the role of the interfaces in the petroleum hydrocarbon concentration and indicates the necessity for studying the content of the petroleum hydrocarbons at two other of the largest interfaces of the ocean: namely, in the bottom deposits of the oceans and in the density discontinuity layers. The results obtained in turn will permit more precise definition of the monitoring of oil pollution of the marine environment.

Knowing the mass of petroleum hydrocarbon contained in the surface microlayer and the rate of inflow (5.5 million tons a year), it is possible to calculate the approximate time the petroleum hydrocarbons stay in this layer. It can supposedly be from 1 to 5 months, which not only coincides with respect to order, but also is close to the halflife of the oil dissolved and dispersed in water which has been found experimentally [7]. The halflife of oil in seawater at a temperature of 10°C is approximately equal to 1.5 months; with a rise in temperature to 18-20°C it decreases to 20 days, and at 25-30°C, to 7 days.

Beginning with what has been discussed, it is possible to state that at low water temperatures only about half of the petroleum hydrocarbons located in the surface microlayer get into suspended and dissolved form in the water, concentrating again in the layers of the density discontinuity or in the bottom deposits, and their volatile components, in the atmosphere. Another half of the petroleum hydrocarbons disintegrate in this layer. At high water temperatures a significant portion of the petroleum hydrocarbons, with the exception of the volatile components, can disintegrate directly in the surface microlayer. This (together with turbulent diffusion) entirely explains the decrease in the petroleum hydrocarbon concentrations in the surface microlayer on going away from the shelf, and also their increase in the temperate and high latitudes of the oceans and, on the contrary, a decrease in the equatorial, tropical and subtropical zones.

A comparison of the time the petroleum hydrocarbons spend in the surface microlayer and their halflife in the water also permits the conclusion that the surface microlayer not only is a powerful concentrator but also a filter of the petroleum hydrocarbons, which offers significant protection to the ocean water from intensive pollution.

This conclusion is extraordinarily important for proper calculation of the basic components of the pollution balance of the marine environment of the petroleum hydrocarbons. Up to now the concentration of a significant part of the petroleum hydrocarbons in the comparatively small microlayer with respect to volume (less than 1% of all of the water in the World Ocean) and their disintegration in this layer were not takeninto account in the consumption part of the budget.

It must be noted that with an increase in the petroleum extraction the absence of serious water conservation measures, the performance of which is difficult for a number of reasons, the pollution of the World Ocean will increase. According to the United Nations data, the world volume of petroleum extraction in 1980 will exceed 4000 million tons, including 1/3 of this amount on the shelf. It is possible to calculate, using the above-indicated loss factor, that more than 9 million tons of petroleum hydrocarbons will get into the marine environment annually. Moreover, there are grounds for assuming that the pollution rates of the World Ocean will also rise in connection with an increase in the petroleum extraction on the continental shelf.

Now let us consider the problem of the pollution of the World Ocean with chlorinated hydrocarbons, primarily DDT and RSV.

DDT (and its metabolites DDE and DDD) and RSV have been detected in many parts of the World Ocean. The relative chemical stability and also the nature of migration of these materials have promoted their entry into the seawater in large quantities.

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The constant accumulation of chlorinated hydrocarbons in the seas and oceans presents a serious threat for animate organisms populating the sea and for man. It has been established that there is a defined relation between the pollution level of the water with pesticides and the accumulation in the fatty tissue of fish and marine mammals.

Accordingly, obviously it is necessary to solve another problem: reliably to estimate the mass of pesticides in the atmosphere and oceans accumulating in the last three decades and also the period of their effect on animate organisms and the zones of their greatest accumulation in the bottom deposits.

By 1968 the DDT production reached approximately 100,000 tons in a year (of this two-thirds in the United States), and on the whole for the period from 1944 to 1970 it was about 2 million tons [8].

The DDT used as pesticides and its decomposition products get into the environment primarily with evaporation.

Thus, the basic channel of inflow of DDT and its metabolites into the marine environment in the vapor phase is the atmosphere. It is this that explains the fact of its broad propagation in the marine environment: the presence of DDT and its metabolites has been recorded in the open and oceanic waters, especially in the surface microlayer. According to the observations made by the GOIN [State Oceanological Institute] in 1976 the total DDT, DDE and DDD content in this microlayer of water in the northeastern part of the North Atlantic reached 90 ng/liter, and in the subsurface, 5 ng/liter.

The production of polychlorobiphenyls (PCB) in the United States and Japan alone by 1970 reached 49,700 tons (in 1961 it was only 21,200 tons [8]). It is true that in 1971 the PCB production was curtailed sharply in connection with restriction of its use in hydraulic mixtures, systems with high temperatures, in which a very high, and in a number of cases, complete dispersion in the environment occurs. In addition, when using the RSB as plasticizers, lubricating oils, materials for sealing and resin filler in glue, they are not extracted later.

The primary channel through which PCB gets into the ocean, just as DDT, is the atmosphere.

According to the data of American specialists, the PCB content in the surface waters of the eastern part of the Atlantic in 1971-1972 reached on the average 30 ng/liter [8]. In 1973 measures were taken in the North Atlantic (at the point 32°25' north latitude and 70°20' west longitude): at a depth of 100 meters the PCB concentration is 0.8 ng/liter, at a depth of 600 meters it is 0.5 ng/liter, 900 meters, 1.9 ng/liter, and at a depth of 5100 meters, 0.4 ng/liter. The American specialists also determined that the PCB content on the average is 20 to 30 times higher than the DDT content.

There is a proposal that the PCB has greater stability than the DDT.

The PCB residue, just as the DDT, is detected in the lipid fraction of the marine organism. Just as in the water, the ratio of the PCB and the DDT masses in the plankton can be expressed approximately as 1:30, but then on moving along the food chains, it decreases to 1:3 in fish.

A brief investigation of the nature of the problems of water pollution in the World Ocean permits the following conclusions to be drawn: the spread of the petroleum hydrocarbons and chlorinated hydrocarbons has a global nature caused for the petroleum hydrocarbons by the colossal volume of their inflow and the transport by the circulation systems, and for the chlorinated hydrocarbons, by their insignificant evolution in the marine environment with comparatively lower inflow; the petroleum hydrocarbon concentration in large quantities in the surface microlayer caused for the petroleum hydrocarbons by their lower density by comparison with the density of seawater and for the chlorinated hydrocarbons, by their inflow predominantly from the atmosphere and capacity to dissolve in the petroleum hydrocarbons.

These general conclusions will undoubtedly promote the construction of a unified system for monitoring the ocean water pollution.

It must be noted that recently quantitative data have been obtained which indicate the ocean surface as a source of atmospheric pollution. Thus, analysis of the observations performed in 1976-1977 by the GOIN in the North Atlantic that there are fully defined direct relations between the concentration of the dissolved fraction of the petroleum hydrocarbons in the surface microlayer and the petroleum hydrocarbon concentration in the layer of the atmospherenext to the water. It is true that these relations are not unique for different parts of the ocean. It is characteristic that their stability decreases on going away from the shelf to the ocean. The reason for this lies in the fact that in the coastal regions usually the freshly discharged petroleum hydrocarbons predominate, in the composition of which the volatile fractions predominate, in turn.

Of course the ambiguity of the discovered relation is also determined by other factors: the anemobaric conditions, the air humidity, the developed partial pressure of the petroleum hydrocarbon in the air, the difference in the surface microlayer and air, turbulence in the boundary layer, and so on.

However, all of these facts -- appreciably lower petroleum hydrocarbon content in the air than in the surface microlayer, lower soluble fraction of petroleum hydrocarbons in it on going away from the shore and presence of a relation between the petroleum hydrocarbon content in the air and the concentration of the dissolved fraction of the petroleum hydrocarbons in the surface microlayer -- indicate the existence of the process of transition of part of the petroleum hydrocarbons from the ocean to the layer of the atmosphere next to the water.

Accordingly, it is necessary to include observations of the chemical composition and the basic meteorological characteristics in the layer of the atmosphere next to the water and also the exchange rate of the pollutants through the ocean surface in the ocean water pollution monitoring system.

3. Principles of the Organization of Monitoring of Seawater Pollution

The above-discussed arguments obviously lead to the following basic principles of the organization of the monitoring of seawater pollution:

Complexity of the chemical (in the water) suspensions, soils, the layer of the atmosphere next to the water) and accompanying hydrologic and meteorological observations which to a great extent determine the evolution of the pollutants in the marine environment and their exchange through the basic interfaces -- the ocean surface, the density discontinuity layer, suspended matter and ocean floor;

Tracing the dynamics of the pollution level of the ocean water when performing long-period systematic observations of the background concentrations of pollutants in the open sea regions most removed from the pollution sources which would characterize the conditions of the environment of significant adjacent bodies of water. It is possible to limit this tracing to a limited number of basic oceanographic stations in each ocean (to 6 to 10 stations);

Tracing pollutant transport. For this purpose it is necessary to organize the observations in the oceanographic sections in the basic circulation systems of the World Ocean. It is possible to take such sections near the base stations and when the scientific research vessel approaches or departs from them.

Coupling of the monitoring of the chemical pollution of the seawater as a subsystem of the monitoring of the natural environment with monitoring of the effect of the pollutants on marine animate organisms. The observations will be logically full-valued and complete only when observing this principle.

The realization of the discussed principles will make it possible simultaneously to approach the study of long-period time-space variability of the environmental conditions, including pollutants. It is these principles, with the exception of the latter, that the author of the article was guided by when compiling the Program for Monitoring Background Levels of Individual Pollutants in the Open Sea..

In the opinion of the authors of this program, eight base stations for discovering the long-period variability of the background levels of the basic pollutants are sufficient in the Atlantic Ocean. The location of these stations is selected considering the hydrodynamic and morphological conditions of the regions of the Atlantic Ocean, each of which reflects defined, and taken together, basic, circulating and thermohaline peculiarities of the water masses of the ocean (see Fig 1). In the program it is recommended that observations at the base stations be taken no less than four times a year for 10 years.

It is proposed that such pollutants as petroleum and petroleum products, chlorinated hydrocarbons (DDT, PCB), heavy metals (lead, mercury, cadmium, and possibly others) and detergents be monitored. In addition, it is recommended that the following definition be introduced into the composition of the accompanying observations:

Physical parameters (temperature and salinity of the water for the removal of water masses and determination of the vertical structure, suspended matter for determining the insoluble pollutants, the temperature and humidity of the air, the speed and direction of wind);

Chemical parameters (dissolved oxygen, alkalinity and pH in the case where the necessity arises for calculating the forms of carbonic acid, including carbon dioxide for studying its exchange with the atmosphere).

Considering the above-discussed principles, at the present time work is being done on the scientific research weather ships of the Soviet Union and the Atlantic Ocean in the vicinity of the "Charlie" weather station located in the North Atlantic current system, beginning in Florida and ending in the Arctic Ocean.

Insignificant variations in the experimental parameters establishing during the course of the observations in the vicinity of the "Charlie" station will undoubtedly characterize the variations in the environment over a significant part of the North Atlantic.

Therefore, this station along with the other seven stations is defined in the mentioned Program for Monitoring the Background Levels of Individual Pollutants in the Open Seas as a station for long-period systematic observations in the background pollution levels of the Atlantic Ocean.

The organization of such observations in the vicinity of "Charley" station can play an exceptionally important role in studying the background levels of the parameters of the environment in the Arctic Seas which individually or taken together can be considered as biospheric sanctuaries.

Thus, it is possible in the future to consider the organization of the special complex observations in the vicinity of "Charlie" station as the contribution of the Soviet Union to the system of international global monitoring of chemical pollutants of the seas and as a component part of the national observation system by the biospheric sanctuary program.

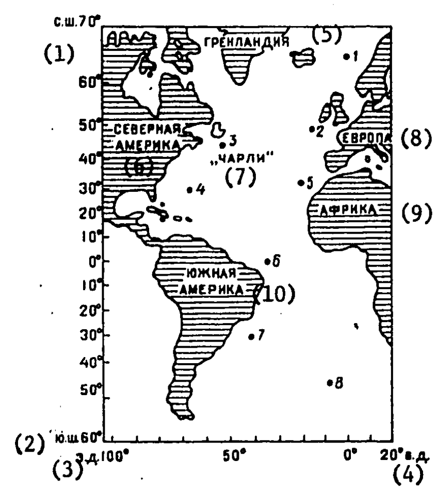

Figure 1. Location of stations for observing the level of basic pollutants in the Atlantic Ocean. 1-8 -- base stations

Key:

1.	North latitude	6.	North America
2.	south latitude	7.	Charlie
3.	west longitude	8.	Europe
4.	east longitude	9.	Africa
5.	Greenland	10.	South America

The goals of the observations at the weather stations include the following:

Study of the background levels of the basic physical, chemical characteristics and pollutants in seawater;

Investigation of background levels, propagation and pollution and trends in the pollutant levels of the Gulf Stream with petroleum hydrocarbons, chlorinated hydrocarbons, certain heavy metals and detergents and also the transport of them by the North Atlantic current system;

The study of background levels of the basic pollutants in the layer of the atmosphere next to the water (petroleum hydrocarbons, sulfur dioxide, heavy metals, clorinated hydrocarbons, sulfates);

Determination of the flow of pollutants through the ocean surface;

Study of the levels of concentration of the pollutants in the basic components of the biological system (phytoplankton, zooplankton and benthos organisms);

The study of the primary productivity and the influence of pollutants on it;

Determination of the number of microorganisms (total and by groups) and investigation of the generic composition of the petroleum-oxidizing microorganisms for estimating their role in the destruction of the petroleum hydrocarbons in seawater;

The development of general estimates of the reaction of the biota to the effect of individual pollutants in order to define the concepts of the "norm" and "pathology" for the entire Gulf Stream system;

The study of the possibility of using marine organisms to indicate pollutants.

Observations in the vicinity of "Charlie" station will be accompanied by observations in the section passing through this station and intersecting the Gulf Stream.

It appears that observations can be organized in a similar manner at the other base oceanographic stations of the Atlantic Ocean and other oceans.

The observations in the open seas must be reinforced by systematic observations in the shelf zones. Only then will it be possible to compile a concept of the time-space variability of the ocean water pollutants and solve the problems discussed above.

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PART II. METHODS OF OCEAN EXPLORATION

SPACE OCEANOGRAPHY: PROBLEMS AND PROSPECTS

[Article by B. A. Nelepo]

Boris Aleksey Nelepo, active member of the Ukrainian SSR Academy of Sciences, director of the Marine-Physics Institute of the Ukrainian SSR Academy of Sciences. His basic scientific interests are experimental hydrophysics. In recent years he has been engaged in the development of satellite oceanography.

The World Ocean is being studied with ever-increasing intensity. The measuring devices by means of which factual data are obtained are being continuously improved. However, the procedure for using them essentially has not changed Observations are performed either from automatic buoy stations put out in various parts of the ocean or on stationary platforms and shore oceanographic stations. The creation of the network of constantly operating oceanographic stations is connected with serious technical difficulties, including operating difficulties. Therefore the development and application of specialized oceanological satellite systems must be considered an urgent and prospective area of modern oceanology.

Space oceanography is based on the recently developed remote methods of measuring the oceanological parameters. The possibility has been established for remote measurement of such ocean parameters as global topography of its surface, the state of the water surface, marine currents, the spectrum and direction of propagation of the waves and the wind in the layer next to the water, the radiation balance on the surface of the ocean, and the ocean surface temperature. Both ships and airplanes can be used as carriers of the remote measurement equipment, but the most prospective is the use of artificial earth satellites having a series of advantages: great duration of operation, fast scanning of a significant area of the earth, and so on.

The first results of using artificial earth satellites obtained both in the Soviet Union and in the United States indicate the possibility of satisfactory accuracy of measuring the oceanological parameters.

However, today the role of the remote methods of investigating the oceans using artificial earth satellites is not so great as one might like. In turn, this is connected with insufficient development of the methods of remote measurement limited by the possibilities of the measuring equipment, the absence of profoundly developed theories and methods of processing and interpreting the information obtained. It is necessary also to note that the remote methods permit measurements only of the surface hydrophysical fields which are only a reflection of the processes occurring in the depths of the ocean and in the foreseeable future these methods will hardly permit direct "looking" into the depths of the ocean, let us say, below the seasonal thermocline layer. Therefore the traditional methods of investigation using scientific research ships and buoy stations for different purposes will be developed and improved as before.

At the same time, the appearance of methods of space oceanography will have (and is already having) a significant effect on the entire nature of investigation of the ocean, which is forcing oceanologists essentially to reexamine the established methods of investigation and proceed with the execution of the large-scale controlled oceanographic programs.

The methods of space oceanography basically are methods of large-scale studies permitting operative surveying of broad bodies of water giving a general concept of the dynamics of the processes occurring in the surface layer of the ocean and also making it possible to obtain quantitative estimates of the hydrophysical parameters in the high-gradient zones.

The photograph presented here (see Fig 1; the photograph was made in September 1973 from the "Soyuz-12" spacecraft by astronauts V. G. Lazarev and O. N. Makarov) gives an idea of the nature of the information received from the satellite orbit. The given picture, in particular, can be used to study the water masses and shoals.

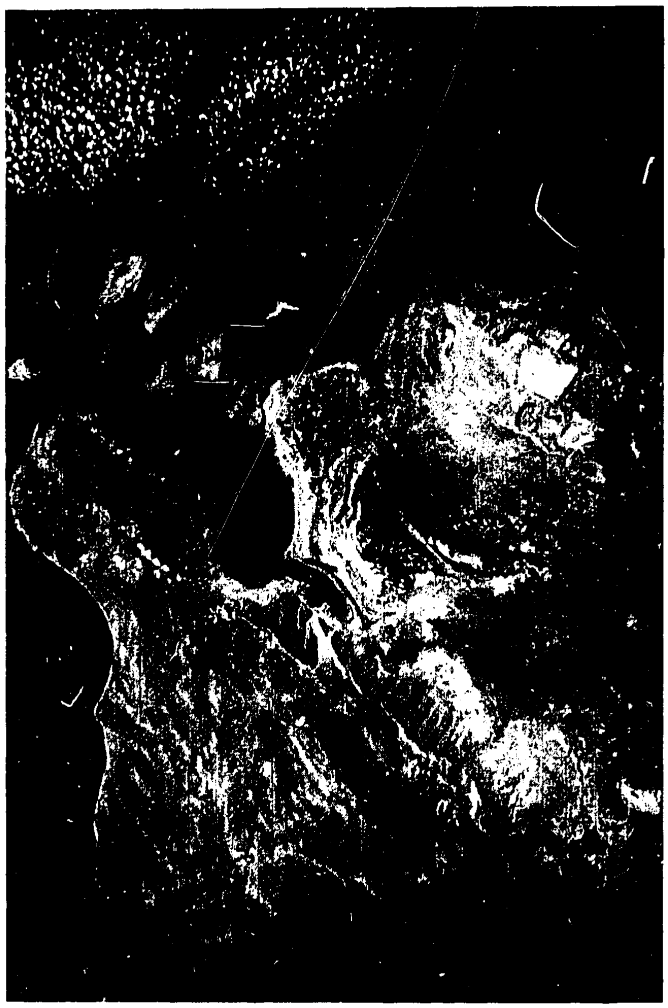

Figure 1. Region of the Caspian Sea (picture taken from on board the "Soyuz-12" spacecraft)

It is difficult on the basis of the primary experiments to give a reliable prediction of the further development of this area of oceanography. However, it is possible to state with certainty that further scientific studies connected with the development of the theory, the methods and means of remote sounding of the ocean from on-board spacecraft will put a powerful tool in the hands of oceanologists.

On the basis of such data it is possible to plan expeditions and scientific research vessels for detailed studies using ship and buoy means in the characteristic areas, the variability of the process of occurring in which determines the dynamics over significant bodies of water.

Oceanologists still have to create a reference network of measuring stations in the ocean to which the results of the remote measurements will be "coordinated" analogously to how the data in meteorology obtained from the meteorological satellites are "referenced" to the ground network of meteorological stations. The systems of automated buoy stations arranged in a defined way will permit us to obtain the vertical structure (beginning with the surface) not only of the active, but also the abyssal layers of the ocean. On the one hand, this permits regular calibration of the remote sounding sensors, and on the other hand, the solution of the problem of transformation of the surface fields to the depths, at least within the limits of the active layer.

Supplementing the given measuring complex with a system of drifting buoys (surface and neutral buoyance), oceanologists can trace the surface and the abyssal currents, eddies and rings and also estimate their speeds. An important element determining the nature of the operation of the entire system of buoy stations can become the geostationary satellite, in the field of view of which the investigated body of water in the ocean is located, and the set of measuring means, including the search vessels, the system of anchored and drifting buoys, and the measuring oceanographic satellites. These satellites, in addition to other missions, can collect information from the buoy system (especially from the "hovering" neutral-buoyance buoys) and relay it to the receiving stations.

1. Problems of Space Oceanography

The intensive development of the methods of remote sounding in the last decade has opened up a new path to the study of the phenomena occurring in the ocean, in particular, the investigation of its mesoscale or synoptic variability. The development of the new equipment, the development of new procedures for remote sounding and methods of decoding information, the use of theoretical models which describe the processes occurring in the ocean -- these are the problems which must be solved before going on to the solution of a number of fundamental problems of oceanology and, consequently, the creation of a closed hydrodynamic model of the ocean and also subsequent prediction of its parameters.

One such problem is determination of the large-scale variability of the ocean. The synoptic, or the mesoscale variability of the large-scale ocean currents, and above, all, the variability of the most intense of them is manifested in variations in position of the current axis, the fluctuations of their intensity and meandering. The indicator factors, in turn, lead to variations of such important characteristics as the carrying of heat northward by the Gulf Stream type currents, the amount of which determines the climate over a significant territory of Europe and the Arctic regions.

The meandering of the intense currents and the processes of so-called barotropic instability connected with this lead to the occurrence of isolated eddy formations of the cold and warm ring type. Having significant reserves of kinetic energy, large-oceanic currents and their variability play an important role in the overall dynamic balance of the ocean, in the processes of the interaction of the ocean and the atmosphere, and to a great extent they determine the dynamics of the atmospheric processes themselves.

A significant contribution to the processes of redistribution of the momentum, the angular momentum, the heat transfer in the ocean is being made by the synoptic eddies. By the calculations of the specialists, the consideration of the heat transport by the synoptic eddies can change the overall balance of the meridional heat flux to the north by 30 to 40%.

In order to estimate the contribution of the synoptic eddies to the overall balance of heat transfer, momentum and angular momentum in the ocean it is necessary to know the areas of generation of the eddies, the periodicity of their formation, the direction of predominant propagation. The existing experience indicates that the remote methods-of detecting the eddy formations and tracing them from orbital scientific stations are opening up the path to operative prediction of the "weather" in the ocean.

Some of the most important factors determining the large-scale variability of the hydrophysical fields of the ocean are the thermal anomalies and frontal zones. According to the modern concepts, quite powerful and long-lasting temperature anomalies and frontal zones to a great extent determine the nature of the processes of heat exchange between the atmosphere and ocean, they influence the stability of the global atmospheric processes which, in the final analysis, is reflected in the formation of weather and climate over significant territories of the earth's surface. It is quite clear that the problem of short-term and then longer-term forecasting cannot be solved without considering the indicated factors, the obtaining of operative data about which it is possible only by remote methods.

The connecting link in the chain of processes determining the interaction of the ocean and the atmosphere is the active layer of the ocean. It is the upper surface layer in which the physical parameters experience significant seasonal fluctuations. The quasiisothermal layer characterized by a small vertical temperature gradient, the discontinuity layer in which the parameters of the environment undergo discontinuous changes and the seasonal thermocline characterized by significant vertical temperature gradients are distinguished in it.

The variability of the active layer leads to the formation of temperature anomalies which, as a result of the great thermal inertia of the ocean have a significant influence on the nature of the atmospheric processes. In addition, the active layer of the ocean, which is the intermediate link in the redistribution of the heat fluxes to a great extent also determines the nature of circulation of the abyssal water.

The quantitative estimates and the large-scale interaction of the ocean and the atmosphere, including the exchange of energy, momentum, heat and moisture, can also be obtained using remote measurements of the radiation budget of the ocean surface, sediment and evaporation, the statistical characteristics of the surface waves and the wind conditions in the water layer of the atmosphere.

The development of the enumerated fundamental problems of the physics of the ocean, the theory and methods of calculating the physical fields and also the transition to the experimental studies of the ocean from space permit arrival at the solution of a number of applied and practical problems of the national economy. The primary ones of them are the following:

Operative short-range and long-range weather forecasting;

Insurance of safety of navigation, the selection of optimal routes for the ships;

Establishment of the control of the ecology of the sea, in particular, when determining the degree of pollution of the sea surface with petroleum products;

Determination of the dynamics of formation of the ice cover;

Determination of the regions of increased biological productivity and forecasting of congregations of fish, and so on.

The discussed problems can be solved step by step. The first step is mapping of the diagnostic fields of the physical parameters (temperature, wave action, and so on) obtained by remote methods. The further development of the theory and methods of interpretation of the observation data will permit identification of the physical formations and proceeding to the compilation of the maps of these formations: namely,

Clouds reflecting the intensity, the position of the axis, the meandering and the process of hydrodynamic instability connected with this leading to the formation of rings and eddies and also the interaction of eddy formations with currents;

Frontal zones with indication of their position, intensity, the locations of the largest gradients;

The upwelling zones with indication of the thickness of the debris cone of biogenic elements;

Thermal anomlies of the active layer of the ocean with indication of their position, dimensions and thickness;

Pollution of the sea surface with petroleum products with indication of the position, dimensions and quantity of the petroleum products;

Water color with indication of the biologically productive regions;

Ice fields with indication of the positions and boundaries of the fields and the openings and areas of open water in the ice.

In this stage it is necessary to develop criteria and methods permitting isolation and classification of the physical phenomena in the ocean.

The second, more complex step is the development of forecasting models of the physical formations in the ocean based on the material obtained over a sufficiently long observation period.

Initially this forecasting will be realized on the scale of synoptic variability, and then on the scale of seasonal variability. In the future it is possible to expect the solution of long-range forecasting, let us say, for a year. In this stage it is necessary to realize a set of organizational-technical measures.

On the one hand, it is necessary to create a powerful computer base which is based on the third-generation computer; a data storage bank; the software for data processing.

On the other hand, it is necessary to organize purposeful trips by scientific research ships to study the physical phenomena occurring in the ocean, to create monitoring and calibration test areas permitting development of the procedure for remote sounding and identification of the physical formations in the ocean; installation of the set of "long-lived" buoys and neutral buoyancy buoys (drifters) for investigation of at least the upper 200-meter layer of the ocean; the deployment of a permanently operating network of autonomous buoy stations (ABS) in the form of "clusters" consisting of one or two base buoys operating in the data gathering and measurement mode and several minibuoys operating in the measurement and data relaying mode to the base buoys.

All of this will permit solution of the problems of the hydrodynamics of the ocean first within the limits of the active layer and then in the deeper layers of the ocean.

2. Informative Hydrophysical Parameters and Requirements on the Determination of Them

The presently accumulated experience in decoding images received from space in various electromagnetic wave ranges indicates the prospectiveness of using satellite data to study the World Ocean [4,15]. Synthesizing this information with the measurement data obtained by traditional (contact) methods from on board the scientific research vessels, or ABC, it is possible to proceed with the study of the entire variety of thermodynamic and other processes occurring in the ocean.

The level of development of technical means and methods of observation from space reached at the present time will in the majority of cases make it possible to obtain high-quality characteristics of the parameters of the state of ocean of interest to us, but in the near future the accuracy of the measurements will be increased significantly, which will permit us also to obtain their quantitative estimates with the necessary level of informativeness [21].

Let us strive to formulate the minimum requirements which are imposed on the accuracy of measuring the hydrophysical parameters by the remote methods. The accuracy of determining these parameters depends on the specific nature of the solution of the specific oceanographic problems. Thus, first it is necessary to formulate the problem and then on the basis of it to generate the requirements on the equipment and accuracy of the measurement.

The requirements must be imposed on the accuracy of the measurements, the spatial resolution and the width of the swath of the investigated part of the ocean, time averaging and the frequency of the readings.

One of the most informative parameters of the marine environment is the surface temperature of the ocean which at the present time can be determined by the natural radiation of the ocean in the infrared and microwave bands.

This parameter is defining when solving such problems of oceanography as the study of mesoscale variability of the ocean, the isolation of frontal zones and intense current zones, predicting the structure of the active layer of the ocean, interaction of the ocean and the atmosphere.

Beginning with these problems, let us also determine the requirements on measuring the temperature and other informative parameters.

Mesoscale Variability of the Ocean. The ocean surface temperature field is to a significant degree subordinate to the nature of the eddy movement in the main oceanic thermocline. Here the basic peculiarities of the distribution of this parameter have been caused primarily by the eddy advective currents disturbing the zonal distribution of the temperature [13].

In contrast to the circulating nature of the eddy movement in the main oceanic thermocline, the model of the temperature distribution of the ocean surface is characterized by the intrusion nature of the displacement of the isotherms.

The characteristic fields of the formations in the upper layer of the ocean are 40 to 400 km. The average rate of spatial displacement is 5-8 km/day. The temperature gradients at the mentioned distances are 0.2-2.0°C in the zones of effect of the abyssal mesoscale eddies and to 2-3°C in the zones where the intensive formations of the Gulf Stream ring type are located.

The isolation (identification) of the synoptic eddy formations by their manifestations in the temperature field of the ocean surface will permit estimation both of the kinematic characteristics of the eddy formations and the nature of the interaction of the upper boundary layer of the ocean with the layer of the basic oceanic thermocline. Recently the interest in the investigations of the variability of the ocean within the scales of 15-50 km has increased sharply. This is connected with high energy movement in these sections. The temperature gradients are usually 0.2 to 1.0°. Therefore the accuracy of measurements of these gradients is 0.1 to 0.2°C with resolution of the equipment of 3-5 km on the terrain.

The temperature anomalies are traced against the average climatic background as formations with characteristic spatial scales from hundreds to thousands of kilometers, a characteristic lifetime from several to tens of months and thickness (with respect to depth) of tens of meters [20]. The extremal deviations from the climatic form of such formations are not more than 2-3°C, but as a result of the high thermal inertia of the ocean by comparison with the atmosphere they have a significant influence on the weather of the planet on global scales. Therefore the remote sounding equipment must have sufficient width of coverage of the regions of the ocean and measurement frequency. It is most expedient to obtain maps of the surface temperature once or twice a week. The spatial resolution in this case must be 30 to 50 km, and the accuracy of determining the temperature, no less than 0.5°C.

Frontal Zones and Zones of Intense Currents. At the present time the position of the basic frontal zones in the World Ocean and the zones of intense currents is defined quite well. Therefore the main goal is to study the variability of the axis of the currents and the fronts, meandering, and so on [19]. As the basic attribute for recognition of the "patterns" of the oceanic fronts and the boundaries of the intense currents we have the temperature gradient at their interfaces which can reach 2-10°C. This permits detection of it by the infrared equipment. With such high temperature gradients the acceptable accuracy of determining the temperature will be 0.5 to 1.0°C. The spatial resolution must be 1-2 km.

Let us add that the information about the position of the frontal zone boundaries carries data on the color of the water, the nature of the clouds above the ocean, the speed and direction of the currents, and so on.

The determination of the current speed is theoretically possible using high-precision altimeters (radio altimeters) which permit us to obtain estimates of the large-scale slopes of the ocean surface level. However, the use of the dynamic method for determining the speed of the current remains problematic as a result of the exceptional complexities on a procedural and technical level. For example, with a current speed of 10 cm/sec, the level gradient across the current axis on a scale of 10 km will be 10 cm. Here the accuracy of determining the difference in altitudes with an error of 20% is required to be ± 2 cm.

The use of drifting buoys (drifters), the position of which can be determined by using satellite navigational systems several times a day with an accuracy on the order of 1 km are highly prospective in this direction. This, in turn, will permit estimation of the velocity with an accuracy of about 10% even for the most intense currents which completely satisfy the requirements of oceanography.

The prediction of the structure of the active layer of the ocean is the most important problem of oceanography, for it is the main intermediate link in the processes of the interaction of the ocean and the atmosphere. This forecast includes determination of the temperature of the ocean surface, the position of the lower boundary of the uniform layer (layers), the position (depth of occurrence) of the discontinuity limit. The temperature and depth of the uniform layer determine the thickness of the temperature anomalies (the heat content) and the lifetime; the position of the discontinuity layer determines the lower boundary of the zone of active photosynthesis of the upper layer of the ocean.

At the present time there are a quite large number of theoretical models permitting calculation of the mentioned parameters of the vertical structure of the active layer of the ocean. The input parameters of such models are the air temperature, the radiant energy flux, the wind speed, humidity, pressure, cloudiness which can be measured by remote methods from the artificial earth satellite. The calculations by these models permit the ocean surface temperature to be used which is measured with an accuracy of 0.1°C, the depth of the mixed layer and position of discontinuity layer with accuracy to 1-2 meters. Such accuracy still has not been achieved during measurements by remote methods.

When the required accuracy of measuring the surface temperature of the ocean and other informative hydrophysical parameters is achieved, their use in the theoretical models will permit conversion to the calculations of the heat fluxes at the boundary of the discontinuity layer and determination of the inflow of heat to the main oceanic thermocline in this way.

On the basis of what has been stated above, the following accuracies of measuring the ocean surface temperature, the resolution on the terrain and periodicity of updating the information permitting sufficiently correct subsequent interpretation of the data received appear to be reasonable.

The water temperature, along with the temperature of the ocean surface, is the most important informative parameter permitting determination of the rate of inflow of heat to the ocean as a result of contact heat exchange with the atmosphere. The calculated value in the theoretical models is not the absolute temperature, but its anomaly with respect to some value. Therefore with an "air-water" temperature difference on the order of 10°C, 10% accuracy of calculating the contact heat exchange component can be achieved with accuracy of determining the air temperature of ~1°C.

With a temperature difference on the order of 2-3°C the required accuracy will be 0.2°C. However, for such values of the "air-water" temperature difference the contribution of the contact heat exchange to the overall heat balance (budget) on the ocean surface will become less than 10%. Consequently, the accuracy of measuring the air temperature of ~1°C is entirely acceptable from the point of view of the assimilation of this parameter in the models of the active layer of the ocean.

For calculations of the local structure of the active layer of the ocean the informative hydrophysical parameter is the modulus of the wave velocity which enters into the formulas describing the heat balance (budget) and the ocean surface, the rate of inflow (generation) of mechanical energy of mixing in the uniform layer and dissipation of mechanical energy in this layer. With 10% accuracy of calculating these parameters, a value of ~1 m/sec is an entirely acceptable accuracy of measuring the modulus of the wind velocity in the velocity range from 1 to 15 m/sec (let us note that the average minimum wind velocity over the ocean is 4-5 m/sec). For wind velocities exceeding 1 m/sec, the required accuracy can be reduced to 3-4 m/sec inasmuch as indeterminacy in the selection of the empirical coefficients becomes significant.

The recently developed methods of scatterometry based on determining the backscattering diagram of the radio microwaves will permit determination of this parameter from satellite orbits with acceptable accuracy.

In the formulas for calculating the components of the heat balance (budget) on the ocean surface the pressure in the layer next to the ground (next to the water) does not play a significant role. For example, in the ranges of pressure variation of 820 to 1080 millibars, the error in determining the pressure of ±1 millibar introduces approximately a 1% error in determining the corresponding heat budget. At the same time the 10% accuracy of determining the relative humidity is entirely acceptable for calculating the heat budget components over the ocean surface.

Using the wind velocity it is possible to estimate the atmospheric pressure in the layer next to the water.

The calculated value is also the cloudiness of the upper and lower levels expressed in the number of octants of the sky covered with clouds. At the present time cloudiness is estimated visually. The accuracy of determining a value of 1/sec is ± 0.1 for a range of variation of the value of {1 to 10}. The information obtained by the remote sounding equipment in the visible, infrared and microwave bands permits data to be obtained both on the cloudiness and the humidity of the air.

The humidity of the air in the layer next to the surface of the ocean enters into the formulas for calculating the expenditures of heat on evaporation and the magnitude of the outgoing long-wave radiation. Considering that in the temperature range of 0-30°C the saturated vapor pressure varies within the limits of 2-50 millibars and adhering to 50% accuracy of calculating the relative humidity, we find that for the average value of the relative humidity of 50% the required accuracy of determining it will be ± 1 millibar. In the heat balance (budget) calculations at the ocean surface two types of radiant energy fluxes participate: the incident short-wave radiation flux (the direct plus the diffusive components) and the reflected long-wave radiation flux.

Not dwelling on the accuracy connected with the specific choice of empirical coefficients entering into the presented formulas, let us discuss the accuracy of the parameters required to calculate these radiation fluxes. When determining the incident short-wave radiation absorbed by the upper layer, broad use is made of the procedure permitting tabulation of the values of the radiant energy fluxes. In this procedure the basic parameter is the radiant energy flux in the upper boundary of the earth's atmosphere Q_0. The values of Q_0 tabulated for each of the seasons, the longitudes and latitudes of the location of the observations are available in the corresponding climatic atlases.

The direct measurement of the radiant energy flux Q_0 from artificial earth satellites will permit us to proceed with the use of it as one of the informative parameters of the developed and available theoretical models. Considering the range of variation of Q_0

$$\{100 \text{ to } 1000\} \text{ cal/(cm}^2\text{-day)}$$

and considering the 10% accuracy of the flux measurements, it is possible to assume that the error in determining Q_0 equal to ± 50 cal/(cm^2-day) in the lower latitudes is entirely acceptable.

3. The Effect of the "Skin Layer" on the Development of the Methods of Remote Sounding of the Ocean

The central element in the system of interaction of the atmosphere and the ocean is the surface uniform layer of the ocean. The temperature field in this layer is formed under the effect of various dynamic and thermal factors, the wind over the ocean, the short-wave and long-wave radiation, precipitation, evaporation, wave action and so on. In addition, as the studies of the synoptic variability of the ocean has demonstrated, the temperature field of the uniform layer is to a significant degree subject to effect of the abyssal synoptic eddies forming mesoscale structures with horizontal scales from tens to hundreds of kilometers.

At the present time the problem of determining the surface temperature of the ocean can be most efficiently solved using the infrared radiometric measurements performed by artificial earth satellite. However, the temperature measured in this way generally speaking cannot be identified with the temperature of the uniform layer. This is explained by the fact that at the ocean surface almost always there is a so-called cold "skin layer" several millimeters thick inside which the thermodynamic properties of the medium change sharply.

The laboratory and the natural experiments with respect to investigating the thermal structure of this layer have demonstrated that the temperature gradient of 0.4 to 2.0°C can be concentrated within the limits of 1 mm, and the cold film is maintained for a wind to 10 m/sec, that is, even under the conditions of developed wave action. During breaking of the waves, a small-scale turbulence is generated, and the cold "skin-layer" disappears. In addition, the turbulent eddies can penetrate into it from the uniform layer and equalized temperature profile, which also leads to destruction of the "skin layer."

In spite of the many causes of destruction of the "skin layer," restoration of it takes place quite quickly. According to the data of the authors of reference [7], the restoration time is approximately equal to 12 seconds.

Thus, it can be proposed that the existence of a cold film is a phenomenon that is everywhere, and on the average it is stable in time.

The infrared radiometers measure the radiation temperature of the thinnest water film, and the temperature of the underlying uniform layer is of practical interest for the researcher; therefore the problem of uniformity of identity of the temperatures of the quasiuniform layer and the surface film or the methods of correcting the measured brightness temperature has great significance. Up to now we have not established the true temperature distribution in the "skin layer," and the laws of horizontal distribution of its characteristics, the inaccuracy in determining the uniform layer will significantly reduce the informativeness of the data obtained. This reduction in informativeness consists in the following. First, inasmuch as the characteristic time for performance of the infrared surveys from the satellite turns out to be comparable to the characteristic time of the systems of the skin layer, the indeterminacy in determining the temperature of the uniform layer can reach the magnitude of the temperature gradient in the skin layer. Secondly, the temperature of the skin layer significantly influences the energy characteristics of the processes of interaction of the ocean and the atmosphere. Here, as a result of the small thickness its correct role in the energy budget of the upper layer of the ocean turns out to be insignificant. For example, the "skin layer" is to a known degree optically transparent for incident solar radiation. Other components of the heat budget such as the expenditures of heat on evaporation, the contact heat exchange, the outgoing long-wave radiation, can be changed by 10-15% by the skin layer. Therefore it is necessary to investigate the simultaneous effect of the processes occurring in the atmosphere and in the uniform layer on the dynamics of the surface cold film.

The purpose of these studies is to establish the mechanisms of local formation and destruction of the "skin layer," determination of the characteristic horizontal scales and "life" times of this layer and also the limits of the meteorological parameters, within which it exists; the estimate of the nature and degree of wave action of the individual meteorological parameters and the characteristics of the uniform layer on the structure of the "skin layer."

The solution of the enumerated problems will permit relation of the surface temperature of the ocean to the temperature of the uniform layer and makes it possible to proceed with the construction of the hydrodynamic model of the upper uniform layer of the ocean with inclusion of the cold "skin layer" in it with the help of this model. As a result of the satellite infrared pictures it will be possible comprehensively to study the processes taking place in the uniform layer which, in turn, permits an idea about the processes occurring in the deep layers of the ocean to be obtained.

4. Transfer Function of the Atmosphere and Consideration of Its Effect

The study of the characteristics of the ocean surface by passive methods in the visible infrared and microwave ranges is connected with measuring the reflected solar radiation and the natural radiation of the ocean. Inasmuch as the solar radiation and the natural radiation are transformed on passage through the atmosphere, in the solutions of the problems of remote sounding of the ocean it is necessary to consider the transfer function of the atmosphere.

The transfer function of the atmosphere is defined as the ratio of the intensity of the radiation I_ν with frequency ν at the upper boundary of the atmosphere to the intensity of the radiation of the same frequency I_ν on the level of the underlying surface [7].

This function which was introduced [6] for determining the temperature of the underlying surface by the radiation measurements from satellites is determined by the vertical temperature and moisture profiles which primarily determine the intensity of the radiation in the given frequency band and also the nature of the aerosol attenuation of the radiation in the atmosphere.

In order to determine the temperature of the underlying surface the measurements are performed in the infrared range in the window of transparency of 10-12 microns and in the centimeter bank on wave lengths of 3 and 8 cm.

In the infrared range when measuring the radiation of the ocean $S_{\Delta\nu} \approx 1$ the radiating capacity of the surface in the frequency range of $\Delta\nu$ and the transformation $P(\Delta\nu)$ depends strongly on the temperature, moisture and aerosol attenuation profiles.

In the radio range of $P_{\Delta\nu}$ in practice does not depend on the temperature and the moisture profiles of the atmosphere at the same time as the value of $S_{\Delta\nu}$ has a strong dependence on the degree of wave action of the sea surface. One of the basic advantages of the microwave band consists in the fact that the interference created by the atmosphere during remote sounding of the ocean is comparatively small even in the presence of clouds. This fact attracts a great deal of attention to the development and use of all weather methods of microwave remote sounding.

The physical principles of the propagation of radiothermal radiation in the atmosphere have been studied well. A detailed discussion of them and corresponding references can be found, for example, in [1, 10, 12, 16, 22, 23].

The basic absorbing components of the cloudless atmosphere are water vapor and oxygen. The oxygen has a system of absorption lines near the wave length of 0.5 cm and an isolated 0.25 cm line; the water vapor has absorption lines at 1.348 and 0.164 cm. The variations in the radio brightness temperature of the atmosphere-ocean system connected with these factors can be caused by variations in the humidity, temperature and atmospheric pressure. In the wave length range of more than 3-4 cm they are negligibly small. For passive microwave sounding of the ocean wave lengths shorter than 0.6-0.8 cm are unsuitable. The variations in radio brightness temperature caused by the cloudiness are the most significant on wave lengths of less than 1 cm, but on longer waves they turn out to be noticeable and must be considered when trying to obtain reliable information about the ocean surface on wave lengths of 8-10 cm.

Considering what has been stated above, the wave lengths of the microwave radiometric equipment are selected so that the equipment will permit (jointly with the infrared equipment) determination of the temperature and humidity profile and also the parameters of the underlying surface.

The radiothermal emission of the ocean as a function of the basic parameters of the surface -- the state and temperature -- appears in practice in the entire microwave range. In the short-wave range the effect of such effects as foam is comparable with respect to magnitude to the effect of clouds. It is also necessary to consider the fact that the temperature of the marine surface turns out to be the weakest of the enumerated factors; nevertheless, high accuracy in determining it is required. From this it is clear that the problem of interpreting the results of passive microwave sounding must be solved complexly with the simultaneous consideration of all defining parameters, including the parameters of the atmosphere. However, with complete statement of the problem of remote sounding of the atmosphere-ocean system, the number of atmospheric parameters is too large. If the problem consists in obtaining information only about the surface of the ocean, then it is only sufficient to consider the effect of variability of the parameters without finding exact values of the parameters themselves.

The variability of the three basic parameters in the cloud layer -- altitude, thickness and water content -- leads to variations in the radio brightness temperature which are indistinguishable with respect to spectrum; therefore for consideration of the cloudiness in the case of remote sounding of the ocean one common parameter is sufficient.

Analogously, for consideration of the variations in moisture of the atmosphere also one parameter is sufficient -- the integral amount of precipitated water (only if a special set of close wave lengths in the vicinity of resonance of 1.35 cm is not used). If it is proposed that the basic information about the ocean be obtained by the channels with sufficiently large wave lengths (more than 2 or 3 cm), then for formal consideration of the variations in the radio brightness temperature on these wave lengths caused by any changes in the state of the atmosphere, it is sufficient to use one generalized parameter and auxiliary measurements on one wave length near 0.8-1.0 cm. From the results of the experiments it also follows that these variations can be taken into account by the active corrections which depend linearly on the indicated formal parameter. In the case of more detailed accounting for the effect of the atmosphere analogous corrections can be used for separate expression of the radio brightness temperature as a function of clouds and water vapor.

This approach is the linear approximation of functionals expressing the measured values as a function of the distributed parameters of the environment in terms of certain formal coefficients obtained by numerical calculations. Thus, for example, the radio brightness temperature as a function of the parameters of the ocean varies somewhat in the short-wave part with variation of the atmospheric parameters, but these variations are small and can be corrected after preliminary estimation of the state of the atmosphere.

For further increase in reliability of the complex use of the microwave band it is necessary to perform studies of the emitting characteristics of the actual sea surface as a function of the radiation wave length, the observation angle, polarization, and so on. An important problem which is still far from solution is the development of a procedure for interpreting microwave measurements in order to determine parameters of the ocean surface in zones considering the possible rain precipitation.

Thus, consideration of the effect of the atmosphere during remote sounding of the ocean acquires special significance inasmuch as it is a weakly reflecting surface and even under conditions of transparency of the atmosphere the outgoing reflected radiation is basically determined by the atmosphere.

5. Studies in the Visible Range of the Spectrum

One of the most informative remote sources of information about the World Ocean is the measurements in the visible band of the spectrum. This is explained by the fact that in this band the transparency of the clear atmosphere reaches the maximum values, and the absorption of light by the ocean water is minimal. The maximum solar radiation is found in the same band.

The deficiencies of the measurements in the visible range can be considered to include the significant dependence of the results of the measurements on the time of day and atmospheric conditions. In the presence of continuous clouds observation is impossible.

The most informative characteristic in the visible range is the spectral composition of the ascending light flux. In the open parts of the sea it carries information about the hydrooptical characteristics of the ocean water. This makes it possible to isolate various masses of water, determine their boundaries, detect eddies, upwellings and other dynamic formations and also the biological productivity. In the coastal regions, the water from the continental runoff, its distribution and interaction with the open seawater are well distinguished by the color of the water. Inasmuch as the analysis of the spectral structure of the ascending flow permits discovery of the most important characteristics in the surface layer of the ocean, let us consider the process and formation of the spectrum of the radiation ascending over the ocean in more detail.

The sun rays passing through the atmosphere are attenuated as a result of absorption and scattering by gas and vapor molecules and aerosol particles constantly present in it.

The light that reaches the ocean surface consists of a directional component -- the direct solar radiation -- and a diffuse component -- the solar radiation scattered by the atmosphere. The light incident on the surface of the water is partially reflected from the air-water interface, but the greater part of it penetrates into the body of the water. The magnitude of the reflected light flux depends on the conditions of illumination, the direction of observation and the state of the sea surface. The direct sun rays mirror-reflected from the water surface form spots, the brightness of which is extremely high. Outside the vicinity of the spot, the surface brightness is determined by reflection of the light of the sky, that is, the light scattered by the atmosphere and the cloud and also the light scattered in the seawater. The reflection of the light in practice is nonselective with respect to spectrum and depends only on the brightness distribution over the sky, primarily the height and direction of observation. For observations close to the nadir, it is approximately 2% of the brightness of the sky in the zenith.

On scattering of the light on large particles of suspended matter, the scattering index can be assumed not to depend on the wave length. If we also neglect the absorption of the light by particles which is in practice satisfied if the particles are of mineral origin, then with an increase in concentration of the terrigenic suspended matter we obtain an increase in the overall level of intensity of the light ascending from the water with practically invariant nature of the spectral distribution.

The presence in the water of absorbing admixtures gives quite another picture. The absorption spectrum of "yellow matter" increases exponentially with a decrease in the wave length. As a result, under the effect of "yellow matter" the energy of the spectrum of the light coming out of the water decreases significantly in the short-wave part, whereas in the long-wave part (for wave lengths of more than 530 nm) there are in practice no changes. The analogous picture is also observed in the presence of absorbed particles in the water to which the cells of phytoplankton containing chlorophyll pigments, and so on, the absorption of which increases in the range of 420-460 and 660-680 nm, primarily belong.

In the open parts of the ocean the hydrooptical characteristics depend primarily on the biological productivity: the higher the biogene content, the greater the attenuation of the light in the short-wave part of the spectrum, that is, the color of the sea is greener.

During satellite observations, distortions are introduced into the spectrum by atmospheric haze. Its effect is especially great on the short-wave part of the spectrum, which requires the introduction of corrections.

The studies in recent years have demonstrated that the investigation of the cloud cover and its spatial structure is useful when solving such oceanological problems as the determination of the efficient regime of the ocean, recognition of the position of the oceanological fronts, the isolation of storm zones, and so on. For such studies it is necessary to consider the various characteristics of the clouds: the type of clouds, their shape, the layering and texture. These characteristics can be determined by the images of the clouds in different parts of the spectrum.

For example, above relatively warm bodies of water with increased evaporation of the moisture, low continuous stratocumulus clouds are formed, and above colder water, the clouds are rarefied or are absent in general. Above a line of such water masses the clouds have a sharp boundary which can serve as an indicator of the oceanological front. The cellular structure of the clouds is characteristic for the regions with ordered convection above the warm ocean surface. The spiral clouds usually are formed in the zones of generation of storms, the evolution of which can be traced by the changes in time of the spatial structure of the cloud and its texture.

The methods of studying the oceanological phenomenon by the cloud characteristic have a number of limitations. Formation of the clouds takes place with defined inertia, and the local winds existing in the observation zone move the cloud formation in uncontrollable directions. The active cyclonic activity also masks the differences in the water masses. However, for stable states in the meteorological fields in the regions of occurrence of oceanological processes, conditions are created for formation of the cloud structures caused by these processes, which in practical oceanological research permits the use of the cloud indicator methods.

The mapping and the study of sea ice is possible in the entire visible range of the spectrum. The weak dependence of the radiation reflected by sea ice on the wave length permits the use of technical means of low spectral resolution to study them, although consideration of the spectral differences of these natural formations permits analysis of their structure.

In the case of satellite optical observations the radiation picked up by the instruments is to a significant degree distorted by the difficult-to-monitor effect of the atmosphere. Therefore it is important, especially in the initial stages of development of satellite oceanography, to take synchronous contact and remote "subsatellite" measurements of the various characteristics of the ocean water.

6. Use of Radar Systems for Oceanological Research

The basis for the development of the methods of active space radiooceanography are the achievements of radio physics in the field of studying the laws of dispersion of the radio waves of different ranges by the wavy sea surface.

At the present time the physical nature of the scattering of the radio waves by the wavy sea surface has been established, its basic laws have been studied, which has made it possible to develop the procedures for determining the basic parameters of sea waves and wind in the layer of the atmosphere next to the ocean using radar in various wave bands both with small ($\psi<10°$) and large ($\psi\gtrsim85$ to $90°$) slip angles [2, 3, 9, 14, 18].

The specific nature of the operation of the equipment in outer space, the peculiarities of the propagation of radio waves in the earth's atmosphere impose significant restrictions on the possibilities of the application of certain methods of radar determination of the parameters of sea wave action. Thus, radar systems in the meter and decameter radio wave bands that have recommended themselves well in "ground-based" radio oceanography have turned out to be unacceptable [14].

Therefore in space radio oceanography basically radar systems in the centimeter band are used (1-10 gigahertz); the radar altimeters, scatterometers (scattered signal power meters) and radar side-scanning systems are basically used.

The radar altimeters permit the following accurate measurements of the distance between the spacecraft and the level of the quiet surface of the ocean and also estimation of the degree of roughness of the scattering surface (the heights of the sea waves).

The optimal construction of the radio altimeter and optimal processing of the radar signals permit the potential accuracy of measuring the flight altitude to be reduced to $\delta_H \approx 10$ to 15 cm.

The solution of a large class of problems of studying topography and dynamics of the ocean surface is becoming possible. However, it does not appear possible fully to realize the high potential of the methods of altimetry as a result of complexity of considering the nutations of the spacecraft orbit and the errors connected with this in determining the absolute altitudes, determination of the reference level in the reflected signal in the case of a wavy ocean surface.

Therefore, at the present time it is possible only in the coastal regions to find a quantitative solution to the problem of determining the dynamics of the ocean surface by "coordinating" the measurement results with the peculiarities of the coastal outline or by using the exact determination of the elements of the spacecraft orbit; in the open seas it is possible to give only a qualitative estimate of this phenomenon.

The satellite dispersion meters (scatterometers) measure the scattering diagrams in the range of angles of incidence determined by the electric potential of the system, which makes it possible to obtain estimates of the wind field characteristics in the layer of the atmosphere next to the water.

The physical basis for the effect of the scatterometric systems is the dependence of the parameters of the scattered signal on the characteristics of the scattering surface.

As is known, the scattering of radio waves at small angles of incidence (0-5°) is subject to the laws of physical optics, and the defining role in the formation of the scattered light is played by the dispersion and the correlation function of the slope angles of the sea surface sensitive to the wind speed W.

The scattering at angles of incidence of more than 5-10° is selective, the intensity of the scattered signal is determined by the spectral density of the corresponding wave lengths where the ripple waves are the dispersing media in the microwave range.

The satellite scatterometers, as a rule, must have high resolution with respect to angular coordinates ($\lesssim 1°$) inasmuch as in the case of worsening of the resolution the sensitivity of the system to the change in nature of the scattering diagram decreases sharply as a result of its integration by the resolution element.

As the results of laboratory and natural experiments show [8, 11, 18], the scatterometric systems theoretically permit sufficiently accurate determination of the characteristics of the wind field above the surface.

The results obtained indicate that in determining the wind velocity above the ocean surface there are certain complexities caused by the presence of the dependence of the effective scattering area not only on the wind velocity, but also on the azimuthal angle between the wind direction and the direction of the orbital plane of the spacecraft and also the imperfection of the procedure.

The improvement of the procedure for taking the measurements, calibration, processing the signal permits full realization of the potential of the scatterometer as an all-weather meter of the characteristics of the wind and wave fields.

The side scanning radar systems (RLS BO) permit recording of the radar images of the surface of the land and the ocean in the scanning band of the radar, insuring resolution on the terrain on the order of 1-2 km for orbital altitudes of 600-800 km. This permits, considering the peculiarities of interpreting the results of the remote measurements, study of the spatial distribution of the wind fields, the characteristics of the ice fields, and so on.

In order to increase the resolution with respect to azimuth, the methods of synthesizing the radiation patterns of the radar are used in the RLS BO. The high resolution along the radar beam is insured as a result of compression of the radio pulse. Here, with respect to the potential characteristics, the resolutions of the RLS BO approach the optical observations media. Further improvement of the resolution of the RLS BO is prevented by fluctuations of the dialectric characteristics of the atmosphere leading to "disorganization" of both the radiation pattern and the radar pulse.

The synthesis method with nonuniform and curvilinear displacement of the radar carrier in space are insufficiently developed at the present time.

However, for the presently existing level of their development the RLS BO permit us to obtain images of the land and water surface at significant distances independently of the meteorological conditions at any time of day with high detail of reproduction of the various sections of the surface. The images obtained can be used to determine the state of the surface of the seas and oceans, to study the dynamics and determine the characteristics of the ice fields, and so on.

In spite of a number of existing technical and procedural complexities in creating satellite RLS BO, they undoubtedly will become one of the basic remote sounding systems, especially when solving the problems of ice reconnaissance.

The space radio oceanographic systems, being a new instrument in the hands of the researcher are theoretically different from the traditional means of oceanographic measurement by spatial averaging of the investigated characteristics, which imposes the corresponding requirements on the organization of the accompanying measurements.

First of all it is necessary to create a network of specialized monitoring and calibration marine test areas with dimensions which are comparable to the resolution element of the space radio oceanographic system.

Along with the traditional methods for the measurements in the test areas, radio physical methods of remote determination of the parameters of the waves must be widely used with the help of shore (ship) and aviation radar systems which realize various methods of obtaining oceanographic information.

Their application for interpretation of the results of the oceanographic satellite measurements is theoretically necessary inasmuch as the operation of these systems is based on using certain laws of the dispersion of the radio waves by the sea surface when determining the investigated characteristics of the spatial wind and wave field comparable with the resolution element of the radio oceanographic system.

In conclusion it is possible to state that the methods of space oceanography, as a result of improvement of the theory and means of remote sounding of the surface will in the near future become an effective tool in realizing large-scale oceanographic projects. This will permit statement of the problem of studying the World Ocean on a new significantly higher level.

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AERIAL METHODS OF STUDYING THE OCEAN AND ITS FLOOR

[Article by V. V. Sharkov]

Vitaliy Vasil'yevich Sharkov, doctor of geological-mineralogical sciences, is working on the development of aerospace methods of studying the floor of shallow seas. The basic works are devoted to the geological-geomorphological structure of certain sections of the Caspian, Black, Japanese and Okhotsk Seas.

When studying the surface of the earth, the oceans and their depths, broad use is made of survey data obtained using various equipment (receivers which are installed on aircraft, helicopters and other air or space carriers. These methods have come to be called remote aerial methods.

The aerial methods, in contrast to other methods of oceanology, observations by means of which are performed in individual regions at different times, permit us to obtain information about the objects and phenomena over broad expanses of the ocean in practice simultaneously or in a comparatively short time interval.

Such phenomena and objects using other methods must be studied only by parts and over a prolonged period of time. First deciphering the materials from the aerial surveys, it is possible to plan the application of other methods of oceanology.

The possibilities of various aerial methods for studies and special mapping of the oceans are still a long way from being completely discovered. It is unquestionably the case that the improvement of the existing aerial methods and also the development of new ones (laser, luminescent, ultraviolet, geochemical surveys and so on) will significantly increase the effectiveness of studying the ocean and will permit solution of many scientific and practical problems of oceanology.

1. Classification of Aerial Methods[1]

The modern, highly sensitive receivers installed on the aircraft and spacecraft are able to record the radiation of the ground and water surface in narrow zones of almost the entire spectrum of electromagnetic waves.

The information obtained can be represented in the form of two-dimensional images (photographs) or one-dimensional profiles, graphs [4].

Depending on the range of electromagnetic waves and the recording equipment used, various types of aerial surveys are isolated, the comparative characteristics of which are presented in Table 1.[2]

In addition, the surveys are broken down into passive, which record the natural radiation of the objects or the reflected solar radiation and active in which the earth's surface is irradiated with subsequent reception of the reflected radiation. The majority of the active methods can be performed at any time of day, and the radar survey in practice in any weather.

The passive surveys, with the exception of infrared, can be performed only in the daytime.

Most frequently when studying natural objects, photographic, television, multizonal, and spectrometric surveys are used (scanner, infrared and also aerial radar and aerial magnetometric, and aerospace surveys). A laser survey is already being used to measure distances and depths of the sea within the limits of the shallow water.

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[1]The majority of these methods are used also for surveys from space carriers.

[2]The data from references[1] and [9] are used in Table 1.

The materials from the aerial surveys and, consequently, the information picked up from them are tied to the geographic coordinates by using radiogeodetic means. There are goniometric, range-finding and mixed systems. The greatest accuracy of the determination (to ± 20 meters) is achieved by the range-finding system.

In cases where the radiogeodetic equipment cannot be used, the objects are gridded with the help of navigational methods in which the heading of the aircraft and the time spent on reaching the defined point are taken into account. During work near the shore line, the aerial survey routes are calculated directly by the shore reference points.

2. Materials of Photographic, Television and Scanner Aerial Photographs

During the process of the above-noted surveys, the reflected solar radiation was primarily recorded in the visible range of the spectrum (0.4-0.74 microns) in the form of two-dimensional images -- aerial photographs. The principles of aerial photographic surveying are widely known.

Aerial television surveying (with nonscanning equipment) differs from the aerial photographic surveying by the fact that the image is constructed on an electrically conducting target -- a vidicon -- and not on photographic film. The images are transmitted from the vidicon to the receivers (ground) in the phototelegraphic transmission mode or they are recorded on board the aircraft on magnetic tape.

The aerial photographic, and television images are constructed by the principle of central projection.

The scanner image is obtained as a result of scanning of the terrain perpendicular to the flight direction by a rocking mirror or rotating drum, on the side walls of which mirrors have been attached which detect a narrow band of the terrain in the form of a line. As the aircraft moves and with synchronous displacement of the photographic film on which the line is recorded, individual lines are added, as a result of which a two-dimensional image of the terrain is formed in an equiangular projection [4].

The materials of these surveys are widely used to study both the surface of the ocean and the surface body of water and to study the structure of the bottom of the shallow seas.

In order to obtain aerial photographic images of the water surface, panchromatic, isopanchromatic or infrachromatic films are used. In order to obtain images of the sea floor, considering the strong absorption of long-wave parts of the spectrum, by the water and scattering of the short-wave part of the spectrum, films are used which are sensitized (sensitive) to the yellow-green (for turbid coastal waters) and the blue-green (for transparent water in the open sea) bands of the electromagnetic spectrum.

Table 1. Comparative Characteristic of the Types of Remote Surveys

Parameters	Types of survey: Gamma survey	Ultraviolet: Far	Ultraviolet: Middle	Luminescent	Spectrometric	Television	Photographic	Laser
Wave length	0.03Å	100-300Å	3000-4000Å	0.3-1.2 microns	0.4-0.76 microns			0.3-11.0 microns
Frequency, megahertz	10^{14}	$3x10^{10}$	$8x10^{8}$		$5x10^{8}$			
Nature of the survey method	Passive	Passive and active		Passive and active	Passive			Active
Absorption by the atmosphere	Very strong	Almost complete	Strong		Weak			
Equipment carriers	Air from an altitude of less than 200 meters	Air			Air and space			
Survey time	In any weather	Day and night		Day and night		Day		Any weather
Depth in solid rock	to 50 cm					Microns		
Depth in water	Somewhat more than 1 meter	Water surface				to 100 meters		
Form of information obtained	Graph	Signal, graph, television image		Picture, signal, graph	Graph, spectrometric characteristic	Television image	Picture	Graph, in picture perspective
Purpose	Search for radioactive ores, classification of rock	Study of objects with specific ultraviolet radiation		Search for luminescent objects	Study of geological-geomorphological and geographic objects			

[Table 1, continued]

Parameters	Types of Survey: Infrared			Radar		Electro-reconnaissance	Magnetometric	Geochemical	Gravitational
	Near	Middle	Far	Radiothermal	Radio location				
Wave length	0.74-1.35 microns	1.35-5.5 microns	5.5-1000 microns	0.3	-1000 cm	Hundreds and thousands of km		-	
Frequency, megahertz	10^8	10^7	10^6	$2x10^4$	$3x10^3$	$10-10^8$	-	-	-
Nature of survey method		Passive			Active	Passive and active		Passive	
Absorption by the atmosphere	Individual atmospheric "windows"; basic: 0.74-1.35; 3.5-5.5, 7.5-14.0, 20.0-1000.0 microns			Weak	Very weak	None	None	-	None
Equipment carriers	Air and space			Air		Air	Air and space	Air	Air and space
Survey time	Night and day				In any weather				Day and night
Depth in solid rock				Centimeters		to 300 m	Km	Surface	Kilometers
Depth in water	Water surface					to 10-15 meters	Same	Water surface	
Form of obtaining the information	Infrared surveys to 1 micron, image more than 1 micron	Thermal photographs	Photographs, graphs, televison image			Signal, graph			Graph
Purpose	Study of geological-geomorphological and geographic objects					Detection of electrically conducting bodies	Detection of magnetic complex of rock, geological mappings	Search for certain elements	Determination of gravitational field of large geological objects

Accordingly, for surveying the sea floor of coastal shoals, it is recommended that isochromatic and isoorthochromatic film be used.

The use of multizonal (photographic, television) and multichannel (spectrometric or scanner) surveys is practiced. Multichannel is carried out by several synchronously operating or multiobjective cameras using films of various types or on one film with different light filters. The images are obtained in relatively wide bands of the spectrum. The multichannel survey permits us to obtain images both in wide and narrow bands of the spectrum.

Thus, the surveys of the water and sea floor can be realized in the optimal spectral bands. In the presence of a set of multizonal and multichannel photographs, during the course of deciphering them it is possible more certainly to isolate the images of the sea floor or the objects in the water from objects on the surface of the sea inasmuch as the former are recorded better in the blue-green and green band of the spectrum and the latter, in the red band of the spectrum. The photographs taken in the various bands of the electromagnetic spectrum in the presence of the corresponding equipment can be matched with high accuracy on one screen.

By using different light filters it is possible to obtain color images that reflect the natural color of the objects or provisional color from black and white images.

These images are distinguished by great informativeness, which significantly simplifies, accelerates deciphering, and it increases its reliability.

The scale of the photographs I/m which depends on the ratio of the focal length of the camera f and the height of the picture H has significant value for deciphering the aerial photographic images: $I/m=f/H$.

The materials of the aerial surveys are separated provisionally by scales into large scale (larger than 1:15000), medium scale (1:15000 to 1:70000), small scale (1:70000 to 1:1,250,000) and supersmall scale (smaller than 1:250,000). The scale of the photographs is selected as a function of the stated problem.

Recently a trend has been noted for the performance of aerial surveys on smaller scales, in particular, from outer space. This is explained by several reasons.

First, the photographs taken from great altitudes, and especially outer space, are better with respect to quality inasmuch as the scattered light of the atmosphere does not fall in the focal plane of the camera. It can be considered in the given case as a natural light filter. During the process of surveying the ocean floor from great heights over a significant area the light beams pass through the body of the atmosphere and the water at more vertical angles than when taking the survey from low altitudes. This predetermines less absorption and scattering of the light by the water.

Secondly, these aerial photographs with high resolution can be magnified a multiple number of times to the required scale without significant loss of quality.

Thirdly, during small scale surveying it is possible to encompass the greater area simultaneously, which reduces the time spent on processing the materials and deciphering them.

The special deciphering of the aerial photographic, aerial television and scanner pictures theoretically does not differ.

2.1. Deciphering Aerial Photographs of the Water Surface, Objects and Phenomena

A number of objects and phenomena, namely, the waves, currents, color and transparency of the water, Langmuir circulation can be recognized at the present time on aerial photographs of the water surface. The color and transparency of the water are determined, and so on.

Sea waves are well depicted on the aerial photographs. For deciphering of them it is possible to discover all of the wave systems and determine their characteristics [10].

The stereoscopic measurements with respect to overlapping aerial photographs obtained from two aircraft by synchronously operating cameras will permit maps to be compiled in the isohypses of the wavy surface of the bodies of water. All the wave parameters can be picked up from such maps.

On single photographs (obtained by one camera) it is easy to measure the wave length of the swell. The application of cylindrical lenses or rotating solutions facilitates the study of various wave systems. This is achieved by the diffraction method for which an aerial photograph with images of the waves is considered as an imperfect diffraction grating. The wave systems are determined by the position of the peaks on the diffraction picture obtained using a special camera.

On the small-scale aerial photographs with images of the wavy surface of the sea with three dimensional waves, it is possible to note ordered wave action not observed from ships or on large-scale photographs.

According to the materials of the aerial photograph theory, it is possible to study the refraction and diffraction of the waves in detail (see Fig 1) and use these data to discover the peculiarities of the bottom relief and sometimes (with respect to wave refraction) also for determination of the depth of the sea by the indirect method [12].

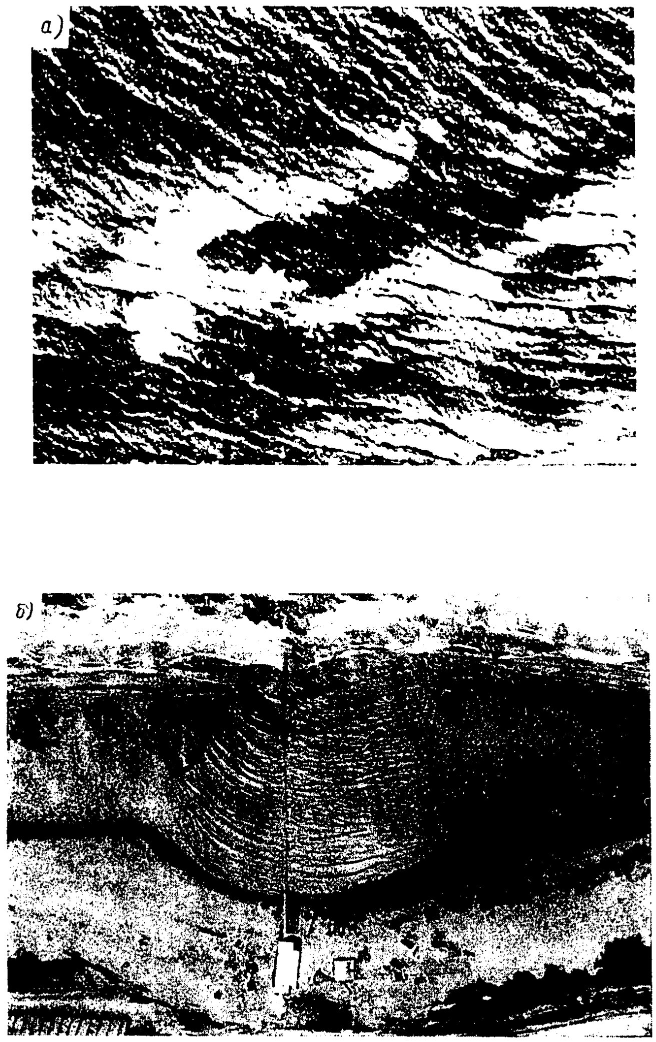

Figure 1. Refraction (a) and diffraction (b) of the sea waves

The sea currents often are easily recognized on ordinary aerial photographs by the image tone. This is possible if the water displaced by the currents, depending on their properties, differs from the surrounding water and also from the water transported by other currents. For example, east of the islands of Japan, cold (Oyashio) and warm (Kuroshio) trends are encountered. The former is enriched by nutrients, and, consequently, is saturated with plankton giving the water a yellow-brown color. The thermal course of the Kuroshio current is different from the transparency of the water of the color of dark aquamarine. Correspondingly, on the aerial photographs these currents are reflected in tones.

A more improved procedure for studying surface currents from an aircraft for the coastal parts of the water has been developed at the Laboratory of Aerial Methods (LAEM) of the Ministry of Geology of the USSR [8]. In accordance with one of the versions of the procedure, the water surface is marked using floats dropped from an aircraft impregnated with fluoresceine salts forming bright spots. Then after defined time intervals, the aerial photograph of the marked body of water was taken twice. After orientation of the aerial photographs, the direction and magnitude of displacement of the spots with respect to stationary reference points (objects on the shore, underwater structures or photographic images of the bottom contours) are measured. Thus, it is possible to study the structure of the currents in detail.

In accordance with another version of the procedure for marking the water surface from an aircraft, a bottom indicator is dropped, from which two floats with dyes are separated and allowed to surface successively using special devices after a strictly defined interval. After the second float surfaces, an aerial photograph is taken so that an image of the dye spots of both floats is obtained directly on the same photograph. Knowing the time interval between surfacing of the two floats and the spacing between them, it is possible also to calculate the speed of their displacement, that is, the drift rate under the effect of the currents. It is possible to record the position of the floats during the course of radio geological measurements.

The color of the water is recognized on black and white aerial photographs by tone, and on synthesized color photographs, by the defined colors. On the black and white aerial photographs turbid water has a yellow or gray-brown hue, it is found to be relatively light, and transparent water, dark. Using these signs, it appears possible to establish and map the areas of propagation of the river runoff water by the relatively light tone of the aerial photographic images; the turbid water formed after storms within the boundaries of the coastal shoals or over sandy banks; the water enriched with suspended matter during eruptions of underwater lava and mud volcanos; the sections where the bottom water rises to the surface (upwellings) usually having a brown color as a result of their enrichment with phytoplankton, and so on. The discharge of groundwater or juvenile water on the sea floor sometimes is manifested on the sea surface in the form of spots of transparent water corresponding to the darker sections on the aerial photographs. By the variation in tone or color of the image of the water in the limits of the coastal shoals (in the presence of uniform ground) it is possible to determine the depth of the sea by the photometric method inasmuch as the tone of the image on the black and white and the color on the color aerial photographs depend on the depth under these conditions.

The Langmuir spiral circulation (eddies), as is known, predetermine the clustering of floating objects on the water surface (surface-active materials, foam, plants, and so on) in the form of long, relatively narrow strips. These strips formed by the surface-active material (Fig 2a) and foam (Fig 2b) are depicted well against a background of wavy sea surface. The analysis of photographs combined with analysis of the hydrometeorological data at the time of taking the aerial photograph can be of significant help when investigating the still insufficiently studied phenomenon of Langmuir circulation. It permits establishment of the interrelation of the strip distribution of the wind directions and the basic wave systems and the depths of the sea, the discovery of the distance of the strips and their structure as a function of the above-noted factors and also internal waves.

Internal waves are formed in the water at the boundary of the layers with different density. On the crests of these waves turbid surface water is less thick than in the troughs; therefore the latter are obtained on photographs of lighter tones than the former [13].

In addition, it is possible to expect that at the interface of water layers with different density dying folds of plankton and other small particles are trapped, and with high transparency of the upper layer of water this helps to isolate the internal waves on the photographs [14].

The analysis of the images of the internal waves permits estimation of their parameters: period, phase velocity, direction of propagation.

The discontinuous currents break up the system of coastal wind-driven waves and the surf zone, which appears on the aerial photographs. In addition, the mass of water of the discontinuous currents usually is distinguished by color as a result of the large quantity of suspended material. This is easily seen on the photographs. The analysis permits detailed study of this phenomenon.

The plankton colors the water in yellow-brown or green tones. These sections are clearly isolated on the photographs (their tone differs from the tone of the remaining sea surface).

The high productivity of the plankton organisms frequently is, as has already been stated, connected with the upwellings or the presence of cold currents.

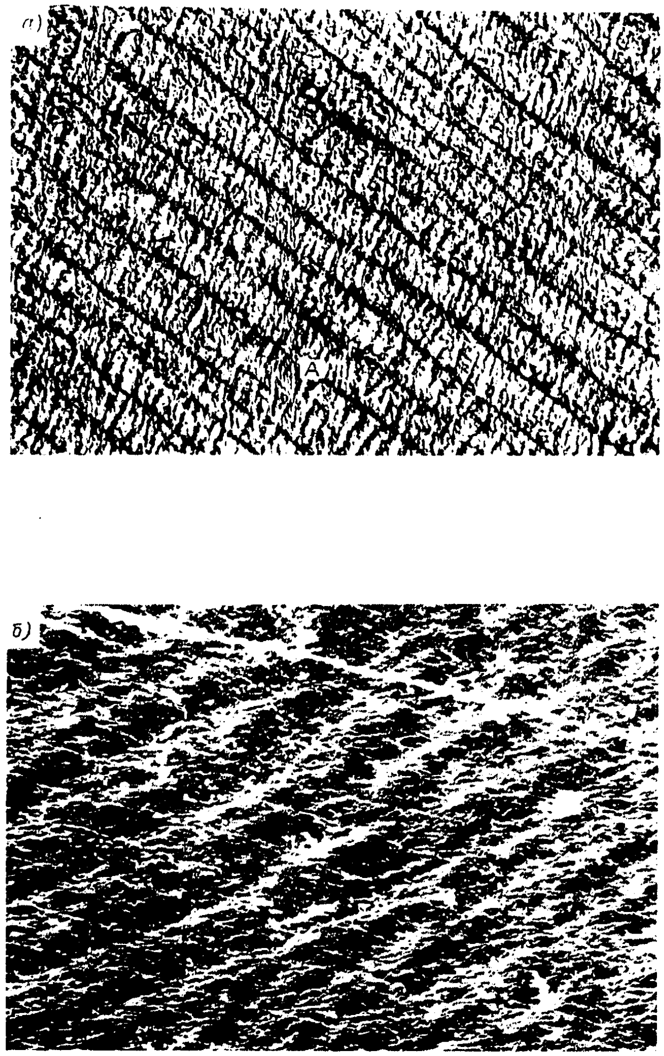

Figure 2. Aerial photograph of strips of surface-active material (a) and foam (b) occurring under the effect of the Langmuir eddies

Turbid water, as has already been noted, is found to be lighter in tone on the aerial photographs than clean sea water. The mapping of the propagation of the turbid water has great significance for discovering the conditions of modern sediment formation within the limits of the shelf.

Here the method of measuring the coefficients of spectral brightness of the turbid water permitting estimation of the quantity of suspended matter in its surface layer acquires special significance [10].

2.2. Indirect Indicator of Local Water Temperature Variation

The American astronauts [19] detected clouds of a special shape, the formation of which is connected with the presence of eddy type circulations of the cold water, for example, in the warm Yucatan Current. Over the cold eddies they observed clear air, at the same time as the edges of the eddies, that is, at the interface of the cold and warm water, there was a powerful crescent-shaped cloud cover. Thus, by the shape of the cloud cover it is possible directly to establish the local areas of propagation of the cold water (for example, upwellings) among the relatively warm surface waters of the ocean. The analysis of the peculiarities of the structure of the cloud cover in a relatively calm synoptic situation can be of assistance in studying the temperature anomalies of the surface water of the ocean, the sea currents,and so on. The materials from the aerial and space photographs give the greatest effect for studying the cloud cover over the ocean.

2.3. Deciphering Objects at the Bottom of the Sea

Modern technical means make it possible to obtain aerial photographs of the sea floor at depths from several meters to several tens of meters depending on the transparency of the water. As a result, the width of the strip of underwater coastal slope, within the boundaries of which it is possible to photograph the sea floor fluctuates from several hundreds of meters to tens of kilometers. In addition, the sea floor is depicted on the aerial photographs within the boundaries of the isolated banks both in the open sea and on the shelf.

Many underwater objects, the office and field deciphering of which promotes a detailed study and mapping of them can be recognized on such aerial photographs [2, 3].

At the present time the materials from the aerial surveys of the sea floor are already being used for geological-geomorphological investigation and mapping, engineering-geological exploration, mineral prospecting, the study and mapping of underwater vegetation, the compiling of land and sea maps of the coastal shoals, and so on.

Geologica-Geomorphological Study and Mapping. The rock and loose soil are often well depicted on aerial photographs of the sea bottom in the coastal shoals, the photographs of which frequently differ sharply depending on their material composition, texture and structural peculiarities [2, 3]. This is quite obvious in the presented aerial photograph of the sea floor (see Fig 3). The disjunctive (continuous) disturbances have been clearly obtained on the same photograph in the form of straight or bent lines outlining individual tectonic blocks.

The deciphering of such aerial photographs permits us to obtain broad geological information: to establish the propagation of various rock complexes on the sea floor, including those with which certain minerals are associated; measurement of the horizontal thicknesses (that is, the width of the outcrop at the bottom) of individual beds, benches, suites, and so on; determination of the elements of occurrence of the beds (azimuth and dip angle); discovery of the stratigraphic and angular unconformity; recognition of various accumulation and abrasion forms of relief, and so on, and also the geological structures and their elements (see Fig 4), the discovery of which has great significance when exploring marine oil and gas-bearing deposits.

As a result of this and also the clear-cut representation of the boundaries between objects, it is possible to put together geological, geomorphological, soil and other special maps of the sea floor which are not inferior to land maps with respect to reliability and detail.

Engineering-Geological Exploration. The aerial photographic survey materials can be used to study the engineering-geological peculiarities and compile engineering-geological maps of the underwater coastal slope and the coastal parts of the dry land which are needed to design hydroengineering structures. These materials have great significance for the discovery and the prediction of the dynamics of the coastal processes. In particular, with respect to nature of the image of the coastal and bottom accumulation and abrasion forms of relief it is possible to establish the direction of displacement of the drift flows along the shore and their relative thickness, sections of abrasion or accumulation of loose deposits, and so on. The consideration of the dynamics of these processes is important when predicting the possible erosion of the shore or, on the contrary, the accumulation characteristics of the hydroengineering-structures during their operation and maintenance.

Mineral Prospecting. On the aerial photographs of bodies of water a number of objects, phenomena or processes are depicted which can be used as criteria when prospecting for certain minerals. This permits localization of the sections of the bodies of water prospective for the statement of more detailed exploration and prospecting work. Thus, the sections of the water, the depths of which possibly contain oil and gas, can be detected on aerial photographs of the oil-containing rock (see Fig 3), anticlinal folds (see Fig 4, a), constantly renewing oil slicks.

Figure 3. Aerial photograph of the rock of different material composition making up suites of different age.
СО, НКП, ПК -- rock of predominantly sandy composition; НКГ, КС -- argillaceous composition. Part of these suites belongs to the oil-containing rock, which can indicate potential oil-bearing nature of the given body of water. The dotted line indicates dislocations with a break in continuity.

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floating on the sea surface (they are recognized in the aerial photographs by the specific aerial photographic configuration of the light tone under which the image of the sea floor can be seen (see Fig 5)), underwater mud volcanoes recognizable by the characteristic shape (Fig 4, b), gas eruptions (Fig 6), and so on.

The sections prospective for the occurrence of coal, iron ore of sedimentary origin, and so on can be isolated by the characteristic images of the underwater outcrops of the coal-bearing, iron ore and other suites and series. In Fig 7 (in the left side) we see a coal-bearing suite represented by rock of argillaceous-aleurite composition with beds of sandstone, coal and coaly shales. It is characterized by clearly expressed layering and severe crumpling of the rock depicted on the photograph. These signs permit establishment of the presence and the propagation of such suites on the sea floor. The coastal sea places of useful minerals are detected by the variation in the photographic density (image tone) reflecting the color of the beach sand enriched with minerals; with respect to images of the elements of the above-water and underwater accumulation forms of relief, it appears possible to localize sections within the boundaries of which separation of the heavy-fraction minerals takes place.

The structural materials within the boundaries of the sea floor and the coastal part of the dry land are primarily represented by loose sediments making up various accumulation forms of relief or filling the U-shaped valleys. These forms, just as the loose deposits, are depicted well in aerial photographs. Thus, the latter provide exhaustive information about their propagation on the floor and possible conditions of exploitation of them without losses to the dynamics of the coastal processes,[1] that is, without disturbance of the dynamic equilibrium of the coast line.

Underwater vegetation is easily recognized on the aerial photographs. Sometimes it is possible not only to recognize various algae, including useful ones (sea grass, sea cabbage, and so on), but also to determine the limits of their propagation and calculate the reserves (see Fig 8).

Compiling Sea Charts. For compiling sea charts in the presence of bottom contours on the photographs, stereomeasurements of the relative heights of the relief at the bottom are performed. In the absence of contours, the already-investigated (2.1) photometric method is used which permits

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[1]It is necessary to consider that the extraction of structural materials on the coast lines frequently leads to disturbance of the dynamics of the shores and destruction of them. The collection of loose materials can be realized in the upper parts of the undersea canyons without harm to the shore dynamics.

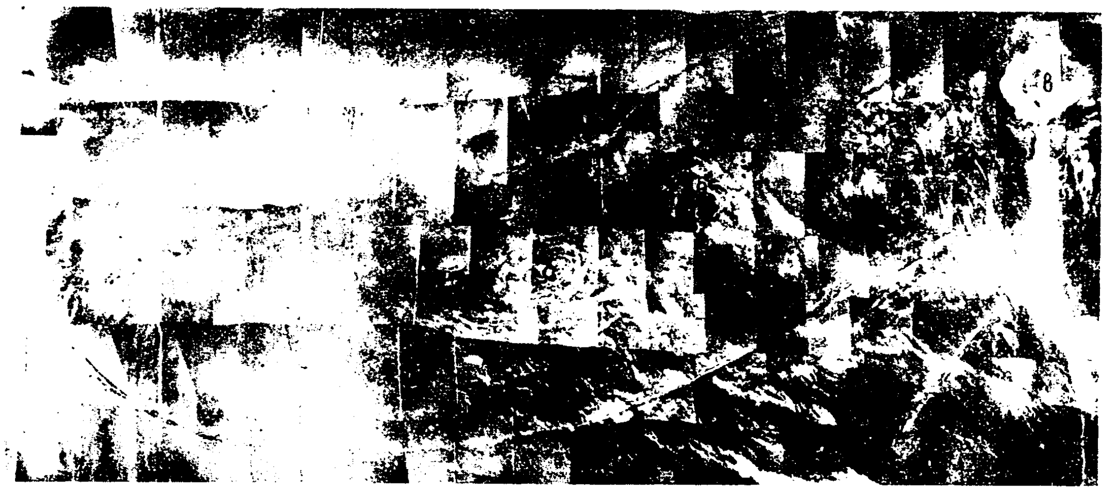

Figure 4. Aerial photographs of complexly constructed underwater anticlinal fold. In the arch part of the fold the following were depicted: the diapir structure (a), underwater mud volcanoes (b) and mud volcano island (c). The anticlinal structures are one of the prospecting criteria for oil and gas-bearing deposits.

Figure 5. Aerial photograph of an oil slick on the sea surface

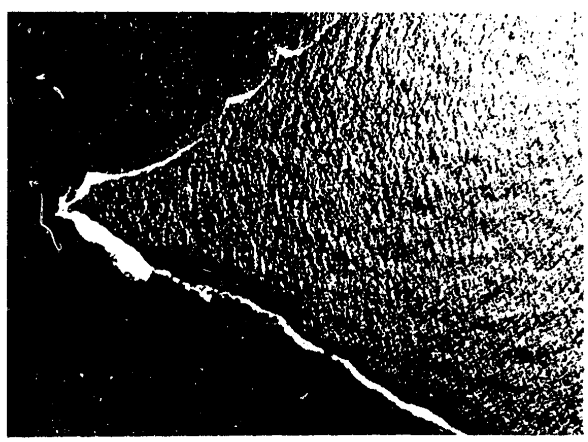

Figure 6. Aerial photograph of the eruption of gases from the depths of the sea floor causing the water to foam on the sea surface

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Figure 7. Aerial photograph of a coal-bearing suite exposed on the sea floor

Figure 8. Aerial photograph of sea grass (Zostera nana) on the underwater coastal slope

determination of the depths of the sea by tone or color of the image of the water (with uniform soil). Sometimes the stereoscopic measurements are combined with data from sonar measurements, measurements of the depths using lasers and the photometric method. The materials from the aerial photographic survey greatly facilitate the performance of hydrographic operations on the compilation of sea charts, especially in the shoal region inasmuch as they give relatively accurate and objective representation of the underwater relief.

Compilation of Landscape Maps. A detailed and objective representation of underwater objects on aerial photographs makes them irreplaceable for landscape studies and mapping of the sea floor. When deciphering the aerial photographs not only are the various components and elements of landscape recognized, but often their mutual relations and interdependence are established.

Study of the Dynamic Processes Occurring on the Bottom of the Sea Shoals. In the presence of repeated aerial surveys within the same body of water it is possible to determine the variations in landscape of the sea floor occurring in a strictly defined time period. Thus, the variations in the forms of the bottom relief, the rate of formation of new or destruction of already existing forms of relief of the coast line, the growing over of the bottom with underwater vegetation, and so on are established. A comparison of the materials from the repeated aerial surveys is one of the most improved and reliable methods of studying the dynamics of the processes occurring within the boundaries of the bottom of the coastal marine bodies of water permitting us to obtain not only a qualitative but also quantitative characteristics of these processes.

2.4. Obtaining Information About Objects on the Sea Floor by Indirect Signs

The materials from the aerial photograph surveys of the sea floor can be used to solve many scientific and practical problems. However, their use is limited to a significant degree to a relatively narrow strip of the coastal part of the body of water and individual shoal banks. Only an image of the water surface is obtained on the aerospace photographs of broad areas of the open sea and oceans.

The proposals of certain researchers [5, 6, 18], according to which when surveying from high altitudes and from outer space, it is possible to observe and photograph the sea floor at depths of several hundreds or even thousands of meters, has low probability. The attenuation of the light by the water is so significant that in practice, as experimental work demonstrates, with modern technical means it is impossible to obtain photographs of the sea floor at depths greater than 100 meters. This is also confirmed by numerous visual observations of scuba divers noting the rapid attenuation of light with depth and measurements of the light flux at various depths of the sea with varying transparency of the water. The maximum depth of the sea for which photographs of the sea floor have been obtained is 70 meters.

In connection with what has been discussed above, it is possible to draw the conclusion that photographing the sea floor outside the boundaries of the underwater coastal slope and individual shallow banks in the seas and oceans is excluded.

Nevertheless, the materials for the aerial photographic surveys and space photographs of the sea and ocean surfaces can be used to obtain information about certain structural peculiarities of the sea floor. This becomes possible as a result of the fact that defined objects and phenomena located at or occurring at the surface of the water and in its depths, are interrelated with the structure of the sea floor and also with the processes occuring in its depths. These interrelations can be used as indicators of certain structural peculiarities of it.

The first effort to study the sea floor using such indicators was undertaken in the LAEM [14].

Indicators of Underwater Volcanic Eruptions. Volcanic eruptions can appear in the form of a change in optical properties of the water as a result of discharges of ash material, the presence of local sections of churning water or powerful and irregular wave action in a quiet sea surface; discharges of ash, smoke and release of steam over the water surface; accumulation of floating fragments of pumice and sometimes the formation of temporary or permanent volcanic islands.

Indicators of Underwater Nonvolcanic Eruptions. These eruptions appear in the form of small gushers, spouts, the release of gases (see Fig 6), foamy water, turbid water as a result of discharge of pelitic material and sometimes in the form of burning flares of hydrocarbon gases. Temporary or permanent islands are also often formed.

Indicators of the Discharge of Underground Fresh, Thermal and Juvenile Water. The discharge of this water at the bottom with a quiet sea surface is manifested in the form of sections of churning water, and in the presence of wave action, in the form of sections of relatively smooth water; sometimes the powerful underwater springs form sections of more transparent water at the sea surface.

Indicators of Possible Oil and Gas Deposits. The oil-bearing nature of the depths of the sea floor sometimes appears on the sea surface in the form of spots of oil, constantly being renewed in certain sections, and gas eruptions, usually causing the water to foam.

In order to discover the shapes of the bottom relief, the following indicators can be used:

Waves. They react sensitively to the positive forms of the bottom relief at depths of less than one-half their length. Beginning with this depth, the waves experience deformation, namely, the length decreases and the height and speed increase. This deformation of the waves can be reflected on the aerial photographs, and by the variation in nature of the photographic image of the wavy sea surface it is possible to establish positive forms of bottom relief, sometimes with significant depths of the sea. For example, Yu. M. Shokal'skiy notes that "even at such great depths as occur on the underwater Wyvile-Thomson Ridge or among the Faeroe Islands in Scotland, that is, at depths of 400 to 500 meters, shortening of the waves was noted" [16, p 277].

In the coastal parts of the sea, it is possible to discover underwater valleys by the variation in nature of the wavy surface, within the boundaries of which during a storm, as a result of the significant depths the waves experience less deformation than in the shallow sections separating the underwater valleys.

Breaking of Waves. Breaking of Waves is observed in shoal water with a decrease in depth of the sea approximately (on the average) to 3/4 of the wave height. When the waves break, surf occurs, and an aerated (foaming) zone is formed which is depicted well in the aerial photographs. Especially energetic breaking of the waves occurs over obstacles. By photographs of the surface it is possible to establish the presence and the number of underwater swells, ridges, rocks, sandbars, and so on. For example, breakers are observed off the coast of Syria over the underwater rocks at depths to 84 meters [16].

Sea Wave Refraction. This is well depicted on the aerial photographs. By the sea wave refractions it is possible to discover the angles of approach of the waves to the shore, to measure the wave length, and under known conditions to establish the steepness of their slopes and even the propagation rate. The latter is determined as the ratio of the shift of the characteristic points of the waves on adjacent photographs determined with respect to the corresponding stationary reference points on the shore or in the sea, to the time intervals between adjacent exposures.

Knowing the length and speed v of the waves at a defined point it is also possible to determine the depth of the sea [12]. For this purpose the Stokes formula is used which establishes the relation between H, v and λ, namely:

$$v^2 = \frac{g\lambda}{2\pi} \operatorname{th} \frac{2\pi H}{\lambda},$$

where g is the gravitational acceleration; H is the depth of the sea at the given point.

In addition, by the bends in the refraction waves, elements of the relief of the underwater coastal slope are discovered -- ravines, elevations, and so on.

Upwellings, that is, rising of abyssal waters to the sea surface, in the open parts of the seas and oceans often are manifested over banks, underwater mountains and ridges.[1] As has already been noted above, the water rising from the bottom predetermines the luxurious development of plankton and the change of the optical properties of the water. A careful analysis of the aerial photographic and space pictures permits us to discover local changes in tone of the ridges by which it is possible to determine the bottom relief, and if the underwater ridges are genetically connected with the faults, then also to determine their location.

Turbid Water. Turbid water appears after storm wave action on the shoals, and it is well predicted on the aerial photographs. The systematic renewal of the turbid water in the form of isolated areas sometimes observed far from shore can indicate the presence of underwater sandbanks. Thus, the turbid water marks a shoal zone on sandy and silty shores and also sand-silt banks significantly removed from the shore.

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[1]Upwellings can also be caused by a drop in water from the shore caused by wind and diverging currents; they can occur on the leeward side of islands, and so on. However, in the open sea if there are no diverging currents, as a rule, they are connected with forms of bottom relief.

Evacuation of Turbid Water by Rivers. These sometimes occur along underwater valleys and at the same time fix the continuation of the latter in the sea.

3. Infrared (IR) Aerial Surveying

IR aerial surveying is based on recording reflected solar and natural thermal emission of the objects of the earth's surface in the form of electromagnetic waves in the range from 0.74 to 1000 microns. It has been established experimentally that for infrared radiation there are three basic atmospheric windows of transparency in the atmosphere determining aerial surveys in three ranges: 0.74 to 1.35, 3.5 to 5.5, 7.5 to 14.0 microns.

In the first atmospheric window (0.74 to 1.35 microns) reflected solar radiation is used; therefore ordinary methods of aerial photographic surveying on photographic films sensitized (sensitive) to this wave range (more precisely to 0.74-1.2 microns) are used. This type of aerial surveying can be called infraphotographic.

The IR aerial surveys in the second and third atmospheric windows at 3.5-5.5 and 7.5-14.0 microns permit the natural thermal emission of the earth and the thermal anomalies of objects occurring as a result of heating by solar radiation (induced thermal anomalies) to be recorded. It is performed by a scanning camera -- thermal viewers permitting two-dimensional images to be obtained (thermal aerial photographs) -- or IR-radiometers which record the variations of the temperature of the earth's surface along the flight axis of the aircraft. Equipment has also been developed which operates in the narrow spectral IR-zones. The synthesis of the photographs obtained by this camera offers the possibility of reproducing color IR-images. This type of aerial surveying is called thermal.

3.1. Infraphotographic Aerial Surveying

The near infrared zone of the spectrum is characterized by less scattering of the beams on passage through the atmosphere and the visible zone, which increases the range of the survey, and the differences in the coefficients of reflection and transmission promote an increasing contrast of individual objects and their parts.

In order to obtain an image of the sea floor the IR aerial surveying is not used inasmuch as the first meters of the water completely absorb the entire long-wave part of the spectrum. However, as a result of the difference in the reflection coefficients of this part of the spectrum and the visible part on the IR-photographs the boundary is clearly depicted between the water surface and the dry land. This is determined by the property of the water to absorb infrared radiation, in connection with which a sharp difference is observed in the reflection of the infrared beams from the dry land and water surface. Therefore IR-aerial photographic surveying can be used for the study and mapping of the shore line, maximum and minimum positions of the sea level during tides, surges, and so on.

3.2. Thermal Surveying

Thermal surveying which is performed using an IR-radiometer permits the temperature of the water surface to be recorded by the flight profile. In oceanology it is used to determine one of the most significant characteristics of the ocean which is variable in space and time -- the water temperature at its surface.

The thermal survey performed using heat viewers permits thermal contracts (anomalies) to be recorded.

It is used to discover the hydrodynamic processes, underwater volcanic and mud volcanic eruptions, pollution of the sea surface, and so on.

The hydrodynamic processes cause nonuniform temperature distribution of the surface of the sea; therefore on the thermal aerial photographs the warm and cold currents, their structural peculiarities, the zones of convergence and divergence of the currents and also the cold water of the upwellings, powerful discharges of groundwater or juvenile water, the cold and warm water fronts, convective cells, Langmuir circulations, and so on are clearly depicted.

The underwater eruptions of volcanoes can raise the water temperature over them either as a result of direct heating with the volcanic pipes located near the sea surface or as a result of rising of the hot bottom water and solid products of the volcanic discharge during eruptions occurring at great depths of the sea to the surface. These "trails" can be recorded on the photographs.

The discharge of groundwater at the bottom of the bodies of water usually causes local thermal anomalies on the sea surface. On discharge of fresh groundwater, the latter rises to the surface and lowers the water temperature. On the contrary, on discharge of thermal water, the water temperature and the sea surface over these sections rises. Thus, the thermal aerial survey can be used to find fresh and thermal water. Considering that the outflows of the latter frequently are associated with fractures, the mapping of the thermal water can be of assistance in tracing the large disjunctive disturbances within the boundaries of the bodies of water.

The pollution of the surface of the sea with petroleum products is recorded well in the thermal pictures. Petroleum products decrease the evaporation of the water, as a result of which in such sections of the sea surface there is no cold layer which to a significant degree arises as a result of evaporation. This situation obviously can be extended also to the sections of the sea polluted with other waste of anthropogenic origin.

Within the boundaries of the coastal shoals by using thermal surveying it is possible also to record the wave and the discontinuous currents, river runoff, sand and rock drainage, vegetation, and so on. As a result of the different heating of the water over the shallower and deeper sections, underwater valleys, shoals, underwater swells and other objects of the shallow sections of the underwater coastal slope are depicted.

4. Radar Aerial Survey

The radar survey is an active method of study [7]. The surface of the terrain is irradiated from the aircraft by radio waves, the reflected signals of which are recorded by the receiving equipment. The survey can be performed in practice in any weather both in the daytime and at night.

On the radar pictures only the surface of the bodies of water is depicted. If the surface of the water is smooth, then mirror reflection of the radio beams takes place in the direction away from the antenna (the receiver), as a result of which the water surface is depicted on the photograph as a uniform dark surface with respect to color. Accordingly, the radar survey must be made with a wavy surface when the radio beams reflected from the slopes of the waves and also scattered from the foamy water hit the receiver. In this case the radar photographs make it possible to obtain information about the sea waves, various hydrologic cycles and other phenomena on the surface of the bodies of water.

The oil slicks are depicted clearly on the radar photographs inasmuch as the latter "extinguish" the capillary waves. The sections of smooth sea surface formed here from which the radar beams undergo mirror reflection in the directions away from the receiving equipment, are found to be dark from the photographs.

With respect to the image of the breaking waves (the strips of foamy water) in the coastal shallows, certain forms of bottom relief are recognized on the radar photographs (underwater banks, shoals, individual cliffs or underwater rock). The radar pictures are successfully used also to estimate the ice situation in the polar seas, inasmuch as they permit discovery of open water and cracks among the pack ice, and sometimes it is even possible to estimate the relative thickness of the floating ice.

5. Laser, Luminescent, Ultraviolet Surveys

The laser, luminescent and ultraviolet surveys are, as has already been stated, in the testing or development stage.

5.1. Laser Surveying

Experimental studies indicate that in transparent water, using a laser on a wave length of 0.55 microns with a zone width of 0.003 microns, it is possible to measure the depths of the sea of several tens of meters. By combining the deciphering of the aerial photographs of the sea floor in measuring the depths of the sea using a laser it is possible to perform a hydrographic survey of the shoals [17].

5.2. Luminescent Survey[1]

The luminescent survey is based on the fact that on irradiation, the atoms of certain materials go into the excited state which is unstable. The return of the electrons to the former level is accompanied by the release of a quantum of energy in the form of beams of greater length than the irradiating radiation. This is nonthermal luminescence. Strong luminescence is characteristic of oils and gases and chlorophyll. Obviously, this survey can be used not only for recording oil slicks on the surface of the water, but also plankton.

With the active method it is proposed that the surface of the ground be irradiated by artificial ultraviolet beams which in the presence of luminescent materials causes nonthermal glow. It is recorded on the film in the visible range. It is possible to carry out such a survey only at night and from low altitudes.

In a passive luminescent survey, special equipment is used which makes it possible to record the deviations of the constant ratio between the intensity of the solar radiation near the Fraunhofer line and directly at its center caused by the luminescent objects. On the basis of this method proposed in the Soviet Union by A. N. Kozyrev, in the United States Khompfill created a special instrument of the radiometer type.

5.3. Ultraviolet Surveying

At the present time effective equipment is being developed for making ultraviolet surveys. In such a survey special types of aerial film must be used, the light-sensitive layer of which includes luminophors which give off a flash of light recorded by sensitive layer on passage of ultraviolet rays through them. The survey can turn out to be useful when studying the pollution of the surface with oil, detecting hydrocarbons coming from the bottom to the surface.

Measuring the spectrum of the reflected sunlight emerging from the sea makes the study of phytoplankton and estimation of the chlorophyll concentration possible. The latter absorbs violet blue (0.42-0.46 microns) and red (0.66-0.70 microns) in the visible part of the spectrum. However, these operations performed from an aircraft are complicated by the fact that the transmission function of the atmosphere, consideration of which

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[1]Items 5.2, 5.3 and also Section 6 were compiled by the data of A. V. Dolivo-Dobrovol'skiy.

makes it possible to use aerospectrometric measurements to study the chlorophyll which determines photosynthesis.

6. Aerogeochemical Surveying

Aerogeochemical surveying will permit areas of the dispersion of gas or finely suspended particles in the air to be recorded. In practice this is done by sucking air from outside into the aircraft by a pump.

The outside air is passed through the system of absorbers which selectively absorb the desired components, and it is analyzed using a counter which measures the radioactivity of the air. The suspended particles can be collected using screens made up of artificial polymers, and so on. Procedures have also been developed which are based on the spectrometric study of the composition of the atmosphere under the aircraft and over it using the method of Fraunhofer lines.

The appearance of new lines in the section of the atmospheric column of air next to the ground indicates the presence of aureoles of certain materials.

In practice the aerogeochemical survey has not been used as yet to study bodies of water. Obviously, it can be used to discover hydrocarbon gases which reach the surface of the sea from the sea floor and indicate the presence of the oil and gas deposits.

The practical use of the aerogeochemical methods has been complicated as a result of absence of a procedure for tying the observations to the objects causing the presence of areas of dispersion of certain gases inasmuch as it is difficult to consider the movement of the air masses.

7. Aerogeophysical Surveying

Out of the aerogeophysical methods for studying the geological structure of the bottom of the sea, aeromagnetic surveying is used; aerogravitational surveying is in the stage of development.

7.1. Aeromagnetic Surveying

Aeromagnetic surveying is designed to study the peculiarities of the magnetic field of the seas and oceans which are predetermined by the rock making up the depths of the bottom of the seas and oceans. The survey is performed using aeromagnetometers installed on the aircraft. The magnetometric studies of the oceans have made it possible to regenerate the mobilistic theory of development of the earth; they served as the basis for creating the theory of new global tectonics; using these studies, abyssal and transform fractures at the bottom of the ocean have been established which are traced over an extent of many thousands of kilometers.

As a result of the magnetic susceptibility of various rock it is possible to use aeromagnetic measurements during geological mapping for tracing individual geological suites (series, bodies and so on). With respect to the discovered magnetic anomalies it is possible to talk about the abyssal geological structure of the depths of the sea floor, in particular, the presence of intrusions of basic and ultrabasic rock and even the geological structures prospective for oil and gas.

7.2. Aerogravitational Surveying

Aerogravitational surveying, along with gravitational studies performed from maritime ships, promotes the discovery of a gravitational anomaly. This type of survey is still of an experimental nature. The analysis of the gravimetric maps offers the possibility of establishing the abyssal structure of the sea floor, the presence of intrusions and sometimes anomalies indicating the presence of anticlinal structures. This makes it possible to use the materials of the gravitational surveys to determine the prospective oil and gas-bearing bodies of water.

The use of the materials from the aerial surveys when studying the ocean in practice has only started, but in the given phase obviously it is necessary for the solution of both scientific problems and certain practical problems of the exploitation of the ocean.

Beginning with this fact, it is possible to expect that the interpretation of the materials of the aerial surveys of the bodies of water will permit us to obtain broad information about the physical phenomena occurring in the ocean, some of its biological peculiarities and the geological structure of the bottom. The complex use of various types of aerial methods jointly with other methods of oceanography can greatly refine our concepts of the laws of the nature of the oceans and seas, which is necessary for efficient use of its resources.

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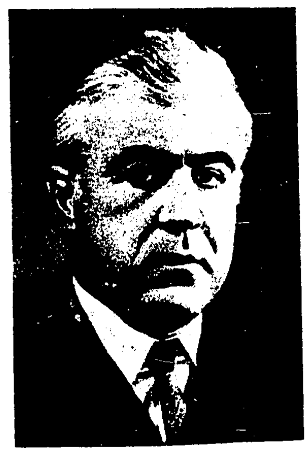
OCEANIC EDDIES

[Article by V. G. Kort]



Vladimir Grigor'yevich Kort, corresponding member of the USSR Academy of Sciences, Honored Scientist of the RSFSR, is working in the field of oceanographic research. Twenty-three expeditions to various parts of the Atlantic, Pacific and Indian Oceans and the first Soviet marine Antarctic expeditions on the diesel electric ship "Ob'" were made under his direction in 1956-1958. He is co-author of the discovery in 1970 of mesoscale oceanic eddies. Under the direction of V. G. Kort, the collective of coworkers of the Oceanology Institute of the USSR Academy of Sciences imeni P. P. Shirshov has made up a ten-volume monograph TIKHIY OKEAN [Pacific Ocean], which won the State Prize of the USSR in 1977.

1. Results of Oceanological Expeditions

During the work of the American Gulf Stream-60 Expedition in 1960 and the Soviet expedition in 1963, hydrologic surveys were made in the Gulf Stream region [2]. They demonstrated an extraordinarily complex spatial structure of the current field and other hydrophysical characteristics (temperature, salinity) in this region. From the data obtained it followed that the position of the main flow of the Gulf Stream varies significantly from survey to survey as a result of intensive meandering of the core of the current. Then it was noted that the strong meanders can be pinched off from the primary current, becoming powerful eddies, which are called rings in the American oceanographic literature. The large-scale rings (about 200-300 km long) involve enormous masses of water (to $30 \cdot 10^6$ m^3/sec) in the rotational motion, and they penetrate to great ocean depths (3000-4000 meters).

In addition to the rings along the outer boundaries of the main flow of the Gulf Stream numerous eddies of essentially smaller scale were observed (50 to 100 km long). These eddies are the consequence of shearing stress in the boundary zones of the Gulf Stream (the Karman eddies). The standard picture of the spatial dynamic structure in the Gulf Stream was constructed (see Fig 1). In the region between 60 and 65° west longitude, a well-expressed anticyclonal (clockwise movement) meander can be seen with three eddies to the south and southwest of it.

The quasisynchronous area hydrologic surveys in the Kuroshio Current zone demonstrated the same complex dynamic structure in the current field.

Thus, the first detailed hydrologic surveys of the regions of the powerful streams such as the Gulf Stream and the Kuroshio Current made it possible to establish the existence in the ocean of large and small-scale eddies connected with hydrodynamic instability of the streams and the influence of the relief of the ocean floor on them.

In 1967, by the initiative of the well-known Soviet oceanologist, Prof V. B. Shtokman, instrument observations of the currents in the test area with autonomous buoy stations with current recorders [6] were organized. The test area 300x240 miles in size was located in the southern part of the Arabian Gulf between 63°-66°30' east longitude and 10-15° north latitude. Two quasisynchronous hydrologic surveys were performed in the test area with respect to a uniform grid of stations with 30 mile spacing. During the course of the observations, eddies 200-250 km in size were detected in the open sea outside the zone of effect of the powerful ocean currents. These eddies have now been called mesoscale. The question of their genesis has arisen immediately. In 1970 under the direction of the Oceanology Institute of the USSR Academy of Sciences imeni P. P. Shirshov [3], an interdepartmental expedition was made to the central part of the Atlantic Ocean, Polygon-70. For 6 months, continuous observations of the variability of the basic hydrophysical characteristics (current velocity, temperature, salinity, and so on) were made from the expeditionary ships and 17 autonomous oceanographic buoy stations arranged in a cross in a test area 120x120 miles. The results of these unique studies of the ocean dynamics turned out to be very interesting.

Large eddy disturbances resembling atmospheric cyclones and eddy cyclones were discovered in the open part of the ocean, in the quasistationary current zone (the northern trade current). The characteristic scale of these eddies is 100 to 200 km in extent and 40 to 70 days with respect to time. The eddies were traced to a depth of up to 1000-1500 meters from the surface. The eddies moved through the test area in a westerly direction with an average speed to 5 cm/sec with average orbital velocity at depths of 200-300 meters at 20-25 cm/sec.

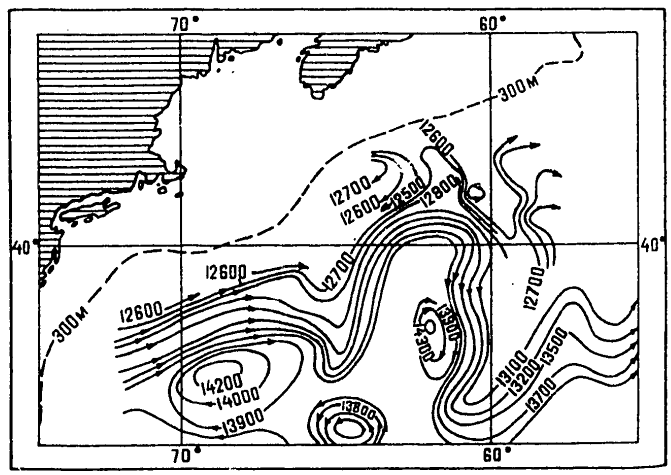


Figure 1. Map of dynamic topography (0-4000 dbars) in the vicinity of the Gulf Stream, June 1960
Dotted lines -- 300-meter isobath. Numbers on the solid isolines -- dynamic altitude, dyn. mm.

A vector diagram was constructed for the variation of the current velocity field (the 300 meter level) in the "Polygon-70" during the period from 13 March to 12 August 1970 (see Fig 2).

From the figure it is quite clear how the nature of the current field changed sharply from 13 March to 22 April in the test area. At the beginning of the observations there was a rear section of eddy disturbance in the test area, and by the end of April a new anticyclonal eddy had advanced to the test area. After a month (24 May) the center of this anticyclone penetrated to the middle of the test area. This observation period is especially successful, for it indicates the total area of the eddy disturbance. The outline of the detected eddy is well approximated by an ellipse with lengths of the axes of 90-100 km and 200 km. A comparison of the parameters of this ellipse and the theoretical model of the free planetary waves in the two-layer ocean on the beta-plane provided a basis for M. N. Koshlyakov and Yu. M. Grachev to consider that the dynamics of the eddy disturbance of the current velocity observed in the test area are close to the dynamics of the baroclinic Rossby waves [5].

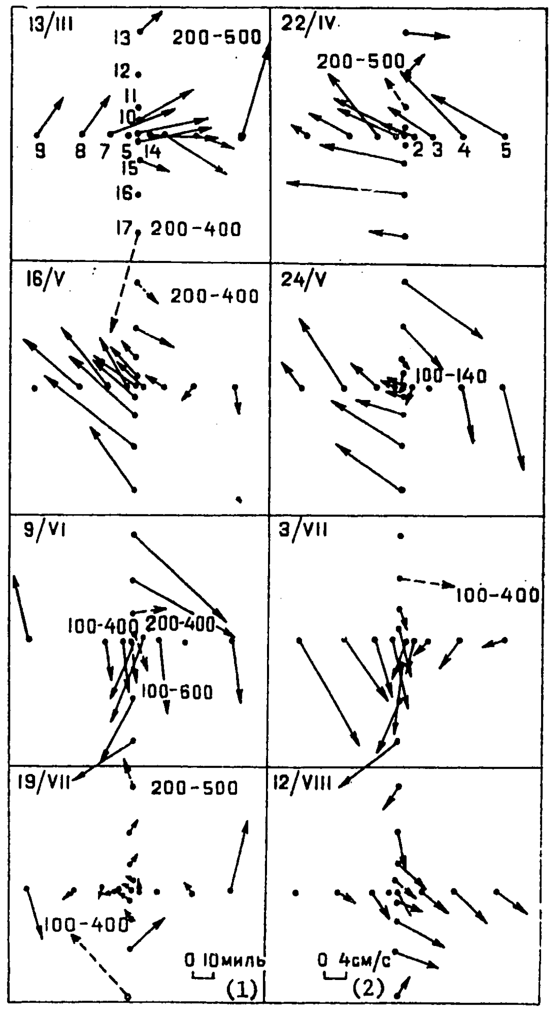


Figure 2. Evolution of the current field at the 300-meter level ("Polygon-70")
The scales for the spacing between stations and for the moduli of the velocity vectors (solid lines with arrows) are indicated at the bottom of the figure. The dotted lines with the arrows indicate the velocity vectors obtained by interpolation with respect to depth indicated near the arrow.

Key:
1. miles
2. cm/sec

Thus, the eddy disturbance detected in "Polygon-70" turned out to be a new class of ocean eddies developed in the open sea under the effect of meteorological disturbances and hydrodynamic instability. On the basis of this, the detected anticyclonal eddy was called the synoptic mesoscale eddy. A characteristic feature of this eddy is the well-expressed dynamic structure in the abyssal layers of the ocean (200 to 1500 meters). In the upper layer of the ocean, in contrast to the Karman eddies and rings, the synoptic mesoscale eddy is less clearly manifested. This is connected with the fact that under the effect of storms the dynamic structure of the upper layer of the ocean is greatly complicated by smaller scale disturbances. The effort to isolate such smaller disturbances in the "Polygon-70" [4] has been crowned with success: in the upper horizons (25-200 meters) small-scale synoptic eddies have been detected with horizontal dimensions of 50-80 km and a period of 3-9 days close to the "natural synoptic period." The phase velocity of such eddies reaches 10-15 cm/sec and they are traced to a depth of 200-300 meters.

It is possible to assume that the small-scale synoptic eddies develop in any parts of the World Ocean as a reaction of the ocean to storms.

The results obtained from the Soviet scientists stimulated the development of similar studies in other countries. Thus, in the United States, beginning in 1973 to 1976, broad studies were made of the eddy disturbances in the southwestern part of the North Atlantic by the Mid-Oceanic Dynamic Experiment (MODE). The results obtained by the American researchers confirm the existence and very great variety of eddy movements in the ocean with respect to scale and genesis.

The discovery of synoptic eddies in the ocean has great scientific significance. It is introducing basic changes in our concepts of the internal dynamics of the ocean, and already today theoretical and experimental dynamic oceanology is faced with the problem of studying the processes of synoptic eddy formation and the interaction of eddies with other large-scale processes. When performing the studies with respect to many divisions of oceanology such as ocean acoustics, the hydrochemical structure of water, biological productivity, pollution and propagation of a passive impurity and so on, it appears necessary to tie the results to the hydrologic and kinematic structure of the ocean formed by the processes of synoptic eddy formation.

2. POLYMODE Experiment

Considering the important role of the eddy disturbances in the dynamics of ocean water and also the great complexity and labor consumption of studying them, a program of broad studies of dynamics of ocean water called the International Large-Scale Oceanic Dynamic Experiment POLYMODE was adopted in 1974 when developing the plan for scientific Soviet-American cooperation. It is a logical development of the studies by the "Polygon-70" and MODE programs, and it was planned for several years.

The basic goal of the POLYMODE program consists in studying the oceanic eddies for proper understanding of the dynamics of the low-frequency and mesofrequency (synoptic) variability of the ocean currents and determination of its role in the general large-scale dynamics of the ocean. During the course of the expedition provision was made for careful mapping of the three-dimensional structure and time variability of the basic hydrophysical fields (current velocity, temperature, density) within the scales significantly greater than previously; measurement of the local dynamic balance in the characteristic parts of the ocean; study of the role of the eddy transfer of momentum, heat and mass and the variability of this transport in space and time; the study of the mechanisms of the occurrence, transmission and dissipation of the energy in the eddies and their interaction with each other and with the average current; study of the distribution of the sizes, intensity and variability of the eddy field over the ocean.

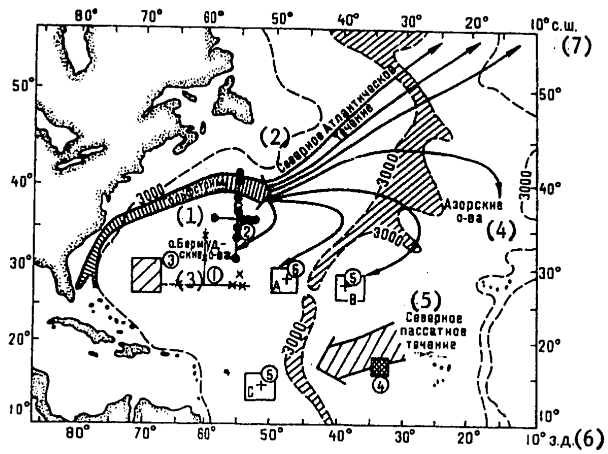


Figure 3. Diagram of the operations with respect to the Soviet-American POLYMODE program
1 -- area of operations by the MODE program using the system of autonomous buoy stations 1; 2 -- area of operations by the MODE-1 program using the autonomous buoy station system 2; 3 -- POLYMODE test area; 4 -- area of operations of the USSR by the "Polygon-70" program; 5 -- area of operations of the United States using the system of autonomous buoy stations 3.

Key:

1. Gulf Stream
2. North Atlantic Current
3. Bermuda Islands
4. Azores
5. Northern Trade Current
6. west longitude
7. north latitude

The successful achievement of these goals will make it possible to create a scientific basis for short-range and long-range oceanographic forecasts and will permit construction of the integrated dynamic model of the atmosphere-ocean system required for further improvement of weather forecasting techniques.

In accordance with the POLYMODE program the Soviet side performed studies for a year (from July 1977 to September 1978) in the hydrophysics test area located in the southwest part of the North Atlantic. The center of this test area 300x300 miles in size was selected approximately at the point with the coordinates 29° north latitude and 70° west longitude. The wind conditions in this area are comparatively favorable for long-term operation of oceanographic buoys. The American side was to continue the studies begun in 1976 using the system of oceanographic buoy stations to the north, northeast and southeast of the Soviet test area and also to perform a local synoptic experiment near the main test area (see Fig 3).

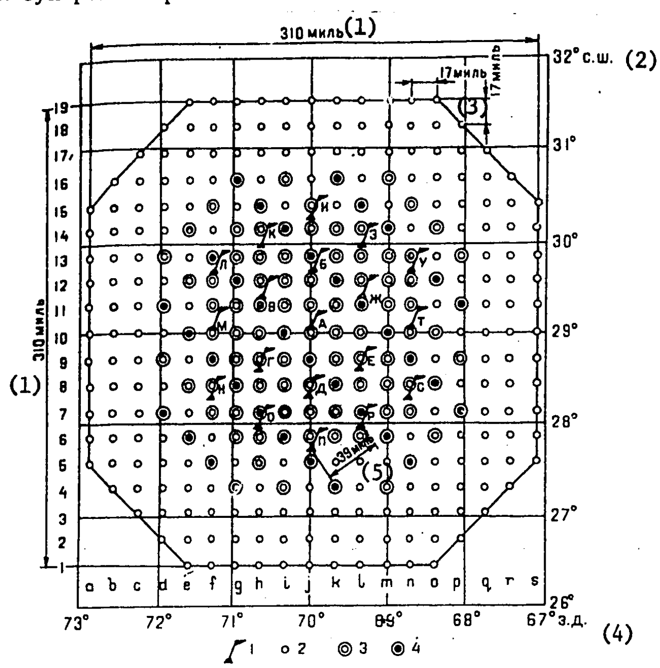


Figure 4. Diagram of the Soviet hydrophysics POLYMODE test area
1 -- buoy station; 2 -- KhVT-sounding; 3 -- STD-sounding;
4 -- series of hydrologic stations

Key:

1. 310 miles
2. north latitude
3. miles
4. west longitude
5. miles

The Soviet studies of the mesoscale eddies in the POLYMODE test area were performed by the diagram presented in Fig 4. The depth of the test area varies from 5100 to 5400 meters.

The work was participated in by the scientific research ships "Akademik Kurchatov" and "Vityaz'" (Oceanology Institute of the USSR Academy of Sciences), "Akademik Vernadskiy" and "Mikhail Lomonosov" (Moscow Hydrologic Institute of the Ukrainian SSR Academy of Sciences), "Akademik Krylov" and "Moldaviya" (Hydrographic Service), "Petr Lebedev" and "Sergey Vavilov" (Acoustics Institute of the USSR Academy of Sciences) and "Viktor Bugayev" (State Committee on Hydrometeorology and Monitoring the Natural Environment of the USSR).

During the period from 11 July 1977 to September 1978, nine expedition ships performed 17 large-scale (over the entire test area) hydrologic surveys, 14 medium-scale (over the body of water in test areas 1 and 2 in Fig 3) and observations at several microtest areas. All of the autonomous oceanographic buoy stations have worked almost continuously for 12 to 13 months. About 3 million components of the current velocity vector were recorded, and about 2 million values of the water temperature were obtained. Observations were made at several thousands of hydrologic stations and temperature sounding stations. The preliminary analysis of material obtained in the first phase of the expedition demonstrated that the region of POLYMODE test area is highly dynamic (Table 1, Fig 5).

3. Analysis of the Data Obtained

An analysis of the displacement rate of the eddies (Table 1) and the nature of their trajectories (Figures 5 and 6) indicates highly intensive dynamics of the eddies in the POLYMODE test area. Their phase velocity varies from 3 to 17 cm/sec. The eddy movement takes place extremely nonuniformly, and the impression is created that it is comparatively random The basic cause of this nature of movement of the eddies probably is their interaction. They collide with each other; some block the path of others. Obviously, further analysis of the observations in the POLYMODE test area will permit understanding and explanation of these complex processes.

A comparison of the maps of the eddy fields constructed by the hydrologic survey data with current maps based on measurements of the oceanographic stations demonstrated their satisfactory similarity. Still closer analogy occurs between the current field and the dynamic topography taking into account the distribution not only of the water temperature, but also its salinity.

The indicated fact makes it possible to consider that the eddy formations in the POLYMODE test area function with high probability in the quasi-geostrophic mode, that is, the pressure gradient occurring in the cyclonic (C1, C2) and anticyclonic (A1, A2) eddies are equalized by the force of the acceleration connected with rotation of the earth (the Coriolis force). Thus, in the defined stage of their development the oceanic eddies can be comparatively stable formations.

Table 1

Displacement Rate of the Eddy Formations in the Test Area

Eddy formation	Survey no	Dates of the middle of the surveys	Traveled distance, miles	Days	Displacement rate, miles/day	Direction of displacement
C1	1a-2	16/VII-27/VII	10	11	1.0	NW
C1	2-2a	27/VII-05/VIII	20	9	2.2	NW
C1	2a-3	05/VIII-16/VIII	60	11	5.5	WSW
C1	3-3a	16/VIII-22/VIII	15	6	2.5	S
C1	4-5	01/IX-28/IX	45	27	1.7	WNW
C2	1-1a	13/VII-17/VII	20	3-4	5.0	NW
C2	1a-3	17/VII-16/VIII	50	29	1.7	NW
C2	3-4	16/VIII-01/IX	30	15	2.0	N
A1	1a-2	16/VII-27/VII	15	11	1.4	W
A1	2-2a	27/VII-05/VIII	40	9	4.4	W
A1	2a-3	05/VIII-16/VIII	30	11	2.9	W
A1	3-4	16/VIII-01/IX	40	15	2.7	NW
A1	4-5	01/IX-28/IX	40	27	1.5	W
A2	1a-2	16/VII-27/VII	10	11	1.0	NE
A2	2-2a	27/VII-05/VIII	25	9	2.8	E
A2	3-4	16/VIII-01/IX	75	15	5.0	WSW

Note: C -- cyclones; A -- anticyclones

The form of the abyssal structure of the eddy formations is approximated by a truncated cone somewhat twisted clockwise (for the northern hemisphere) with the apex turned upward for cyclonic eddies and downward for anticyclone. The shape of the bases of the cone formed by the closed isopycns, as a rule, must be complicated, but in the majority of cases can be approximated by a circle or an ellipse. The spatial scale of the synoptic eddies in the POLYMODE test area is characterized by 150-200 km, and their period is 60 to 80 days. In the cyclic eddies in the northern hemisphere ascent of the isopycns in the central part is noted, and in the anticyclonic eddies, descent. Accordingly, the cyclonic eddies have a negative temperature anomaly in the center as a result of a rise of water and can be called "cold"; the anticyclonic eddies have a positive temperature anomaly connected with a descent of the surface water, and they are called "warm." The lower boundary of the penetration of the eddies is 3000 to 4000 meters, which in general corresponds to the American determinations obtained in the MODE test area which was somewhat south of the POLYMODE test area.

The existence of warm and cold eddies in the ocean creates specific conditions for heat and moisture exchange with the atmosphere, which has an influence on the weather.

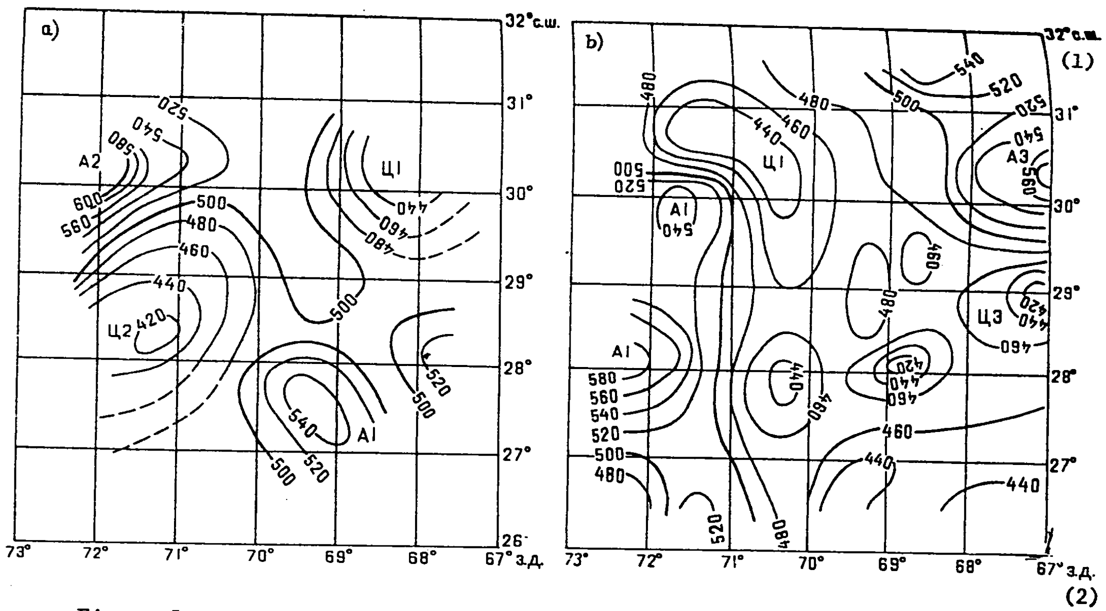


Figure 5. Topography of the 17°C isotherm by the data from the first hydrologic survey (a) and the fifth survey (b). The isolines depict the structure of the eddy field. The numbers on the isolines depict the depth of the isotherm, meters.

Key:
1. north latitude
2. west longitude

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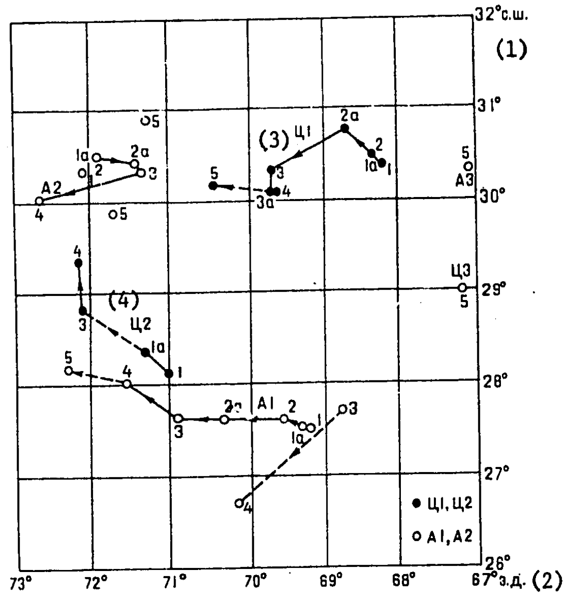

Figure 6. Location of the centers of the eddy formations and the trajectories of their motion (schematic) at a depth of the 17°C isotherm according to the data of eight hydrologic surveys.
The surveys were performed: No 1 -- 11 July to 18 July; No 1a -- 13 July to 21 July; No 2 -- 24 July to 1 August; No 2a -- 1 August to 10 August; No 3 -- 10 August to 21 August; No 3a -- 18 August to 27 August; No 4 -- 23 August to 11 September; No 5 -- 22 September to 4 December.

Key:
1. north latitude
2. west longitude
3. C1
4. C2

An interesting characteristic feature of the dynamic eddies is the presence in their frontal regions of higher orbital velocities by comparison with the rear regions (with respect to the general direction of motion of the eddy). As a result, at the boundary between the eddies hydrologic fronts are observed which are confirmed by the data from the hydrologic observations.

The discovery of the oceanic eddies of synoptic scale permits discussion of the existence of a characteristic "weather" in the body of the ocean, the consideration and forecasting of which have important practical significance for navigation and marine industry.

The cold cyclonic eddies are distinguished not only by their thermal structure. The rising of the abyssal waters to the surface in these eddies is accompanied by the transfer of water masses rich in biogenic elements. On getting into the photosynthesis zone, these elements promote an increase in biological productivity in the surface layers of the central part of the cyclonic eddy. In other words, the regions of cold oceanic cyclones are prospective for fishing in the open parts of the ocean. A classical example of such productive areas is the regions of quasistationary large-scale eddies in the waters of Antarctica. Here in the zones of upwelling of abyssal water, in the center of the eddies the plankton biomass reaches a record magnitude -- 1000 mg/m^3 [1].

American oceanographers have given a great deal of attention to the study of large-scale eddies -- rings spawned from the meanders of the Gulf Stream having significance for navigation.

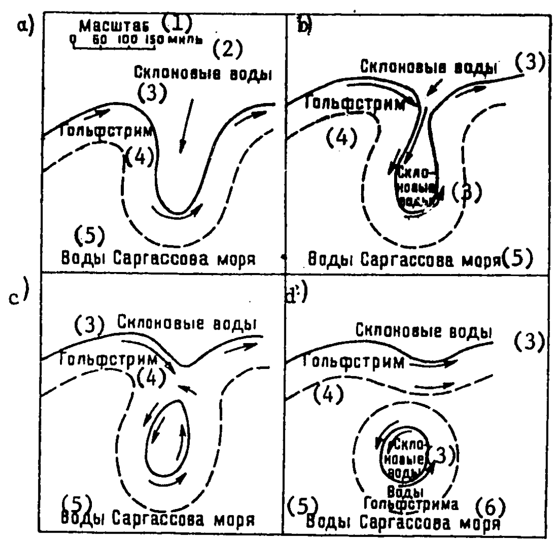

Figure 7. Diagram of the formation of rings in the Gulf Stream (according to Parker): a-d -- formation stages

Key:

1. Scale: 2. miles; 3. Continental slope water; 4. Gulf Stream; 5. Water of the Sargasso Sea; 6. Gulf Stream water

Using radiation thermometers to measure the temperature of the ocean surface from aircraft and artificial earth satellites and also ship and aircraft ejectable temperature probes, acoustic buoys with zero buoyancy, American researchers have already obtained quite complete information about the structure and conditions of these rings (Fig 7). The statistical processing of the observation data demonstrated that on the southern periphery of the Gulf Stream, in the region between 65 and 55°C west longitude, from 5 to 8 cyclonic rings are produced annually [7]. Their spatial scale found by the 15°C isotherm reaches 150-200 km, and all of them drift in the general direction to the southwest with an average speed to 10 m/sec. Here the orbital velocity of the surface current in the rings reaches 150 cm/sec, and it remains almost unchanged for the first 6 months of its "life." The total duration of the existence of the rings reaches 2 to 3 years.

The central core of the cyclonic "cold" rings to a depth of 2000 meters contains slope water on the coast side of the Gulf Stream and at the same time cools and freshens the surrounding water of the Sargasso Sea (see Figures 7 and 8) [9].

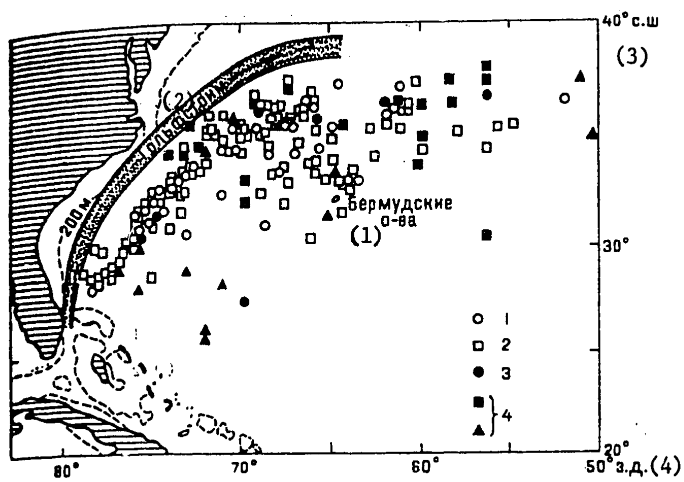

Figure 8. Diagram of the spread of the Gulf Stream rings in the period of 1970-1976 (according to Lai and Richardson). 1 -- by the temperature sounding data; 2 -- by the satellite observation data; 3, 4 -- single observations from experimental ships

Key:

1. Bermuda Islands
2. Gulf Stream
3. north latitude
4. west longitude

The analysis of all of the hydrologic observations (more than 50,000) in the western part of the Sargasso Sea in 1970-1976 made it possible to isolate 163 rings (see Fig 8).

Their identification by hydrologic structure offers the possibility of tracing the displacement of a large series of warm and cold rings. Fig 9 shows an example of the movement of the identified ring in the 1971-1973 period, during which it traveled from the place of generation to the vicinity of Florida where, in the opinion of the authors of reference [8], it again joined the Gulf Stream. The displacement of the rings in the southwesterly direction is connected with the existence of a weak quasi-stationary countercurrent in the southern boundary zone of the Gulf Stream in which the rings also drift to the southwest at an average speed of 3 km/day (Fig 9).

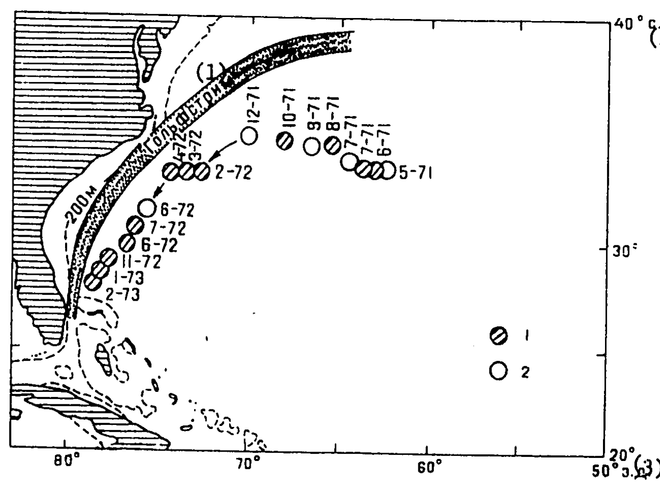

Figure 9. Diagram of the movement of the ring during the period from May 1971 to February 1973 (according to Lai and Richardson).
1 -- position of the ring determined by the water temperature anomalies in the three abyssal horizons; 2 -- by the water temperature of the anomaly in one or two horizons.

Key:
1. Gulf Stream
2. north latitude
3. west longitude

According to the data of a number of authors [7, 8] in the Gulf Stream zone between 65 and 55° west longitude 6 to 8 cold and 5 to 7 warm rings are spawned per year.

Both the large-scale rings and the mesoscale eddies have high kinetic energy. It has already been noted above that the orbital current velocities in the rings can reach high values. As a result of this the eddy kinetic energy in the rings calculated per unit mass of the surface currents can reach 1000 cm^2/sec^2, that is, exceed by 30 to 40 times the mean kinetic energy in the regions with weak currents. According to the measurements in the POLYMODE test area, the main kinetic energy of the mesoscale (synoptic) eddies exceeds by 3 to 5 times the kinetic energy of the average current. Thus, the large-scale and mesoscale eddy disturbances basically change the structure of the quasistationary oceanic current field during their spread, and at the same time complicate consideration of them during navigational calculations. The presented examples quite clearly indicate not only the high scientific, but also applied significance of studying ocean eddies.

The oceanographic studies in recent times indicate almost ubiquitous spread of the eddy disturbances of different scales in the oceans. However, the nature of them still has far from been studied. In the modern stage of the investigations the oceanographers have only the most general idea about the fact that the large-scale eddies (rings) are spawned in the regions of meandering powerful oceanic currents. The synoptic mesoscale and small-scale eddies are the result of the barotropic and baroclinic hydrodynamic instability of the average currents and the frontal zones in the ocean caused by the effect of powerful meteorological disturbances (storms) and the effect of the relief of the ocean floor on the movement of the water masses.

With discovery of the eddy field in the World Ocean, many new complex problems arose, in particular, the origin of the mesoscale eddies, their evolution, internal dynamics, interaction with the surrounding water, and so on, the solution of which is an urgent problem of modern oceanographic research.

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OCEANOGRAPHIC BUOYS AND BUOY LABORATORIES

[Article by B. V. Shekhvatov]

Boris Vasil'yevich Shekhvatov, candidate of technical sciences, senior scientific coworker of the Oceanology Institute of the USSR Academy of Sciences imeni P. P. Shirshov, is engaged in the development of sounding and autonomous instruments, hydroacoustic equipment, autonomous buoy stations and other oceanological equipment.

The basic research of the physical-chemical and biological processes occurring in the water masses and at the water-atmosphere interface and also the performance of constant observations of the hydrometeorological situation in the ocean are realized by various methods. This is a broad network of hydrometeorological stations located along the coast of the continent and on the islands, and the weather ships equipped with hydrometeorological and aerological equipment. The number of weather ships is comparatively small, and the cost of their operation is high. An important source of information about the state of the weather in the open sea is the meteorological summaries of the ships navigating there, but their distribution with respect to area is nonuniform; the vast regions of the World Ocean remote from the dry land are outside the observation zones.

The information coming from the meteorological earth satellites permits determination of the large-scale process occurring in the atmosphere and at the ocean surface. However, measurements of the hydrometeorological parameters from artificial earth satellites cannot at the present time insure the required accuracy and completeness of the data.

One of the most prospective methods of obtaining hydrometeorological data and also performing long-term scientific research observations in the ocean under any weather conditions is based on the application of autonomous buoy stations (ABS). The first buoy stations were used primarily for navigational purposes and were installed in the coastal zone at shallow depths.

In the middle of the 1950's, the first experimental installations of the ABS took place in the open sea which immediately attracted the attention of scientists. In 1967 it was reported at a special International Conference in Washington that about 85 different ABS systems had been built and tested in the United States alone, among which the most improved structural designs were selected [1].

The use of artificial earth satellites to relay the data made it possible significantly to increase the reliability of transmission of the information and simultaneously to simplify the equipment, lower the energy consumption of the radio transmitters of the ABS. Their application made it possible to reduce the number of expeditionary ships.

In the last two decades the ABS have solidly entered into the composition of the technical means used for various observations in the seas and the oceans. Thus, for example, when studying the large-scale synoptic eddies in the Atlantic Ocean by the international POLYMODE program in 1977-1978 Soviet oceanologists alone installed 19 ABS. Hundreds of drifting stations are used to study the surface currents. In connection with intensification of the extraction of oil and gas and other natural minerals, the number of ABS installed on the continental shelf and in the inland seas has increased significantly. The plan calls for the creation of regional and international networks of hydrometeorological stations encompassing the most important parts of the World Ocean. Within the framework of the European Community by 1980 it is proposed that a network of hydrometeorological ABS be installed in the North Sea, the Baltic Sea and the Bay of Biscay. The United States plans to create a network of 500 ABS in the Atlantic, Indian and Pacific Oceans. Plans for building an International Global ABS Network are being discussed.

At the same time the problem of creating the ABS for long-term observations at great depths in the ocean cannot be considered solved. Out of the large number of developed stations in 1978 there were a few more than 20 ABS operating in the open sea. The intense operations with respect to improvement of the structural design of the ABS and finding new solutions are being carried out in various countries of the world.

1. Types and Composition of ABS

Depending on the purpose and the method of installation it is possible to isolate four basic types of ABS (see Fig 1):

With a surface buoy installed on an anchor;

With sunken buoy;

Combined with sunken and surface buoy;

Drifting.

The areas of their application, the advantages and disadvantages have been investigated below. The manned and unmanned laboratory buoys have been separated into an independent group.

The ABS include a set of installed equipment: a carrier buoy, anchor rope, line release and bottom anchor; measuring complex: hydrologic, meteorological and other measuring instruments; systems for conversion, processing and recording the data obtained; a program device which controls the operation of the measuring and the auxiliary systems of the ABS; telemetry systems -- transceivers, communication lines with primary converters, including the hydroacoustic channel, auxiliary equipment -- storage batteries, power plants for charging them, ventilation and heat regulating systems, navigational equipment, and so on.

Carrier Buoys

The carrier buoy holds the anchor line with instruments suspended to it; the equipment complex, measuring sensors, radio transmitting devices, power supplies and auxiliary systems are placed in it. The form and structural design of the buoy and the requirements on its hydrodynamic characteristics are determined to a significant degree by the installation system of the ABS. The ABS with surface anchored buoy are under the most unfavorable conditions. These buoys are subject to the effect of waves, currents and wind. Therefore dynamic loads occurring on the anchor line will depend on their hydrodynamic characteristics. Even insignificant improvement of these characteristics will improve the reliability of installation of the ABS and will permit simplification of the anchor system. It must be considered that the coefficient of frontal resistance of the buoys can change significantly under the effect of irregular wave action. The magnitude and sign of these changes depend on the shape of the buoy.

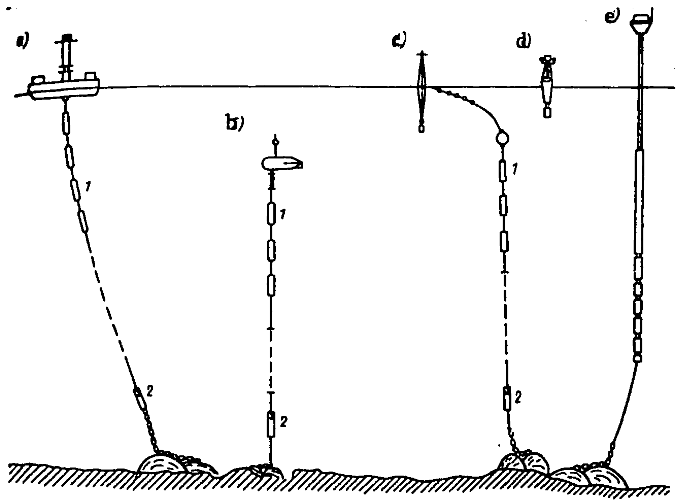

Figure 1. Diagrams of the installations of buoy stations:
a -- with EEP surface buoy; b -- with sunken buoy;
c -- combined ABS; d -- with drifting buoy; e -- manned
laboratory buoy.
1 -- hydrologic instrument; 2 -- line release

The sunken ABS are under the most favorable conditions; their carrier buoys are basically subject to the effect of currents. The buoys of these ABS must have a minimum coefficient of frontal resistance and sufficient buoyancy to stay at a given depth with maximum current velocity expected in the area where the station is installed.

The surface anchored buoys frequently have the form of a disc, a toroid, vertical-oriented cylinder, stakes or ships.

Buoys in the form of balls and horizontally oriented cylinders are used in the sunken ABS.

The hulls of the large buoys are made of steel; buoys with a displacement of several tons are made of aluminum alloys which, as a result of the low specific weight and good anticorrosion properties have become widespread.

Synthetic materials, including in combination with metal, are used when manufacturing buoys having low buoyancy. A number of American companies are producing series of standardized buoys with buoyancy from tens of kilograms to several tons made of aluminum alloys. In order to increase the buoyancy, several such buoys are installed.

One of the important problems arising when developing marine buoys is protection of their hulls from corrosion and fouling. As a rule, the hull of the buoy is covered with special antifouling paints. The operating time of the buoy is 1 to 2 years depending on the region of installation (in tropical regions no more than 6 to 8 months). However, the antifouling paints, in addition to the limited service life, have other deficiencies: they contain up to 90-95% toxic materials and only 5-10% film material. The toxic materials have ionic particles which promote electrolytic corrosion as a result of which it is necessary to apply an additional layer of anticorrosion coating between the antifouling paint and the metal.

The American company V. F. Goodhard has proposed a method of protecting the metal hulls of the buoys from fouling and corrosion by using rubber plates with a special composition which are glued to the metal structural elements operating in the submerged state. By a special process, toxic materials are introduced into the rubber which stay in it for a long time. Such coatings have an entire series of advantages by comparison with paints. Their service life increases to 5-7 years and can be regulated by the thickness of the rubber plates and the amount of toxic materials introduced into it. The coatings are inert with respect to the hull material and simultaneously serve as additional protection for the buoy. Their cost is 1.5-2 times more than the cost of the ordinary paints.

An effective protective coating for buoys is used by the "Hagenuk Company (Federal Republic of Germany). Zinc layers are applied to the hulls of the buoys made of aluminum and other metals by hot deposition. This coating reliably protects the buoy hull against corrosion and, simultaneously, as the use of them has demonstrated, against biological fouling. It turned out that individual organisms attached to such hulls soon are washed away with the water. The coatings are estimated to last 1 year, after which they can be renewed.

In recent years a number of coatings have been developed on the basis of epoxy resins which demonstrate good operating qualities.

Anchor Line. One of the most responsible elements of the station, especially with surface anchored buoy, on which its "viability" depends to a high degree, is the anchor line.

At the present time both steel wire cables and cables made of synthetic fibers are used. The advantages of the former must be considered to include high strength with comparatively small diameter, which is very important for its hydrodynamic resistance to the frontal component of the current and small elongation under load.

A disadvantage of them is that they are subject to corrosion. The fact is that oceanologists are using ordinary lines designed for industry. Seawater usually washes away the lubricant and destroys the zinc coating. As practice has shown, the service life of galvanized steel cables in the equatorial regions does not exceed 1 to 1.5 months. First of all the upper part of the cable is damaged under the effect of the corrosion.

A number of foreign companies are producing sections of steel cable with nylon or urethane coatings, which greatly increase the service life.

These sections have tips which permit them to be joined together. Such a cable can also be used as the cable for data transmission from the hydrologic instruments.

The deficiencies of the steel cables must be considered to include high mass and, consequently, inertia, as a result of which they experience large dynamic loads in the presence of wave action. This frequently is because of breaking of the strands of the cable near the point where it is attached to the buoy. As a result of untwisting of the cable, redistribution of the load takes place on individual strands and there is a significant reduction in strength.

When installing the ABS at great depths in order to reduce the mass, cables of variable cross-section are used with smaller diameter at the bottom. This permits more uniform distribution of the load with respect to length of the cable and improvement of its operating conditions. As a result of the low tension the metal cables are especially convenient when installing ABS.

With the appearance of cables made of synthetics, the qualities of the anchor systems improve significantly. One of the basic advantages of synthetic cables is their low specific weight, close to 1. As a result of this, the carrying capacity of the supporting buoy is decreased, which permits the use of a cable of one diameter for installation. The lifgt weight and, correspondingly, low inertia lower the dynamic loads occurring on the cable during waves. The lines made of synthetics are not subject to corrosion. Their elasticity permits the ABS to be installed without "slack" in the line. Thus, when searching for the submarine "Thresher" at a depth of 2.5 km six ABS were installed. A 14-millimeter nylon rope was used as the anchor line, the length of which considering the stretching was 15% less than the depth.

Until recently nylon and dacron lines have been the most widespread. Polypropylene lines having little elongation and positive buoyancy are rarely used, for at low temperatures they reduce their strength. Cables made of fiberglass, in spite of high strength (to 35 tons/cm^2) are easily damaged under mechanical effects. The recommended load of dacron and nylon lines is 20% of their rupture strength. The elongation for dacron will be about 6% in this case, and for nylon, 20%.

For optimal loads corresponding to 20% of the rupture strength, the service life of the anchor line made of synthetic materials is estimated at 1 year. In the case of an increase in load to 85%, this time is reduced to a week. However, during operation of the ABS, all the cables are damaged by marine life, especially at depths to 1000 meters. Therefore, it is recommended that steel cable be installed here.

A synthetic line made of Kevlar aramide fiber developed in the United States has the strength of steel and the lightness of nylon. The results of the operating tests run on the cables and lines made of this fiber have demonstrated the prospectiveness of its application as anchor line for the ABS [1].

When installing ABS with a surface buoy in order to decrease the dynamic loads on the anchor line, "slack" is left. In the absence of currents, part of the line lies on the bottom, and loops form in it. With subsequent stretching of the line, its strands are broken. In case of installing ABS on steel line, in order to increase the reliability, a section of chain is installed in the lower section. When using the cables made of synthetic materials, a section is installed which has positive buoyancy.

In spite of the intensive search and effort applied by the developers to the creation of reliable anchor lines, they remain as before the most vulnerable part of the buoy stations.

In practice the time of installation of the ABS is determined by the reliability of the line.

Bottom Anchor. As the bottom anchors for the ABS, cast iron cast segments, chains, Stimson and Danforth anchors and also anchors which are buried in the ground by using explosives are used. In contrast to the ordinary installation of a station on an anchor in shallow water when installing the ABS at depths, a small scope angle of the anchor line is formed which has a negative effect on the holding of the anchor in the ground. Under the effect of waves, it is possible for the anchor to pull loose from the ground and for the station to drift. In order to avoid this, an anchor is used in the form of anchor chains or sectional anchors with distributed load. They are made up of several cast iron segments connected in series by segments of chain or cable, as a result of which the probability of complete separation of the anchor from the ground or breaking of the line is reduced.

Cable Release. Reliable holding of the anchor in the ground which an effort is made to achieve when installing the ABS complicates removal of the station. In the majority of cases, the station anchors are buried in the ground, and when they "jerk" on the line, large dynamic loads occur which lead to breaking of the line. Therefore previously usually a weak link was installed in the lower part of the line near the anchor. In case of overload this element broke, and the line with the instruments was brought on board. At the present time instead of the weak link, cable releases are used, among which the most widespread are the hydroacoustic ones. These releases include a mechanical lock with servomechanisms, hydroacoustic receiver, decoder, code instructions and feed batteries placed in the pressure hull. The release usually is installed in the lower part of the cable. The hydroacoustic releases are controlled by means of code signals sent by the ship transmitter. The received signals go to the decoder, after which the drive of the mechanical lock is switched on which disconnects the lower section of the cable fastened to the anchor. The most widespread is the digital coding system using two carrier frequencies. It has high noise resistance and permits a significant number of different instructions to be received.

In order to increase the reliability of the response in a number of releases, the hydroacoustic systems are redundant with time-program devices which activate the release drive after a given time interval. Analogous program-time devices are used in the sunken ABS which must be raised after a given time, for example, when installing the stations under the ice in the winter. In this case the electronic circuits of the release are switched on when raising the station. This blocking excludes the possibility of response from interference, it permits a significant decrease in the energy consumption and the capacitance of the feed batteries. An electronic clock with counting circuits is used as the program-time devices.

Simplified designs of the program-time releases are also used which respond in the case of electrochemical destruction of the stop rod made of magnesium and aluminum alloy. The rate of the electrochemical reaction is given by the electric circuit, and in case of failure of it, only the response time of the release mechanism changes. These releases are used for redundancy of the hydroacoustic releases on the sunken stations.

System for Gathering, Storing and Transmitting the ABS Data. These systems provide for calling the measuring modules by a given program, fixed or variable, the reception of the information from the measuring modules and individual sensors and its conversion to digital code, the storage of the data received on the carriers and their transmission over the radio channel. The basis for the system control is the principle of time programming of the measurement cycles, activation of individual assemblies and modules, the recording systems, the radio transmitting and receiving devices and auxiliary equipment. The program circuit generates the command signals after a given time interval, by means of which a series, sometimes series-parallel interrogation of all of the measuring systems takes place, including the monitoring equipment (see Fig 2).

The measurement cycles, their sequence and priority of interrogation are determined by the fixed program or by instruction from the receiving center. Provision is also made for automatic variation of the measurement regime and the data transmission regime. Thus, during stormy weather the ABS go to the continuous measurement and data transmission mode. The instructions to the measuring modules and also the results of the measurements are transmitted to the data conversion systems and the measuring modules over internal cable communication lines. In a number of cases for transmission of the data from the hydrologic instruments to the buoys, a hydroacoustic channel is used. The results of the measurement are recorded on magnetic carriers, and then they are transmitted during communication sessions or on request over the radio channel to the shore data gathering centers.

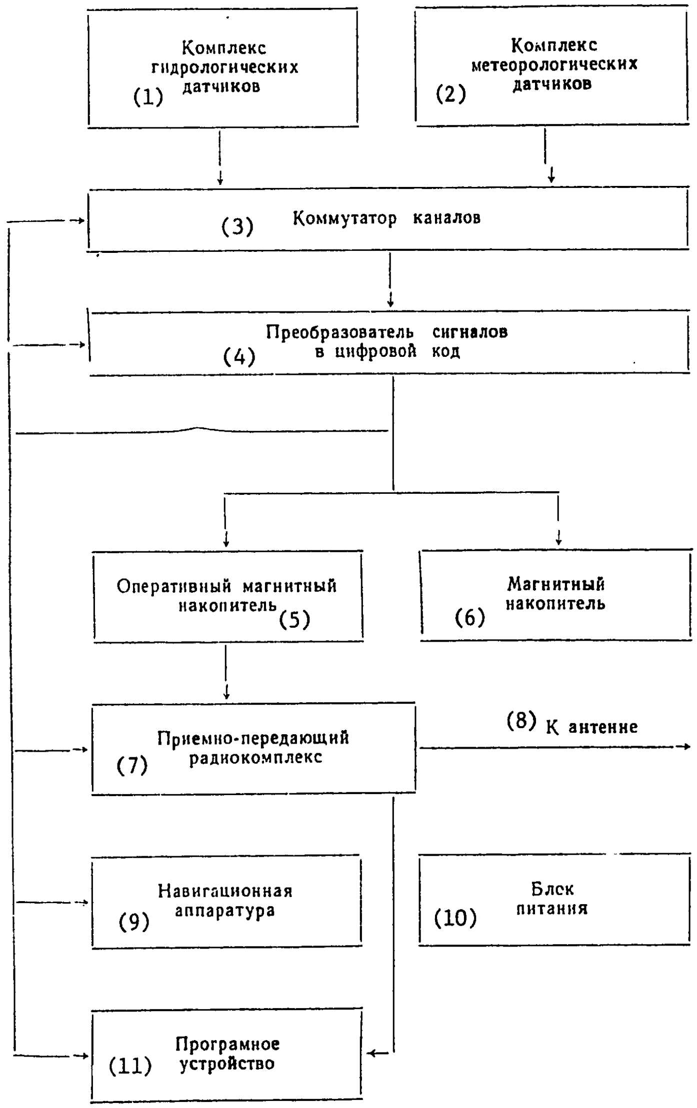

Figure 2. Structural diagram of an automated buoy station

Key: 1 -- set of hydrologic sensors; 2 -- set of meteorological sensors; 3 -- channel commutator; 4 -- signal to digital code converter; 5 -- ready-access magnetic storage element; 6 -- magnetic storage; 7 -- transceiving radio complex; 8 -- to the antenna; 9 -- navigational equipment; 10 -- power supply; 11 -- programming devices

The information is transmitted in the majority of cases in the short wave and ultrashort wave bands on frequencies from 2 to 40 megahertz. In order to increase the reliability of the communications, the large ABS are equipped with multichannel transceiving systems permitting selection of the optimal frequency band, for transmission of signals with a minimum number of errors. The command containing the code signal received by this system from the shore station is relayed to shore where it is checked by computer. In the absence of errors the command is again sent to the buoy as the executive command. After receiving it, the programming circuit of the ABS generates the permission to transmit data recorded in the ready-access memory. In the presence of errors as a result of poor communications the shore center repeats the command in other frequency bands. The data are also transmitted through communications satellites.

Power Supply. Auxiliary Equipment. The autonomous operating times depend on the power supply of the ABS to a significant degree. The direct feeding of the ABS equipment is realized from the storage batteries which must periodically be charged during long-term installations of the station from different generators. As the power supply usually diesel generators, thermoelectric generators operating on liquefied gas are used on the large buoys. The latter, as a result of small size, are also used on the small buoys. A number of radio isotopic devices have been developed which it is expedient to place on the sunken stations where the fresh air supply required for operation of the above-indicated generators is complicated.

The auxiliary equipment includes a navigational complex, which includes the lights, active transponder, a horn which is included when there is fog and also a system for monitoring the operation of the units generating the electric power, and the condition of the storage batteries, and so on.

2. ABS with Surface Anchored Buoy

Such ABS are used for performing standard hydrometeorological observations and also for navigational purposes. One of the first hydrometeorological stations which has become quite widespread is the NOMAD station (Navy Oceanographic Meteorological Automatic Device) (United States). For 25 years the stations of this design have been operating successfully in various parts of the World Ocean. The carrier buoys of the station is made of aluminum in the form of a boat 6 meters long and 3 meters wide. The buoy weighs 20 tons. Inside the hull which is divided into 12 compartments are the measuring equipment, the radio and power supplies. A set of meteorological sensors and an antenna are installed on the masts of the buoy.

During operation the station was modified significantly. Initially it measured the atmospheric pressure, speed and direction of the wind, the temperature of the air and the surface layer of the water. Subsequently, the measuring equipment included a chain of heat gauges for measuring the vertical temperature distribution of the surface layer of the water. A system was installed for transmitting the data through an artificial earth satellite and also a system for rocket sounding of the troposphere to a height of 7 km. A rocket launched from the station measures and transmits data on the vertical temperature profile, pressure and relative humidity of the air during its descent on a parachute, which are recorded and then transmitted jointly with the hydrometeorological information to a shore station. The communications sessions are held four times a day, and when the weather becomes worse every hour [1, 3]. The power of the radio was increased from 1 to 4 kilowatts.

The NOMAD ABS is designed for operation in the shelf zone. However, the stations were also installed at depths to 4-5 km. The time of their operation without repair was 8 months. The "Monster," XEPB-1, EEP, PEB buoys developed by the General Dynamics Company (United States) are used to install the ABS in the deep ocean. The buoys of the Monster type underwent successful testing under unfavorable weather conditions in the open sea in 1964 to 1966. The most vulnerable element turned out to be the anchor system. Although the station withstood hurricanes in which the wind velocity reached 100 miles/hour, and the wave height reached 15 meters, the operating time of the anchor line turned out to be less than planned (less than 1 year).

The installation of the station on a steel cable turned out to be unreliable, and the cable was replaced by a combination cable -- dacron-polypropylene.

The "Monster" type buoy was used as the basis for developing the XEPB-1 ABS. The hull of this buoy was welded from 12-mm sheet steel and was in the shape of a disc 12 meters in diameter with truncation in the lower part. The displacement was 100 tons. A 12-meter mast was installed on the buoy, which is the support for the antenna and simultaneously the ventilation and exhaust pipe of the internal combustion engine. Meteorological sensors and a powerful navigation xenon tube were fastened to the mast. The buoy was divided into 16 watertight compartments. In four of them there were generators and electronic equipment, eight were filled with foam plastic, and in four there were ballast tanks with seawater.

The ABS was designed for autonomous operation for a year, and can be installed in practice at any depths. The station equipment makes it possible to connect up to 100 oceanological and 10 meteorological sensors. The underwater measuring complex includes depth, temperature and salinity gauges. The containers with the measuring sensors can be installed on the anchor line at a depth to 3000 meters. In each container there are three sensors, an analog signal to frequency converter and battery feed. The interrogation and inclusion of the individual sensors are carried out by command from the buoy; the anchor cable is used as the communications line. The input of the data to the communication line from the underwater sensors and the command signals from the surface buoy is realized by the method of inductive coupling using special transformers with split core. The signals received on the buoy are filtered, converted to original code and recorded.

The sensors installed on the buoy mast measure the direction and velocity of the wind at a height of 5, 10 and 15 meters from the water surface, the magnetic heading, atmospheric pressure, solar radiation, temperature of the seawater at the surface, the dewpoint and the dry air temperature. In addition, the acceleration of the buoy vertically is determined, the slope angles and angular velocity are recorded. These data are used to determine the wave characteristics. The speeds and directions of the current in the surface layer of the ocean are also recorded. The current sensors are fastened to the bottom of the hull of the buoy approximately 1 meter below the surface (Fig 3).

The readings of the meteorological sensors are represented as an analog voltage which is converted to an FM-signal, and then to a 12-bit binary code. In connection with the limited capacity of the power supply the station transmits only part of the gathered information, which is primarily needed to compile meteorological forecasts. Long-term ready-access magnetic memory modules are provided on the station. The memory size is designed to store the information gathered by the station over the entire operating period. The ready-access memory stores the data gathered in the last 24 hours. The equipment installed for gathering data from the sensors can execute up to 20 different commands: change the interrogation rate of the sensors, perform selective interrogation, and so on. The buoy output over radio waves takes place on command from a shore station. For greater flexibility provision is made for the possibility of communication on 6 bands in the frequency range from 3 to 30 megahertz. The power of the transmitter is 1 kilowatt. The telemetric system provides reliable communications within a radius to 4500 km, using high frequencies and ionospheric reflection.

The station is powered by nickel-cadmium storage batteries which are periodically charged by two generators with drive from the internal combustion engines operating on propane.

Later versions of the XEPB-1 are the EEP buoys (Engineering Experimental Phase) and PEB buoys (Prototype Environmental Buoy) [1]. A reinforced mast without guys with an antenna height of 7.5 meters was installed on the EEP buoy. The total height of the buoy with the equipment on the mast is 11 meters. At the levels 5 and 10 meters from the water surface, gauges are installed both to measure the general radiation, temperature, precipitation, atmospheric pressure, dewpoint, wind velocity and direction.

On the PEB buoys, the set of meteorological sensors is installed only at the 10 meter level.

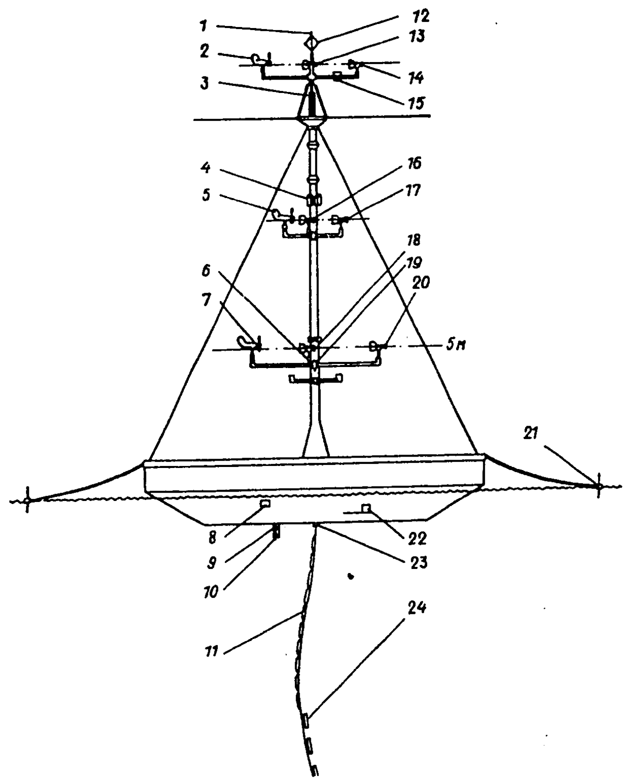

Figure 3. Diagram of the placement of measuring sensors on the alpha buoy station.
1 -- solar radiation sensor; 2, 5, 7 -- wind speed and direction sensor; 3 -- navigational light; 4 -- horn operating during fog; 6 -- barometer; 8 -- precipitation gauge; 9 -- current direction and speed meter; 10 -- water temperature gauge; 11 -- thermistor circuit for measuring water temperature to a depth of 45 meters; 12 -- radar reflector; 13, 16, 18 -- dewpoint meter; 14, 17, 20 -- air temperature gauge; 15 -- rain gauge; 19 -- compass; 21 -- water surface temperature gauge; 22 -- gyroscopic acceleration sensor; 23 -- dynamometer; 24 -- pressure, temperature, salinity gauges (10 instruments are installed at depths from 50 to 500 m)

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When developing the EEP station, special attention was given to reliability and stability of the readings of the meteorological sensors which, as the operating experience has demonstrated, quickly fail and are one of the most frequent causes of cessation of operation of the stations.

The hydrological current velocity and direction meters, the meters measuring the temperature and salinity of the seawater, the hydrostatic pressure and the speed of sound are placed in titanium housings which are attached at 12 levels to a depth of 500 meters. For transmission of the data from the measuring modules to the cable, the inductive communications method is used. The power of the measuring circuits is fed from the power supplies in the buoy through the communications line analogously. The data transmission sessions from the ABS take place after 1, 3 and 6 hours and also on request. The buoy is anchored on a synthetic line. For the upper 500 meters an 8-strand dacron cable is used, and in the lower part, a nylon cable. The cable release is connected to the anchor by a chain. The power for the buoy equipment is generated by a diesel generator which periodically charges the buffered storage batteries. The buoy is designed for operation under any weather conditions. The buoy will operate independently for one year. The proposed service life is 10 years. The cost of the station is five hundred thousand dollars.

The DB-1 buoy station of analogous design for installation in the vicinity of the continental shelf has been built and undergone successful operating tests in England. In order to eliminate rotation of the buoy, three anchors are used. Tests have shown that the anchor system can last up to one year in service. The thermomechanical generator operating on liquid propane is designed for 2 years. In order to increase the reliability of measuring the hydrometeorological parameters the sensors are installed in a redundant system.

For the national network of Norway, ABS have been developed with a cylindrical buoy designed for gathering and transmitting hydrometeorological data. The hull is 6.8 meters long and 0.8 meters in diameter. It is made of metal and fiberglass. The positive buoyancy of the buoy is 2 tons. The equipment weights 0.7 tons. In the hull of the buoy there is electronic gear, a transceiver and hydroacoustic station. The station is powered from dry cells designed to operate for 8 months. The hydrologic sensors are included in autonomous containers which have their own power supplies. The information received from these pickups is transmitted over the hydroacoustic channel in digital code to the carrier buoy and is then relayed by radio.

3. ABS with Sunken Buoy

On the ABS with surface buoy during measurements in stormy weather as a result of vertical displacement of the cable, sharp distortion of the readings of the instruments suspended on it takes place. The submersion of the carrier buoy permits this to be avoided. In addition, the ABS with sunken buoy can be installed in the areas covered with ice in the winter and removed after the ice thaws. The absence of dynamic loads on the cable caused by surface waves will permit significant decrease in the positive buoyancy of the carrier buoy and use of lighter anchor systems.

The deficiencies of this type of buoy include the impossibility of measuring the hydrometeorological and hydrologic parameters in the upper, most active layer of the water above the buoy and the absnce of radio communications. All of the information gathered by the station is stored on recorders and is available only after raising the buoy.

These stations have become most widespread for scientific research work and measuring the hydrologic parameters in icy regions.

The installation system is like that of the ABS. Special attention is given to the anchor lines which must not change their length during operation. The cable releases for disconnecting the bottom anchor must have increased reliability. In a number of cases they are redundant. In order to detect the stations, hydroacoustic transponders are installed on them which frequently coincide with the cable releases.

4. Combination ABS

Quite frequently in recent times combination ABS are used with sunken and surface buoys. The removal of the carrier buoy from the surface wave zone makes it possible significantly to simplify its structural design and that of the anchoring system. The basic measuring equipment, the power supplies and the data gathering and storage system are concentrated in the carrier buoys. As a result, the surface buoy, which is relieved of the greater part of the load, can be significantly decreased in size, as a result of which its hydrodynamic drag is diminished. The set of hydrometeorological sensors and radio transmitter with antenna are installed on the surface buoy. The communications of the sunken buoy with the surface buoy are over the cable.

One of the most successful systems of this type must be considered to be the combination ABS built in France. As the surface buoy, the L-55 marker buoy is used which is made of soft plastic and fiberglass. It is 10 meters long, and 0.3 meters in diameter in the central section, together with equipment it weighs 100 kg. In the upper part of the buoy is a pickup unit with a set of meteorological sensors, antenna, flashing light and radar reflector. As the ballast, a container with electronic gear, radio transmitter and batteries is suspended from the lower part. The container weights 275 kg. The basic anchor line is held by an additional spherical buoy which is located at a depth of 15-20 meters with which the surface buoy is connected by a polypropylene cable. This system reduces the probability that the line and the cable will become entangled to a minimum.

The buoy was tested a multiple number of times under unfavorable conditions, with a wind velocity of 100 to 130 km/hr and a current velocity to 4 knots (here the slope of its hull did not exceed 15-20°). The buoy which was installed 1000 km from the coast of France for a month transmitted data via artificial earth satellite. The 5 watt radio transmitter operating on a frequency of 40 megahertz provided communications in a radius of 100 km. In one communications session 12 parameters were transmitted, including the values of the wind velocity and direction, atmospheric pressure, water and air temperature. The Fifth International Oceanographic Commission of the IOC made the decision to use the L-55 buoy in the global ABS system.

5. Drifting ABS

When studying the surface currents and also the hydrometeorological measurements in the areas covered with ice where installation of anchored ABS is impossible, drifting ABS are widely used.

As an example of such an ABS we can consider the "Sea Robin" drifting buoy developed by the General Electric Company. The underwater part of the buoy is in the shape of a cylinder 0.6 m in diameter which in the upper part has a conical expansion 1.2 meters in diameter. In the lower part there is a dynamic shock absorber in the form of a lattice cylinder. The total length of the buoy is 4.3 meters, it weighs 0.7 tons with full equipment. A 3-meter stanchion with antennas and hydrometeorological sensors is fastened to the upper base. In the hull of the buoy there are transceivers, measuring equipment, storage batteries and thermoelectric generator with propane reserve. The buoy has 19 different oceanological, meteorological and measuring and monitoring sensors (Fig 4).

In Canada several drifting ABS have been built with hulls made of plastic and aluminum. The latter turned out to be stronger, easily treated and cheap. The buoy 2 meters long and weighing 90 kg was designed to operate for 6 to 12 months.

Atmospheric pressure and water temperature gauges, a measuring converter, radio transmitter with antenna and storage batteries are installed on the buoy. About 100 drifting ABS were built and launched in 2 years.

In order to determine the location of the drifting buoys, the Omega radio navigation system and the navigational systems connected with artificial earth satellite were used. When working with the Omega system the signal received on the ABS is recorded and then relayed together with the stored hydrometeorological information to the shore center where the buoy coordinates have been calculated. The accuracy of determining the location by the automatic system is about 4 to 5 km.

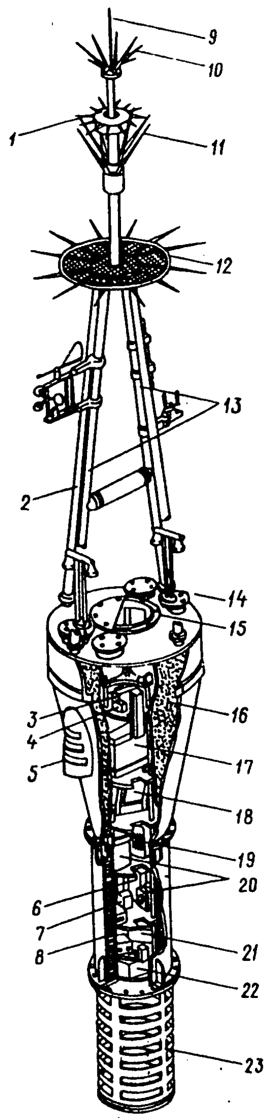

Figure 4. Structure of the "Sea Robin" drifting buoy.
1 -- Zemlya [Ground] ultrashort-wave transmitter panel; 2 -- SW-transmitter antenna; 3 -- USW transmitter transponder; 4 -- communications equipment module; 5 -- cooling system of the thermoelectric generator; 6 -- electronics module; 7 -- heat regulating module; 8 -- tank for storing liquid propane; 9-10 -- USW antennas for transmitting information and satellite communications; 11 -- antenna of the decimeter band transmitter for communications with the satellite; 12 -- "Zemlya" [Ground] panel of the decimeter transmitter; 13 -- short-wave transmitter antenna stanchion; 14 -- thermoelectric generator; 15 -- cover of the removable unit with electronic equipment; 16 -- storage having positive buoyancy; 17 -- remote correlator; 18 -- SW transmitter; 19 -- decimeter transponder; 20 -- measuring converter; 21 -- system for regulating the operation of the thermogenerator; 22 -- storage battery; 23 -- dynamic shock absorber.

The systems based on using the artificial earth satellite are the most prospective. They have small dimensions, weight and cost. The accuracy of determining the buoy coordinates (about 3 km) is entirely adequate for the performed studies. The artificial earth satellites insure reliable communications with the drifting ABS in any parts of the ocean under the most unfavorable weather conditions.

6. Laboratory Buoys

For testing the acoustic equipment and also for prospecting and scientific research work which must be performed from noiseless and low-mobile platforms, a number of manned and autonomous laboratory buoys have been built. These buoys have a number of advantages over the expeditionary ships, as a result of minimum distortion introduced by them into the physical fields and the possibilities of good spatial stabilization.

The manned laboratory buoy BORNA-1 developed by the French Underwater Research Service OERS is executed in the form of a 60-meter tube of variable cross section (1, 2, 3 meters). The total weight of the buoy is about 250 tons. The underwater part of the buoy is submerged to a depth of 50 meters. This depth can be adjusted by using an air bell located in the lower part of the buoy. In the upper part of the buoy at a distance of 15 meters from the sea surface a superstructure is installed in which the laboratory, the crew compartments for a crew of 4 or 9 people, auxiliary facilities, radiotelephone equipment and diesel generators are installed.

The flat cover serves as a helicopter pad. Sensors for gradient observations are placed on the signal mast.

The underwater laboratories are in the central part of the buoy. In the laboratory there are windows for observation and structures for taking samples. In the tube, in addition to the laboratories there are workshops and storage facilities. In its lower section are fresh water and fuel tanks and compressed air bottles. There is an elevator for communication between laboratories.

The operating experience has demonstrated that the oscillations of the buoy even during storms do not exceed 3°, the roll period is 22 seconds.

In the United States at Scripps, a manned laboratory buoy FLIP (Floating Instrument Platform) has been developed and has been in operation since 1962. The bow of the buoy is made, just as a ship, for convenience of towing in the horizontal position to the point of installation. After filling the ballast tanks with water the buoy moves to the vertical position.

The diameter of the lower part of the hull is 6 meters, the upper part is 27 meters long and 3.8 meters in diameter. The buoy is divided into four vertical compartments: the machine room, living facilities, electronics laboratory and compressor room. There is also a laboratory compartment filled with water. The total weight of the buoy with equipment is 590 tons. The displacement in the horizontal position is 1500 tons, and in the vertical position, 2000 tons. Three diesel generators are installed on the buoy (2x60 kilowatts and 1x20 kilowatts). On the above-water platform there are telescopic booms, capstans, winches and other equipment. The buoy is equipped with a navigation system, radar, the Loran radio navigation equipment and special radio equipment. The installed equipment is designed to measure the sound signals, seismic and internal waves, the microthermal structure of the sea, the currents and other parameters of the water environment and the layer of the atmosphere next to the water. The oscillations of the buoy under the effect of waves 1.5 meters high with a period of 11 seconds do not exceed 0.2°. The amplitude of the vertical displacements of the buoy in this case is 4 cm.

The buoy has high sensitivity to vertical loads. Therefore efforts to use it to work oil fields in the open sea have ended unsuccessfully.

On the basis of the experience in operating the FLIP laboratory buoy, the POP laboratory buoy has been designed with smaller dimensions. Its total length is 70 meters, and the submersible part, 55 meters. The buoy weighs 150 tons. The oscillation period on a resonance frequency is 21 seconds.

Scripps has also designed an unmanned laboratory buoy SPAR (Seagoing Platform Acoustic Research) for performing acoustic research. It has a cigar shape. It is 118 meters long and 4.8 meters in diameter. It weighs 587 tons. The displacement in the vertical position with the ballast tanks full at a depth of 92 meters is 1720 tons.

The buoy can rotate around the vertical axis by using propellers to orient the hydrophones during sonar tests. In its upper part are radio direction finding antennas. Along the hull are hydrophones and other instruments, and inside it, electronic gear, pumps, compressors, fuel, a 10-kilowatt diesel generator and storage batteries. SPAR operates jointly with two auxiliary ships: one is used for towing and supplying the buoy with electric power by a kilometer-long cable during measurements, and the other, for transmission of the electromagnetic and acoustic signals in a radius of up to 100 miles.

The signals received on the buoy are transmitted over a cable to the ship for analysis. The period of the vertical oscillations of the buoy on a resonance frequency is 19 seconds. For surface buoys with a period of less than 10 seconds the vertical displacements of the buoy are insignificant.

It is necessary to note that the cost of building the autonomous SPAR laboratory buoy with remote control is almost twice the cost of the manned FLIP type laboratory.

When planning the hydrometeorological networks of ABS a great deal of attention is being given to the problems of their installation, pickup, operation and maintenance and periodic monitoring by special ships. The expenditures on operating the support vessels constitute a large part of the overall expenditures and depend to a significant degree on the technical characteristics of the stations, the duration of their autonomous installation. During planning of the national ABS network of 300 buoys in the United States, the following esimtate was made of the proposed expenditures for its operation for 10 years.

When performing a review of the buoys every 2 months, 28 ships are required to service the network. The cost of their operation will be $3.4 billion. With an inspection interval of once every 6 months the number of ships decreases to 9, and the expenditures, to $1.8 billion. With annual, unmonitored operation of the ABS, five ships are required, and the expenditures drop to $0.8 billion. [2].

In spite of such a significant expenditure, the buoy stations and laboratories will be further improved; new designs will appear, for they are a necessary part of the global system for studying the World Ocean.

An increase in operating reliabilty of the ABS requires the solution of an entire series of problems. One of the main problems is improvement of the installation complexes of the "buoy and anchor system." The creation of special lines and cables and methods of fastening the measuring equipment to them, improvement of the hydrodynamic characteristics of the buoys as a result of using new structural materials and reducing the mass of the anchor cables will permit the "viability" of the ABS to be increased.

The application of new electronic equipment will offer the possibility of sharply decreasing the dimensions, mass and the energy consumption by the measuring devices, which will permit installation of redundant systems on the ABS and at the same time improvement of the operating reliability of the station.

The improvement of the data relay systems via artificial earth satellite will significantly simply the solution of the problems of supplying power to the ABS and increase their autonomous operation.

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SCIENTIFIC RESEARCH SHIPS

[Article by G. K. Krupnov]

Gennadiy Konstantinovich Krupnov, department head of the Central Scientific Research Institute imeni Academician A. N. Krylov, is working on the forecasting of the development of prospective technical means of studying and exploiting the World Ocean -- scientific research ships, floating drilling rigs, support ships, and so on.

Scientific research ships (NIS) have remained for a hundred years the basic means of studying the World Ocean. This noted fact is indirectly confirmed by the distribution of the number of parameters measured by various technical means involved in studying the oceans and seas (see Fig 1).

The proposed diagram borrowed from the book by N. F. Medvedev[1] characterizes not the competitiveness of individual types of technical means (a few parameters measured once is no competition!), but only the possibilities of certain means which primarily depend upon the goals set for them, the composition of the measuring equipment, the speed and other tactical-technical data.

Therefore, for example, the submarine sometimes will not, indded must not, be competition for a ship or satellite. All of the indicated means represent a well-balanced system designed for comprehensive study of the World Ocean, and each of them must have a clear area of application.

Thus, the scientific research ship must be considered as part of the system of technical means designed for all-around study of the oceans and seas.

The primary function of the scientific research ship is the gathering and primary processing of information about the World Ocean, the atmosphere above it, the structure of its bottom and also the flora and fauna. Accordingly, the scientific research ships are performing the following basic research:

Hydrologic (determination of the temperature on various horizons, the speed and direction of the currents, transparency, turbulence, and observations of wave aetion);

Hydrochemical (taking water samples and further analysis of them for the content of the various components, determination of salinity, and so on);

Geophysical (measurement of the magnetic, gravitational and electric fields, performance of seismic exploration and radiometry);

Geological (taking soil samples and subsequent analysis of them);

Hydroacoustic (study of the laws of propagation of sound in seawater);

Hydrographic (the performance of marine and coastal measurements, compilation of maps and navigational directions, servicing of the navigational buoyage system);

Meteorological (determination of the air pressure and temperature, wind direction and velocity, humidity, solar radiation, and observation of clouds);

Biological (observation of the flora and fauna of the sea).

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[1] N. F. Medvedev, SUDA DLYA ISSLEDOVANIYA MIROVOGO OKEANA [Ships for Studying the World Ocean], Leningrad, Sudostroyeniye, 1971.

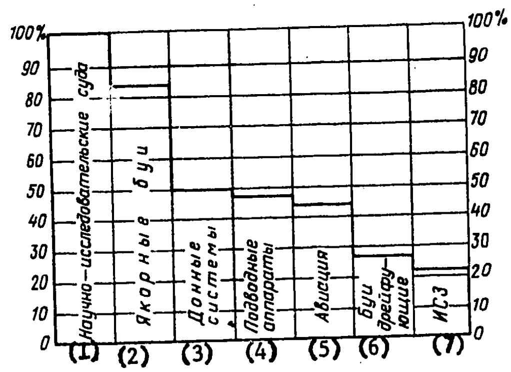

Figure 1. Volume of research of the World Ocean (%) performed using various types of technical means

Key:
1. Scientific research ships
2. Anchored buoys
3. Bottom systems
4. Submersibles
5. Aviation
6. Drifting buoys
7. Artificial earth satellite

The construction of the scientific research ships has developed in two directions. Approximately until the 1960's the scientific research ships were considered only as means of locating the required equipment, apparatus and scientific personnel. For research purposes transport, fishing and auxiliary ships were used. During this period the planning and design of the scientific research ships in general were not carried out inasmuch as the proposed ships only required further equipment.

This situation to some degree satisfied everyone inasmuch as the equipment used at that time was highly primitive, it was not assembled into measuring systems, and the requirements of measurement accuracy remained low. Increasing the requirements imposed on the information about the processes occurring in the oceans and atmosphere over the oceans, as a result of the development of science, industry and even agriculture (in the final analysis the harvest is also influenced by the number of scientific research vessels participating in the gathering of information to compile weather forecasts), involved complication of scientific research equipment, the appearance of theoretically new models of it and the improvement of the methods of performing the research.

Accordingly, it was necessary to reexamine the requirements imposed on the scientific research ships.

Beginning in the 1960's, all of the leading maritime countries began to create scientific research ships by specially developed designs, and today the reequipment of the ships that were built for other purposes to become scientific research ships is not the rule, but a rare exception. Since that time it is possible to talk about the appearance of a new class of vessels -- scientific research which were not similar to any other type of ship.

Inasmuch as the specially designed scientific research ships are of the greatest interest, below we are talking about them exclusively, and the statistical date will be presented basically by the ships constructed after 1960.

Until recently there has been no generally accepted classification of scientific research ships which is caused by a significant number of problems solved with their help. However, depending on the composition of the basic equipment and, to some degree, the departmental ownership of the ships they can be subdivided provisionally into the following: oceanographic, hydrometeorological, geological-geophysical, hydrographic, hydroacoustic, biological and scientific-fishing.

When investigating the proposed classification, a justifiable question can arise: and where are the carrier ships for the submersibles? Modern submersibles can be considered as expensive and highly complex scientific research equipment inasmuch as they in practice cannot operate normally without a carrier ship. The set of laboratories available on such a ship is designed for operations thematically connected with the problems solved by the equipment. Therefore it is sufficient to add the words "submersible carrier" to the definition of ships by purpose so that the structural peculiarities of the given vessel can be isolated.

In contrast to the classification of ships of the transport or fishing fleets where not only the purpose but also the architectural-structural type are taken into account when determining the class of vessels, the scientific research ships are divided up only with respect to purpose inasmuch as the architecture of the various types of scientific research ships can be very similar.

Table 1 gives information about some of the scientific research ships built in the 1970's.

Before considering the peculiarities of the scientific research ships, let us try to formulate the basic general requirements which they must satisfy.

The scientific research ships must first of all have good seakeeping capacity, especially when the ship moves at low speed or is adrift.

Table 1

Basic Characteristics of Scientific Research Ships

Characteristic	"Hollis Hedberg"	"La Suroit"	"Shoye"
Owner country	Canada	France	Japan
Year built	1974	1975	1972
Purpose	Geophysical research	Complex oceanological research	Hydrographic and oceanographic research
Displacement, tons	1700	1090	1960
Length, meters	61.6	56.3	80.0
Width, meters	12.8	11.0	12.3
Hull height, meters	5.6	6.3	6.5
Laboratory and special facility area, m^2	130	65	-
Type of power plant	Diesel	Diesel	Diesel
Power of the power plant, hp	2x1950	2x825	2x2400
Speed, knots	14.0	14.3	17.4
Navigational range, miles	9000	8500	12000
Navigational capacity, days	60	-	40
Number and power of thrusters	-	1x200; 1x150	1x310
Type of roll dampers		Passive tanks	

*Deadweight indicated
**The Hayes is a catamaran, maximum beam indicated.

The fact is that 50 to 80% of the trip time such a ship either is operating at low speed (with towed systems) or makes so-called stations, that is, operations are performed from it with a launch unit. In addition, the ship must be adapted to perform scientific research with force 5 seas, desirably, even for force 6. The given requirement follows from analysis of the probability distribution of encountering waves with different intensity in the ocean. If the ship is suitable for performing scientific work to force 4, then almost half of the time set aside for research it will be idle waiting for improvement of the hydrometeorological conditions. The possibility of performing operations at force 5 waves reduces the idle time by almost threefold, and for force 6 waves this time in practice is close to zero. The further improvement of the seakeeping qualities of the ship is inexpedient for the probability of meeting waves with an intensity of force 7 in the ocean and higher is low, and the difficulties in operating under such conditions are obvious. This requirement is met by applying various roll dampers.

Table 1

Built in the 1970's

"Tudeman"	"Polarbjern"	"Professor Sidletski"	"Explora"	"Hayes"
Holland	Norway	Polish People's Republic	Federal Republic of Germany	United States
1976	1975	1972	1973	1971
Hydrometeorological research	Oceanographic research	Fishing research	Geologic-Geophysical res.	Hydrographic & oceanographic res.
2980	600*	1100*	1900	3270
90.2	42.4	89.3	72.6	75.2
14.4	11.5	15.0	11.8	22.9**
7.3	6.1	6.6	6.5	
–	–	–	-	350
Diesel-electric	Diesel	Diesel-electric	Diesel	Diesel
3x1230	1x2495	3x1150; 3x700	2x1760	2x2700
15.0	13.0	14.0	17.0	15.0
15700			12000	6000
63	–	80	90	30
1x450; 1x300	1x300	2x300	Yes	None
				None

These ships must have good handling characteristics in order to support operations with a launched unit and also when navigating near underwater obstacles or in narrows (hydrographic ships). Usually double-shaft propulsion, electric propulsion, active rudders, thrusters and telescopic turning columns are used for this purpose on a scientific research ship.

The scientific research ships, especially oceanographic ships, must be all purpose. By this we mean their adaptability for performing various research without significant reequipment during the period between trips. For satisfaction of this requirement, the necessary platforms, tanks are reserved on the ships, and "standard" laboratories are provided to which various forms of electric power are supplied. Depending on the specific purposes of one trip or another, interchangeable equipment is installed on board. Recently "removable" laboratories have been used on certain ships in which the equipment is set up on shore and then the laboratories are installed on the ship. Only various cables and pipelines for supplying electric power, water, air and other power components required to support the normal operation of the removable laboratories are laid in advance in the locations where these laboratories are installed on the scientific research ships. The use of such laboratories also permits the time required to fit out the ship for the trip to be reduced.

All scientific research ships must be equipped with modern radio navigational systems, and on some of them it is expedient to install navigational systems using artificial earth satellites inasmuch as the accuracy of determining the location of the ship at sea, especially when performing the studies is to a high degree determined by the reliability and value of the information obtained.

It is no less important to provide for sufficiently expansive open parts of the upper deck on the scientific research ships for placement of the required number of winches and working with cable and line systems of relatively long length.

All the peculiarities of the scientific research ships follow from the requirements which are imposed on them and the specific conditions of their operation.

What are the peculiarities of the scientific research ships?

Hull Shape and Principal Dimensions. The characteristic features of the shape of the scientific research ship hull insuring good seakeeping qualities are as follows:

High freeboard combined with significant flare of the sides forward and sufficiently sloping stem to decrease the wetness and also soften the pitching and improve the rising of the ship on the waves;

V-frames combined insofar as possible with a bulbous bow to decrease the amplitude of the pitching;

Low block coefficient to decrease the loss of speed in the waves and to insure the required draught under the condition of optimal placement of the screws;

Low ratio of length to width required to improve the handling characteristics.

The design experience and the analysis of the elements of the existing scientific research ships indicate that the ratio of their length to width will usually be 4.4 to 5.5, and the width to draught, 2.5 to 3.0, the length to hull height 9.0 to 12.0, and the block coefficient varies within the limits of 0.50 to 0.63.

Architectural Type. With respect to architectural and structural type the scientific research ships can be divided into the following:

With forecastle and long aft superstructure, similar with respect to type to that adopted on fishing trawlers with side trawling;

With bow and bridge superstructure;

With bridge superstructure;

With long forecastle evolving into a bridge superstructure;

Catamarans.

The ships of the first two types have comparatively small open area of the top deck; therefore, part of the equipment is launched from the decks of the superstructures, which increases the danger of impact of the instruments against the side of the ship when rolling, and, consequently, damage or loss of the equipment.

On ships of the third class, the forward and aft parts of the top deck can be used for performing research, but in the case of powerful wave action, one of the open parts of the upper deck, and when lying beam to the sea, both parts of it can be flooded with water, which limits the possibility of operating the ships in the open sea.

Ships of the fourth class are free of the above-indicated deficiencies. On some ships built in recent years the bridge superstructure is shifted to one side, as a rule, to the port side. This nontraditional design has possibly roused unfavorable criticism on the part of some designers, but it has turned out to be highly successful, and the majority of modern scientific research vessels are made "askew." The after part of the top deck and the passage along the bridge superstructure are used on these vessels to perform research. The asymmetric positioning of the bridge superstructure offers the following advantages:

Work areas on the top deck are well protected from the wind and flooding from the bow and one side;

The width of the work area both on the starboard side is increased as a result of eliminating the passage way and work areas on the port side;

Operations with the launched equipment are performed in "clean water," for all of the openings of the overboard systems can be put on the non-working side;

When the ship is adrift it is possible to operate several winches (with their symmetric arrangement relative to the bridge superstructure -- on the sides -- joint operation is in practice excluded inasmuch as entanglement of the lines or cables under the keel of the ship unavoidably leads to loss of scientific equipment);

The communications between work areas on deck and the general organization of the performance of the operations are simplified;

The observation of the operations with the overboard equipment from the command stations is improved.

At the beginning of the 1960's when, as has already been noted, a transition was made to the design of special scientific research ships, the possibility of using ships of the catamaran type which have significant upper deck area to study the World Ocean aroused a great deal of interest. It was calculated that with the same top deck area a catamaran has approximately 50% less displacement and 30% less engine power (with equal speed) than the monohull ship. The attention of the designers was also attracted by such qualities of the twin-hull ship as good stability and handleability.

However, almost 20 years have already passed, and the number of scientific research catamarans is reckoned in units (basically these are small ships less than 25 meters long). What is the matter? Obviously, the deficiencies of catamarans basically are the effect of wave impacts (slamming) in the vicinity of the forward seetion of the connecting bridge and high construction cost as a result of an increase in weight and complication of the hull designs and also the necessity of duplicating a number of mechanisms reduce their advantages to nothing. Nevertheless, it is possible to consider that shipbuilders will find acceptable methods of decreasing the slamming, and therefore it is necessary to recognize this architectural type as prospective for scientific research ships.

Stability and Unsinkability. Scientific research ships must, as a rule, have increased stability, which is explained by the number of facts. In particular, the navigational range of modern ships of the investigated type reaches 15,000 to 20,000 miles, and the navigational capacity, 150 days. Accordingly, it is necessary to have significant reserves of liquid cargo on board the ships -- fuel, water and oil, the total mass of which reaches 30% of the total displacement.

Let us remember that on transport ships this figure is a total of 4 to 8%. As a rule, it is impossible to place such amounts of liquid cargo on a double bottom; therefore fuel deep tanks or side fuel tanks are provided on the ships. The presence of such tanks or deep tanks separated by longitudinal bulkheads can in an emergency lead to serious consequences inasmuch as asymmetric flooding or symmetric flooding is possible, but with high center of gravity of the entering water. The stability is reduced to a significant degree in the presence of free levels, including water in the damping tanks. For example, the presence of passive damping tanks on the Canadian hydrometeorological ship "Vancouver" has led to the reduction in the initial metacentric height by 0.3 meters (by approximately 33%). As a result, the superstructure of the ship must be made lighter -- made of aluminum alloys -- and the thickness of the bottom skin to the bilge stringer increased. When calculating the stability of the scientific research ships it is necessary to consider that on modification of it usually a significant amount of additional equipment is installed above the upper deck.

Therefore the scientific research ship usually has increased initial transverse metacentric height. Its ratio to width reaches 0.08, and for cargo and passenger ships with total displacement, about 0.05.

The unsinkability of scientific research ships is desirably insured when flooding two adjacent compartments at least in the bow, for these ships frequently operate in little-studied regions and there is a danger of going aground. On ships 75 meters long and more with bulkhead deck brought to the forecastle deck in the bow which extends to 40% of the length of the ship, insurance of a two-compartment unsinkability standard does not present special difficulties. The unsinkability when flooding the two adjacent compartments is insured, for example, on the Hekla class English hydrographic ships having a length of 75 meters, 6 watertight bulkheads and underwater hull height of 3.3 meters and also on the "Meteor" ship (Federal Republic of Germany) which is 77.3 meters long, has seven watertight bulkheads and freeboard of 2.2 meters.

On shorter ships this is more difficult to do with respect to the entire ship: it is necessary to break it down into compartments of comparatively small size in which the power plant is placed.

Roll Measurement Means. Scientific research ships with increased stability must have smooth roll inasmuch as sharp roll is felt negatively on the condition of the people forced to work for a long time in the open sea (the trips can last up to 6 months). In addition, in the case of violent rolling, the probability of damage to the equipment increases, the accuracy of the measurements decreases, and in individual cases the performance of certain studies becomes in general impossible (for example, when studying the earth's gravity). It is known that the requirements of increased stability and smoothness of roll are contradictory, for an increase in stability leads to sharper rolling.

The scientific research ships must be designed so that they will have favorable nature of rolling with sufficient stability. This is achieved by the corresponding selection of the hull shape, efficient distribution of the load of the masses and application of various types of roll dampers. As has already been noted, it is especially important to decrease the rolling of the ship when adrift, when executing stations.

An analysis of the means of measuring roll used on ships at the present time permits establishment of the following. The gyroscopic dampers moderate the roll equally efficiently both when the ship is underway and when it is adrift. However, as a result of the large mass, significant intake power and relatively high cost, this type of roll damper has not found application on scientific research ships.

The steerable side rudders operate efficiently only at high speeds, but they are highly complicated to maintain and have relatively high cost. However, as has been noted, scientific research ships are operated a significant part of the time either making small runs or adrift; therefore this type of roll damper also has become widespread.

The active damping tanks effectively moderate the rolling both with the ship underway and adrift, but they require highly complex equipment and additional expenditures of power. Thus, the power of the pump drive for the active tanks installed on the "Meteor" ship is 150 horsepower.

At the present time the passive damping tanks have become the most widespread as means of moderating the roll on scientific research ships.

Quite frequently bilge keels are used, as a result of their exceptional simplicity. However, since the effect of moderating roll is insignificant (to 25%) they are installed on the ships jointly with other types of dampers.

Power Plant. The primary mechanical device of the scientific research ship has high requirements imposed on it: it must provide for maneuvering of the ship both when changing speed and when backing, during sustained stable slow speed (at a speed of 2 to 6 knots) be reliable, economical and simple to service.

These requirements arise from the conditions and the nature of operation of scientific research ships. Let us consider certain types of mechanical devices from the point of view of expediency of their application.

Steam engines, just as steam and gas turbines, are not in practice used on scientific research ships, basically as a result of increased fuel consumption.

In the world scientific research fleet there are only two specially built American ships equipped with a steam engine ("Atlantis-II") and steam turbine ("Surveyor").

The diesel engine which is the most widespread on transport and fishing fleet ships has turned out to be preferable also for scientific research ships, it is true, with relatively small (to 1000 tons) displacement, as a result of low fuel consumption and comparatively small engine room. This type of plan has a serious deficiency: the operation of the diesel engine at low rpm is unstable. This deficiency can be eliminated by using either an adjustable-pitch propeller (then, of course, it will have increased fuel consumption at low speed) or a special slow-running engine (which leads to complication and an increase in cost of the power plant).

The most suitable power plant for the scientific research ship of sufficiently great displacement is a plant with electric propulsion which has the following advantages:

Constancy of the drive engine rpm with variation in the propeller rpm; the engine operates under the most economical conditions with respect to fuel consumption;

The capacity to maintain constant power under any conditions: from free travel to towing, which can be realized both by manual and by automatic regulation;

The possibility in installations made up of several diesel generators of switching off one or several of them and insurance of a high loading factor of the diesel generators, thus increasing the operating efficiency of the entire power plant as a whole.

The DC plants have the first two advantages. In the AC plants the electric motor rpm adjustment with variation in the propeller rpm is realized only by varying the frequency of the current generated by the diesel generators. This implies a change in rpm of the drive engine, which is connected with known difficulties. Therefore the DC electric unit is preferable for scientific research ships.

Let us briefly discuss two types of power plants -- nuclear and ... sail.

It appears highly enticing to use a nuclear power plant as requiring a small quantity of fuel to achieve significant range and navigational capacity. Therefore in various countries of the world in the 1960's designs for scientific research ships with a nuclear power plant were developed.

In 1962 the ENEA International Organization which finances work with civilian nuclear ships in Western Europe, developed a design for a nuclear oceanographic ship having a reactor with a thermal power of 26 megawatts [2]. On this ship with a displacement of about 6,000 tons it was proposed that two steam engines of 3500 horsepower each be installed which provided a speed of 17 knots. The spare 1000 horsepower turbine was provided which operates from an auxiliary boiler on petroleum fuel.

The plans for nuclear scientific research ships have also been developed in the Federal Republic of Germany and Japan, but have not been built to the present time. This is explained by the fact that the nuclear power plant is highly complex and expensive and also requires approximately a 20% increase in the number of crew to service it. In addition, only a low-power plant can be economically justified, and the intake power even for the largest scientific research ships does not exceed 9000 horsepower.

The statements of the French specialists made in the 1960's about the use of sailing ships for oceanographic research are also of interest [1]. In their opinion, the advantage of such ships is economy of fuel (specially under the conditions of the energy crisis), lower cost of construction, operation and maintenance and also the small number of crew by comparison with ships equipped with mechanical power plants. This proposal is unconditionally of interest, but it is beyond the scope of this article.

When designing and building scientific research ships by the developed tactical-technical assignment, as a rule, there are no specific problems that arise with the exception of perhaps the problems of improving the seakeeping qualities of catamarans.

The basic problem when building scientific research ships consists in developing highly accurate automated measuring complexes.

The high cost of building and operating the scientific research ships, which exceeds by 1.5-2 times the cost of transport or fishing vessels of analogous size predetermines the necessity for performing technical-economic analysis when designing them. This analysis permits the selection of the optimal version of the investigated ones. It is performed, as a rule, in the initial design stages, when forming the technical assignment, by the method of operations research, the basis of which is the category of effectiveness by which we mean the relation between the useful effect from one solution or another and the expenditures connected with achieving this effect. It is known that the effectiveness criteria of any technical designs reduce to two: namely, the maximizing of the useful effect with limited expenditures on its realization or minimizing the expenditures to achieve the given effect.

These criteria are equivalent to each other, and the results of the calculations by them must be the same. The basic difficulty consists in calculating the effect obtained from using scientific research ships.

It is more correct to calculate the effect in money; then it is easy to compare with the expenditures required to achieve this effect and to estimate the expediency not only of the technical solutions adopted, but also the creation of one means or another. However, finding the effect in money expressions is connected with significant difficulties which can be illustrated by the following example.

Let headings for the ships of the transport fleet differing from the traditional ones for the given region be recommended as a result of compiling the weather forecast. Let us also propose that it be possible to calculate the prevented losses, considering the fuel economy, timely delivery of the cargo to the recipient, and so on. However, it does not appear possible to determine the development of such recommendations in practice, inasmuch as when compiling the forecast data are used which are also obtained from the shore meteorological stations, aviation and artificial earth satellites.

If we try to carry out such a calculation, it is necessary to make a number of prerequisites and assumptions that can raise serious doubts in the validity of the results obtained. Still greater difficulties arise when calculating the effect from using the scientific research ships for the USSR Academy of Sciences expressed in money.

An interesting statement on this question has been made by A. A. Narusbayev, who classifies the ships as a function of the method of estimating their useful effect: "The second group is made up of ships, the useful effect of which can theoretically not be reduced to economic indexes, although the necessity for the services rendered by them is unquestioned and is caused by urgent social demands, and the services themselves are clearly manifested. Characteristic representatives of this group are the scientific research ships which study the World Ocean, outer space, and so on.

It is obvious that the operation of these ships, consisting in obtaining new scientific information, new knowledge about the material world around us, cannot be reduced only to the economic effect, for scientific progress, especially in the field of basic research, has always provided for and will provide for the achievement of more global purposes than increasing the productivity of social labor during the given historic period.

It is possible to state that in developing science, man is producing the 'intermediate products' for the future, which cannot be fully evaluated by the present generation."[1]

The above-presented arguments appear to be valid, but they are more suitable for scientific research ships used for the so-called fundamental studies of the World Ocean, from which it would be improper to expect an "immediate" effect. For scientific research ships performing applied operations (compiling weather forecasts, exploration and prospecting for minerals), probably it is necessary to estimate the effect in a cost expression in spite of the difficulties that arise.

It is highly tempting to express the effect of using scientific research ships, remembering their basic purpose -- gathering of information about the World Ocean -- in the amount of this information. The information, considering it "infinite," can be summed with respect to individual types of observations (hydrologic, meteorological, and so on). However, the calculations using this criterion can also be complicated. First, there are not always initial data on calculation (the distribution law of the values of the measured variable or characteristic of the equipment can be unknown), and, secondly, the amount of information expressed, let us say, in bits is extraordinary.

Many authors are making efforts to determine the effect from the application of scientific research ships in natural units. Sometimes the number

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[1] A. A. Narusbayev, VVEDENIYE V TEORIYU OBOSNOVANIYA PROYEKTNYKH RESHENIY [Introduction to the Theory of Substantiated Design Solutions], Leningrad, Sudostroyeniye, 1976.

of clocked miles, the developed geophysical profiles, and so on are taken as the product of the scientific research ships, and it is matched to the corresponding expenditures. This criterion suggests a value which is familiar and understandable to everyone, for example, one ton of hauled freight or caught fish. The advantages of this criterion are obvious inasmuch as there is no necessity for a priori establishment of the values of the useful effect, but many specialists consider it among the components, considering the possibility of unobjective compensation for deficiencies in the solution (for example, a small number of measurements) by its advantages (low expenditures) the main flaw.

Thus, the basic problem which arises when designing scientific research ships and, above all, when forming the tactical-technical assignment, is the development of methods of estimating their effectiveness, including the substantiated choice of criteria, the construction of mathematical models of functioning, and so on. Only after calculating the effectiveness is it possible to solve the problems of the optimal speed of the scientific research ship, expedient combination of studies performed with its help and other measures which to a great extent determine the type and size, and that means the cost of construction, operation and maintenance of the ship.

In conclusion, a few words must be said with respect to the trends in the development of the investigated ships or, in other words, what they will be in the year 2000.

In the opinion of the author, the type of scientific research ship which has developed at the present time undergoes no significant changes. The ships will as before be monohull, with relatively small displacement (2000 to 4000 tons), with a limited number of laboratories (no more than 10) having a diesel power plant with adjustable-pitch propeller or electric propulsion equipped with means of moderating rolling and various thrusters. When creating more economical engines it is possible to expect an increase in the speed of the scientific research ships, and on the appearance of economical low-power diesel power plants, scientific research ships with nuclear power plants, although this has low probability. Unconditionally, the measuring systems will be improved on the part of increasing speed and accuracy, equipment will appear which will permit measurements to be taken at high speeds. The latter will also promote an increase in speed of the ships. The "standard" and "removable" laboratories will find broad application.

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PROBLEMS OF UTILIZING RADIO ELECTRONIC EQUIPMENT FOR EXPLOITATION AND EXPLORATION OF THE OCEAN

[Article by V. I. Vinokurov]

Viktor Ivanovich Vinokurov, doctor of technical sciences, professor, specialist in the field of radio electronics, electronic equipment for maritime ships and submersibles, has scientific interest in systems engineering and statistical radiophysics.

Radio electronic devices play a significant role in solving a number of problems connected both with the exploitation and utilization of the ocean and with its exploration. The number of such problems is growing continuously, and this leads to an increase in the concentration of the radio electronic devices on the ships and marine targets, an increase in their intake power and also complication of the joint operating conditions. Accordingly, and also with the necessity of increasing the operating reliability of the radio electronic devices, lowering their weight and size, a number of new problems have arisen which must be solved in the near future.

Before analyzing these problems, let us consider the problems for the solution of which the radio electronic devices are used. In the first approximation it is possible to isolate several types of such problems. It is possible to consider among the problems of the first type the search, detection and measurement of the coordinates of the various targets, for example, ships and other targets (floating and submerged), schools of fish, occurrences of minerals, and so on. Fields of various types are used and created for detection of them. Here the properties of the target in one field or in several must differ significantly from the properties of the environment. For detection of the target in the air, electromagnetic waves are used which include the range of light waves; in the water, acoustic, magnetic, electrical and electromagnetic fields are used.

In order to measure the coordinates of the targets, one or several parameters of the created field (intensity, amplitude, frequency or phase of the oscillations) vary in time. Comparing the parameters of the reflected and the emitted oscillations, the distance to the target is determined. In order to measure the angular coordinates it is necessary to insure emission of the energy within the bounds of a small spatial angle.

The solution of problems of the first type complicates the presence of interference caused by wave (field) reflection from the water surface and bottom and also the propagation of the corresponding oscillations as a function of the condition of the environment (the ocean and adjacent layers of the atmosphere).

The problems of the second type are connected with measuring various parameters and characteristics of the World Ocean, and also the characteristics of the objects operating in the ocean. When solving them, special complexity has been caused by the appearance of characteristics bearing the most information about the investigated phenomena or monitored object and finding methods of decreasing the measurement errors caused by many factors. An increase in accuracy of the measurements is usually connected complication of measuring devices.

The third type problem can be considered to include the realization of communications among the targets and groups of targets with the control center. The problems of this type are realized using electromagnetic, acoustic and light waves and for a number of objects, by cable lines. Their solution complicates the presence of a set of factors which significantly influence the quality of communications and also the interference.

The fourth type problems are connected with orientation of the targets in the ocean. The radio electronic devices play an important role in insuring navigational safety, especially in the areas with intense ship traffic, in narrows, and so on. In order to determine location in various parts of the ocean, radio and inertial navigational means are widely used. For exploration and exploitation of the shelf it is necessary to determine the coordinates of the targets (ships, buoys, towers) in the coastal zone with high accuracy. When solving these problems, the same difficulties arise as when solving the first type problems and also difficulties connected with the necessity for considering the specific nature of the movement of the ships and submersibles caused by the presence of currents, waves and other factors.

The methods of solving problems of each type are varied and depend on the type of object on which the radio electronic devices are installed. Thus, the problems of target detection at a distance of tens and hundreds of kilometers from on board a submersible will be solved by various methods; communications will also be realized differently at distances of hundreds and thousands of kilometers between ships, a ship and base, submersible and support vessel. It is possible to present a number of examples. As the measuring equipment it is possible to use a separate sensor (temperature gauge, current speed meter, and so on) or a converter with auxiliary devices, or an entire measuring system, for example, the specialized radar type for remote measurement of the parameters and characteristics of the waves. Its structure depends on the type of measured parameters.

In spite of the variety of radio electronic devices that solve the above-enumerated problems, they are characterized by common features. The operation of the majority of them is connected with energy emission and the creation of a field in the vicinity of the target. The structural diagrams of the radio electronic devices for various purposes contain circuitry which executes identical functions, for example, signal amplification, radiation, oscillation conversion, logical operations connected with the operation of digital devices, and so on.

The set of radio electronic devices on a carrier will be made up of its radio electronic equipment.

In the radio electronic equipment the interaction of the radio electronic devices with each other (that is, intercommunications when operating) can be varied. It is possible approximately to distinguish three types of interaction.

1. If all of the radio electronic devices are designed for the performance of one or several operations, then their operation is interconnected and is carried out with respect to a single program. The set of radio electronic devices is also called the radio electronic complex. When using such a complex it is necessary to consider the mutual effect of the radio electronic devices which is expressed primarily in the appearance of mutual interference. This interference upsets the operation of the individual radio electronic devices and also their interaction.

2. If the radio electronic devices are designed to solve various non-interrelated problems, then they function independently of each other. However, this does not mean the absence of mutual effect, that is, mutual interference.

3. If the interrelation between the operation of the radio electronic devices is weak or if part of the devices make up a complex which operates by a united program and the remaining operate independently, then in this case the appearance of mutual interference will also be noted.

This type of interaction occupies an intermediate position between the first two.

A characteristic feature of the modern radio electronic equipment is the widespread use in it of computer and information engineering means.

As the problems solved when exploiting and exploring the ocean become broader and deeper, the radio electronic equipment of the objects, ships and submersibles for various purposes becomes complicated, and the requirements on it increase [5, 6].

At the present time the radio electronic devices designed for operation under sea conditions must: function with required accuracy and efficiency for the given time interval; be stable with respect to external effects and have minimal size and weight.

The radio electronic devices on the submersibles and autonomous carriers must also consume minimum power.

Today such problems as efficient (optimal within the limits of the established criterion) structure of the radio electronic equipment, insurance of joint operation of the radio electronic devices (electromagnetic compatibility -- EMC), and the combination of them are also arising.

Let us briefly consider the enumerated problems.

It is possible to provide for the performance of defined operations by a marine unit by various methods, calling on radio electronic devices that differ with respect to purpose, composition and output parameters for this purpose. Consequently, there can be several versions of the structure of the radio electronic equipment.

For example, the prevention of collisions of several marine objects which maneuver in a defined area can be provided for by using detection stations installed on each of them and operating independently of each other or by means of a detection station installed on one of them (or even on shore) and transmitting information about the navigational situation over the communication channels. The composition of the radio electronic equipment and the characteristics of radio electronic devices will be different in each case. It is necessary to determine the efficient (best within the framework of the established criterion) structure of the radio electronic equipment providing for execution of defined operations by the marine object with given quality. For example, the criteria can be the least cost of the radio electronic devices entering into the equipment, minimum power consumed by simultaneously operating radio electronic devices; least frequency band occupied by the spectra of the signals emitted by the radio electronic devices, and so on.

The solution of this problem is connected with great difficulties, in particular, with the complexity of installation of the generalized functional and even statistical relation among the functional characteristics of the radio electronic devices and the weight, size, intake power, and so on; complexity of the comparison of the structural versions of the radio electronic equipment with each other with respect to generalized characteristics, and so on.

The second problem -- the provision for joint operation of radio electronic devices used for various purposes (radio engineering, acoustic) -- is referred to as the EMC (electromagnetic compatibility) problem. Increasing the number of means on the ships and other marine objects has led to the necessity for considering mutual effect, that is, mutual (unforeseen) interference which these devices create on each other in reference [3]. Here the effect on the radio electronic devices that transmit the information (emitters) and on the information receivers and processing units and, in a number of cases, also the channels of penetration of mutual interference (air or water, the power supplies and circuitry, and so on) is possible.

When analyzing the electromagnetic compatibility it is expedient to consider the groups of radio electronic devices of two types. The groups of the first type made up of radio electronic devices which are functionally connected to each other, and the second type, in which the radio electronic devices are not functionally connected to each other and carry out different missions, are in the mutual effect zone. When analyzing the groups of the third type, it is possible to reduce them to the second.

In the groups of first and second types, the mutual effect of radio electronic devices depends on the parameters characteristic of each means (the transmitted power, the working frequency, the frequency band of the emitted signal spectrum, the level of such emission, and so on) and called the EMC parameters. The set of EMC parameters can be broken down into two subsets (in general case intersecting) with respect to the attribute of their effect on the quality indexes of the functioning of the individual radio electronic devices. The first subset includes the parameters, variation of which can involve variation of the quality of the functioning of both the given means and the quality of operation of their radio electronic devices in a group. The parameters of the given set are provisionally called organizational.

The second subset includes the parameter, the variation of which improves the operating quality of certain radio electronic devices and does not reduce theoretically to a negative effect on the operating quality of the ballast. They can provisionally be called technical.

Accordingly, the organizational and technical methods of supporting the EMC are provisionally distinguished with this division of parameters. The organizational methods are divided into centralized and combination. The centralized methods presuppose the presence of the control functions at a single center which assigns the numerical value of the organizational parameters to each of the radio electronic devices. The decentralized methods are based on the presence of the control functions in each individual medium. The combination methods provide for the combination of both types of control methods.

The enumerated methods of supporting the EMC are based on deterministic or stochastic models of the operation of the groups of radio electronic devices which do not always provide optimal solutions under the conditions of the complex and nonstationary electromagnetic situation. Other approaches are necessary, one of which is adaptation (for example, with respect to frequency, power, polarization, and so on) of each of the radio electronic devices.

In order to support the EMC it is necessary to define the criteria (indexes) which would be the numerical characteristics of the mutual effect of the radio electronic devices. A united criterion of the EMC defining the operation of all of the radio electronic devices in the group can rarely be introduced. Therefore frequency criteria are introduced which characterize the compatibility of the individual radio electronic devices in the group. The number of such criteria is equal to the number of devices.

Each special criterion depends on the EMC parameters: the operating frequencies of the radio electronic devices, the power transmitted by them, the gains of the transmitter and receiver antennas, and so on and also the external parameters: the oscillation propagation conditions, the presence of side reflectors, and so on.

The problem of insuring the EMC can be formulated as finding the compatibility parameters which will make the index a maximum (minimum) for the given external parameters or will insure a value of this index no less than (no more than) the given one. The compatibility index is a complex function of the parameters of the EMC, which in the general case have many maxima (minima), of which one is global.

Let us consider the case of insuring compatibility when the operating frequency of each radio electronic device in the group can vary as a function of the mutual interference level. Let the set of frequencies exist in which the work is possible and also the compatibility index which characterize the functioning of the given radio electronic devices in a group. The purpose of adaptation is finding the value of the operating frequency during the process of functioning of the radio electronic devices for which the compatibility index is maximal (minimal). In order to find the extremum it is possible to propose the set of adaptation algorithms realized by the automata of various types. When giving the specific values of the possible operating frequencies a convenient model of the adaptive (training) circuit is the finite automaton. Let us discuss the simplest version of the finite automata with binary input alphabet [4]. The operating principle of the automaton consists in the fact that when realizing random wandering with respect to a set of values of the frequencies, it establishes the one for which the probability obtained is the highest (see Fig 1). The entire system (the radio electronic devices and the adaptation module BA) will have purposeful behavior in the probability of "gain" obtained by the automaton for the executed act (operation in a specific frequency) is monotonically connected with the quality index. In order successfully to use the finite automaton in the adaptation process, it is necessary to match its input alphabet (the set of possible signals at the input) to the output alphabet of the quality index meter (IPK). This can be realized as follows. Let us map (monotonically) the set of admissible values of the quality index on to the interval 0,1 by using the functional converter. If we place a random variable ("gain") with the probability of appearance equal to the output value of the functional converter in one to one correspondence to each value of this interval, then it is possible to solve the problem of matching the output alphabet of the quality index meter to the input alphabet of the finite automaton. This matching is realized using a controlled random number generator (UDSCh) which forms the "gain" with probability equal to the values of the output signal of the functional converter and the "gain" with additional probability.

Thus, with the corresponding selection of the quality index of the functional converter and the automaton, the radio electronic device equipped with the adaptation module will operate predominantly on the frequency for which the quality index is minimal (maximal). The gain obtained as a result of adaptation depends on the specific situation and can fluctuate from 0 decibels (all of the operating frequencies are equivalent with respect to the quality index) to the maximum, which corresponds to operation on the optimal frequency.

For solution of the compatibility problems, the adaptation of the power emitted by each radio electronic device is of interest, that is, provision for operation of the given radio electronic devices with given quality with the least magnitude of the emitted power. Analysis shows that even in this case it is possible to expand the possibilities of joint operation of the radio electronic devices. One method of estimating the effectiveness of adaptation can be comparison of the number of situations in which joint operation is insured in the presence of adaptation of power with the number of situations in the absence of it. The analysis of the gain is conveniently made on the basis of the compatibility criterion using the above-investigated models of the EMC. The possible conditions of joint operation of the radio electronic devices can be given by the set of coefficients C_{12}, a_{21} entering into the compatibility criterion (see Fig 2). Each situation corresponds tothe defined values of the coefficients C and a. The rectangular region bounded by the coordinate axes and the straight lines 1, 2 corresponds to the situation in which the systems are compatible both in the absence and on introduction of adaptation. The region bounded by the coordinate axes and the curves 3,4 correspond to the situations in which the systems are compatible only in the presence of adaptation. The number of situations in the latter case increases by more than a third.

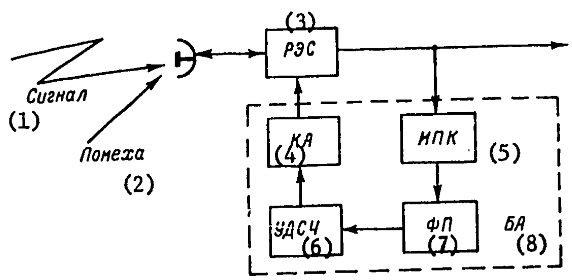

Figure 1. Structural diagram of radio electronic devices with a finite automaton

Key:

1. Signal
2. Interference
3. Radio electronic devices
4. Finite automaton
5. Quality index meter
6. Controlled random number generator
7. Functional converter
8. Adaptation module

The adaptation of the power of the radio electronic devices entering into the equipment of individual objects promotes lower mutual interference level penetrating through the circuit power supply. The mutual interference of the given type can be significant for marine units equipped with low-power power supplies.

The effectiveness of the EMC method is determined in the final analysis by the ratio of the gain in functioning and expenditures on implementation of the method. The effectiveness criteria can be varied.

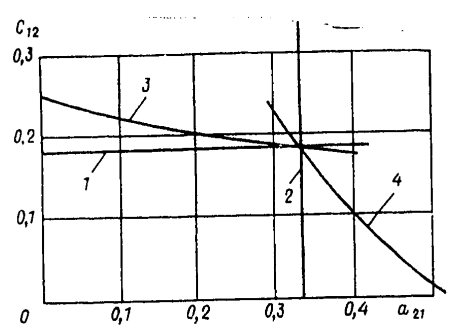

Figure 2. Results of estimating the joint operation of the group of radio electronic devices made up of two detection systems

The third problem -- putting together the radio electronic devices -- is connected with improving the operating quality of the individual radio electronic devices entering into the radio electronic equipment. By complexing we shall mean the construction of radio electronic equipment in which the radio electronic devices (or individual circuitry) can be combined in various combinations providing for the best execution of the mission (by the established criterion). The purpose of complexing can be, for example:

An increase in reliability of detection or accuracy of measurements;

Improvement of the operating reliability;

Solution of new problems which cannot be provided for by the available individual radio electronic devices;

A decrease in volume, mass and dimensions of the equipment while maintaining the tactical-technical characteristics.

The first complexing method is based on the application of computers which, on the basis of analysis of the information contained in the signals coming from the radio electronic devices, control their operation, that is, change the operating characteristics of these devices in order to increase their effectiveness (complexing with control). By control it is possible to understand the following:

a) The variation in analysis time of the signal as a function of the volume of information received, the required accuracy of the measurements or interference;

b) The variation of the signal parameters of the radio electronic devices, search and selection of the optimal for the available interference situation or other factors;

c) Application of several systems to measure the given parameter having various characteristics: different measurement accuracy (rough determination of the region of values of the fixed parameter using one device and, precise determination by means of another), having a different law of error accumulation or random error distribution (including as a result of the interference). Usually these meters are based on various physical principles: for example, radio technical and inertial; radio technical and acoustic; radio technical and thermal, and so on or on one principle, but using signals of different types. In the general case for complexing the meters it is necessary to have a statistical relation between the measured variables (processes) present. The determined relation is a special case of this relation.

The selection of the method of complexing the meters depends on the peculiarities of the investigated process and also the obtained gain in accuracy or noiseproofness. It is important that the technical difficulties in implementing it not decrease the gain significantly obtained as a result of the complexing;

d) Selection of the best combination of meters (item "c") and the law of joint processing of the signals received from them.

The analysis of the automation contained in the signals and computer control are needed in the case where the a priori information about the investigated processes is insufficient or the processes are nonstationary. Frequently, however, the analyzed processes are stationary, and there are sufficient a priori data on their peculiarities. Therefore it is possible to select the best combination of complexed means in advance and establish the optimal law of processing the information from them. The computer functions in this case are significantly simplified.

The second complexing method consists in matching the functions performed by the individual circuits of the different radio electronic devices (functional complexing). The basis for it is the difference in signal characteristics and also the functional dependence of the individual circuits of the radio electronic devices. Let us present some examples.

The structure of the detection means has become widespread for which several radar sets operate on one antenna executed in the form of a phased antenna array (PAA). In this case one phased antenna array performs (matches) functions executed in the case of usual construction by different antennas entering into the composition of the corresponding radar. The signals of the various radar coming to the phased antenna array are shifted in time. The radiation pattern control signals of the phased antenna array have a structure which provides for alternate operation of the radar.

The complexing of the radio technical systems for different purposes in one radio channel based on time frequency separation of the signals is realized analogously. The indicated methods permit complexing of the radio electronic devices and the circuits which process both the near and far signals with respect to structure and informativeness.

For the complexing it is possible to use different structures of the signals belonging to different radio electronic devices, for example, to provide with one device for the amplification of several signals (with subsequent separation), the spectra of which overlap. The basic steps in the complexing in this case are as follows: additive summation of the signals of different sources -- the formation of a group signal; processing of group signal and the channel which is united for different radio electronic devices; separation of the group signal into components which is done using the Kalman filter in the circuit execution (see Fig 3).

The third method -- structural complexing -- is based on the possibility of joining the structures of several individual systems or devices into a new system. This system can perform new functions not characteristic of the systems making it up or the same functions but with improved quality.

The formed system is constructed by the structural diagram differing from the structural diagrams of the complex media. Here the circuitry of the complexed systems (completely or partially) enter into the new system together with the additional circuits.

In the absence of complexing, the individual systems can operate independently of each other. The switching from the independent operating mode to the complex operating mode can be done by the operator.

The complexed radio electronic means can be optimal or different types, based on identical or different physical principles.

For example, let us consider the complexing of the detection systems (radio or acoustic) to obtain high resolution with respect to angle with separate reception. This is necessary, for example, when determining the point targets with increased precision of the coordinates in the open sea at distances to the radio horizon using shore stations.

The high angular resolution when complexing is determined by the width of the spatial coherence function using complex signals similarly to how the range resolution is determined by the autocorrelation function of the signals. The spatial coherence function characterizes the degree of coherence of the signals reflected from the targets at different angular directions with respect to the measurement point [1]. The width of the spatial coherence function is related to the width of the spatial frequency spectrum by the same relation as the width of the autocorrelation function with the width of the time frequency spectrum. The spatial coherence function can be measured by different methods. For monochromatic signals, this can be done measuring the mutual correlation of the signals received at different points in space, by varying the distance from them.

When using multifrequency or multiband signals, the measurement of the spatial coherence functions at different frequencies -- the signal components -- is equivalent to measuring it at different points in space. This is the so-called principle of spatial-frequency equivalence. Thus, for a multifrequency signal at fixed points in space it is possible to measure the entire spectrum of the spatial frequencies and as a result to obtain measurements of the spatial coherence function which will determine the degree of angular closeness of the point targets. For realization of high angular resolution, two radar or sonar stations are required or, more precisely, two receivers and one transmitter. Both receivers contain processing devices matched to the signal emitted by the transmitter.

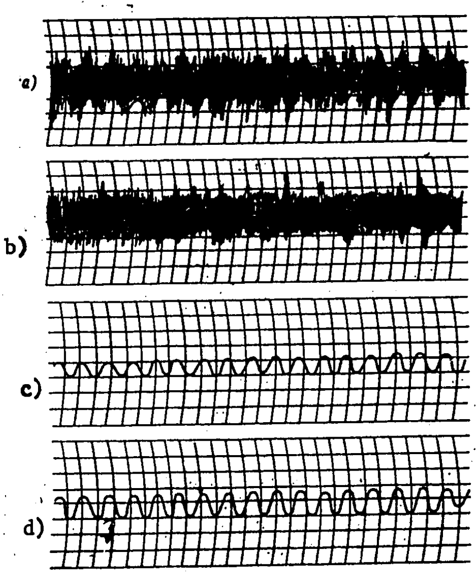

Figure 3. Types of recordings characterizing the operation of the Kalman channel for amplification of voice communications and the harmonic synchronization signal: a -- communication and harmonic oscillation; b -- separated voice signal; c -- separated harmonic oscillation; d -- initial harmonic oscillation

Before complexing the station, the problems are executed independently. When it is necessary to insure high angular resolution they enter into the matched functional interaction, that is, they simultaneously receive the complexed multifrequency channel reflected from the space of the target. After preliminary processing in the circuitry of each radar, this signal goes to the auxiliary device for matched processing (for example, adders) which shape the spatial coherence function.

The voltage amplitude at the output of the adders permitting addition of the oscillations at the output of the channels of one frequency depends on the direction of the arriving waves.

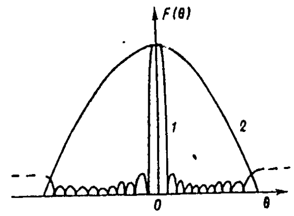

Figure 4. Radiation patterns. 1 -- in the complexing mode when receiving a multifrequency signal; 2 -- main lobe of the radiation pattern of one of the stations in the independent operation mode.

Further summation of the voltages from the outputs of the adders corresponding to two different frequency channels will lead to the formation of the radiation patterns of the complexed system and the multifrequency signal reception mode (see Fig 4). When using phase manipulation in the radar by the law of code sequences it is expedient to carry out mutual correlation processing of each component of the signal using the difference frequency correlators [2] and successive summation of the output voltages. The correlation processing of the signals will promote elimination of the ambiguity of the angular reckoning and also additional separation of the side lobes.

It must be noted that the direction characteristics in the reception mode with complexing can be changed by changing the signal parameters.

The above-presented examples far from exhaust the entire variety of problems connected with using radio electronic equipment in the exploitation and exploration of the World Ocean. There is no doubt that intense searches in this highly prospective and interesting area will permit us to find interesting solutions, but they will simultaneously advance ever-newer unresolved questions and problems.

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PART III. EXTRACTION OF MINERAL AND BIOLOGICAL RESOURCES OF THE OCEAN

ECONOMIC EXPLOITATION OF THE OCEAN RESOURCES[1]

[Article by S. S. Sal'nikov, S. B. Slevich]

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Solomon Borisovich Slevich, doctor of geographic sciences, participant in the Second Soviet Antarctic Expedition, specialist in the field of economic geography of the World Ocean, has scientific interests in political and economic geography.

[1]The biological resources of the World Ocean are not considered here. They are discussed in a special article by P. A. Moiseyev in this collection.

1. Exploitation of Mineral Resources

The procedure for involving the ocean resources in economic activity of human society is determined by the level of development of the production forces, and the nature of their use depends to a great extent on the social-economic factors. At the present time the marine economy represents a set of various, weakly connected branches. The main part of the income comes from extraction of mineral resources and fuel (up to 40% by approximate calculation), shipping (30-35%) and fishing (to 10%), and the rest is the utilization of hydrochemical, hydropower resources and marine tourism [7].

The modern phase of exploitation of the ocean is to a high degree connected with the development of marine oil and gas deposits.

The marine extraction of oil has a long history. In 1824 in the vicinity of Baku 20 to 30 meters from shore wells were constructed which were isolated from the water and oil was extracted from the shallow horizons. In 1870 an island for oil rigs was built near the city of Idzaumosaki (Japan). In 1891 the drilling of directional wells at a distance of up to 200 meters from the shore began on the California coast.

The exploitation of marine petroleum deposits in the first half of the 20th century took place comparatively slowly, and it was only in the 1960's that the situation changed -- the number of countries working on the shelf increased sharply. Up to 24% of the total oil extraction and more than 10% of the natural gas extraction fall to the lot of the latter. Expressed in cost, from the beginning of the 1960's to the middle of the 1970's the extraction of oil and gas from the marine deposits increased by tenfold.

With respect to volume of extracted marine oil, first place is held by the Persian Gulf, then come Lake Maracaibo and the Gulf of Venezuela, the Gulf of Mexico and Gulf of Guinea, the north shelf of Alaska and also Gulf of California and Cook Inlet (Southern Alaska), and so on. The North Sea has acquired special significance. More than 53 million tons of oil and 42 billion m^3 of gas per year are extracted here. As a result of working the marine deposits, Great Britain and Norway and also Malaysia, Indonesia and Australia are becoming large petroleum extracting countries.

At the end of the 1970's, the potential reserves of oil and gas on the earth amounted to 325 billion tons of which more than half were marine deposits [3].

In recent years the area of potential oil and gas sedimentary series in the ocean prospective for exploration has been estimated at 50 million to 80 million km^2, including 20 million km^2 on the shelf. With the development of exploratory operations by deep drilling the forecast will be more precisely defined, and reliable data on the presence of industrial accumulations of oil and gas not only on the shelf but also in the deep-water parts of the ocean will be more precisely defined and expanded.

According to the modern data, in the sedimentary series of the ocean floor about 1,000 oil deposits have been discovered, including 10 supergigantic ones with reserves of more than 1 billion tons. Seven of them are concentrated in the Persian Gulf.

The predicted reserves of the marine deposits in the Soviet Union are significant. About 70% of the continental shelf of our country is prospective for oil and gas prospecting. We are talking in particular about the Caspian Sea, the Sea of Okhotsk and the Sea of Japan [14].

The rates of exploitation of the marine oil and gas deposits depend not only on the explored reserves and the equipment capabilities, but also economic factors.

As a rule, the exploration of underwater oil and gas structures is cheaper than on dry land, but the expenditures on constructing off-shore drilling rigs significantly exceed the corresponding expenditures on dry land. With an increase in depth and distance from the shore, the expenditures increase in a geometric progression; nevertheless, in the Caspian Sea every ton of extracted oil costs more than 10 rubles less than the "land" extraction, and the investments in operational drilling are returned in 6 years [14].

A decisive role in the exploitation of oil and gas reserves of the ocean is also being played and will be played by the relation between the minimum market price of oil insuring a profitable return on it and production expenses. The higher the price level, the greater the quantity of oil reserves at great depths and in areas that are difficult of access that will become involved in the economic cycle. At the present-day price level for oil it is expedient to extract it from reserves at depths of no more than 200 meters.

A fivefold increase in the price of oil will lead to the necessity for extracting about 120 billion tons, that is, in practice all of the reserves of the shelf and a significant part of those in the deep zone.

Specialists propose that the extraction of oil in the ocean will increase, and by the 1980's it will be 30 to 40% of all of the oil extracted in the world.

Some developed capitalist countries consider that by expanding the extraction of marine oil, they will strengthen their own energy resources and lessen dependency on imports. This pertains primarily to Japan which imports 99% of the oil it uses and 74% of the natural gas. In the opinion of American specialists, the exploitation of marine oil and gas deposits can have decisive significance in implementing the program for self-sufficiency of the country in the 1980's.

The solid minerals of the ocean began to be mined before oil, but the growth rates of the mining operations are low as a result of the little-studied nature of the ocean, the presence of more profitable deposits on land and the absence of modern engineering equipment. In 1966 the value of the extracted raw minerals (without oil and gas) was a total of $25 billion, but recently changes have been noted: by the beginning of the 1970's the value of the extracted mineral resources had more than doubled.

The solid surface minerals are primarily extracted in shallow coastal regions (beaches, lagoons, bars), and the solid buried minerals, in direct proximity to the shore using shafts and mines laid out on shore or on natural and artificial islands. Some of the mines and shafts reach 2400 meters below sea level and are 8 km from the shore to depths of 120 meters or more. The mining of the iron, copper, zinc, lead and other metals deposits is planned by building concrete shafts to a depth of 140 to 150 meters below the sea floor.

A significant role is played by the extraction of coal. In Japan 30% of all of the extracted coal comes from the bottom of the sea, and in Great Britain, 10%. By the beginning of the 1970's, 57 underwater coal mines were in operation in the world.

Japan, Canada and Finland have underwater shafts extracting iron ore with a total value of $17 million.

Copper and nickel are extracted in large quantities from underwater shafts in Hudson Bay (Canada) and in Cornwall (Great Britain).

Numerous sedimentary basins are known which contain sodium, potassium and magnesite salts. Their reserves are enormous, but in recent decades broad exploitation of them has barely started, for the demands of industry are satisfied at the expense of deposits on the dry land and extractions from seawater. It is known that the United States is working two salt domes in the Gulf of Mexico; the same drilling method is used to extract sulfur (15% of that extracted in the United States).

Out of the underwater placers at the present time 7% of the ore extracted abroad is taken from the placer deposits, including about 100% of all zirconium and rutile, about 80% of ilmenite, more than 50% cassiterite [5]. The ilmenite-zirconium, ilmenite-monacite placers are mined on significant scales in India, United States, Sri Lanka, in Brazil, Australia, and New Zealand, and tin-bearing placers, in the countries of Southeast Asia. The titanium-magnetite and magnetite placers and ferrous sands are mined in Japan and New Zealand. Prospective deposits of tin-bearing sands have been detected in the Laptev Sea.

On the southwest coast of Africa industrial exploitation of diamond sands has taken place for more than half a century, and beginning in 1962, the extraction of diamonds on the shelf began. It is possible to consider the mining of gold-bearing and platinum sands prospective.

The extraction of building materials from the sea floor is of great interest: sand, gravel, shell, but here it is important to trace the dynamics of the coastal alluvium in order to avoid the disappearance of beaches and intensified abrasion of the sea coast.

The phosphate raw material reserves in the sea are significant. They are estimated at millions of tons. Although the demand for them is satisfied from the deposits on land, such countries as Australia, Peru, Chile, Japan, and so on which do not have such deposits plan to begin marine mining of them.

A number of developed capitalist countries attach special significance to the mining of the ferromanganese (polymetal) nodules spread over the entire ocean floor. The richest reserves are constituted in the Pacific Ocean between 6 and 20° north latitude and 110-180° west longitude at depths of more than 4000 meters, and also in the Indian and Atlantic Oceans. The high-grade concentrations contain 27 to 30% manganese, 1.1 to 1.4% nickel, 1 to 1.3% copper and 0.2 to 0.4% cobalt. According to the calculations of J. Mero the nodule reserves accessible for industrial exploitation amount to from 10 to 500 billion tons [19].

If we consider that the land reserves of the metals contained in the nodules are limited, and the demand for them is increasing, then the urgency of mining them becomes obvious. By the calculations of American economists, an enterprise extracting 3 million tons of nodules per year will have an income of $150 to 260 million (without considering payment of taxes and deductions). Even if it gives a future international agency for exploitation of the sea floor reserves half of the income, an approximately 36% profit will be received, that is, 3 times the usual profit.

The intensive exploitation of other mineral resources contained in the deep-water regions of the ocean floor, for example, metal-bearing, limestone and silicon silts, red clays, glauconite sands will barely begin in the next decades.

2. Marine Navigation

One of the most ancient areas of economic exploitation of the ocean is its use as a "common vast highway of all nations."[1] The World Ocean was and remains the basic transport route insuring the development of international and partially internal (coastal) shipping. The proportion of marine transportation is more than 70% of the cargo of all forms of transportation, which is determined by the significant distances to which the cargo is hauled (the average distance is 8000 to 9000 km, and the average distance of shipping by rail is 649 km) [11]. The necessity for

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[1] K. Marx, F. Engels, Collected Works, Volt 15, p 439.

such marine shipping is caused by lack of correspondence between the placement of the production facilities and the natural resources, non-uniformity of the economic development of countries, the ever-deepening international division of labor. For many, especially island countries, uninterrupted marine communications have become vitally important, for example, for Japan, which imports about 600 million tons of predominantly raw cargo per year.

The main part of the marine shipping (83%) is realized on international lines. The portion going to the Atlantic Ocean is about 60% of the shipping volume, the Pacific Ocean, only 25%, and the Indian Ocean about 15%.

The volume of international shipping in the world maritime fleet in the 1960's and 1970's alone more than tripled, and in 1977 it reached 3,400 million tons.

Maritime shipping primarily is made up of bulk liquid cargo -- petroleum and petroleum products (50%), then piece (general) cargo (20%) and bulk dry cargo (iron ore, grain, coal and so on) (16%). The rest is made up of dry cargo (with the exception of general).

The proportion of crude oil has increased persistently in the shipping of petroleum cargo. At the present time it has reached 86%. Its basic importers are the countries of Western Europe, the United States and Japan.

The hauling of general cargo is most developed on the lines connecting the United States to South America and Japan, Western Europe to South America and the Western European ports to each other. In recent years container shipping has increased sharply, which promotes an increase in the efficiency of loading and unloading operations.

The shipping of bulk dry cargo, primarily ore, has increased. Thus, in 1977, 283 million tons were shipped by sea. A significant part of the ore was delivered to countries of Western Europe, the United States and Japan by the countries of South America and Southeast Asia, Australia, Canada and India. The high-quality ore comes to Western Europe from Sweden and Liberia.

The marine grain shipments have increased noticeably (in 1977 they were 143 million tons), the large exporters of which are the United States and Canada (67% of the world grain exports by sea) and also Australia and Argentina. Among the rice exporters, in addition to the United States, there are Burma, Thailand and Italy. The principal importers of grain are the countries of Western Europe (35%), Japan (17%), and some of the socialist countries and the countries of South Asia.

Almost 25% of the bulk dry cargo shipped by sea is coal (in 1977, 125 million tons), which is transported from the United States and Canada to Japan, Western Europe, South America, and also from Australia to Japan [2].

In connection with the increase in volume of shipping and growth of the freight prices, the revenues from world shipping have increased significantly -- in the mid-1970's they reached 42 to 45 billion dollars. The transport costs amount to a significant part of the export price of many goods (for raw materials 20 to 30%). Nevertheless, the cost of marine shipping is appreciably below rail. Therefore the tonnage of the maritime fleet of a number of countries is increasing rapidly. In the developed capitalist countries it significantly exceeds the demand for their own shipping and is used to service foreign brokers. Thus, the petroleum extracting countries -- OPEC members, which account for more than 90% of the export deliveries of petroleum in the capitalist world transport less than 1% of the petroleum exported by them on their own ships.

At the beginning of 1978 there were more than 32,000 maritime ships in the world with a total displacement of about 365 million gross registered tonnage (a displacement of no less than 300 gross registered tonnage each) [18]. The greater part of all the tonnage of the maritime fleet is the bulk liquid cargo vessels; then come the vessels for hauling general cargo and the vessels for bulk dry cargo; the number of specialized ships is increasing: container carriers, combination, for shipping bulk cargos.

In modern shipbuilding a trend is being observed toward an increase in the capacity of the ships, especially tankers. In 1976 there were about 700 supertankers in the world (of them 48 had a capacity of more than 300,000 tons); tankers with a capacity of 540 tons, which were built in France, have been put into operation.

Many of the developing countries are building their own fleet, for example, India and Brazil have fleets with a displacement of more than 5 and 3 million bulk registered tons, respectively. Tanker fleets are being created in Mexico, Venezuela, Algeria, and Egypt. Accordingly, the monopoly position of the developed capitalist countries has been eliminated in the world freight market. This has also been promoted by the increasing role of the socialist countries in the transport support of foreign economic relations of the developing countries.

The Soviet merchant fleet which numbers about 3,000 ships with a displacement of more than 14 million gross registered tonnage [15] is sixth in the world with respect to total tonnage. Soviet ships call at 1400 ports in 120 foreign countries, and they operate on 70 sea and ocean lines. In the Tenth Five-Year Plan the merchant fleet of the USSR was supplemented primarily with high-output specialized ships: barge carriers, container carriers, bulk carriers.

The growth of the maritime fleet of the country, its specialization and the modernization of ships -- all of these are promoting an increase in the efficiency of the marine shipping.

Marine transportation of the countries of socialist cooperation which is realizing international marine shipping of cargo with a volume of more than 350 million tons is powerful.

A significant role in the concentration of foreign trade at defined points along the coast is played by the ports which are not only complex transport junctions, but also large industrial centers.

In the world there are about 2000 ports, but only several hundred of them process more than 1 million tons of cargo each per year, and a total of 150 ports, more than 10 million tons. The concentration of the transshipment operations in the giant ports is a characteristic feature of the modern transport process. It is interesting that the freight turnover of certain ports reaches "astronomical" values: in 1976 the port of Ra's at Tannurah has processed 390 million tons of cargo, Rotterdam processed 288 million tons, Kobe, 138 million tons, Tiba, 139 million tons, Ameriport (the ports at the mouth of the Delaware River) 126 million tons, New Orleans 124, New York 119, Yokahama 114, Marseille-Fosse 104, Nagoya, 99, Kawasaki 96, Houston 90, Le Havre 80, Mena-el-Axmadi (Persian Gulf) 70 [2].

An important area of development of modern ports is their specialization. Thus, the largest oil ports are located in the developing countries (Iran, Kuwait, Oman, Abu Daby, Saudi Arabia, Lybia, and so on).

Among the largest ports specializing in shipping bulk dry cargo it is necessary to mention the iron ore ports of Brazil (Vitoria), Venezuela (Puerto Ordas), Norway (Narvik), the coal port complex of Hampton Roads (United States), the grain ports of New Orleans (United States) and Vancouver (Canada), and so on.

In recent years the construction and equipment of ports for container shipping has acquired a special scale. The largest of them are Newark and Oakland (United States), Rotterdam, Antwerp, London, Bremen, Hamburg, Sidney, Tokyo, Yokahama and Kobe. At the present time such cargo is handled in more than 150 ports of the world.

However, the shallow depths and limited bodies of water of many ports do not permit large-tonnage ships to be taken, especially tankers; therefore it is necessary to build outer harbors and equip roads docks at the approaches to them.

The deepening of the international division of labor, the development of the liberated countries, the growth of the economies of socialist countries, the intensive economic exploitation of the resources of the World Ocean and a number of other factors will promote further development of world shipping and growth of maritime trade. The technical base of marine transportation will also be improved, and the new process of ships will appear. Their speeds will increase, and so on. The ocean as a transport artery is acquiring more and more significance.

3. Exploitation of Hydrochemical Resources

The hydrochemical resources of the ocean are first of all table salt which is obtained by evaporation from seawater. Today about 30 to 35% of the salt in the world is produced in this way. Its reserves in the ocean are in practice inexhaustible.

Seawater is called "poor ore" -- magnesium is extracted from it (United States, England, France, Italy, Tunisia and the USSR); it is the only source of bromine; in many countries of the world potassium and iodine are obtained from this water by the processing of seaweed.

The search is being made for "cheap" methods of extracting gold and uranium from seawater. Japan, for example, is planning to obtain 3400 tons of uranium by this method by the year 1990.

On the whole the raw material extracted from seawater (without considering the value of the desalinated water) was estimated at $500 million at the beginning of the 1970's [10].

It is especially necessary to talk about the World Ocean as a source of fresh water. As a result of the nonuniformity of distribution of ocean water on the land, the rapid increase in consumption and faster growth of pollution in many parts of the world, an acute shortage of it is felt. In order to cover the shortage, strict and daily natural conservation measures are needed.

One of the additional sources of fresh water can become and is becoming seawater. The method of filtering it through sand and then a still has been known to man since antiquity. Now navigators are the basic producers and users of desalinated seawater. Industrial desalinators appeared on the land only at the end of the 19th century and the beginning of the 20th century.

In 1970 throughout the entire world there were only about 800 large desalination plants with a total output capacity of 1.25 million m^3 per day. It is proposed that by 1985 the total output capacity of the desalinators in the world will be 40 million m^3 per day, and by the end of the century, 1290 million m^3 or 472 km^3 per year, which will play a noticeable role in covering the "water" shortage [4].

In 1973 the first nuclear water and electric power plant (AVES) was put into operation with a fast-neutron reactor. The reactor supplies a 150,000 kilowatt electric power plant and a 100,000 m^3 per day desalinator with electric power. The plans are being developed, and the construction is underway for an AVES [nuclear water and electric power plant] to obtain cheap electric power and fresh water in many other countries.

The methods of obtaining fresh water based on the natural and artificial freezing, ion exchange, hyperfiltration, electrodialysis and others are being realized.

Experiments are being successfully performed in the use of slightly mineralized water, for example, the water of the Baltic Sea for agriculture needs. Modern equipment and technology are permitting the expansion also of the sphere of the use of untreated seawater in industry and city management.

The largest fresh water reserve is the glaciers of the earth, which contain 24.3 million km^3 of water, that is, 69.5% of all of the fresh water. The greater part of the fresh water ice is concentrated in the Antarctic dome (they slide into the ocean in the form of glacier rivers which break up and pyramidal icebergs are formed) and also in the shelf glaciers of the continent. The amount of fresh water contained in the latter exceeds by almost 300 times its content in all the rivers of the world. We must not forget about the floating ice cover of the ocean which is an area of 1.5 million km^2.

Enormous table icebergs break off the shelf glaciers, each of which contains more water than the annual runoff of a river of significant magnitude. It is no accident that plans have recently appeared for towing icebergs to the dry continents. It is calculated that to tow an ice mountain weighing 10 billion tons at a speed of 2 km/hour, a detailed large ocean-going tug with a combined power of 225,000 horsepower is needed [9]. However, the value of the water contained in the iceberg would pay for all of the expenses of transporting it. Although it is necessary to solve a number of problems for the execution of such plans, it is possible to consider the transportation of icebergs, for example, to the dry shores of Saudi Arabia or Australia entirely realistic in the near future.

4. Exploitation of Recreational Resources

The process of using marine recreational resources has been developing rapidly in recent times.

By recreation resources we mean the rest, therapeutic and tourist areas with defined climatic conditions combined with technical bases and the infrastructure required to restore the labor potential of the population. The volume of recreational resources of the ocean is growing continuously as a result of an increase in mobility of the population, the development of transportation, communications, and so on. The geography of using the resources is also changing.

Tourism, including marine tourism, is developing rapidly as a branch of the economy. The number of tourists is increasing not only in the countries of Europe and North America which provide 90% of all of the receipts from international tourism [12], but also the countries of Asia, Australia and Oceania. The number of tourists is increasing by 2 to 8% annually. The basic transport expenditures of international tourists alone are estimated at $11 billion [17]. For example, in the United States the expenditures of the population on organizing leisure time by the sea reached $14 billion in 1970.

Tourism is becoming a significant economic factor also for the developing countries, for it is permitting them to obtain currency faster than in the tooling up to produce export goods. However, the currency effectiveness is noticeably lowered as a result of an increase in the importation of goods designed for the tourists.

Marine tourism is developing in two directions: the use of coastal regions (traveling by sail boat and cruise ships, swimming, water skiing, sport fishing) and expansion of the marine cruise traffic. For the further development of tourism, it is necessary to increase the number of domestic service and eating enterprises, the creation of special ships and motorized means and also coastal facilities required to service the fleet (passenger docks, ports, bunkering bases, railroad stations, and storage facilities). As a result of the increased cruise business, reorientation of the passenger fleet, reequipment of the ships and improvement of their comfort are taking place, special routes and lines are being created, combination air-sea cruises are appearing where the tourists travel to the starting point on airplanes or return from the end point ("fly-cruises").

The marine cruises are basically in the Caribbean and Mediterranean Seas and also on the following routes: United States to the Bermuda Islands, United States to Europe, round-the-world cruises from the United States, and so on. At the present time a Pacific Ocean section of cruise traffic is in operation, and an Indian Ocean section has been created. In the enumerated areas of cruise traffic alone, including the Pacific Ocean, there are more than 150 ships employed with a displacement of about 3 million gross registered tonnage designed for 100,000 people.

It is obvious that marine tourism is becoming one of the important areas of economic exploitation of the ocean.

5. Exploitation of Power Resources

The power resources of the World Ocean began to attract the attention of scientists comparatively recently, especially in connection with the energy crisis of the capitalist countries in the middle of the 1970's.

The mineral fuel and power resources of the ocean have been brought into economic activity (this has been mentioned above). We are talking about the possible areas of use of ocean power engineering itself.

The application of the power of the tides has been technically developed and realized in practice. The potential power reserves of the tides suitable for development are estimated at 10 million megawatts [21]. They are distributed in time and space nonuniformly, which creates difficulties in their use. Accordingly, it is expedient to build tidal electric power plants (PES) in combination with other types of electric power plants. Then the tidal electric power plants can eliminate the power shortage during the "peak" periods.

In France the "Rans" 240,000 kilowatt tidal electric power plant has been operating successfully since 1967. It generates 560 million kilowatt-hours annually. Plans have been created for more powerful tidal electric power plants: for 12 million kilowatts in France, 4 to 7 million kilowatts in England, and 6 million kilowatts in the United States, and so on [21].

In our country the experimental Kislogubskaya tidal electric power plant (400 kilowatts) erected by the floating method has been in operation since 1968.

The construction of the Lumbovskaya tidal electric power plant on the Kola Peninsula with a capacity of 360,000 kilowatts, the Mezenskaya tidal electric power plant in Arkhangel'sk Oblast with a capacity of 10 million kilowatts, and also the Penzhinskaya and Tugurskaya tidal electric power plants on the Okhotsk Sea coast is planned.

The use of only the mechanical power of the currents, the power of which by some estimates exceeds by 50 times the power of all modern electric power plants can become one of the sources of electric power. There are plans for using the power potential of the Gulf Stream and the Straits of Florida. A device is being designed with an enormous underwater rotating disc with vanes on the south coast of Sicily to use the local current for producing cheap electric power [10].

It should be considered entirely realistic to create marine geothermal plants that make use of the temperature difference between the upper and lower layers of the seawater. The first marine geothermal plant on the coast was built in 1927 in France on the Maas River. After World War II a marine geothermal plant of 14,000 kilowatts was built on the Atlantic coast of Africa near Abidjan. The hot water for the station comes from a shallow lagoon, and the cold water comes from depths of 500 meters.

Marine geothermal stations have also been designed in the regions with favorable conditions where the water temperature on the surface reaches

28 to 30°C, and at a depth of 400 to 500 meters, 8-10°C, in temperate latitudes with a small temperature variation.

Provision is made for the creation of multipurpose hydrothermal plants for producing electric power and simultaneously obtaining fresh water, the recovery of concentrated brine formed in the evaporators which undoubtedly will increase the efficiency of overall production.

The use of hydrogen from seawater as a power supply to replace short hydrocarbon fuel is planned. Although obtaining hydrogen is expensive, the introduction of thermochemical procedures with the application of low-temperature heat will permit the cost to be reduced.

Plants are being designed for production of hydrogen from seawater that operate on solar energy and wave energy.

More frequently it is possible to hear about the expediency of partial return to the use of sails that will make use of the free power of the wind for propulsion [8].

Plans are being developed for wind power plants in the marine oil fields and in densely populated coastal regions. A chain of many thousands of windmills installed along the coast of New England (United States) can provide 2.5 times more energy than the New England states consume, and the cost of the system will be 45% less than the cost of building nuclear electric power plants of the same capacity.

The most important spheres of economic activity of man in the ocean were investigated above. They have to be considered to include the development of the science of the ocean itself, for today during the scientific and technical revolution it is becoming a direct productive force although it is quite complicated to calculate the returns on each ruble of investment in research. These returns are expressed in improved quality of long-range weather forecasting, an increase in biological production, mineral raw materials, improvement of the profitability of the operation of marine transportation, and so on.

For successful economic exploitation of the ocean the scientific cooperation of all "users of nature" and the coordination of their actions are required. The private approach determined by immediate gain can have disastrous consequences. A unified program of broad economic research and exploitation of the resources of the ocean, the development of the optimal criteria for their effectiveness which must take into account the long-range and short-range consequences including the possible weakening of the self-regulating ecological systems as a result of economic activity is required. The all-around exploitation of the wealth of the ocean needs the development of scientific principles. This is one of the goals of Soviet scientists.

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PROBLEMS OF CREATING EQUIPMENT AND TECHNOLOGY FOR MINING UNDERWATER DEPOSITS OF SOLID METALS

[Article by G. M. Lezgintsev]

Georgiy Mikhaylovich Lezgintsev, director of the All-Union Scientific Research and Planning and Design Institute of Gold Extracting Industry, is director of the development of technical means of extracting solid minerals on the shelf and in the World Ocean. He is the author of many inventions and a member of the Writers' Union of the USSR.

For the practical realization of the grand plan for the development of the national economy of the country, scientifically substantiated searches for new methods of extracting minerals are needed which will permit an increase in mineral extraction without disturbing the environment and simultaneously make it possible to lower the cost, increase the productivity of labor, and exclude the need for people to work underground. The volume of mineral extraction at the present time has reached colossal proportions; nevertheless, the demand for mineral raw materials is increasing every year, which is giving rise to the necessity for putting the leaner deposits occurring under complex geological and mining conditions into operation. Therefore, it is becoming obvious that the solution of the mentioned problems is an important and highly complex problem. One of the possible paths of its solution is exploitation of the mineral deposits of the World Ocean.

The profitable industrial extraction of minerals from the bottom of the seas and oceans is becoming more and more realistic. The industrially developed countries are intensely expanding scientific research and experimental design work aimed at the fastest creation of the technology and the special engineering means of exploiting underwater deposits [4, 5]. In order to solve the technical problems arising when creating effective marine mining equipment, first of all powerful experimental bases with test units and also specialized scientific research ships are required. Therefore all of the first steps in performing experimental research operations in the Soviet Union with respect to the creation of new marine mining equipment and comprehensive testing of it were the organization and construction in the Latvian SSR of the Baltic Marine Experimental Base of the VNIIprozoloto Institute and the creation of a specialized scientific research ship "Shel'f-1" (see Fig 1), which is used for testing new marine mining and enrichment equipment and also for the experimental mining of underwater placers and sedimentary deposits in the shelf zone of the Baltic Sea [6].

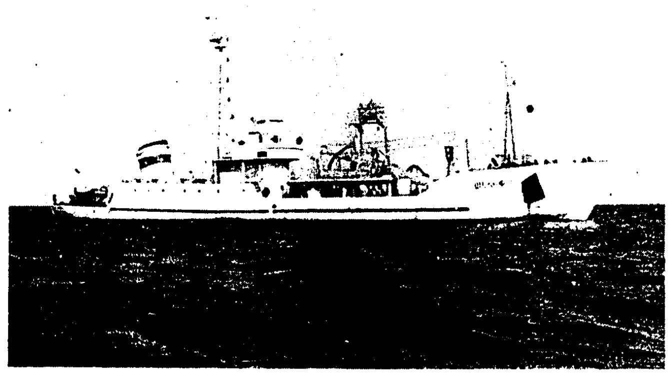

Figure 1. "Shel'f-1" scientific research ship with a displacement of 590 tons has two 110 horsepower main engines, a 500 kw diesel electric power plant, compressor and pumping station, mechanical workshop and powerful launching arrangements with remote platform and П-type boom. An enrichment plant has been mounted on the upper process deck. In addition to the facilities for the crew and the scientific coworkers the ship also has laboratories.

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1. Basic Areas of Research

Today three basic methods of marine and water extraction of solid minerals have been planned: from floating means, using underwater or bottom installations and submersibles; using the methods of geotechnology, in particular, the method of underwater borehole hydraulic extraction.

The first procedure has been assimilated best of all. This is promoted by the existing Soviet and foreign experience in underwater extraction from floating means both specialized and adapted for this purpose (hydraulic or suction dredges, draglines). It must be noted that the operation of the existing dredges and draglines is limited to comparatively shallow depths, and the majority of them have not been adapted to work with sea waves of more than force 3 or in ice [2]. For the further development of this method it is necessary to perform the corresponding research work of creating the systems of extraction elements with special rippers and underwater mining boosters which require rigid connection to the floating means [3].

The creation of marine dredges and draglines with unanchored system of displacement equipped with improved roll dampers is prospective.

The basic advantage of the second method of extraction is the possibility of using it independently of climatic and ice conditions. It is possible to assume that this method will be the principal shelf extraction for our country, for more than 80% of the shelf area of the USSR is in Arctic waters, the operating season in which is extremely limited. Thus, in Van'kina Guba Bay, in the Laptev Sea, on the average it is less than 50 days per year. Probably unmanned submersible robots must be improved for this area. It will be expedient to use them for marine extraction of ferromanganese nodules.

There are systems for marine extraction of mineral raw materials from depths of 60 and 200 meters (Fig 2). The advantages of the second extraction procedure must also include the possibility of organizing complete or partial bottom enrichment and storage of the "tailings" in the mined areas. Unmanned, remote-controlled transport-extraction units and an entire set of devices are being designed to make improvements in this area.

The third procedure for underwater mining of mineral deposits using the methods of geotechnology, above all, the method of borehole hydraulic extraction, is in the stage of theoretical and experimental study. The first positive results of the application of this process have been obtained when mining the continental sedimentary and placer deposits and also when extracting sulfur from the ocean floor [6]. This indicates unquestioned prospectiveness of the given method primarily when mining the buried marine placers and also underwater deposits hidden under ice, for example, on the Arctic shelf.

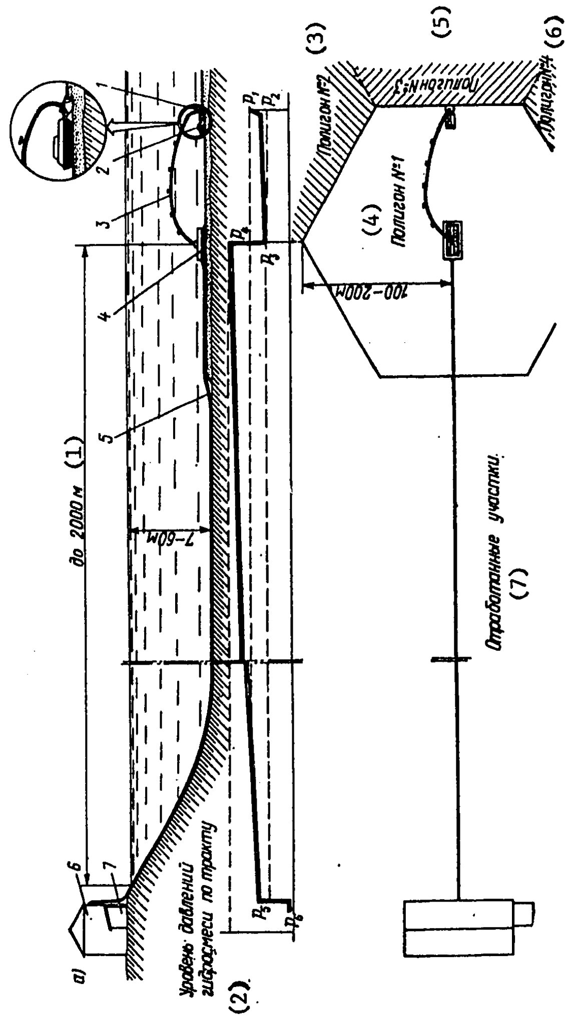
2. New Extraction Units and Selection of the Flow Chart for Mining Deposits from Floating Facilities

During the experimental work performed from the "Shel'f-1" scientific research ship when using the base airlift with flexible lift lines 150/250 mm in diameter (Table 1), a number of extraction units of mechanical, vibrational and hydraulic pneumohydraulic types have been tested, namely, the hydraulic excavator, vibration ripper, pneumohydraulic soil collector, mechanical-hydraulic scraper, and so on.

During the operation of the hydraulic excavator (Fig 3), active mechanical separation and loosening of the mined rock of the underwater face and simultaneous constant suction and hydraulic transportation of the slurry formed take place. This clearly increases the efficiency of mining bound sediments by comparison, for example, with the hydraulic ripper (see Fig 4). The flaps of the clamshell bucket are driven by alternately feeding the working fluid from the ship's oil pump to the upper and lower cavities of the hydraulic cylinder. Water jet monitor heads are used in the bucket cavity to promote additional disintegration of the rock mined by the clamshell directly before "suction," which improves the preparation of the slurry and insures relative uniformity of the consistency of the hydraulic mixture raised by the airlift. As a result of testing it was established that because the drive for the jaws of the hydraulic excavator clamshell is made in the form of a hydraulic cylinder, the plunger of which is the suction tube, equal cutting force is insured for both jaws, and the reliability of monitoring the mining of the underwater face is improved.

Under the effect of the vibration ripper, as a result of its structural design it is possible to use the effect of directional vibration for successful underwater destruction of the caked and packed sand and gravel. Here, as a result of the presence of a mechanism for turning the vibrating mass the vibration ripper connected to the flexible lines of the airlift automatically realizes reciprocal displacement in the underwater face in accordance with the given program. The horizontal component force of the vibrators is equal to 1000 kg/sec^2 with a total perturbing force of 3000 kg/sec^2. The torque is equal to 170 kg/sec^2 with a distance from the axis of the suction tube to the longitudinal axis of the vibrator of 340 mm. On the whole, the tests run on the vibration ripper demonstrated good results.

For underwater mining of sediments of medium consolidation and also packed sedimentary rock without preliminary mechanical loosening, a pneumohydraulic soil collecting system has been built (see Fig 5). The outstanding future of it consists in the presence of pneumohydraulic heads which to a significant degree permit an increase in the effect of the water jet monitor, for in the exit zone of the compressed air the surrounding water is forced away and the jets operate in reality on a dry face.


а)
до 2000 м
(1)
7–60м
Уровень давлений гидросмеси по тракту
(2)
Полигон №2
(3)
Полигон №1
(4)
Полигон №3
(5)
Полигон №4
(6)
100–200м
Отработанные участки
(7)
1
2
3
4
5
6
7

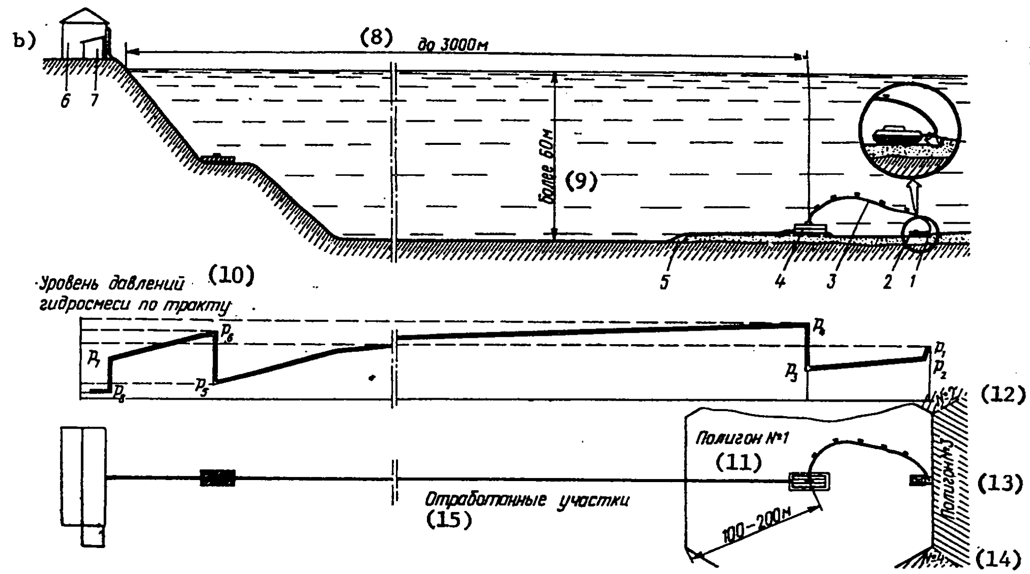


Figure 2. System for bottom marine extraction of solid minerals: a-- at depths to 60 meters, distance from shore to 2 km; b -- at depths of more than 60 meters, distance from shore to 3 km.
1 -- oil collecting device; 2 -- submersible (unmanned, self-propelled, remote controlled) electric tank; 3 -- flexible lines (slurry line, high pressure water, electric cables, signal and control conduits); 4 -- base with pumps and electrical equipment; 5 -- pipes and cables from shore installations to the base 1; 6 -- enrichment plant (prefabricated and demountable); 7 -- power unit and control panel.

Key:
1 -- to 2000 meters; 2 -- pressure level of the hydraulic mixture along the channel; 3 -- test area No 2; 4 -- test area No 1; 5 -- test area No 3; 6 -- test area No 4; 7 -- depleted sections; 8 -- to 3000 meters; 9 -- more than 60 meters; 10 -- pressure level on the hydraulic mixture along the channel; 11 -- test area No 1; 12 -- test area No 2; 13 -- test area No 3; 14 -- test area No 4; 15 -- depleted sections.

Table 1

Basic Parameters of the Base Airlift Mounted on the Scientific Research Ship "Shel'f-1"

Коэффициент относительного погружения эрлифта (1)	Производительность по воде, м³/ч (2)		Расход воздуха, м³/ч (3)	
	$D_п$ = 150	$D_п$ = 250	$D_п$ = 150	$D_п$ = 250
0,74	85,5	245,0	310	834
0,85	104,0	290,0	228	632
0,89	109,5	306,0	212	588
0,92	114,0	316,0	208	563

Коэффициент относительного погружения эрлифта (1)	Производительность по пескам, т/ч (4)			
	γ = 1,1 т/м³		γ = 1,2 т/м³	
	$D_п$ = 150	$D_п$ = 250	$D_п$ = 150	$D_п$ = 250
0,74	12,2	34,2	19,6	57,0
0,85	13,8	38,2	23,4	64,3
0,89	15,1	41,2	24,4	68,6
0,92	15,8	43,2	26,2	70,5

Коэффициент относительного погружения эрлифта (1)	Производительность по пескам, т/ч (4)			
	γ = 1,3 т/м³		γ = 1,4 т/м³	
	$D_п$ = 150	$D_п$ = 250	$D_п$ = 150	$D_п$ = 250
0,74	25,6	71,6	28,1	77,0
0,85	30,1	82,4	32,7	90,2
0,89	31,6	88,4	34,1	95,1
0,92	33,4	91,2	36,8	99,5

Key:
1. Coefficient of relative submersion of the airlift
2. Output capacity with respect to water, m³/hr
3. Air consumption, m³/hr
4. Output capacity with respect to sand, tons/hr

Notes: $D_П$ is the diameter of the flexible airlift lines, mm; γ is the density of the hydraulic mixture, tons/m³.

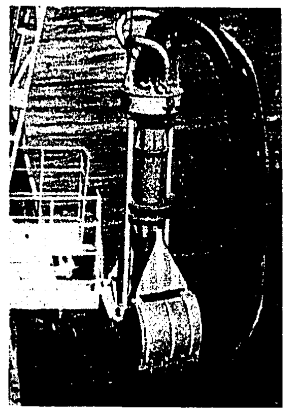


Figure 3. Hydraulic excavator clamshell with 0.25 m^3 bucket capacity jointly with the airlift provides for efficient underwater mining of packed sedimentary rock. The device weighs 2.5 tons, and its extraction capacity is 20 m^3/hr.

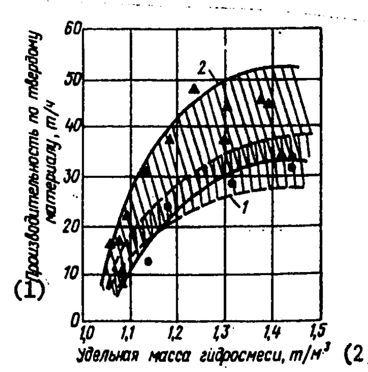


Figure 4. Comparative characteristic of operating parameters of the hydraulic clamshell. 1 -- zone of theoretical output capacity of the airlift; 2 -- zone of practical output capacity of the clamshell. The upper boundary of the zones with a coefficient of relative submersion of the airlift line of 0.76, the lower boundary of the zones with a coefficient of 0.71.

Key:

1. Output capacity with respect to solid material, tons/hr
2. Specific weight of the hydraulic mixture, tons/m^3

Several versions of the mechanical-hydraulic scrapers have been tested from on board the "Shel'f-1" ship. They have a scraper bucket with hydraulic suction line. These systems performed dredging operations on the underwater deposits while the ship moved and, consequently, the scraper bucket moved relative to the underwater face. Under the effect of the mechanical-hydraulic scraper, mechanical separation of the rock from the face takes place because of the cutting edge of the bucket and simultaneous auxiliary water jet monitor disintegration of the rock with the formation of a slurry directly in the bucket cavity and airlifting of the hydraulic mixture to the ship.

As a result of the test it was established that for efficient operation of the underwater equipment it is necessary to have a flexible hovering system which provides for cutting off the rock of constant thickness. This requirement is satisfied by the underwater mining system used when performing experimental operations from on board the "Shel'f-1" ship, which consisted in displacing the scraper bucket relative to the underwater face by pulling the ship on a stern anchor.

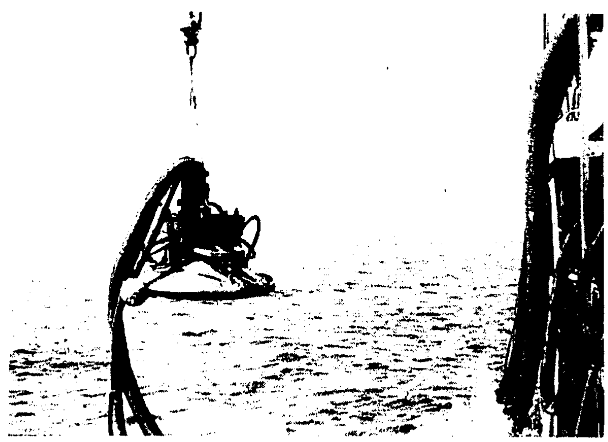


Figure 5. Pneumohydraulic soil collecting device. The additional consumption of compressed air on pneumohydraulic ripping does not exceed 5% of the total air consumption in the airlift.

The studies of the development of underwater extraction technology have demonstrated that efficient mining of marine placers from floating facilities using new marine mining equipment and flexible lines can be realized by various methods of underwater excavation.

It is expedient to mine thin underwater deposits by the method of layer-by-layer excavation with the application of mechanical-hydraulic scrapers (see Fig 6).

During operation the ship is held on bow and stern anchors. The scraper bucket of the mechanical-hydraulic system is lowered from on board connected to the airlift line for discharge of the rock.

When the ship moves by being hauled on the anchors, the scraper bucket, by hovering, picks up the rock of one swath equal with respect to width to the geometric dimensions of the cutting edge of the bucket. For the next swath the ship must move in the opposite direction the length of the swath.

The medium and thick underwater deposits are expediently mined by the method of crater stoping which is the simplest and does not require constant (or frequent) movement of the extracting ship with respect to the underwater face. It is possible to perform this type of mining with several scarps or with one (when mining unbound grainy sedimentary rock) with subsequent stripping of the placer firm by the soil collecting intensifiers with respect to area and also the scrapers of various designs or the method of layer-by-layer excavation.

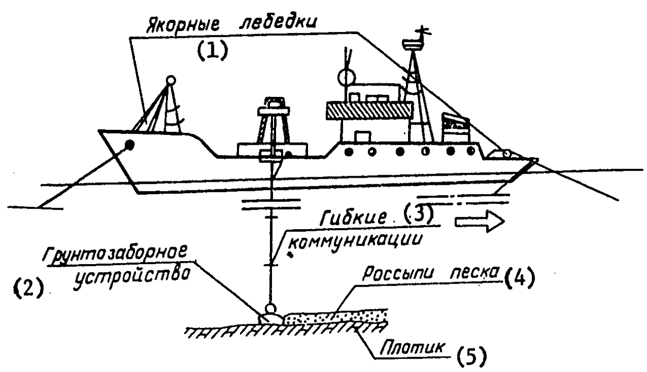


Figure 6. Process diagram for the underwater mining by the method of layer-by-layer excavation

Key:
1. Anchor winches
2. Flexible lines
3. Soil collecting unit
4. Sand placers
5. Firm

When mining a marine placer deposit by the method of crater stoping the specialized "Shel'f-1" class ship moves over the area of the section of the deposit using a powerful stern anchor. The bow anchor is used to maintain the required direction of displacement with variable wind directions. After working the next crater, the soil gathering unit is raised above the face and the ship moves by means of the stern anchor a distance equal to twice the diameter of the crater. The two anchors permit a fixed position to be taken up above the placer.

Depending on the specific mining-geological conditions and the hydrodynamic characteristics of the bottom deposit in the given vicinity of the underwater deposits and also the ratio of the geometric dimensions and shape of the placer in plan view, the mining operations can be performed with longitudinal and frontal (transverse) arrangement of the faces.

The use of the system with longitudinal placement of the faces is the most expedient when mining a narrow placer coinciding with respect to width with an integral number of passes, which permits the losses of productive sand to be decreased. The distance of displacement of the ship along the placer is determined by the length of the anchor chains and the power of the winches.

When using this method of placing the faces, the maneuvering is simplified, but the discovery and the working of the industrial areas outside the placer boundaries are complicated. With this system the placer must be clearly outlined during the prospecting work.

The mining system with frontal faces permits the mining of the deposit outside the placer until the useful component content drops to the admissible average industrial level. With this system the maneuvering of the ship is complicated significantly, especially with a decrease in width of the placer, and the losses of work time on moving from swath to swath increase. This system is preferable in cases where the placer boundaries have been approximately established.

The selection of the extraction devices is made depending on the physical-mechanical properties of the mined rock, the thickness of the productive bed and the stoping procedure. Recommendations for this selection are presented in Table 2.

3. Underwater and Bottom Devices

At the Baltic Marine Experimental Base the VNIIprozoloto Institute has been successfully testing several dragged and self-propelled type devices designed for underwater mining and bottom enrichment of shelf placers. Examples of this equipment include the specialized underwater extraction unit on a caterpillar track equipped with a suction dredge with vibration ground working element (see Fig 7) and also a bottom vibration scraper, the operating displacements of which are realized by

Table 2

Most Efficient Process Schemes for Underwater Mining of Deposits from Floating Facilities

(1) Разрабатываемая порода	(2) Мощность залежи, м	(3) Технологическая схема	(4) Добычное устройство
Пески рыхлые зернистые неслежавшиеся (5)	>1 1–5 <1	I IIa IIa	4 3
Пески слежавшиеся, гравелистые, супеси, илистые пески, лёсс (6)	>1 1–5 <1	I IIa IIb	4 1, 2, 3 1,2
Илы слежавшиеся (7)	>1 1–5 <1	I IIa IIb	1, 3, 4 1,3 1,3
Глины легкие нежирные (8)	>1 1–5 <1	I, IIa IIb IIb	1, 3, 4 1
Глины плотные (9)	>1 1–5 <1	I, IIa I, IIb I, IIb	1,4 1,4 1,4
Скала легкая, разборная (10)	>1 1–5 <1	IIa IIb IIb	I I I

Key:
1. Mined rock
2. Thickness of occurrence, meters
3. Process scheme
4. Extraction device
5. Loose, grainy, uncaked sand
6. Caked, gravelly sand, sandy loam, muddy sand, loess
7. Caked ooze
8. Light lean clays
9. Tight clays
10. Light collapsible rock

Notes. The Roman numerals indicate the process schemes: I -- stoping; IIa -- with crater stoping in several bench banks; IIb -- one bank; Arabic numerals: extraction devices; 1 -- hydraulic clamshell; 2 -- vibration ripper; 3 -- pneumohydraulic device; 4 -- mechanical-hydraulic scraper.

a powerful underwater caterpillar tractor. New prospective mechanisms of the walking bridge type (Fig 8) have been built and tested for moving the bottom extraction and enrichment units at the underwater faces. Structurally such mechanisms include an elongated bridge-forming hull with supports and ballast tanks at the ends. The supports have devices for rotation of the hull around them. The mechanism moves over the sea floor by the walking method as a result of alternate purging of the ballast tanks with compressed air and partial rotation of the hull around the supports.

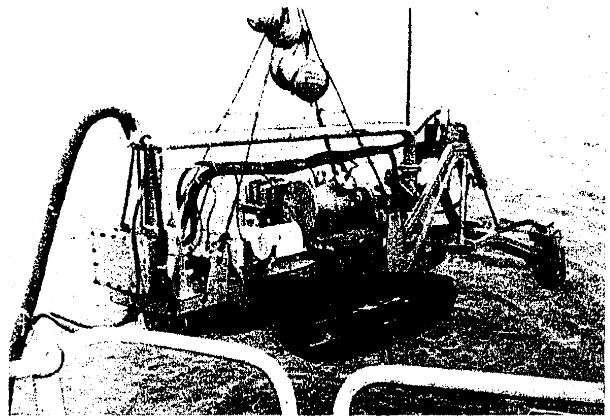


Figure 7. Experimental self-propelled remote controlled extraction unit before launching to the underwater face. The output capacity of the suction dredges of this device equipped with a vibration ripper is 44 m^3/hr. The device can negotiate a bottom slope to 15°. The thickness of the removed layer in one pass is 0.2 meters.

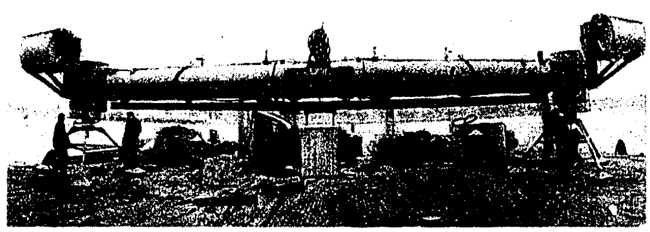


Figure 8. Underwater rocking bridge -- prospective mechanism for movement of the extraction and enrichment equipment over the sea floor. Length of girder 14 meters. The supports have hinged coupling to the girder, which increases the stability of the bridge on an uneven bottom.

As applied to the bottom devices and units that have been built, underwater enrichment equipment designed to obtain a concentrate from the mined sand directly at the underwater face has been developed and studied on test stands.

4. Prospects for Underwater Borehole Hydraulic Extraction

The essence of the method of underwater borehole hydraulic extraction is quite simple, but the structural execution of the corresponding industrial equipment, the determination of the optimal parameters and technological procedures for applying it are highly complex problems.

It is necessary for the well drilled from the surface of the deposit to pass through the covering barren rock to the productive bed and by a special extraction tool equipped with a water jet monitor and airlift to break up the mineral bed by the water jet and discharge the slurry formed in the chamber to the surface for extraction of the useful components from it.

The tests run on the drilling rig and the hydropneumatic drilling tool with flexible water jet monitor from on board the "Shel'f-1" ship during experimental development of the underwater chambers confirm the theoretical possibility of the method of underwater borehole hydraulic extraction. However, in order to build and introduce the equipment and the process for this underwater extraction, it is necessary to perform a set of additional research and experimental studies, above all:

To determine the possibility of using the existing floating facilities (barges, pontoons and various types of platforms) or redesigning them for installation and mounting of the equipment for the underwater borehole hydraulic extraction;

To develop designs for the undersea drilling tool to experimental industrial models. It is expedient structurally to combine the drilling and extracting elements of the tool;

To perform semiindustrial studies and prepare the equipment and the technology for underwater borehole hydraulic extraction for introduction in the mining industry.

This method of extraction can be implemented during industrial mining of the deposits of the Arctic shelf in sections with limited movements of the ice.

5. Equipment for Taking Sediments Samples Off the Ocean Floor

In order to evaluate the underwater mineral deposits and obtain process samples, the AP-6000 clamshell type autonomous sampler has been built (see Fig 9). The group application of the new samplers, for example, for exploration and prospecting work on the nodules will permit a significant increase in output capacity of the sampler and a reduction in cost of a single sample.

The operating principle of the AP-6000 consists in its submersion and reaching the ocean floor under the effect of the weight of the ballast left on the bottom. After it hits bottom and drops the ballast, the flaps of the clamshell bucket take a sample of the bottom deposits, which is brought to the ocean surface by means of the sampler float.

The industrial testing and introduction of the newly designed samplers were performed during expeditions of the USSR Ministry of Geology in the Atlantic and Pacific Oceans.

The creation and improvement of the equipment and the process of mining underwater deposits of solid minerals is impossible without profound scientific research and experimental-design work on a broad scale, without intensive development of mining science encompassing newer and newer areas. The attraction of the attention of many engineers and scientists

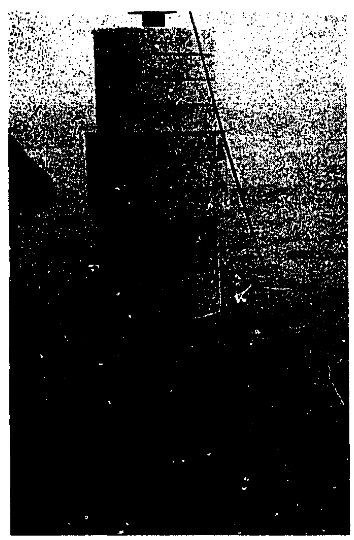


Figure 9. AP-6000 autonomous sampler in the ready state before being launched overboard. The clamshell servoelement is equipped with four ballast weights weighing a total of 120 kg. The float made of "sintaktik" has a buoyancy of 130 kg, which provides for vertical displacement of the sampler at a speed of up to 1.5 m/sec. The operating depth of submersion is 6 km.

to the problems of marine mining unconditionally will promote the successful solution of an entire series of problems. With the expansion of the marine mining and exploitation operations, the volume of mineral extraction will increase, the proportion of which will increase more and more as the deposits on the dry land are depleted.

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CONSTRUCTION AND DESIGN OF EQUIPMENT FOR MARINE EXTRACTION OF OIL AND GAS

[Article by V. N. Samarskiy, K. G. Suvorov]

Viktor Nikolayevich Samarskiy, deputy chief of the "Glavmorneftegas" has been engaged in developing the structural designs of floating drilling rigs, stationary platforms and filled structures.

Constantin Gennad'yevich Suvorov, department head of the Central Scientific Research Institute imeni Academician A. N. Krylov is working in the field of future planning of the construction of oil platforms, supply ships and other means of exploiting the continental shelf and also determination of their basic technical-operating characteristics.

The construction of floating technical means of exploiting the marine oil and gas deposits basically began in the 1960's with the creation of drilling platforms. The intensification of the study of the oil and gas deposits in the sea belongs to the end of the 1960's when large oil and gas reserves were discovered in the North Sea. In the 1970's a sharp increase in world prices for oil and gas made it possible to talk about the competitiveness of the marine oil and gas deposits, for the exploitation of which large capital expenditures and significantly more expensive equipment are required than when working the dryland deposits. The expenditures on drilling at sea depths of 20 to 30 meters are approximately twice the analogous expenditures on the land, at a depth of 50 meters the drilling costs increase by three to four times, and at a depth of 200 meters, by 6 times. The expenditures on laying underwater pipelines to transport the oil to shore are also significantly higher (1.5 to 3 times), as is the cost of building oil storages in the marine fields (4 to 8 times).

However, in spite of such high expenditures the volume of oil and gas extraction in the sea is increasing constantly, which can be explained by the depletion of the old land deposits, the necessity for exploiting new deposits in regions that are difficult of access and little developed.

The available data indicate that the world explored oil reserves amount to 85 to 90 billion tons, including 19 to 20 billion tons of marine reserves. At the present time about 3.5 billion tons of oil have been extracted at sea, which amounts to less than 10% of the total amount of extracted oil (46 billion tons). Here it is necessary to consider that petroleum extraction in the sea has been going on for about 25 to 30 years, and on the dryland, about 100 years. The annual proportion of marine extraction of petroleum is increasing constantly and will be about 20%; by 1985 it will reach 30 to 50% of the total amount of oil consumed by all countries (Figure 1).

The development of the operations with respect to petroleum extraction in the sea has required the construction of a large amount of technical means theoretically differing from traditional means. The set of devices which are needed for the exploitation of marine oil and gas deposits basically include the following:

Drilling platforms and ships for exploration and prospecting drilling;

Stationary platforms for drilling operating wells;

Means of laying underwater oil lines;

Specialized barges for delivering sections of stationary platforms to the point of installation;

The crane installation ships;

The supply ships for the drilling platforms;

The special extracted oil storages.

In connection with the constant expansion of the regions of the continental shelf where drilling is done, the technical-operating characteristics are

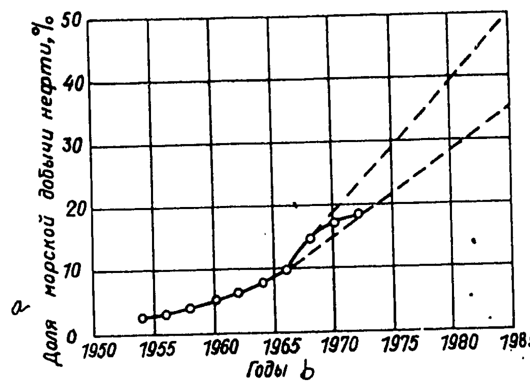

Figure 1. Growth rates of the world petroleum extraction in the sea.

Key: a. proportion of marine oil extraction, %
b. years

improving and changing. The growth of the volumes of oil and gas extraction in the sea and, consequently, the drilling operations will lead first of all to an increase in the number of drilling platforms and ships. According to the estimates of foreign specialists, in order to provide for the expected growth rate of the marine petroleum extraction by 1985 up to 40 drilling platform ships will be required annually, which will lead to the loading of 50% of the production capacity of the shipbuilding enterprises. At the present time 55 companies form 15 foreign countries, including the United States with 18 companies, Japan with 7, the Federal Republic of Germany and Singapore with 4 each, Great Britain, Norway, Canada and Australia 3 each and Finland 2, are engaged in building such technical means.

Today it is possible to consider the creation of drilling platforms and ships which are adaptable for working in deep-water areas and also under complex hydrometeorological conditions as a general trend. Accordingly, the structural design is becoming more complicated, and the cost of the structures is rising (see Figures 2 and 3).

The technical means from which the drilling is performed in the sea have one characteristic feature — they are distinguished by a high degree of stabilization over the mouth of the well under the effect of waves, wind and currents. This stabilization can be achieved with rigid fastening of the structure to the ground. Initially the drilling was performed at depths of 30-40 meters; therefore submersible type drilling platforms were used which have vertical cylindrical columns, in the lower part of which there are ballast tanks. After filling the ballast tanks the platform sat on the ground. The height of the columns permitted the upper platform to be above the water surface at a height preventing waves from striking the platform.

The stability of the drilling platform during submersion was created as a result of the waterline area of the cylindrical columns. After completion of operation the ballast tanks were drained, the submersible platform was floated and transported to a new point.

The submersible platforms are simple in operation, but their application is possible only at limited depths, for an increase in their height leads to complication of the construction process and causes difficulties when insuring stability during transportation and submersion at the operations point. In addition, for successful operation of them, exact information is needed about the nature of the soil and the depth of the sea. During prolonged standing on the ground, sucking in of the lower ends of the supports is possible along with erosion of the soil under the effect of the currents which can lead to emergencies.

The submersible platforms were constructed primarily until 1960, and at the present time there are a total of 22 in operation. The largest of all of the submersible platforms is the "Kermak-54" platform of the American "Transword Drilling" company. It can operate at depths to 53 meters, it is 63 meters high with a column diameter of 9.1 meters and a deck area of 2800 m^2.

In recent years submersible platforms have been built for operations near the shore in the Gulf of Mexico and off the African coast at depths of no more than 10 meters.

Stabilization as a result of being installed on the ground is also achieved on the self-raising drilling platforms. Their distinguishing structural characteristic is the displacement of the supporting columns relative to the pontoon. The stability of the self-raising platform is insured during the transport process and when submerging the supports using the pontoon. After driving the supports into the ground the pontoon is raised above the water surface to a height permitting waves from striking its bottom. The dimensions and the special design of the self-raising platforms are selected beginning with the following conditions:

The necessity of locating the drilling equipment, the technological reserves and living facilities;

The creation of sufficient stability on the ground under the effect of the calculated wind, waves and currents;

Insurance of unsinkability when transporting with maximum raised supports;

Creation of the required additional buoyancy when sinking the pontoon and to facilitate release of the supports from the ground.

The self-erecting platforms is the most numerous group of technical means designed for exploration and prospecting drilling. The intense construction of self-erecting platforms has been carried beginning in 1972. Their maximum annual output was 20 units (Figure 4); 108 self-raising platforms were built

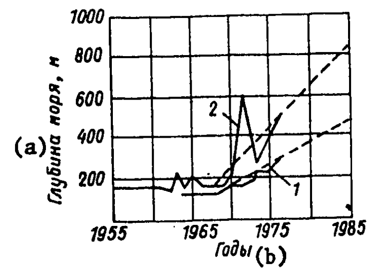

Figure 2. Variation in depth of the sea at the operations point of the platform (1) and drilling ship (2).

Key: a. depth of sea, meters
b. years

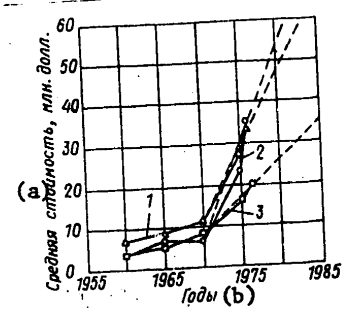

Figure 3. Increase in average cost of construction of the drilling platforms and ships. 1 — semisubmersible platform; 2 — drilling ship; 3 — self-raising platform.

Key: a. average cost, millions of dollars
b. years

(21% for sea depths to 63 meters, 63% for depths of 75 to 90 meters, 16% for depths of 96 to 107 meters).

Initially, basically self-erecting drilling platforms were built with a rectangular pontoon and four supports (Figure 5). This design made it possible to insure stable positioning of the platform in case of failure of one of the supports. As the design of the mechanisms was improved, and also the operating experience was accumulated, it was discovered that it is possible to proceed with the construction of self-erecting platforms with pontoon and three supports triangular in plan view. These structures have less metal consumption and require lower expenditures to manufacture. At the present time the majority of self-erecting platforms are built with three supports having girder construction. They experience lower wave loads by comparison with the cylindrical supports.

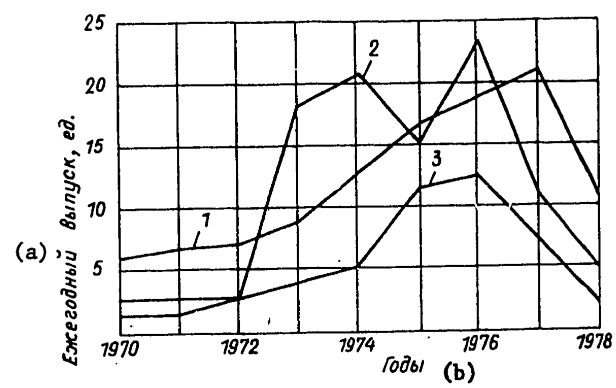

Figure 4. Rates of construction of drilling platforms and ships. 1 -- self-erecting platforms; 2 -- semisubmersible platforms; 3 -- drilling ship.

Key: a. annual output, units
b. years

The lifts on the self-erecting platforms are electromechanical and hydraulic. The electromechanical devices include a toothed rack fastened to the support and pinions with electric drive through a reduction gear placed on the pontoon. The hydraulic system has several cylinders with transverse crossmembers entering into the grooves of the toothed rack fastened on the support. The rate of raising the pontoon is 0.3 to 0.4 m/sec. The operations with respect to installing the self-erecting platform on the ground or removal from the operations point are the most dangerous and responsible (during this period 30% of the accidents with this type of platform occur). Significant difficulties in adjusting the self-erecting platforms can arise in the case of strong pressing of the supports into the ground and jamming of them. In order to prevent this from happening, the practice has developed of using platforms that connect the lower ends of the supports (called mats). The mats are used especially frequently in the structures with three supports when it is impossible alternately to pull them out of the ground as is usually done on a platform with four supports.

Great structural complexities are arising as a result of an increase in length of the supports, especially when insuring the reliability and strength during transportation inasmuch as the supports are raised 100 meters or more over the pontoon, and in the transport position the self-erecting platform experiences a sharp jerking roll. In order to avoid these deficiencies on some of the self-erecting platforms the upper sections of the supports are made removable. There are special cranes for laying them on the deck of the platform. This design permits the height of the raised supports to be reduced and the dynamic loads to be decreased and it also leads to an increase in stability without increasing the size of the pontoon.

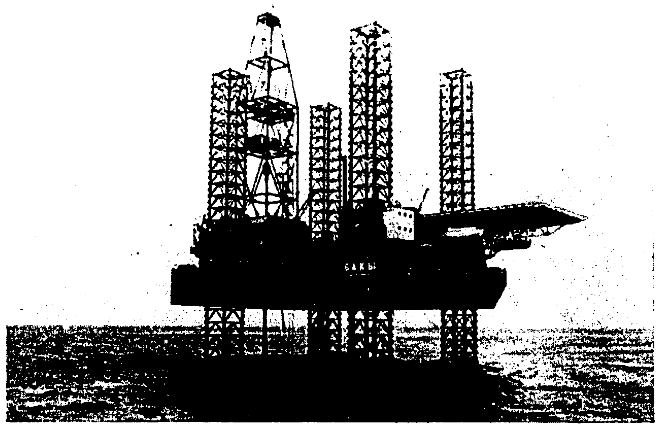

Figure 5. Self-erecting platform "Baky" (USSR) operating in the Caspian Sea.

Another structural design also permitting the solution of this problem is the use of telescopic cylindrical supports. The self-erecting platform of this design "Storm-Y" built in the United States has a record depth for platforms of the investigated type of 115 meters. The length of the cylindrical supports is 123 meters. The outside telescopic support is 77 meters long and 4.6 meters in diameter, and the inside one is 71 meters and 4.3 meters, respectively. However, such designs must have transverse reinforcing at the point of the telescopic connection in order to insure rigidity, and as a result the supports cannot be fully raised, and during transporting operations the platform usually has a large draft.

The proposals regarding the self-erecting platform with a supporting module which is installed separately on the ground and has ballast tanks providing for submersion and floating of it must also be recognized as interesting. The self-erecting platform is loaded on the supporting module and fastened. Using such structures the self-erecting platform designed for a depth of 60 meters can be used to drill to 160 meters.

The drilling rig on the self-erecting platforms is installed over a special cut in the pontoon or on cantilevers.

When designing the self-erecting drilling platforms it is necessary to solve a complex problem -- to satisfy several contradictory requirements. Thus, it is desirable to increase the spacing between the supports to increase the stability on the ground, but this leads to an increase in weight of the pontoon, the lift mechanisms, and consequently, the overall dimensions, which, in turn, causes an increase in wind load and capsizing moment. It is of interest that in 1967 a self-erecting platform "Ocean Master" was built with inclined supports at an angle of 7-12° to increase the stability on the ground. This type of structure is capable of withstanding wind and wave loads that are 1.5 times greater by comparison with the platform having vertical supports. However, the self-erecting platforms with inclined supports have not become widespread as a result of the complex lifting device which must operate at different slope angles in the process of lowering the supports.

Thus, the self-erecting platforms are most adaptable for drilling operations on the shelf inasmuch as they depend less on the weather, and being rigidly connected to the ground do not require the application of special roll compensators and systems for holding them at the drilling point which simplifies the technological equipment used.

The structural designs of the self-erecting platforms have been developed along the path of their simplification, reduction in number of supports, finding the possibilities for increasing the sea depths at the operations point.

At the same time, the self-erecting platforms have deficiencies, the basic ones of which are the following:

The dependence of the transporation and installation at the operations point on weather conditions;

Limited operating depth;

A reduction in mobility as a result of difficulties of running them through narrows and channels.

The semisubmersible platforms are used in regions with depths at which stabilization of installation on the ground is possible. Their intense construction has taken place since 1972. A total of 99 semisubmersible platforms have been built (43% for depths to 240 meters, 47% for 300-450 meters and 10% for 500 to 1830 meters) (see Figure 4). Stabilization of them on the waves is achieved by submersion of the pontoons creating the buoyancy below the sea surface to the level where the waves are felt to a lesser degree and also by using separate vertical stabilizing columns providing minimum water line area. This, on the one hand, promotes a decrease in disturbing forces, and on the other hand, the creation of the required stability. The technological equipment, the power plant and the living facilities are located on the platform above the water surface at a level sufficient to prevent striking by waves of the calculated height.

The semisubmersible platforms are held in place, as a rule, by means of anchors, the number of which reaches 8 (each weighing up to 13 tons).

In 1976 the first semisubmersible platform "Sedco-709" was built (the United States) with a dynamic holding system as a result of the operation of thrusters. This platform can operate at depths to 1830 meters. The required holding precision is insured for waves up to 12.2 meters high from the operation of engines with a total power of 25,000 horsepower.

There are semisubmersible platforms of three types:

With two longitudinal submersible pontoons and 6 to 8 stabilizing columnes (Figure 6);

With four longitudinal cylindrical floats and a large number of stabilizing columns;

With five vertical columns having separate cylindrical pontoons (Figure 7).

Until recently the semisubmersible platforms were built not selfpropelled, and they were delivered to the operations area by special tugs. To simplify transportation platforms have begun to be designed which are self-propelled. This has not caused any significant change in the power plant, the composition and power of which will be determined from the conditions of providing for the operation of drilling and anchor winches, pumps and other process equipment.

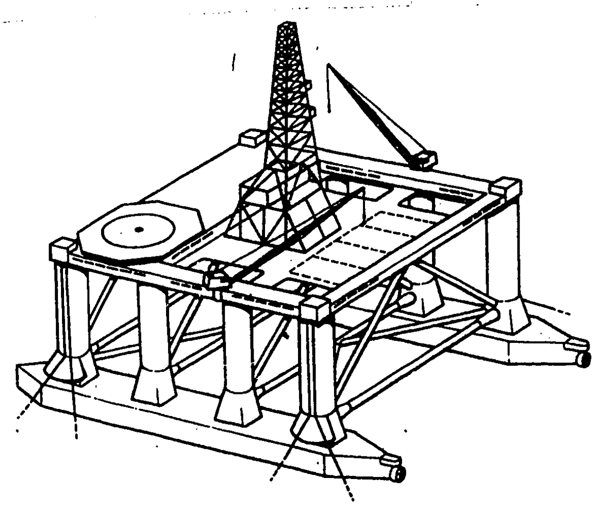

Figure 6. Semisubmersible platform of the "Aker" class (Norway).

The dimensions of the semisubmersible platforms depend on the roll limitations. In 1977 the largest semisubmersible platform "Hakuryu-IV" was built in Japan. It has a length of 104.5 meters, width of 67 meters and overall height of 104 meters (Figure 8). For this platform the designed characteristics provide for waves up to 27 meters high, wind velocity of 60 m/sec and a current speed of 3 knots. The choice of the dimensions of the semisubmersible platforms is also determined by the requirements on their stability and unsinkability. For semisubmersible platforms it is necessary to calculate the stability with respect to diagonals and not only in the transverse and longitudinal direction, inasmuch as the waterline area is made up

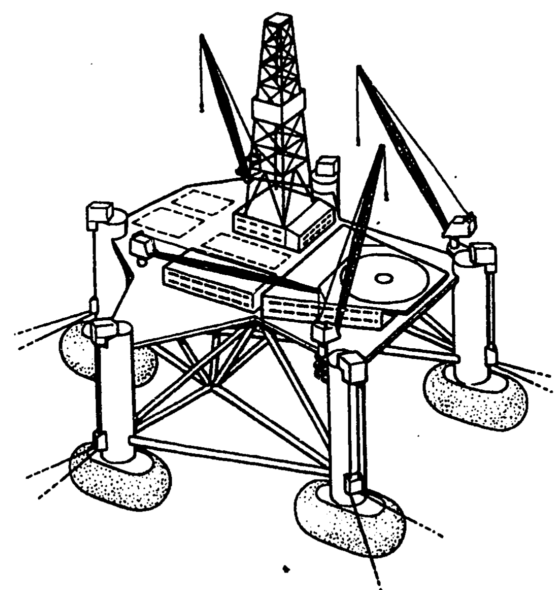

Figure 7. Semisubmersible platform of the "Pentagon" class (France).

of cross sections of vertical stabilizating columns. The excess increase in stability of the semisubmersible platforms will lead to negative effects on the economic indexes inasmuch as the dimensions increase as a result of separation of the stabilizing columns or their diameter, as a result of which the rolling increases. This, in turn, leads to an increase in idle time in waiting for favorable hydrometeorological conditions.

The deficiencies of the semisubmersible platforms must include their large dimensions, complexity of installation and construction operations and also docking. In addition, as a result of the small waterline area, the semisubmersible platforms are highly sensitive to a change in load, which limits the volume of technological reserves. They must be constantly serviced, for the platform is at the operations point for several months. Significant dimensions of the semisubmersible platforms, especially height, increase the labor consumption of the construction operations, for the performance of which it is necessary to use heavy floating cranes with long boom span.

Recently as a result of the application of the dynamic holding systems, the depth of the sea at which semisubmersible platforms are used are increased. This leads to a change in the structural type of the platform, for the most widespread at the present time are the platforms with two longitudinal pontoons, which does not insure constancy of the disturbing forces as a function of direction. The semisubmersible platforms with dynamic holding will have symmetric structural design; studies are being made with respect to the hydrodynamics of the platform with annular pontoon and disc upper platform (Figure 9).

A prospective area in the creation of drilling problems can be considered to be the construction of semisubmersible platforms held at the operations point as a result of vertically stressed cables fastened to weights on the bottom (see Figure 10). The platform has excess buoyancy, as a result of the vertical additional force it is stablized better on the waves. Such designs are especially effective when working at great depths where the weight of the supports increases sharply in connection with an increase in size of the platforms.

At the present time designs of such structure have been developed; a large scale model has been tested under field conditions in the United States.

The drilling ships are being used for exploration and prospecting billing in areas that are remote from shore bases and at points where floating ice can be encountered. They have good seakeeping characteristics, high load capacity and navigational range. In contrast to the semisubmersible platforms, the drilling ships can be built at any shipbuilding yard. The creation of special drilling ships was begun in 1962-1968 in the United States by the "Global Marine" company. In 1968 it built the drilling ship "Glomar Challenger" designed for operations at sea depths to 6000 meters with repeated insertion of the drilling tool and the well.

It can be considered that the drilling ships of the "Pelican" type built in Holland since 1972 are the most perfect. The first ships of this series were adapted for drilling at a depth of 600 meters, and the last ones, for a depth of 1500 meters. The drilling ships have ordinary ship hull designs and the following structural elements and systems:

Amid ships there is a hole and a drilling rig for lowering the tool and the drill stem;

A dynamic holding system at the operations point as a result of developed thrusters;

Special roll compensators that decrease the effect of the vertical displacements of the ship on the drill stem.

The accuracy of holding the drilling ship at the operations point is determined by the magnitude of the admissible bending of the drill stem, and it is 4 to 6% of the sea depth. Thirty of the drilling ships out of the 52 built are equipped with the dynamic holding system. The experience in the operation of the "Pelican" drilling ship in 1973 to 1974 demonstrated that the idle time as a result of bad weather was 6.5%. As a rule, the drilling was done from the ship with vertical displacements of 1.2 to 1.5 meters.

For acceleration of the operation, the drill stems are located in racks directly on the back of the ship forward and aft of the drilling rig.

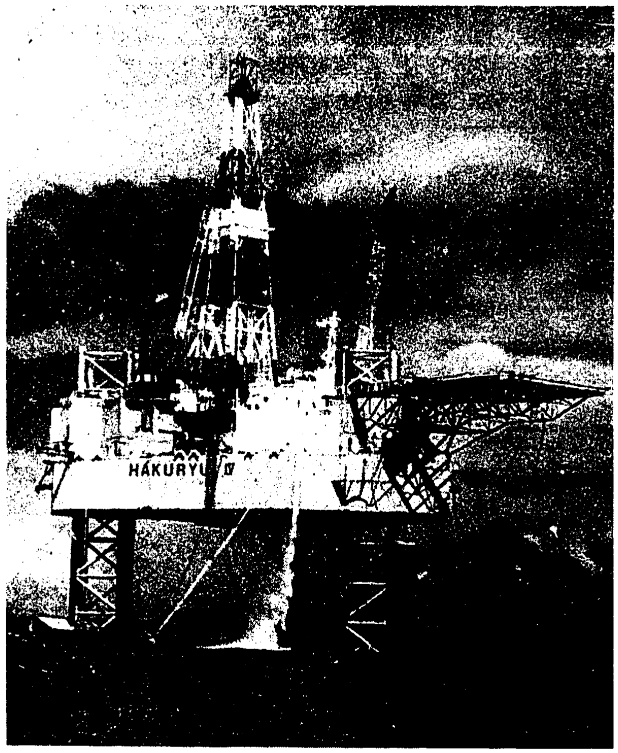

Figure 8. Japanese self-erecting platform "Hakurio-IV"

The techological process reserves and other cargo (cement, clay, pipe, assemblies, large-scale equipment, and so on) are delivered to the drilling platform by supply ships, the number of which in the world exceeds 2000. In accordance with the specifics of the operating conditions, the ships of this class have architectural-structural distinctions. They have forward superstructure and free after deck for the placement of deck cargo which makes up to 70% of the deadweight of the ship. The ships are single-deck, low-freeboard with high foracastle on which a 2 to 3 level wheelhouse is located. The freeboard height of the ships even designed for the North Sea will be a total of 1.0 to 1.2 meters, and the freeboard of the ships operating in the Gulf of Mexico, a total of 0.6 meters. As a result of this, the weight of the hull structures is decreased, which permits an increase in load capacity, but complicates the work of the crew under severe hydrometeorological conditions.

The supply ships are usually highly maneuverable, inasmuch as they frequently must operate in direct proximity to the drilling platform under high wave conditions. This quality is insured by a two-shaft power plant and bow thruster.

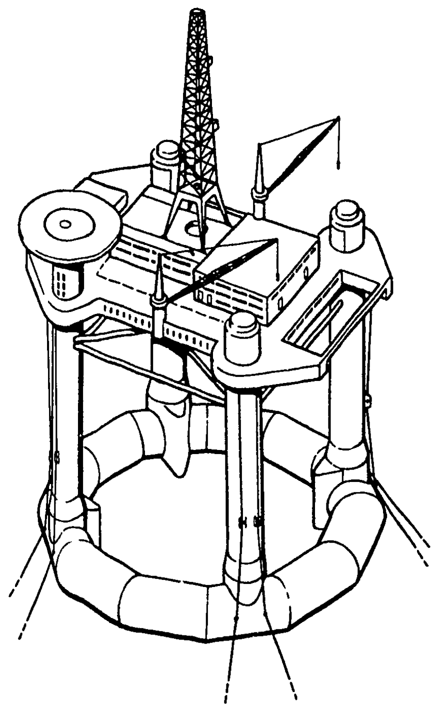

Figure 9. Semisubmersible platform of a prospective type with annular pontoon.

There are up to 8 cylindrical tanks with pneumatic unloading for transporting bulk cargo.

Recently, along with the specialized supply ships, all-purpose ships are being built which provide for towing the platforms, putting down and raising their anchors, and also, if necessary, fire-extinguishing. For these purposes, on the forward deck of the ships there is a special winch, and in the stern, a horizontal roll for bringing in the anchor chain.

The power of the all-purpose supply ship power plant can reach 8000 horsepower, and the ships occupied only with delivering cargos, 3000 hp.

The normal functioning of the marine oil fields is impossible without performing a number of auxiliary operations, including diving operations. For the performance of them, the supply ships are equipped on deck with a set of decompression chambers with the necessary equipment. However, these operations depend on the conditions of displacements of the ship; therefore recently auxiliary ships of semisubmersible design with lower roll parameters have begun to be built.

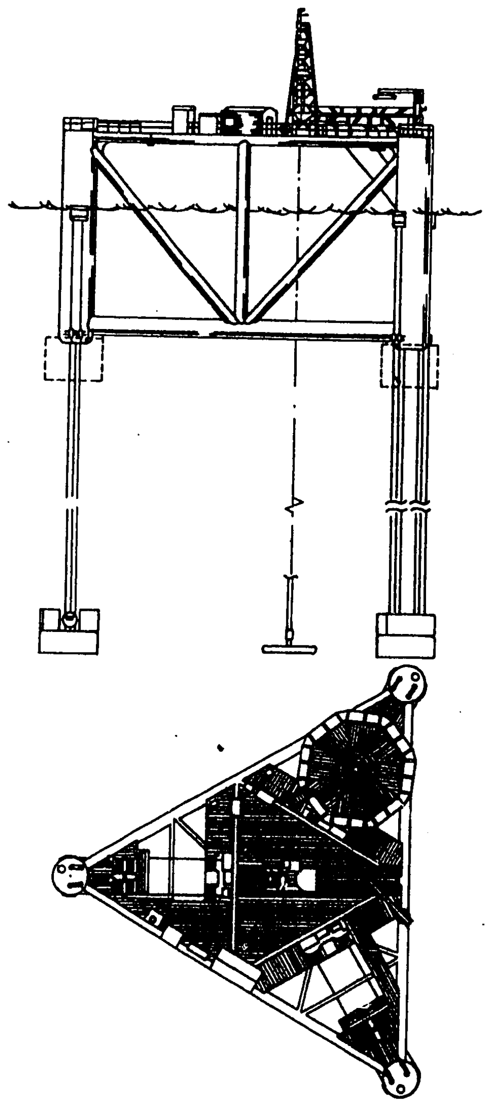

Figure 10. Platform held vertically by stressed cables.

After determining the dimensions and the reserves of the oil and gas deposits on the continental shelf, operating wells are drilled. This operation is performed from stationary drilling platforms. Up to 30 to 40 wells can be drilled from each. It is possible to distinguish platforms of two types: the girder designs installed at the operations point from individual modules and the reinforced concrete, completely made at the shipbuilding yard and delivered to the point of installation on a float.

The stationary drilling platform with girder design is held by pilings in the ground. Modules with the power plant, the process equipment for drilling and refining the petroleum coming from the wells, living and other facilities are installed above the sea surface on this structure. The weight of the individual modules reaches 1600 tons; up to 8 modules are installed on each stationary drilling platform. The platform is located at the operations point for the entire process of extracting the petroleum, and the modules can be replaced depending on the type of operations (drilling, and then refining the petroleum to remove impurities, and so on).

The installation of the largest girder platform in the world (United States) was completed in 1978 in the Gulf of Mexico 15 miles off the coast at a depth of 310 meters. The process equipment installed on it is calculated for drilling 62 wells, the drilling of which will be completed by 1982. The total height of this stationary platform is 385 meters, and the weight is 46,000 tons. In order to perform the installation operations the platform is broken down into three modules. The lower base installed on the ground weighs 14,000 tons, the height is 53.4 meters and the overall dimensions in plan view are 116 × 122 meters. The lower base of the platform was delivered to the operations point on a special barge, and it was fastened to the ground using 24 piles. The maximum pile-driving time was 3 days. Each pile weighing 450 tons, which is a cylinder 2.12 meters in diameter and 188 meters long was towed in the horizontal position by two tugs, and then by filling the ballast compartments was converted to the vertical position and was delivered to the installation point. After attaching the lower base, the midsection weighing 8000 tons and 96 meters high was successive installed, and then the upper section weighing 11,000 tons and 16,000 meters high. The installation of the above-water platform where two drilling rigs, the process and other equipment were placed was made up of modules weighing 500 tons.

The girder designs can be transported from the shore platform to the installation point on special barges or using cylindrical metal pontoons or as a result of natural buoyancy.

Practice has demonstrated that it is expedient to transport the light-weight platforms installed in shallow water by barge. When transporting platforms of significant weight it is more complicated to insure stability, especially with a heavy load with high-placed center of gravity. For transporting the girder structures it is more efficient to use cylindrical pontoons. In this case the girder structure is assembled in a horizontal position in dry dock directly on the cylindrical pontoons connected together and having sufficient buoyancy. After floating and towing to the operations point, part of the pontoons are filled with water for conversion of the structure to the vertical position and setting on the ground; then the pontoons are disconnected and usually this is repeated.

The process of constructing stationary platforms is selected beginning with the weight and size characteristics and the adopted structural type. As a rule, the structural elements are assembled on open platforms from individual sections which are formed from standardized rectilinear elements and assemblies. The assembly and saturation of the modules for the upper platform having rectilinear formations are carried out also on specialized platforms.

The reinforced concrete platforms for drilling and subsequent extraction of oil and gas at depths to 160 meters are used in the oilfields of the North Sea. They are distinguished by long service life and economy in operation. When building them it is possible to use low-skilled workers. The installation operations in the open sea are significantly reduced in time. The wide spread use of the reinforced concrete platforms are being held up as a result of their significant draft when towing (about 30 meters), that is, as a result of absence of deep-water waterways. It is necessary to remember the possibility of emergencies as a result of erosion of the soil under the weight of the platforms.

At the present time it is possible to distinguish two types of reinforced concrete platforms. The first type includes structures with wave-extinguishing wall having a large number of openings for observing the wave energy. Four platforms of this type have been installed in the North Sea. The first of them, the "Ekofisk" (Norway) was built in 1973. The second class includes platforms with cylindrical supports that connect the upper platform and the lower hull installed on the ground with the tank for buoyancy when transporting. Oil from the well is stored in these tanks; their volume reaches 160,000 to 200,000 m^3.

The reinforced concrete platforms are enormous structures. Let us present an example: 120,000 m^3 of concrete were consumed for the manufacture of only the lower hull of one of the "Cormorant-A" platforms 58 meters high. The construction of such platforms is initially done in a special pit where the lower hull is formed to a height insuring the possibility of obtaining sufficient buoyancy and draft for floating at which it can be taken out of the pit. Then the pit is flooded, the cross pieces broken and the lower hull is completed afloat, and the forming of the columns begins. Then the structure is sunk in a deeper location and the upper platform equipment is installed.

It is possible to consider it prospective to use underwater chambers installed directly at the mouth of the oil well and equipped with the necessary equipment for transferring oil to the collecting tanks. This permits exclusion of large expenditures of metal to manufacture the stationary platforms and also complication with navigation.

The extracted oil is transported to shore using underwater pipelines, the laying of which in the open sea is possible from special pipelaying ships. A distinguishing feature of them is the presence in the stern of a girder type frame -- stinger -- for lowering the pipe without bends along a smooth curve. The length of the stinger must be 2 or 3 times the depth of the sea (Figure 11).

The required accuracy of holding the pipe layer on course is 30 to 100 meters, and the accuracy of the translational displacement determined by the necessity of placing the next joint of pipe within the limits of the welding station, ±0.5 meters. This displacement is provided by a system of anchor winches; the anchors are put down by special ships.

High requirements are imposed on stabilization of the pipe layer inasmuch as the pipe is welded from individual sections to 24 meters long; the heel must not exceed ±3%, and the trim, ±2°.

In order to decrease the effect of rolling, the pipelayers are built in a semisubmersible design, and in order to insure constant draft which influences the bending and the stresses in the pipeline, a special ballast system is used with automatic control.

The pipeline is assembled with stops for monitoring and insulating the joints. During operation the ship must undergo cyclic displacements with high precision, and in addition, be able to be held at one point.

In connection with the expansion of the marine oil and gas extraction, the efficiency of laying the pipelines must be increased, but this will be possible only on altering the technological process used in these operations. Beginning in 1970, the United States has developed pipelayers in which the pre-welded pipeline is wound on a drum. Its diameter provides for elastic bending without plastic deformations. In 1978 the construction of the pipelaying ship operating by this process was completed. A drum 16.4 meters in diameter and 6.7 meters wide with a rim 25.2 meters high on which the pipe from 102 to 405 mm in diameter can be wound with a length of 50 or 5 miles, respectively was installed on it. The speed of the ship at which the laying takes place is 1.5 to 2 knots.

When laying pipeline from such a ship the angle of entry of the pipeline into the water can reach 50° (instead of 15° on the ordinary pipelaying vessels), which permits operations without a stinger at depths of 400-900 meters and with wave height to 4.6 meters.

The technological process of installing and laying pipe by a ship equipped with a drum consists in the following. The lengths of pipe up to 1.5 km long are welded at the base. They are put on a drum which permits the pipe to bend within the limits of the radius of its elastic bending. The finished pipeline is wound on the drum on the ship which sets out to sea, and the next segment of the pipeline is mounted on the base.

In connection with working deeper and deeper oil and gas deposits under the water, it is necessary to solve the problem of transporting them in a new way. Th laying of underwater oil lines for tens and hundreds of kilometers is connected with the necessity for the following:

Regulation of the stresses arising in the pipelines at great depths;

Overcoming natural obstacles to the deep-water route.

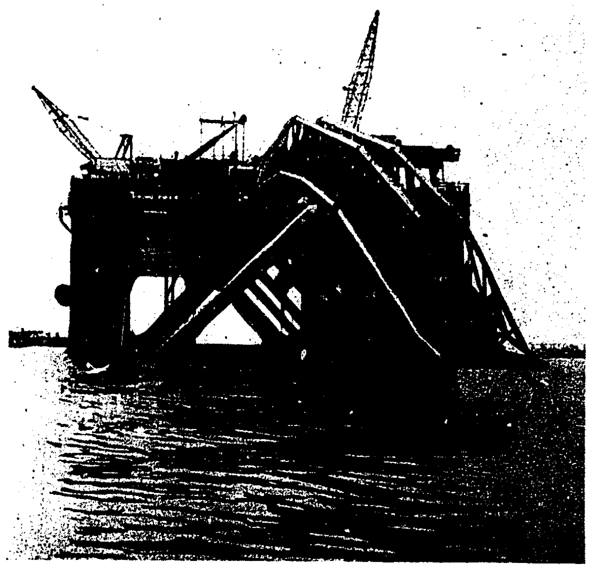

Figure 11. Pipelayer with stern stinger.

Here, the cost of the underwater pipelines increases sharply, which significantly reduces the profitability of the field. Therefore it becomes expedient to install tanks for oil storage on the bottom of the sea.

These underwater storages are connected by pipelines to the primary preparation point for the oil located on a stationary platform and to the special loading systems. The tanks can be made of steel and reinforced concrete.

The loading of the tankers directly at the point of extraction of the oil is no less efficient. For this purpose, special loading stations are used either in the form of a tower which is hinged to the underwater storage or to the bottom or in the form of a floating buoy.

The latter is also connected by a flexible pipeline to the oil storage. The tankers are moored to these loading systems.

In connection with the exploitation of the mineral resources of the continental shelf in the Arctic regions, it is necessary to create equipment for drilling under icy conditions. Here it is necessary to consider the nature of the effect of the moving ice on the structure standing at the drilling site. It is identical to the effect of the ice on the hull of a moving ship; therefore when designing the drilling platforms it is possible to use the experience of building icebreakers. The ice around the platform can be broken either under the effect of the weight of the structure and the

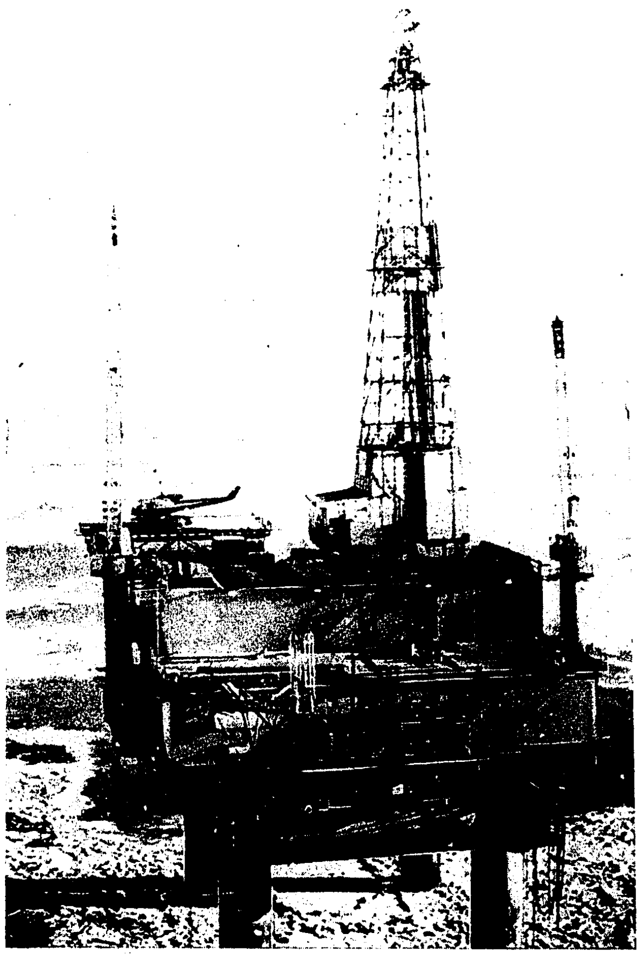

Figure 12. Japanese drilling platform.

specific formations of the hull or by using blasting or sawing it with special equipment or melting it. The first is the most reliable and best tested method.

When designing the ice drilling platforms it is necessary also to consider the possibility of their being iced over. It is important that the building up ice break under its own weight before it influences the strength and stability of the platform.

In regions where there is no drift ice, the freezing of artificial ice islands is possible by spraying water for the installation of the drilling equipment on them. Off the coast of Canada a well 924 meters deep was drilled from such an ice island. The maximum thickness of the ice was 5.5 meters, and the spraying of the water took place for two months with an initial ice thickness of 1.5 meters.

Recently designs have appeared for ice drilling platforms with a small number of stabilizing columns in contrast to the previously constructed ones (Figure 12). It is proposed that the hull of such a drilling platform be made in the form of two truncated cones joined together by bases of smaller diameter. The hull of this shape breaks the drifting ice fields better with vertical displacements of the platform as a result of taking on or discharging water ballast.

Thus, for exploitation of the oil and gas deposits on the continental shelf numerous different technical means have been built which are distinguished from traditional types with respect to their structural design, dimensions, the equipment used on them and their operating maintenance conditions.

BIOLOGICAL RESERVES OF THE WORLD OCEAN AND PROSPECTS FOR THEIR UTILIZATION

[Article by P. A. Moyseyev]

Petr Alekseyevich Moiseyev, deputy director of the All-Union Scientific Research Institute of Marine Fishing and Oceanology, doctor of biological sciences, professor, is widely known in the USSR and abroad for his work in the field of biological productivity of the ocean.

1. Characteristics of the Biological Reserves

The rapid growth of the population of our planet, the number of which in 1975 was 4 billion, and by the year 2000, according to the estimates from the United Nations data, will exceed 6 billion, the everincreasing world shortage of food products and also significant demands of animal husbandry for high-calorie feeds of relatively low cost -- all of this is forcing governments to turn their attention to the biological resources of the World Ocean.

In the last decades the progress in agriculture has become significant, especially in densely populated countries such as India, Pakistan, and so on where this process is called the "green revolution." However, the satisfaction of the demands of the population for animal proteins is decreasing persistently. Thus, in 1938 the ration of almost 59% of all of the inhabitants of the earth included less than 15 grams of animal proteins, which is considered to be intolerable for normal nutrition, and in 1970, the ration of 62% of the inhabitants of the earth included less than 15 grams of animal protein. Thus, about 2 billion people systematically undereat or, simply speaking, are starving.

The World Ocean is the most important source of varied food products which are valuable to the highest degree. Presently catching all together more than 60 million tons of sea fish, mollusks, mammals and other objects per year, mankind provides about 20% of his requirement for proteins of animal origin at their expense, which permits a significant increase in quality of nutrition, it makes it possible to include many trace elements, various vitamin components and well-assimilatable proteins of the characteristic amino acid composition.

It must be noted that a number of countries are satisfying their demand for animal proteins almost completely at the expense of products of water origin.

The marine objects have no less significance as raw material for obtaining high-calorie feed meal, the volume of the processing of which reaches 4.5 million tons and also as raw material for medical and a number of technical branches of industry. Therefore, naturally the world catch of water objects is increasing with each year, its assortment is increasing, and today for each inhabitant of our planet there are three times as much of the products of the sea as in 1948.

Today 210 countries and territories are fishing the seas and oceans, hundreds of thousands of fishing ships are casting their nets in various parts of the ocean, and tens of millions of people are working in the vast expanses of the "blue cornfield."

The fishing industry of many countries has in a short time converted to a highly developed industrial branch of the economy.

In the Soviet Union in 1976 the demand for fish products per capita reached 18 kg (instead of 5 kg in 1950), and in the near future their volume is to be brought to 20-22 kg. This large scale national economic goal must be met at the expense of further exploitation of the various biological resources of the different parts of the World Ocean, above all at the expense of marine and ocean fishing (our country is already receiving 90% of the fish products from this type of fishing).

The existing ideas about the biological reserves of the World Ocean and their potential capabilities have developed as a result of comprehensive studies performed by the scientific research institutes of many countries, the crews of the research and fishing ships, the co-workers of the experimental stations, space laboratories and submersibles. This has made it possible to establish the basic laws of ocean bioproduction processes and with a sufficient degree of reliability determination of the possible volume of the catch of the water objects.

The special attention of the researchers has been attracted to the discovery of the role of the processes of vertical mixing of the water, including the effect of large-scale eddies, meanders and rings in the creation of the zones of increased fish productivity, determination of the value of the slope of the continental shelf and the peculiarities of the underwater relief, including the relief of the ocean bed, for the formation of fish-productive regions and also the establishment of the law of biological reproduction and the development of methods of estimating the potential biological reserves of the ocean.

Soviet scientists have made a large contribution to the resolution of these problems.

It is undoubtedly so that the results of Soviet fishing research and the development of ocean fishing itself in our country have to a significant degree promoted the creation of the modern concept of the biological resources of the ocean.

2. Methods of Efficient Use of Biological Resources

It is entirely obvious that under modern conditions, maritime fishing, the scales of which are increasing with each year, especially in the traditional fishing regions, has been converted to a powerful factor influencing the biological resources, and without the proper control it can lead to dire consequences, especially in a number of zones, the reserves of the fishing targets have turned out to be at the maximum low level as a result of an entire series of natural factors. In accordance with the estimate of the potential capabilities of the ocean, the catch of fish, large invertebrates and marine mammals can increase by approximately 30 million tons by comparison with the existing volume. At the same time the minimum human demand for fish and other water targets in the year 2000 will be defined as 150 to 160 million tons. No more than 15-20 million tons (at the present about 10 million tons) can be obtained at the expense of fresh water inhabitants, both natural and artificially bred, in the next 20 to 25 years. Thus, the only possibility for satisfying the rapidly growing demand of man for the products of the sea is more effective and at the same time efficient utilization of the potential capabilities of the biological resources of the World Ocean, which will become realistic only with a basic change in attitude toward the entire problem of ocean fishing and marine fishing.

A great deal of attention must be given to the development of the scientific methods of fishing. It is well-known that modern fishing techniques and equipment can inflict significant losses on the fished populations if they are used without considering the biological characteristics, the nature of the distribution, age composition and number of the schools. Extraordinarily intense fishing will lead to a significant reduction in the total mass of the population and its young, reduction of the area of inhabitation and a decrease in the extent of the migrations, a reduction in the reproduction level and, as a result, a decrease in the biological stability of the species. The number of the population consisting of young age groups turns out to be under the defining effect of the fluctuations in the degree of "productivity" of the individual generations replenishing the catchable part of the school, and the probability of repetition of "unproductive" generations will become greater, and the results of the fishing will drop.

It is possible to present a set of examples of this type; it is sufficient to remember the populations of such fish as Atlantic cod and herring, golden red fish, plaice, and so on. It must be noted that the rash conduct of fishing and also nonuniform removal of individuals of different sexes, generations and genetic groups from the population will lead to highly unfavorable consequences for stability and productivity.

Consequently, not only is it desirable, but widely necessary to fish on the basis of scientifically developed recommendations. It is required that selective fishing equipment be built, the deep-water trawls be improved, fishing techniques be used which promote the separation of small immature fish, and so on.

Another method of increasing the efficiency of modern fishing is significant improvement of the method of using the traditional objects of fishing. Today about 10 million tons of potentially possible catch of the fished populations will be lost as a result of inefficient fishing.

The development of the fishing for certain new objects of the fishing industry, primarily the inhabitants of the ocean epipelagic and deep-water zones (to 2000 meters) is requiring special significance.

Until recently, a negligibly small amount of tension on the part of scientists was attracted to the biological resources of the enormous body of water represented by the ocean epipelagial zone making up about 100 million km^2; no research of the sort conducted in coastal regions was performed in these zones. However, the reconnaissance fishing operations here and also the quite substantial oceanographic surveys indicate the reality of inhabitation by quite large populations of such pelagic subjects as skipper [Scomberesox saurus L.], flying fish, bonito, dorado, squid, and so on. Moreover, it turned out that in many parts of the World Ocean within the oceanic pelagic zone, the inhabitants of the neritic and far-neritic zones can live and form highly dense accumulations (mackerel, scad, anchovies, sardines, and so on).

By some estimates, the volume of potentially possible catch of the different marine objects within the boundaries of the oceanic epipelagic zone can exceed 10 million tons. For successful fishing, the creation of artificial accumulations of relatively diffusely scattered subjects in the epipelagic zone is acquiring special significance: skipper, flying fish and squid.

A quite voluminous catch can be expected as a result of the corresponding research and organization of fishing within the boundaries of the uplifts of the ocean floor at relatively great depths (800 to 2000 meters) of the World Ocean.

Let us remember that the part of the ocean with depths of 2000 meters or more amountes to 84.1%, and with depths to 200 meters, a total of 7.4% of the ocean surface. However, within the limits of the shock zone and the regions adjacent to it making up approximately 20% of the entire ocean area, at present more than 90% of all of the world catch of marine objects is caught. This is explained primarily by the common laws of oceanological and biological processes which in the final analysis determine the fish productivity of the ocean and individual parts of it.

In 1975 out of 49.3 million tons of fish extracted in the World Ocean, 43.2 million tons were inhabitants of shelf waters, 3.0 million tons were extracted in the upper part of the slope (to 500-800 meters) and the same in the epipelagic zone. Whereas in the last 30 years the catch in the shelf regions increased by 30 million tons, within the boundaries of the upper part of the slope, it increased by 1.8 million tons, and in the epipelagic zone, by 1.3 million tons.

The extraordinarily slow increase in volume of catch within the boundaries of the relatively deep areas is explained by the peculiarities of the distribution of the fishing accumulations here, poor study of them, complexity of the research work, insufficient technical equipment of the fishing fleet.

The operations of recent years have demonstrated defined prospectiveness of the discovery and use of biological resources in certain parts of the World Ocean to depths of 1900 to 2000 meters.

Positive results were obtained when catching accumulations of halibut, Macruridae, alepocephalidae, sharks, burbots and other species in the North Atlantic.

In the Central Atlantic at depths to 1900 meters, dense accumulations of Alepocephalidae, Zeiformes, and so on were discovered.

The fish accumulations have been detected at depths of more than 1000 meters, and in the regions of the Seamounts in the Indian Ocean and in the southern part of the Pacific Ocean[1].

According to the preliminary estimate, the area of the ocean floor to a depth of 2000 meters beyond the 200 mile limit is 2.7 million km^2; in the depth range of 1000 to 2000 meters, it is 2.3 million km^2, and in the depth range to 500 meters, a total of 0.06 million km^2.

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[1]For more details on the problems of deep-sea fishing see the article by A. D. Druzhinin and B. P. Pshenichnyy in this collection.

The available data indicate that the overwhelming majority of the accumulations of relative deep water fish are associated with the horizons from 800 to 1600 meters (see Table 1).

Table 1. Distribution of accumulations of macruridae with respect to depth (according to Nizovtsev)

Depth, meters	Volume of accumulations			Number of accumulations	Average height of accumulations, meters
	$1 \cdot 10^6$ m^3	%			
600–800	50.43	9.4		11	60
800–1000	193.92	36.0	83.3	44	75
1000–1200	179.45	33.4		44	70
1200–1600	74.45	13.9		25	70
1600–2000	13.18	2.4		5	70
2000–2400	26.05	4.9		4	100
Total	537.43	100.0		133	70

The area of the underwater seamounts is 1.0 to 1.5 million km^2. Within the limits of the mentioned seamounts it is possible to expect detection of accumulations of fishing targets with a total catch to 2 million tons.

The objects of a low trophic level, primarily Antarctic krill, the volume of possible catch of which is estimated by many specialists at tens of millions of tons (we provisionally estimate it at 30 million tons) has defining significance in increasing the volumes of the removal of the biological resources of the World Ocean in the next decades.

In addition, the time has come to make the transition from uncontrolled fishing to cultivation of the objects of fishing, the number of which will be determined and will increase as a result of the active input to the biological process. We are talking about the creation of large-scale coastal marine underwater farms for growing algae, mollusks, crustaceans, and fish, the realization of the complex also of the highly voluminous measures with respect to biological improvement of the marine fishing areas and transplantation of the objects of fishing to new regions of their habitation. These conditions could give an increase of more than 40 million tons[1].

On the basis of what has been discussed above it is possible to put together an idea of the composition and volume of the oceanic water subjects which can be obtained as a result of taking an enormous set of measures implemented by the interested countries both in the coastal waters and open seas. In the next 25 to 30 years they would at least permit doubling of the total catch which, according to our ideas, could be made up as follows:

[1] For more detail on the methods of developing aquaculture, see the article by V. P. Zaytsev, A. N. Dmitriyev in this collection.

Contemporary and future use of marine and fresh water biological reserves

	1975	2000	Change
Catch, millions of tons	70	160	+90
Including:			
fresh water and migratory (including fishing)	10	20	+10
marine subjects	60	160	+100
including as a result of			
fishing	52	80	+28
rationalization of fishing	--	10	+10
aquaculture, biological improvement, and transplantation	8	40	+32
objects of a low trophic level (krill)	--	30	+30

Thus, the biological reserves of the World Ocean are and will remain the primary source of meeting the ever-increasing demand of man for food resources. As has been emphasized, this can be achieved only under the condition of a cautious additive toward its wealth and also the efficient conduct of fishing.

3. Prospects for the Use of the Biological Reserves in the USSR

In the Soviet Union, along with the improvement of the methods of using biological reserves of the coastal waters, an enormous amount of attention must be given to fishing in the inland seas, aquaculture and biological improvement.

In the light of what has been discussed it appears that the probable catch in our country in the future will be made up approximately as follows:

Contemporary and probable composition of the catches in the USSR

	1975	2000	Change
Total catch, millions of tons	10.3	15.0	+4.7
Including:			
in the inland bodies of water,	1.2	2.0	+0.8
among them:			
in the lakes, rivers and inland seas	1.0	1.0	0
fishing in fresh water and acclimatization	0.2	1.0	+0.8
in the seas and oceans,			
namely:			
in the nearby coastal waters	3.5	4.0	+0.5
in the distant coastal waters	5.6	2.0	-3.6
in the epipelagic zone,	0.1	1.0	+0.9

(continued)	1975	2000	Change
at great depth	0.1	1.0	+0.9
aquaculture and biological improvement	--	0.5	+0.5
objects of a low trophic level	0.1	3.0	+2.9

Table 2. Probable volume of the catch in the USSR of different oceanic objects in the future

Object	Volume of catch, mil. of tons	Object	Volume of catch, mil. of tons
Near coastal zones		Epipelagic zone	
Cod, haddock	0.5-0.7	Bonito	0.5
Arctic cod	0.2	Tunny	0.2
Herring	0.5-0.8	Skipper	0.3
Walleye Pollock	2-3	Putassu	0.2
Capelin	0.5-1.0	Mackerel, scad	1.0
Plaice	0.2	Total	2.2
Lemonema, and other bathypelagics	0.1	Far coastal zone	
Salmon	0.1	Hake	0.3-0.6
Squid	0.3	Mackerel	1.0-2.0
Other	0.3-0.5	Scad	1.0-2.0
Total	4-6	Sardines	0.7-1.0
Great depths		Others	0.4
Macruridae	0.8	Total	2.0-4.0
Prestipoma	0.2		
Golden Redfish, halibut, and so on	0.5		
Total	1.5		

It is also possible to a high degree to approach the evaluation of possible catches of the basic fishing objects in the World Ocean approximately (see Table 2).

As is obvious, the national coastal 200 mile limit is acquiring increased signficance (especially adjacent to the Far Eastern Coast of the USSR), within the boundaries of which more than 4 million tons of different species of fish and valuable invertebrates can be extracted. Naturally, such a significant size of catch can be made only under the condition of recovery of the reserves of a number of species of fish and, above all, the herring and cod, the reserves of which are in a depressed condition.

It appears that the presented data indicate not only finding significance for further development of ocean fishing, the exploitation of the biological reserves of the far neretic zones, the bathypelagic zone and the epipelagic zone (skipper, bonito, anchovies, squid, and so on). and relatively great

Table 3. Basic types of fishing gear and probable sizes of the catch of the USSR in the World Ocean

Type of fighing gear	Object of catch	Volume of possible catch, mil. of tons
Trawls:		
for deep-water trawling (800-2000 m)	Macruridae, lemonema, prestipoma, halibut, and so on	1.5
for trawling at various depths (to 600 m)	Mackerel, herring, sardines, scad, Alaska pollock, hake, capelin, putassu, cod, squid, krill, and so on	6-8
for bottom trawling (to 500 meters)	Cod, plaice, perch, and so on	1.0
Purse seines	Herring, mackerel, anchovies, bonito, and so on	1.0
Hooked fishing gear:		
horizontal longlines	Tunny, Far Eastern cod, angle fish, and so on	0.4
vertical longlines	Squid	1.0
Hoisting nets	Skipper	0.3

depths (skipper, squid, and so on), but also the necessity for large-scale research and exploratory work in these broad regions of the World Ocean which were new to fishing and also the creation of a specialized fishing fleet considering the potential of the World Ocean (see Table 3).

Just as before it is most expedient to use the spread trawls to catch the above-enumerated targets; the main part of the catch (to 80% — see Table 3) will be obtained with their help. However, as before the trawls for different depths capable of operating within the limits of relatively small depths (to 500-800 meters) will predominate sharply, and only a defined part of the trawlers and the fishing gear on them must be designed for trawling within the limits to 2000 meters.

When organizing fishing special attention must be given to the prevention of the effects of the gear and the fishing techniques that are negative for the reserves. Thus, the overwhelming majority of trawling must be done without letting the trawl reach the bottom in order not to disturb the bottom ecologic systems. When selecting the mesh sizes and the design of the fishing gear it is necessary to provide for saving the young, and so on. These are some of the arguments with respect to the biological resources of the World Ocean and the prospects for further utilization of them.

TECHNICAL ASPECTS OF THE DEVELOPMENT OF AQUACULTURE

[Article by V. P. Zaytsev, A. N. Dmitriyev]

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Aleksandr Nikolayevich Dmitriyev, candidate of technical sciences, one of the creators of the submersibles "Sever-2," TINRO-2, "Atlant-2" and so on, chairman of the Underwater Engineering Section of the Scientific Council of the Shipbuilding Industry imeni academician A. N, Krylov.

By the term "aquaculture" we mean algae, mollusks, crustaceans, and fish grown in seawater and used as human food, feed for domestic animals and also as raw material for various branches of industry.

The growing of plants and animals in the water has a history many centuries old. For example, the first known treatise on breeding fish was written by the Chinese author Fan Li in the year 475 B. C. In Japan, ancient Greece and Rome oysters were grown 2000 years ago, and pond fishing is just as old.

However, the growing of marine animals and algae has been set up on an industrial basis only comparatively recently.

In 1969, throughout the entire world 4 million tons of sea products were grown; the total world extraction of the latter in the same year was 63 million tons. At the present time the aquaculture production is reaching approximately 10 million tons per year. In the opinion of the specialists, in 1985 the aquacultural production will increase to 20 million tons, and by the year 2000, to 40 million tons. However, in order to realize these forecasts, a number of scientific-research and experimental design problems must be solved.

The answers to many of the problems of the technology of aquaculture are being found by marine biologists by prolonged observations of the life of marine animals in the artificial and natural habitat. For this purpose, aquariums, maritime ships and submersibles are being used which permit the researcher to work under water for a prolonged period of time.

Many scientific research operations are performed in the laboratories or in the coastal scientific complexes simulating actual marine conditions. Such complexes are equipped with a seawater preparation system. The various filters and batchers clean the treated water, they introduce the required elements into it, they heat or cool and maintain a constant composition. The monitoring and measuring instruments are constantly informing about the state of the water environment and if necessary, they automatically maintain the given conditions.

The basic problems facing researchers are determination of the most favorable conditions for the breeding and development of the cultivation, selection and sorting of the most viable organisms and the study of their interrelations to the environment under industrial conditions.

The program also includes cultivation of valuable algae and organisms and definition of the ecologic systems. It is no less important to develop improved technical means required for successful development of aquaculture.

On the modern level the aquaculture farms are specialized primarily in growing algae, mollusks, crustaceans and fish.

1. Cultivation of Algae

The flora of the seas and oceans is represented by more than 10,000 species of plants called seaweed and algae. These include microscopic single-cell algae -- phytoplankton -- and large seaweed -- phytobenthos -- or macrophytes. Some of them, for example, macrocystis reach 60 meters in length or more and weigh more than 300 kg.

The biomass of seaweed and algae in the World Ocean, including phytoplankton, is estimated at 1.7 billion tons, and the world extraction of it is a total of 600,000 tons per year, that is, less than 1% of the reserves. The reserves of the algae of the seas washing our shores are reckoned in hundreds of millions of tons; a total of about 2000 tons have been extracted, which amounts to 0.5% of the cultivated reserves.

This situation is explained by the absence of special harvesting equipment, the design of which is far from completed, and the small number of processing plants. Often algae and seaweed are extracted by primitive methods: from boats, draglines, rakes, trawls in some places and by divers.

Out of the hundred species of industrial algae growing in our seas, red algae (anphelcia, filophora and furcellaria) and brown algae (laminarian Fucus and cystosira) are extracted. The basic reserves of them are in the seas of the Far East, the White Sea, the Black Sea and the Baltic Sea.

The algae serves as an excellent raw material for obtaining valuable medicines, producing food products, feed for domestic animals, fertilizers, and so on. At the present time the demands of industry are met basically by gathering wild algae. In the countries of Southeast Asia and Japan alone there are specialized farms for growing sea cabbage, red laver, anfelcia, laminaria and other algae. In these countries broad lagoons and bays, coastal waters with solid shell or rocky bottom have been satisfied as algae plantations. Under favorable conditions the harvest will be up to 150 tons of green mass per hectare, and the farms have a large profit.

In some countries the algae is grown not in the soil at the bottom, but in the water itself, using storm-resistant structures in the form of pilings driven into the ground or anchored floating buoys to which cables are attached, for fastening the algae. The latter procedure permits high yields to be obtained when there is an abundance of biogenic flowing water and sun.

This procedure is becoming more and more widespread inasmuch as it permits mechanization of the processes of planting, gathering and processing the algae. For these plantations it is expedient to set aside bodies of water in the ocean which are distinguished by an abundance of biogenic salts and sunlight.

The proposals to grow algae on floating structures held by anchored buoys and floats in the upper photic layer deserve attention. These ocean plantations will occupy large bodies of water, they will be marked off by signal lights, recognition buoys and sound signals which operate when there is fog. These aquafarms will come to be served by special ships: base ships equipped with submersibles for installing underwater structures, setting anchors, putting in anchor lines, floating buoys, recognition signs, and so on, ships from which the spores will be planted. In addition, ships were needed to guard the marine field, observe the growth of the algae and maintain the engineering structures. Special ships must be built for gathering and processing the harvest. They will raise the net from the water and probably process the algae. In the presence of such ships, year-round growing of algae in the summer in the North and in the winter in the southern seas will be possible.

Significant means are required to create the special equipment and ships, but the expenditures, according to the calculations of the specialists, are quickly repaid.

Thus, the creation of mechanized complete-cycle algae plantations is a matter of the future and economically advantageous.

A no less important problem is growing microscopic algae which are the food of small marine animals -- zooplankton and also the larvae of fish, mollusks, crustaceans developed in the surface layer of the sea.

Their industrial breeding is connected with defined difficulties, but in recent years the designers in cooperation with marine biologists have developed original growing systems. There are two methods of growing single-cell algae: under the open sky and in closed units, in a strictly controlled environment.

The systems are made up of pools, filters, water heaters, pipelines, pumps, instruments, lighting and other equipment which is used for continuous monitoring and batching of the nutrient salts, the gas composition of the seawater, maintaining the given temperature and stability and also continuous monitoring of the most important parameters.

In such systems there is constantly the danger of infection of the organisms and the appearance of infestations that cause too vigorous growth or retard growth. This is one of the problems which requires the fastest resolution. It is no less complicated to preserve and store the product obtained.

Recently devices have been developed for growing mixtures of various algae: diatomic, dynoflagellate, flagellates, which are excellent food for copepoda, Rotifera, artemisia and other foods or plankton organisms required to feed young fish and other young animals. The most widespread are the devices in the form of vertical cylindrical tanks -- cultivators. The low-output cultivators are made of glass or plastic.

The high-output units are made in the form of large cylindrical tanks equipped with lighting, frequently automatic, a system of tubes for supplying gas, fresh water, circulation, purification and removal of the ready alae suspension.

The suspension obtained is pumped into nurseries for animal food. The output capacity of the simplest devices is from $2.2 \cdot 10^6$ to $6 \cdot 10^6$ cells of different types of algae per cm^3 in 17-30 days. The first "harvest" can be taken after 10 days. With more favorable lighting and a temperature of 10"C the harves is doubled.

2. Growing Young Marine Animals

The first steps in breeding marine animals, whether they be mollusks, crustaceans or fish, is obtaining fertile roe and incubation of it. Frequently the roe is taken from the sires trapped at sea shortly before spawning or from sires grown under artificial conditions. In these cases the breeding gate begins with fertilization and incubation of the roe. Sometimes the fertilized roe is picked up in the spawning areas, and then it is incubated and the larvae and young fish are grown under artificial conditions.

The roe matures in special incubators of various designs with constantly circulating water. There are rectangular shaped incubators with large water surface which causes increased water consumption for aeration. The cylindrical incubators with funnel-shaped bottom made of glass or plastics are considered more effective.

For aeration and maintenance of the eggs in a suspended state, air is fed to the lower part of the incubator from a compressor. With continuous aeration about 10 grams of roe are incubated in one liter of water. A special separator separates the larva from the shells and the eggs and transports them to the growing pools.

Some incubators are equipped with a special system which maintains optimal water parameters: its temperature, gas and the salt composition, sterility, purity, and so on.

In recent years automated devices have been developed for growing feed larvae. The water parameters, aeration, supplying of nutrients, catching of the larvae and removal of the production waste are regulated in them in accordance with a program.

With the appearance of such automatic devices it was necessary basically to reconstruct the incubation shops. Instead of awkward trough-type incubators which take up a great deal of area, vertical shelf incubators appeared in which more than 10 plastic incubation tanks were installed in tiers one above the other. As a result of this fact, it was possible not only to decrease the area of the shops and the water consumption, but also to increase the larvae output per unit area by tens of times.

In the case of artificial incubation, the survival rate of the larvae is up to 95%, whereas under natural conditions it doe not exceed 5%.

These larvae are used as food for fish larvae. After many years of experiments scientists have established that the best food is the nauplia of the artemia salinia.

Artemia-salinia is a characteristic Copepoda living in seawater. It multiplies very quickly; ten to 15 young nauplia are born to each ever five days; therefore the offspring of one female can reach hundreds in a month. The artemia is eaten by the bright red single-cell algae -- dunaliellia.

It is very simple, it lives excellently with a small amount of oxygen, high density, with drying or freezing of the water the artemia forms eggs capable of remaining viable for 10 years, and it tolerates hot sun well.

The dimensions of the artemia fluctuate within broad limits: from 0.3 to 0.4 mm to 10-15 mm. The nauplia have the greatest value of food at the age of two days after hatching out of the eggs, for there is no solid chitinous cover on them for this period of time.

Artemia and other large copepoda, Rotifera, and so on up to 1 mm in size are grown in high-output units with water recirculation and systems that reduce the dissolved organic matter in the water, removing waste and solid particles 5 to 100 microns in size.

The scavenger copepoda are also put in which clean the walls of the pools from adhering algae and eat the dead larvae. The density of the population of Rotifera is 100 to 200/cm^3, and copepoda, 5-20/cm^3.

Today the process of growing them has been mechanized and automated; the tanks have an inclined bottom which provides for gathering waste.

3. Growing Mollusks

Mollusks include three classes: Elasmobranchii (oysters, scallops, mussels); Gasteropoda (maktra, stentor, rapana); Cephalopoda (octapus, squid and cuttlefish). To one degree or another they are used as raw material for th food and pharmaceutical industry, sometimes as feed.

Mollusks have high nutritive value, which is explained by the high protein content in them, valuable trace elements and vitamins, and they have good taste qualities.

The oysters enjoy the greatest demand. Wild oysters attach their valve to a solid surface of an underwater object and they live their entire lives that way. At three or four years old they lay millions of eggs, from which free floating larvae appear. Time passes, and the larvae sink to the bottom and also take up the "sedentary" way of life. Wild oysters are extracted by special wooden tongs or drag lines, separating them from the bottom or the rest of the overgrown shells.

The greater part of the oysters are grown in special farms.

The basic principles of growing mollusks and other species of marine animals and plats are identical for all parts of the ocean, but the methods of growing them differ depending on the specific conditions.

Oysters. Cultivated oysters are provisionally separated with respect to shape of shell into flat and cup-shaped. The flat or European oyster is grown in England, France, Spain and Norway; the cup-shape or Portuguese oyster is cultivated in Europe and in the southern seas of the Soviet Union. The world production of oysters is about 800,000 tons.

The first place in the world with respect to oyster growing is occupied by Japan -- Japan produces about 40,000 tons of oyster meat per year; 700 oyster farms grow the so-called giant Japanese oyster.

There are three methods of growing oysters: on the bottom, on floats and in nurseries.

Growing oysters on the bottom, on natural banks, is the oldest method and gives high yield if they are not contaminated and silted in. These farms have come to be widespread in the southern maritime countries, on shores where there is a lot of sunshine and heat. Oysters are grown in the estuaries of small rivers, in semiclosed bays and other coastal zones of the sea with favorable conditions. Here the title currents and surfs are skillfully used to enrich the water on the shores with new nutrients and oxygen required for development of the oysters.

The most favorable is water with a salinity of 19 to 33 parts per thousand and a temperature of 10 to 30% C. When growing oysters on the ground, machines are used for feeding and also for gathering the harvest, and cleaning the bottom of mud and ooze.

Thus, in the oyster farm on Long Island (United States) dredges are used for this purpose. They are used regularly to remove the mud from the oysters using jets of water from a pump with a hose installed on a barge. During the growing period, periodically the oysters are moved to other sections free of mud previously selected by divers.

In order to gather the larvae and for growing the young, special collectors are suspended in the water. The substrate for the larvae is empty shells, tile or plastic tiles lowered on galvanized wire.

For attaching the larvae these tiles are covered with lime. The collectors are suspended on floats, bottom or floating devices, the frames of fixed trap nets, piles and other supports. The length of the collector chain can be from 1 to 20 meters and depends on the depth of the area, the type of mollusks, the conditions of habitation and other factors.

In the middle of the summer the mollusks begin to lay the eggs. The eggs are attached to the plates covered with lime, and after three months it is possible to discern small mussels.

After 9 months the larvae are transformed into small oysters 1-2 cm long. Then, without removing them from the collectors, they are transported to shore and manually removed from the tiles. This primary product of the oyster, a type of seedling, is called spat. The lime layer makes it possible to separate the mussels from the tiles, especially from thin plastic plates — when bending the plates the spat is easily flipped off together with the lime. One kilogram of spat contains approximately 800 to 1200 oysters weighing 0.7-2.0 grams.

The second growing phase takes place on enclosed banks with a pure sand and gravel bottom or in suspended baskets. The complete growing cycle of the oysters to commercial size is one to 3 years old. During this time they are extracted from the water several times. The three-year old oyster up 5 cm long weighs 60-100 grams (there are 30 grams of meat in it).

The oyster farms usually are divided into two types: full-cyclic and semicyclic.

In the former, the breeding and growing take place with respect to the full cycle: the sires are contained and cultivated in them, the eggs are obtained from them, and then incubated; the spat is separated from the larvae and then the adult individuals are grown.

In some farms the larva of this type are obtained at any time of year in tanks and pools from a small number of sires, which excludes the dependence on natural conditions. For this purpose, the larger sexually mature oysters are selected from the growing pools, they are transplanted to the spawning basins and breeding is stimulated by temperature, mechanical and chemical effects. The fertilized eggs are placed in the incubation tanks with good water exchange; the larvae are sorted and are transferred to the growing tank. After two weeks the larvae are transplanted to large pools, the bottom of which is covered with the oyster shells. The larvae settle on these valves after two days which then are removed to the growing pools. This method of obtaining spate is more efficient than collecting in the sea.

In the second, semicyclic farms, mature individuals are grown only from the young obtained, like from "seedlings." These farms are appreciably more simpler and more profitable; therefore they are more widespread.

The farms have become quite widespread in which the oysters are grown in the water floats, cables (stages), shelves and other similar structures. This method has a number of advantages by comparison with growing on the ground: the oysters are protected against bottom predators, as a result of improvement of the conditions (the floats were towed to warmer and cleaner water), the growing time is reduced to one year, and the harvest is increased by more than three times. As a result of the necessity for multiple removal and cleaning of the collectors with the mollusks, the process of growing them has not been completely mechanized up to the present time.

In countries with temporate climate where there is no seawater convenient for breeding, shore plants are constructed. Thus, several shore enterprises are in operation on the Atlantic coast of the United States. They are made up of pools for the sires, incubation tanks for containing the eggs until the larvae hatch, settling tanks with collectors and pools for growing the feed algae. Although the expenditures on building and maintaining such farms are significant (300,000 and 50,000 dollars, respectively), the net profit, not considering the depreciation reaches 220,000 dollars per year. The annual growth of young is equal to approximately 20 million units.

There are shore farms with a complete oyster growth cycle. In such farms, in addition to the nurseries for the young, there are large basins for growing commercial oysters, breeding the feed algae and also basins for holding the oysters before sale. The latter are serviced by systems for regeneration, sterilization and the heating of the water. In order to save energy, on such farms frequently warm waste water from electric power plant units are used.

The mussels are a less valuable food product than oysters, but their meat is not inferior to oysters with respect to taste. In some countries the meat products from these mollusks enjoy large demand among the population.

From one hectare of sea floor convenient for growing mussels it is possible to obtain 56 tons of pure meat from this mollusk annually.

The mussels are grown, analogously to the oysters, on collectors, frames, piles driven into the ground and on the bottom. The mussel farm must be located in an area with high tidal current, good heating of the water to 12-18°C, protected from predators and contamination by waste water or oil.

In Europe such farms exist in Spain, France, Holland, Italy, Norway, Ireland, Scotland and other countries (see Figure 1).

In France farmers have bred mussels by the "bouchot" system for many centuries. By this system oak poles 15-20 cm in diameter and about 3 meters long are driven into the ground in the tidal zone. The base of each of them at a height to 25 cm from the bottom is covered with a net or plastic film which protects the mussels from crabs and other predators. Dibbles are placed at a depth such that they are completely exposed at low tides. The mollusks are inspected at this time. The dibbles are driven in rows at a distance of 35 cm from each other perpendicularly to the shore. Between the rows there is space for boats to run. The young are gathered on freely twisted cables 125 mm in diameter and 3 meters long. Sometimes the cables are wound in a spiral around the dibbles driven into the ground.

During spawning the larvae are attached to the cables. When they grow to the spat stage, the cables are transferred to other sections and are attached to oak poles driven into the ground. In order to avoid loss of the mussels, the dibbles with the cables and the young are covered with synthetic nets. As the mussels grow, they fall off under their own weight; therefore the outer layer is removed and transferred in special bags to a new location. This operation is repeated 2 or 3 times a year until the mussels reach a length of 5 cm. The mussels require less care than oysters; therefore the farms for growing them are more profitable.

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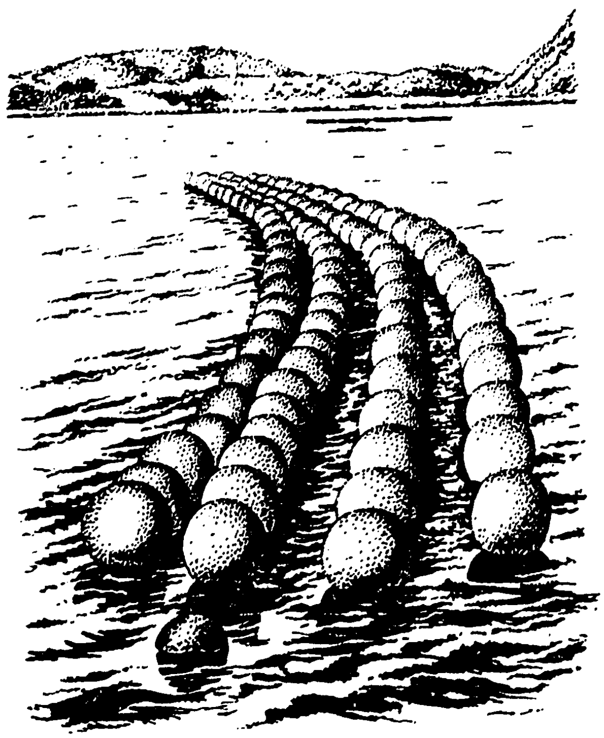

Figure 1. Rows of buoys supporting collectors for growing mussels (Scotland).

In Japan recently a new method of growing mussels has been used from special rafts 20 × 20 meters made of fiberglass floats. From one raft on which 500 collectors are suspended, 60 tons of mussels are gathered annually, and the annual harvest per hectare (approximately 10 rafts) is about 600 tons.

Sea scallops are mollusks with very tasty and nutritious meat. They reach commercial size in 2 years. In contrast to the oysters, scallops lead a mobile way of life; therefore they are grown in closed areas. The large scallop reaches 250 grams in weight. The scallop farms are located in areas with sand and gravel bottom 50 to 60 meters deep, with a current velocity of 5 to 15 cm/sec, a water temperature of 8 to 10° C, salinity of 37 parts by thousand and oxygen saturation of 90 to 100%.

The feed for the scallops is diatomic algae.

For growing the scallops in the water on long lines, the body of water used for this farm must be protected against high waves, the inflow of river or rain catchment water. The industrial production of sea scallops has been set up in Japan, the United States and a number of other countries. The Soviet Union has such farms in the Far East.

Modern oyster and mussel farms require the application of manual labor. Scientists and engineers are faced with the problem of developing a new process for growing mollusks which will permit mechanization and automation of a number of processes. This must be preceded by scientific research work.

Crustaceans, above all, shrimp, enjoy the greatest demand among the population. Industrial growing of them has been well-developed in Japan, Indonesia, the Phillipines, Great Britain and the United States.

In countries with a warm climate usually the shrimp are grown in tidal zones adjacent to rivers and estuaries. The areas of such plots can be from several hectares to 100 hectares or more. The tides are used to change the water. When the tides are high the farmers open the upper sluice gates daily, and the water from the sea together with the shrimp and food enters the pond. At low tide the lower sluice gates are opened and the water is filtered back into the sea.

The construction of shrimp farms begins with cleaning the selected plot that is flooded by the tides, leveling it, constructing a dam and the sluice gates, the size and number of which provide for calm entry of the water and complete filling of the pond or discharge from it in one tide cycle. Channels are made in the bottom which run from the sluice gate to the most distant corners of the spot. The shrimp are caught at night. After reaching the full-water level, a wire screen in the lower sluice gate is replaced by fish net with 21 mm mesh in the mouth and 9.5 mm in the codend. When the water passes through the net the shrimp are held back in the codend, and they are selected for sale (see Figure 2). In countries with temperate climates where there are no favorable hydrologic conditions for growing shrimp, special ponds and basins are constructed with forced circulation, aeration and heating of the water. The young shrimp are caught at sea or they are grown under artificial conditions. The single-cell algae are used as feed for the young, and ground mussel meat, low-price fish, and so on are used to feed the growing shrimp. For example, in Japan shrimp are grown in concrete tanks $10 \times 10 \times 2$ meters or $100 \times 10 \times 0.6$ meters in size with a sandy bottom. Water is pumped into the tanks from the sea to a height of 15-30 cm. Under favorable conditions the shrimp reach commercial size in 6 to 7 months.

Depending on the growing conditions the shrimp harvest will be from 2 to 6 tons per hectare.

The growing of lobsters and spiny lobsters is less advantageous than shrimp, but they enjoy a high demand, which promotes the development of specialized farms for breeding them. In the opinion of specialists, a lobster weighing 450 grams can be grown in two years, using the warm discharge water from electric power plants and good feed. At such growth rates the expenses on creating the farms should pay for themselves in a short time.

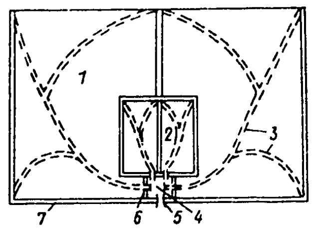

Figure 2. diagram of a 10 hectare pond for growing shrimp (Phillipines): 1 -- breeding pond; 2 -- young shrimp pond; 3 -- discharge channel; 4 -- head pond; 5 -- main sluice gate; 6 -- auxiliary sluice gates; 7 -- main dam.

4. Cultivation of Marine Fish

Recently more and more farms have appeared for growing fish in seawater. The basis for this type of aquaculture has been the experience of pond fish growing and the results of scientific research work with respect to incubation, removal of larvae, young and creation of live feed for marine fish. Now such fish as grey mullet, yellowtail, rainbow trout, salmon, plaice, tunny, carp, telapia, and so on are grown artificially. Today methods of efficient feeding, mass production of granulated feed, mechanization of the production processes and the application of new synthetic materials in sea water have been worked out in detail.

The development and industrial production of microcapsulated feeds have made it possible to grow certain species of fish without live feeds. The creation of systems that automatically maintain the optimal physical-chemical parameters of the water in the growing pools has played the greatest role in the development of industrial fish farming.

On the modern level marine fish farming has developed in four basic areas: pond, fish farming, fish breeding in enclosed bodies of seawater and growing areas, pasture fish growing in the open sea and industrial fish growing in special plants. The selection of one area or another is determined by the geographic, climatic and hydrologic conditions.

Pond fish farming using seawater is used in countries which do not have convenient bodies of water.

The advantages of pond farming include independence of weather conditions and involvement of bodies of water which have low suitability for other purposes in the economy. The deficiencies include the difficulty in creating intensive circulation and maintaining optimal parameters of the water environment.

Usually the pond area is about a hectare. Their productivity increase as a result of the application of fertilizers, artificial feeds and heating of the water.

In the northern countries salmon, rainbow trout, plaice are grown in such ponds, and in the tropical countries, heat-loving fish: telapia, eels, red and black tay and pompano. The trout harvest reaches 6 to 10 kg per m^2, eels 4.5 kg, and telapia, 0.3 kg.

The coastal farms are using natural water exchange and the enclosed plots and planting areas are more effective (see Figure 3). Recently the increase in the production of fish grown in this way in all countries of the world is from 20 to 30% per year.

For example, Norwegian fish farmers are obtaining 35,000 tons of trout and salmon per year, and by 1990 they are planning to grow up to 20,000 tons of these valuable fish.

The method of growing salmon and trout in England, the Federal Republic of Germany, France, United States and other countries is becoming widespread. The advantage of this method is the free maintenance of the fish and partial satisfaction of their food requirement at the expense of the living organisms grown in the pens or brought in by the trap from the sea.

The deficiencies include the poor water circulation which becomes worse when algae and mussels grow on the screen. In addition, the enclosures are frequently damaged by waves, the bottom quickly becomes polluted, and predators get into the pens from the sea. In the enclosures it is difficult to monitor the condition of the fish and trap them. With all the positive qualities the enclosures are effective only in areas with especially favorable climatic and hydrologic conditions.

The structural design of the enclosures and plots, the methods of construction and the operation and maintenace of such farms are highly varied and depend on the local conditions.

The enclosure separating part of a bay, strait or part of a coastal body of water from the open sea, on the one hand, must pass the water and plankton organisms from the sea freely, be storm resistant, and on the other hand, not let the grown fish back into the sea. At the present time the enclosures are made of netting usually used to manufacture fish nets and trawls, most frequently made of nylon or galvanized steel consisting of individual links. The mesh of such a net must be of a size that does not permit the smallest fish to leave the enclosure.

The nets are fastened to wood or reinforced concrete piles driven into the bottom. The lower edge of the net is held to the bottom by weights, and the upper part is raised above the average sealevel by about 1 meter.

In the marine fish farms, staked or floating growing batteries are used with a volume from 50 to 500 m^3 also made of nylon or galvanized steel nets. The batteries are installed in protected bays, fjords and sea ponds. The nets sometimes are fastened to pilings similar to construction scaffoldings with trestles. Steel pipe is used as the trestles.

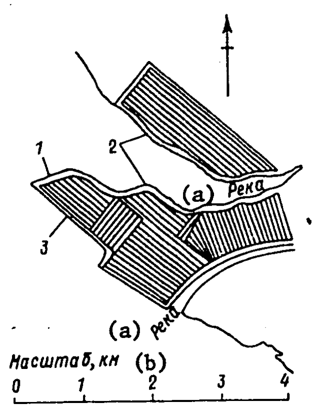

Figure 3. Diagram of gray mullet ponds with discharge channel in France: 1 -- sea dam; 2 -- internal channels; 3 -- sluice gates.

Key: a. river b. scale, km

In some countries floating batteries are widely used, the upper fittings of which are kept afloat by barrel buoys made of plastic or foam plastic included in fabric or rubber bags. The buoys also are enclosed in a thin plastic shell which is replaced after it becomes fouled. The batteries are made of nylon or flexible galvanized steel nets of the "chain mail" type. The steel net becomes less fouled, but as a result of fast wear, it is replaced every year by a new one to avoid breaks and the escape of the fish.

The shape of the rigid frame and the buoys can be the most varied, and the dimensions of the batteries depend on the location and species of fish grown. The diameter of the circular batteries reaches 60 meters, and they reach 10 meters and more in depth. All of them have common deficiencies: the necessity for frequent replacement of the nets, expensiveness of construction and difficulty of servicing.

In Japan the most widespread is the fish cage made up of a rigid square frame 10 × 10 meters in size held on the surface of the water by plastic floats. A net bag 3-5 meters deep is suspended from the frame. In bodies of water protected from waves, usually single-layer nets are installed, and in the open sea they are made stronger and two-layered. Weights are tied to the lower corners of the net bag so as to give the cage the required shape.

Ten of the floating square cages joined together form a large raft held by anchors at each corner.

The floats hold the entire cage in the water; therefore the volume is determined by the mass of the weight, the frame and the netting. A large number of floats are required to hold large cages; therefore they are more complicated to service, tow and hold in the current and waves.

In open areas subject to waves, floating breakwaters are used.

In the winter the floating cages frequently are towed closer to the coastal electric power plants that discharge warm water into the sea.

The cages which are fastened to pontoons are connected by bridges required for the service personnel are considered more improved and profitable. Such cages have square or rectagonal shape; a nylon or metal net is fastened to their rigid frame. The cages usually are connected to each other, they are fastened to common floating pontoons from which the fish are cared for. One end of the extended cage complex has an exit to shore. The useful volume of the rectangular and polyhedral cages can reach 500 m^3 or more. The cages of this type are distinguished by cheapness, strength, mobility, simplicity to service (see Figure 4).

Norway has more than 10,000 large octagonal cages in operation (12 meters across and 4 meters deep) in which rainbow trout, Atlantic and Pacific Ocean salmon are grown. The density of the fish in the cages reaches 30 kg per 1 m^3, and the finished product sometimes exceeds 100 kg per m^3.

Recently underwater cages at a depth of 10-12 meters have appeared with rigid ring frame. In the central part of the cage a steel cylinder is installed in which there is a system for regulating the buoyancy for automatic sinking of the cage or floating of it to the surface for feeding and care of the fish.

The pasture fish farming in the open sea has an ancient history. In the past century ichthyologists began to release fish larvae into the sea. At the beginning of our century special fishing stations and enterprises appeared which grow dozens of species of industrial fish: beluga [white sturgeon], sturgeon, northern salmon, caspian salmon, humpbacked salmon, plaice, cod, and so on.

The technology of this fish farming usually consists of catching the sires in the sea, holding them in special cages, obtaining fertilized eggs, incubation of the eggs in various types of apparatus, growing the larvae and young.

Pasture fish farming has justified itself in the feeding of settled populations of fish in the inland and semienclosed seas. It is becoming profitable to fishermen of other countries. Accordingly, ichthyologists have begun to develop a procedure for keeping the grown fish in their own water. It is known that certain species of fish prefer the sedentary way of life if this is promoted by conditions for spawning, the maturing of the larvae and the development of the young. In addition, underwater observers have established that fish in large numbers accumulate near reefs, rocks, growths of algae and coral where they find shelter from predators and also near various sunken objects, for example, sunken ships, barges, concrete slabs, and so on. In the sea they quite quickly grow over with colonies of mollusks or algae which are reliable shelters for the young.

Thus, Soviet researchers, working in the TINRO-2 submersible in the Hyere Bank in the Atlantic Ocean have established that on the rocky, sharply broken relief the fish concentration increases by 500 times by comparison with the level sections of the bottom covered with loose ground.

The conclusions regarding the laws of concentration of the fish have brought on the idea of creating artificial reefs in the areas set aside for pasturing fish, which will promote the holding of the fish.

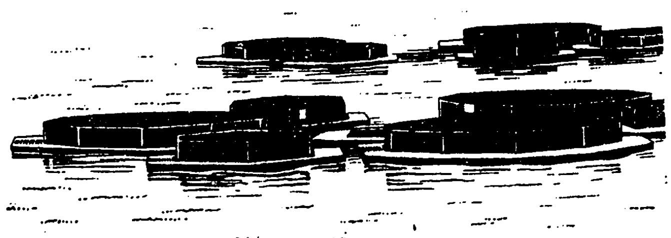

Figure 4. Polyhedral cages for growing salmon (Scotland)

The structural designs of the artificial reefs are varied and are determined by the hydrologic conditions and also the type of fish grown. Metal and capron nets are used which are attached to pilings or special frames.

The ichthyologists of the Magadan division of the TINRO have proposed the creation of artifical spawning grounds in the Sea of Okhotsk for herring in the sections of the sea that are poor in vegetation. Nets have been installed in the sea, on the threads of which the herring begin to lay their eggs just as abundantly as on the algae. The experiment turned out to be successful.

According to the calculations of the specialists, it is possible to obtain 3000 tons of fish a year from 500,000 hectares of sea with depths to 100 meters bounded by artificial reefs with a total volume of 30,000 m^3.

Modern fish farms, in spite of the low level of technical equipment, are quite profitable. Further improvement of the cost effectiveness depends on solving a number of problems, namely improving the technology, the mechanization and automation of the processes of breeding the fish, catching them, and so on. Only in this case will aquaculture become the greatest source of protein food for the going population of the earth. However, the World Ocean as a colossal natural factory of food protein never will lose its significance.

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SOME PROBLEMS OF DEEP-SEA FISHING

[Article by A. D. Druzhinin, B. P. Pshenichnyy]

Anatoliy Dmitriyevich Druzhinin, candidate of biological sciences, laboratory head of the All-Union Scientific Research Institute of Marine Fishing and Oceanography is studying the fish resources of the oceanic and shelf waters of the World Ocean.

Boris Pavlovich Pshenichnyy, candidate of biological sciences, senior scientific co-worker of the All-Union Scientific Research Institute of Marine Fishing and Oceanography is studying the biological resources of the World Ocean.

As is known, deep-sea fishing has been developed the most widely in the postwar years. Thus, beginning in 1955, the annual increase in the world catches began to rise and reached on the average 2.5 million tons as a result of intensive fishing in the highly productive parts of the world ocean, primarily on the continental shelf, that is, in the regions in direct proximity to the continents.

This increase in the catches has promoted the spread of the opinion of inexhaustibility of the biological resources of the World Ocean. However, recent studies of the fishing situation have refuted this idea and have demonstrated a clear-cut relation between the decrease in the catches in certain traditional fishing areas and the growing intensity of fishing. The reduction of the reserves of certain commercial species of fish indicates that in a number of cases the industrial exploitation of their reserves has exceeded the admissible limit. (There are also other causes of a reduction in the world catch -- economic, pollution, shoaling, and so on).

All of this taken together has forced many, primarily the technically developed countries to turn their attention to the exploitation of the biological resources in the open seas beyond the limits of the 200-mile economic zones. This is being done in two areas at the present time: fishing in the pelagic zone and at greater depths.

By greater depth we now mean the sections of the continental slope with depths of more than 600-700 meters and seamount regions.

In the given article a study is made of some of the problems of deep-sea fishing which are acquiring special urgency.

Until the 1950's, the majority of deep-sea expeditions were of a faunistic nature. As a result of the studies that were made, it was discovered that life in the ocean exists at the greatest depths, to the maximum known. The greatest depth at which the fish was caught during the expedition by the Soviet ship "Vityaz'" was 7500 meters. Fish were detected at depths of 9000 to 10,000 meters using bathyscaphes.

The study of great depths with respect to fishing began quite recently, but there is already positive experience in catching certain fish in the North Atlantic and in the northern part of the Pacific Ocean indicating the presence of quite large reserves of deep sea fish.

This permits the hope that it will be possible to obtain a significant part of the protein required by man as some of the technical problems connected with fishing these great depths are solved.

By comparison with the surface waters and the shelf waters the habitation conditions of deep sea fish are quite stable. There are in practice no seasonal phenomena in the abyssal waters. These waters are entirely saturated with oxygen, they have no sunlight, and they are characterized by reduced heat content. The phenomena of mixing of the water at these depths are very poorly expressed.

The ichthyofauna of the abyssal waters of the World Ocean consist of two components; oceanic-deep sea (ancient or characteristically deep sea fish) and shelf-deep sea (continental or secondarily deep sea fish) [2, 3].

The oceanic-deep sea component is represented by fish adapted to the life conditions at great depth. They usually have a number of special organs and adaptations (organs of luminosity, touch, sight). The bodies of these fish are bare or have small scales. These species of fish are rarely encountered in the vicinity of the shelf and the upper layers of the water.

The shelf-deep sea species of fish for the most part do not have alterations in the body structure and belong to the groups widespread predominately in the vicinity of the shelf. They have been altered only slightly (the bright color has disappeared, and they have become red or black); frequently they have underdeveloped scales. Their geographic ranges are smaller than the geographic ranges of the ocean-deep sea fish.

There are families of fish having characteristics which are apparently transitional between these two groups.

During the process of evolution, the deep sea fish have adapted to the new conditions: the volume and surface of the body have increased, and its density has decreased, which promotes an increase in the "hovering" effect in the water. This takes place as a result of a decrease in the degree of calcification of the skeleton, the fat deposits in the tissues, the water content of the body, the presence of various growths, and so on. The low water temperatures at great depths have also been felt in the metabolism of the deep sea fish. Obviously, they have a lower food requirement than the fish of the upper layers (shallow-water fish).

Some of the deep sea fish can adapt to a change in habitation conditions. They undergo diurnal and seasonal vertical migrations to the upper layers. The roe and larvae of many deep-sea fish which spawn at the bottom float to the upper layers of the water as a result of the presence of defined adaptations, and the growing individuals return to the bottom layers. Some deep-sea fish spawn in the upper layers of the water.

At the present time deep-sea fishing is going on for representatives of 7 or 8 families of fish. In addition, another 35 to 40 families of fish, about 20 families of which live in schools, can theoretically become objects of fishing (at depths of more than 6000 to 700 meters). In general out of the 1500 species of oceanic-deep sea fish known at the present time, about 900 species (61 families) of pelagics and about 600 species of fish (19 families) live at the bottom [4].

The representatives of the grenadiers, moronidae, dogfish, Zeiformes, Alepocephalidae Pleuronectidae, Brotelidae, and so on have the greatest significance for open-sea fishing. Let us mention some of them, primarily those which at the present time are used to some degree by man as protein food.

One of the most important groups of deep-sea fish with respect to fishing are the Macrouridae family or grenadiers. Numerous representatives of the family, numbering about 300 species, are widespread in the waters of the Pacific, Atlantic and Indian Oceans. These large school fish populate in practice all parts of the World Ocean from depths of 150-200 meters to 2500-3000 meters.

Quite large fishing congregations of representatives of this group — M. rupestris — have been detected in the North Atlantic and Nematonurus pectordlis, in the northern part of the Pacific Ocean. The meat of the majority of species of Macrouridae have good taste and are a valuable food product.

Just as the Macrouridae, there are numerous representatives of Moridae. They also are of great interest as the targets of deep sea fishing. Quite large fish are encountered among the fish in this family. Thus, the Antimora rostrata reaches a length of 70 cm. The representative of the Eretmoforidae family, Laemonema longipes, fishing congregations of which are detected in the northern part of the Pacific Ocean, reaches a length of more than 70 cm. Its meat resembles cod in taste.

The Zeiformes basically inhabit the upper part of the continental slope. Representatives of the family Oreosomatidae — Allocyttus verrucosus and Neocyttus rhomboidalis — have been detected at a depth of more than 1000 meters. These fish have quite tasty meat and can be used for the preparation of, for example, canned goods, smoked and dried products.

The Alepocephalidae form large congregations at depth to 2000 meters. Their meat is in need of special culinary preparation as a result of the high water content.

The representatives of Pleuronectidae, although they are not standard oceanic deep-sea fish (the lower limit of their habitation does not exceed the limits of 1000 to 1500 meters), can become targets of deep-sea fishing. The taste qualities of their meat are high.

There is no doubt that the list of fish which should become targets of deep-sea fishing can be continued.

In order to realize this goal, it is necessary to solve many problems connected with the detection and extraction of deep-sea fish and with the preparation of high-quality food products from them and so on. Let us consider some of these problems.

One of the basic problems in organizing deep sea fishing is the detection of congregations of them. Usually sonar is used, which permits rapid examination of large bodies of water, the establishment of the presence of fish and also aimed catching of them. Thus, the "Paltus" or "Kal'mar" type fish-finders can detect dense congregations of fish at depths to 800 to 900 meters. However, the deep-sea fish frequently remain dispersed; individual fish, of course, fall into the range of the sonar. Consequently, for successful detection of deep sea congregations of fish sonar must "sense" individual fish at great depths.

When building this type of equipment, the designers encounter great technical difficulty; the equipment is found to be awkward and complex and has limited capability.

A further increase in depth of detection of the fish is realizable with significant constriction of the sound beam and an increase in power of the emitted signals, but this leads to greater complication of the fish-finding equipment.

The problem of increasing the depth of detection of fish is simplified significantly when the sonic system of the fish-finding device is brought closer to the target, that is, when using a towed submerged antenna. The Soviet "Igla" fish-finder operates on this principle. This fish-finder has a towed sonic system which is connected to the onboard equipment by a cable. The equipment can operate in the search or the trawl probe mode. In the former case the towed sonic system can be submerged to 1100 meters, and the search instrument will be in a position to detect disperse bottom and pelagic congregations to a depth of 1800 meters. In the latter case, the equipment permits determination of the vertical opening of the deep sea trawl, the distance of it from the bottom or surface of the water and the presence of fish in the vicinity of the mouth of the trawl. The instrument records these parameters for a depth of travel of the trawl to 1500 meters.

At the present time an improved fish-finder has been developed and is being tested. Its towed sonic system can submerge to 2000 meters. This instrument will record disperse fish congregations to 3000 meters and deeper.

The equipment of the fishing ships with modern navigational equipment permitting determination of exact location has great significance when fishing for deep-sea fish. With an increase in depth of fishing, the labor and energy expenditures increase, the unproductive time for lowering and raising the trawl increases. The problem arises of increasing the power of the ships, the traction characteristics of the trawl winches, the strength of the cable that pulls the trawl, and so on.

The problem of organizing deep-sea fishing has been far from completely solved, and the fishing tactics far from worked out.

Thus, traulers must develop a thrust of 25 to 40 tons and a trawling speed of 4.5 to 5.0 knots.

It has been established that the density of the fish congregations decreases with depth. Accordingly, it is necessary to increase the dimensions and the opening of the trawl. The deep water trawls, in addition, must be equipped with instruments which monitor the vertical and horizontal opening of the trawls, the distance from the bottom, and the length of the cable that has been paid out.

The set of modern fish-finding, navigational and trawling instruments must provide for aimed trawling of fish at great depths. In connection with detecting large congregations of fish at depths of 2000 meters, theoretically new methods must be developed and fishing equipment built with artificial concentration and selective catching of fish. In order to exploit the deep-sea fishing, it is necessary to reequip the fishing boats and expand the scientific research and experimental design work. It is no less important to solve the problems of processing deep-sea fish, for the meat of some of them has lower food value, and sometimes a "noncommercial" appearance as a result of increased water content and weakening of the skeletal formations.

When organizing the industrial catching of deep sea fish on large scale it is necessary to be especially careful, for long life span, later achievement of sexual maturity and relatively low reproductive capacity are characteristic of the majority (for example, Macruridae). The reserves of such fish are to a high degree influenced by fishing which must be rational and on a scientific basis, for the losses in this case will be difficult to recover.

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PART IV. EXPLOITATION OF THE OCEAN DEPTHS

UNMANNED SUBMERSIBLES: STATE OF THE ART AND PROSPECTS FOR DEVELOPMENT

[Article by V. S. Yastrebov]

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The unmanned submersibles (NPA) are a large independent group of underwater engineering devices for studying the ocean and performing comparatively simple operations in its depths.

As the experience of investigating NPA shows, a number of scientific problems, for example, the majority of hydrophysics and geophysical studies at the bottom, can in practice be solved by high-quality level only with their help.

The NPA have also been recognized as a mobile and quite effective means of rendering aid to manned submersibles in emergencies. Obviously, the NPA will also be effective for performing a number of underwater engineering operations at great depths.

The existing models and those being built are distinguished primarily by the depth of submersion, which essentially determines their structural execution, the degree of complexity of the control system and also the functional possibilities. Depending on the depth of submersion it is possible to isolate three groups of submersibles: shallow depth (to 600 meters), medium depth (to 2000 meters) and great depths (more than 2000 meters).

The largest number of NPA [unmanned submersibles] belong to the first group. These are the unmanned submersibles KERV-I and KERV-II (United States), Telenot-I (France), "Skat" (USSR), BATFISH (United States), "Gloria" (England), "Penquin" (Federal Republic of Germany), WARS (United States), RUFAS (United States), and so on. All of them are simple systems capable of performing just as simple, limited functions, and they are first-generation submersibles.

The second group of medium depth submersibles includes the "Telenot-II" (France), "Erik-I" (France), "Aida" (United States), "Troika" (France), "Manta-1,5" (USSR), "Krab" (USSR). With an increase in depth, primarily problems of information exchange between the submersible and the support vessel arise. This smaller group with respect to composition includes more improved submersibles with greater functional capabilities, among which we find the second-generation systems.

The third group of submersibles of greater depths or deep-water submersibles is the fewest in number. At the present time the NPA have been built which operate effectively at depths to 6000 meters. These include the RUVS, MPL, SPURV, "Sea Drone," "Sea Probe," NRL (United States), "Erik-II" (France).

The NPA can also be divided with respect to functional attribute into autonomous and captive. In turn, the captive submersibles are divided into towed and sounding.

The autonomous unmanned submersibles are designed for research missions by a previously defined program. At the present time they are among the first-generation robots. These submersibles can operate either in the body of the water itself or directly on the bottom. The unmanned submersibles can operate both in the strictly vertical sounding regime, and in the three-dimensional sounding regime where they are lowered and raised, for example, in a spiral.

At the bottom they work, moving along a previously given trajectory either in a straight line or in parallel tacks or along an untwisting spiral. During movement the parameters of the environment are measured and recorded also according to a program or the bottom is photographed. In individual cases it is possible to program the taking of water samples or lying on the bottom for a prolonged period of time during which the parameters of the environment are also measured and recorded.

The exchange of information between the autonomous submersibles and the support vessel is, as a rule, conducted over a hydroacoustic channel in limited volume.

The captive submersibles make up a large group. The towed systems by means of which it is possible to perform prolonged measurements of the parameters of the environment at given levels, to chart the bottom and find sunken objects, are distinguished by high effectiveness. Usually these systems are towed by the support vessel on a strong cable (see Figure 1). Information exchange between the submersible and the support vessel is realized over the cable, the characteristics of which and also the depth of submersion determine the volume of transmitted data.

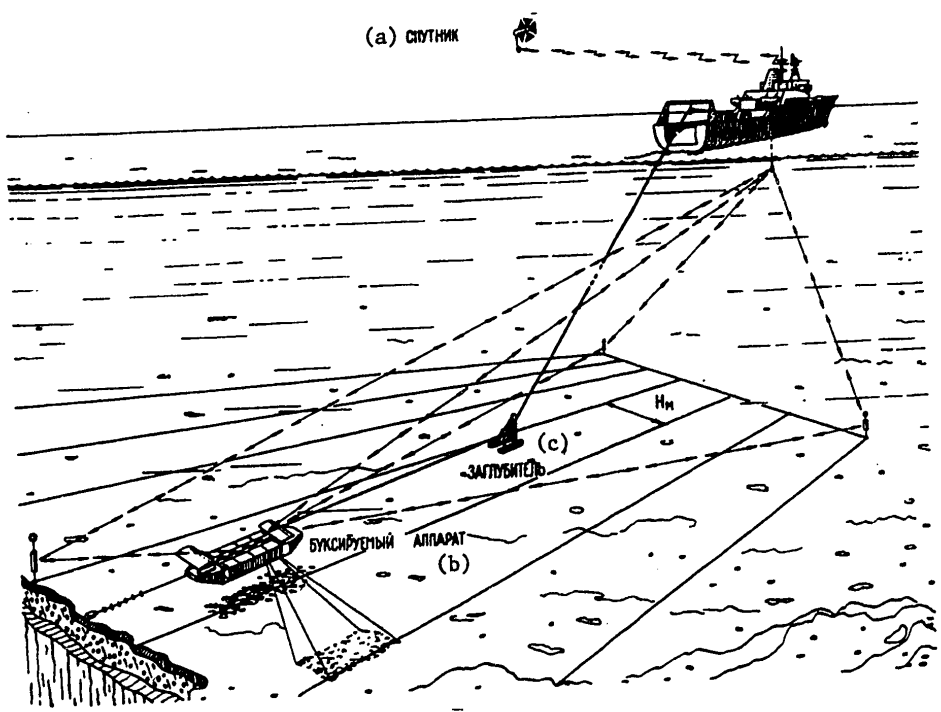

Figure 1. Diagram of a towed unmanned submersible.

Key: a. satellite
b. towed submersible
c. depth keeper

The captive sounding NPA usually are lowered from a stationary support vessel. Their effectiveness depends on the capacity of the ship to maintain an invariant position. Usually the captive sounding submersibles are equipped with engines which permit them to maneuver above the bottom and above the target of their operations. The information exchange between the submersible and the support vessel is also realized over a cable which determines the maneuvering of the submersible.

Recently the idea of building a combination type NPA has come up. The sounding captive submersible is equipped with a device for changing the position of the point of attachment of the cable to the submersible. This permits the craft to be used both in the towing mode and when the support vessel is stationary. In spite of the functional differences of the NPA, very much in common has been detected in their structure which permits a generalized characteristic to be presented.

The NPA contains the following assemblies and systems: a pressure hull, a propulsion system, a control system, communications and information system, observation system, navigation system, power system, and research equipment.

The pressure hull of the NPA is used to give it some positive buoyancy. The hull contains the control, observation, communications and navigation systems. Usually this submersible has one or several strong hulls of cylindrical or spherical shape.

In order to give the submersible zero or low positive buoyancy at depths of 1000-1500 meters, buoyancy modules of synthetic materials are also used, the specific weight of which is 0.5-0.7 tons/m^3. They withstand high external hydrostatic pressure.

The propulsion system of the submersibles has been improved as they have been developed. The first models had from 2 to 3 propellers which provided for their movement in the principal directions. As the operations performed by the submersibles became more complicated, the requirements on their controllability increased. The necessity arose for applying a developed propulsion system capable of monitoring and altering all 6 generalized coordinates of the submersible in space.

The propulsion system must keep the submersible at the given level or in the given regime of motion. Energywise, static regulation of the zero buoyancy of the submersible turns out to be more suitable, for which further expenditures of dynamic constrol are appreciably lower. This regulation is realized by using a special equalizing system available, for example, on the TROV submersible (Canada). The energy required for movement is transmitted to the towed submersible over the cable. The maneuvering of the towed submersible in space is realized either as a result of a change in speed of the ship and a change in length of the cable or as a result of adjustable hydrodynamic surfaces. It must be noted that the latter turned out to be effective only for towing speeds of more than 3 knots. At low towing speeds propelling devices can serve as quite effective means of measuring the trajectory, which are capable of maintaining the required parameters of motion together with the stabilization system. Obviously, energywise this solution is disadvantageous although quite effective.

The control system is designed to maintain the given parameters of motion or position of the NPA in space. Here, all of the unmanned submersibles are faced with the problem of controlling the sustaining of a given trajectory of motion. For the captive sounding submersibles, along with this problem there is the problem of prolonged keeping of the position above the target of their operations invariant — the problem of dynamic positioning. In the regime of movement along a given trajectory usually the following parameters are monitored: the depth or distance from the bottom, heading, heel and trim. The values of all these parameters are recorded by the corresponding gages: depth, sonar, angular velocities of the gyroscopic system of the submersible. The linear coordinates of the position of the submersible in the inertial system (of course, with low accuracy) can be obtained, for example, by using the doppler system.

As NPA have developed, the principles of controlling them have improved. In the first-generation submersibles the parameters of motion were given by separate control elements. As the number of drive mechanisms increased and, consequently the complication of the trajectory of motion of the submersible, the necessity arose for the application of complex control elements. Thus, complex mnemonic arms appeared by means of which control is realized in the code of the movement of the arm of the operator. Later, supervisory control systems were built. In the simplest version of such a system the operator gives the coordinates of a point in the region into which it is necessary to maneuver the submersible on a television or sonar display screen. A special computer module takes this assignment and forms the required control signals for each of the drive mechanisms of the submersible. The operator only determines the point to which it is necessary to get the submersible and gives its coordinates.

The communications and information system actually determines the choice of control principles of the NPA. The shallow-depth submersibles usually are connected to the support vessel by means of a multistrand cable. In a number of cases individual strands (lines) of the cable are designed for different types of commands. However, this use of the communications channel is inefficient. Its time or time-frequency multiplexing is more expedient. Usually control information is transmitted to the submersible, and information about the parameters of state of the submersible and also the video information from the television and hydroacoustic system are transmitted to the support vessel. Information is transmitted to the shallow and medium-depth submersibles usually over individual coaxial lines. With an increase in the working depth of the submersible and the length of the cable, this type of information transmission system will become impossible. The multistrand cables are replaced by a cable made up of one coaxial pair beginning with a depth of 2000 meters. The exchange of information between the autonomous submersibles and the support vessel takes place over the hydroacoustic communications channel. As a result of instability of its parameters and also the frequency restrictions, the exchange on the level of the simplest commands is possible.

The possibilities of the cable communications channel are limited, which is essentially felt in the effectiveness of the NPA. In addition, the information coming to the support vessel is most frequently difficult for the operator to pick up: the data on the depth, the heading, the heel and trim of the submersible are led to separate instruments, which complicates estimation of its position in space. Obviously, integral representation of the information is necessary. Such a system -- CONALOG -- was built in the United States and used for submarine control. The information about the parameters of motion is represented on a display in the form of a "traveling track" the corresponding slopes of which determine the heel and trim. The system tests demonstrated its high effectiveness.

The solution found by American specialists is very interesting. They propose the use of a special helmet with miniature video control unit built into it to create the "effect of being present" for the operator. The operator's helmet is kinematically connected to the chair. If the operator turns his head in space, the positions are recorded by sensors, by the signals of which the submersible is synchronously deflected. This method of controlling the movement of a remote control submersible provides for rapid adaptation of the operator to the system, high speed and effectiveness.

It is obvious that further improvement of the principles of representation of the information will develop along the path of greater and greater use of various human receptors with a mandatory integral method of representing the information.

The NPA observation system usually contains two subsystems: television and sonar. As the former, predominately small scale sets with transmitting tubes of the vidicon type are used. The quality of the image observed by the operator depends primarily on the transparency of the water, the characteristics of the lights, the observation range and the parameters of the transmitter. An extraordinarily important role is played by the length and frequency characteristics of the cable communications channel. It is easy to obtain high quality of the television image on the shallow-depth NPA. With an increase in length of the cable, its properties become significantly worse, the attenuation increases, and the distortions of the television system increase. It is necessary simultaneously to transmit an entire information file and electric power to the deep-water submersibles over one coaxial pair. All of this unconditionally has a noticeable negative effect on the quality of the television image and, as a rule, complicates the operation of the submersible.

Additional information about the surrounding situation is obtained by using side-scanning sonar. Here it is possible to obtain a picture of the bottom from sufficiently great distances (several hundreds of meters) in the most general form, without details and with low resolution. However, this preliminary data is extremely important. First of all it permits orientation in the underwater situation until visual contact is established by means of a television system and, secondly, it gives a general idea of the investigated region, which supplements the information about the local space observed by the television system well.

The navigation system of the NPA functions on the basis of the hydroacoustic beacons. Systems with long and short base are distinguished.

The system with long base provides for the installation of several bottom transponder beacons with spacing of several miles between them and also one hydrophone on the support vessel and one transponder-beacon on the submersible.

The system with a short base at the bottom includes one transponder beacon and two hydrophones on the ship, fore and aft. In addition, the transponder beacon is installed on the submersible. The bottom transponder beacons and the NPA transponder beacon answer on demand from the ship. The direction to each beacon and to the submersible is determined by the time difference of the arrival of the signals at the ship hydrophones. The slant range to the beacons is determined by the transmission time of the response signal. The depth is measured to calculate the horizontal range. All of the calculations usually are performed by computers.

The power systems of the NPA are distinguished by structural design, depending on types. Thus, on the autonomous unmanned submersibles usually there are onboard storage batteries.

The captive shallow-depth submersibles receive power, as a rule, over the cable. In the presence of a cable with one coaxial pair the transmission of electric power to the NPA grows into an engineering problem.

As one of the versions of supplying power to the deep-water unmanned submersibles, a system can be used with intermediate power anchor, power depth keeper (for towed submersibles) or a carrier of greater displacement than the NPA. In this case the NPA has the required amount of control and observation equipment onboard, and the power supply and part of the auxiliary equipment are placed on the power anchor, the depth keeper or intermediate carrier. The power carrier is connected to the support vessel by a cable. It can be connected to the submersible by a multicore cable over which the electric power is transmitted. During operation the storage battery is charged with electric power which is fed through a uniaxial cable from the support vessel.

The power anchor can also simultaneously serve as a carrier-hangar for the NPA in which it is delivered to the bottom and raised to the surface. At the bottom the NPA is let out of the carrier-hangar to perform its operations. This system is used on the "Erik-II" submersible (France).

The research equipment of the NPA usually includes measuring equipment, manipulators and various sample-takers.

The special sensors record the direction and speed of the current, temperature, pressure, electrical conductivity, speed of sound and, more rarely, the concentration of dissolved oxygen and other parameters. Magnetometers measure the directionalness of the Earth's magnetic field. Side-scanning locators and profilographs are frequently installed on the NPA.

Manipulators are used to perform operations on the bottom. The structural design and the methods of controlling the manipulators are just as varied as the NPA themselves. At the present time manipulators have been developed which are designed for performing quite complex and tedious operations. They have up to seven degrees of freedom; therefore their control systems can be quite modern. The kinematic structure of a manipulator depends primarily on the stated goals. As a rule, for the performance of simple operations the simplest designs are provided for with minimum required number of degrees of freedom. As an example we have the manipulators of the unmanned KERV submersibles which are used only for grasping objects of a defined shape on the bottom.

Miniature soil tubes and bottom scoops are used as the sample takers on the NPA. Sometimes the grapple of the manipulator is made in the form of a bottom scoop. Then the soil samples are taken by the manipulator itself. In the rest of the cases the manipulator is used as an auxiliary transport device. Special bathometers are used to take water samples.

As analysis of the structure of the NPA shows, these are highly complex systems, far from perfect.

There are also problems characteristic of only one group of submersibles. One of the main problems is the problem of increasing the operating efficiency of the captive sounding submersibles, which are the basic means of active performance of maneuvers on the bottom using manipulators which still remains very low. There are several reasons for this. The execution of the operations is complicated primarily as a result of mobility of the NPA over the target. Placing the submersible on the bottom obviously is the simplest method of stabilizing the position. However, in this case the bottom layers of the water become intensely turbid, which has a negative effect on visibility and complicates the monitoring of the operation of the manipulator.

The effectivness of the functioning of the NPA in direct proximity to the object depends on its maneuverability and the accuracy of the stabilization at any point in space. As a result of the maneuvering, the servoelements of the manipulator are put in a position which is convenient for performance of the operations, and the stabilization of the submersible makes it possible to keep the adopted position unchanged.

Therefore the interaction of the manipulator with the submersible becomes central in this problem. Consequently, the problem of creating a fit model of the manipulator must be solved complexly, considering the purpose of the submersible and the interaction of all of its systems.

The analysis of the experimentally obtained materials indicates that the local maneuvering of the NPA and hovering of them over the target of the operations usually take place with extraordinarily low accuracy and require significant time.

The primary cause for this consists in imperfection of the control methods. The control of the displacement of the submersible is realized by changing the speed and therefore it completely depends on the skill of the operator. The closed control system with positional feedback can bring about reliable stablilzation of the submersible itself both with respect to angular and linear coordinates. The analysis of the processes of displacement of the manipulator and the submersible as multidimensional controlled objects permits the conclusion to be drawn of the necessity and sufficiency of monitored alteration of only one parameter — the distance of the object to the target. This can be achieved by using one complex control element which operates by the principle of copying the movements or a system with control with respect to the velocity vector or moment.

This mnemonic, multistep control arm gives instructions for the displacement of the submersible with respect to all six generalized coordinates. In order to hold it over the targetof operations continuous arrival of information about variation of all six of these coordinates is necessary. The latter requirement is most difficult to satisfy. The data on the variation of the angular coordinates is easy to obtain with the help of a gyroscopic system installed on the submersible; it is more complicated to determine the values of the linear coordinates of the submersible with respect to the target of the operations located on the bottom. One of the possible technical solutions of this problems was proposed by the Institute of Oceanology of the USSR Academy of Sciences imeni P. P. Shirshov.

Similarly to the dynamic positioning system of the research vessel "Triton" (France), the coordinate-measuring device is a system consisting of a light weight connected by a flexible cable to a drum. The latter is fastened in the lower part of the submersible and has a drive which keeps constant tension on the cable in one mode, without raising the weight off the bottom, and in the other mode, completely takes up the weight on operator command. The angles of inclination of the cable are measured by induction sensors. The length of the cable let off the drum is determined by the drum rpm. This device makes it possible to obtain sufficiently exact information about all three linear coordinates of the submersible (±10 mm) with respect to a point on the ground where the weight is lying.

Then the information about all six generalized coordinates is input to the motion control system of the submersible. Dynamic positioning of the NPA over the target of operations is realized in this way.

During the process of the operation of the manipulator, as a result of its interaction with the target, disturbances act on the NPA. They unavoidably lead to disturbed movements of the NPA which complicate the performance of the operations. The operator can objectively judge these and the controlled movements of the submersible only by the dynamics of the television image. However, this is insufficient both for control of the actions of the manipulator and for accurate control of the local maneuvering of the submersible over the target. It is obvious that it is necessary significantly to increase the volume of the informative information which must come to the operator in convenient form for reception and analysis. This can be achieved by a maximum involvement of the neuromotor apparatus of the human operator in the process of controlling the submersible and the manipulator and also active dynamic reflection on the control panel of the data characterizing their state. Only with such support information does the operator have the "effect of being present" which is extremely necessary for efficiency of action during control (Figure 2).

In this case the control system of the submersible becomes an information control system. The information about the movement and the maneuvers of the submersible and also the smallest changes in the angular velocity will be picked up almost automatically. These data are supplemented by visual information represented on the screen. The variation in noise of the operating propellers also gives an idea about the change in speed of the submersible.

The operator shapes the control signal on the basis of the processing of the received information. In the above investigated case the thinking about the information and the search for it are in practice absent. The control of the submersible can in this case be concentrated on one command arm, which leads to definite simplification of the process of issuing commands. In this case the information processing by the operator will consist of the steps of detection (determination of the position of the submersible by the analyzers of the visual and vestibular apparatuses), decision making (synthesis of the operating algorithm in accordance with the overall strategy) and the solution itself (the displacement of the command arm to the position corresponding to the selected direction and speed of the submersible).

Quite frequently during the process of remote control of the moving object it is necessary for the operator to solve the problems requiring almost instantaneous preliminary processing of the information. The speed of the operator reaction serves as the basis for estimating the control input.

Let us consider the method of remote control of the submersible in the search mode. In this case the operator reaction in the first approximation can be defined as a simple sensomotor reaction, the delay time of which is made up of the latent period and the motor action period [2]. The period of thinking about the information and information retrieval in practice are absent, which permits significant simplification of the algorithm of his actions and determination of the specific measures for increasing their effectiveness and reliability. This can be achieved, decreasing the volume of informative information presented to the operator, for which it is necessary to select the information which most completely characterize the state of the object of control.

At the present time the operator receives this information over the television channel. However, as a result of absence of reference points that are customary for the eyes of man and also the optical properties of the water environment, the spatial position of the submersible is perceived in somewhat distorted form.

The method developed at the Institute of Oceanology of the USSR Academy of Sciences for constructing the NPA control system on the basis of using its

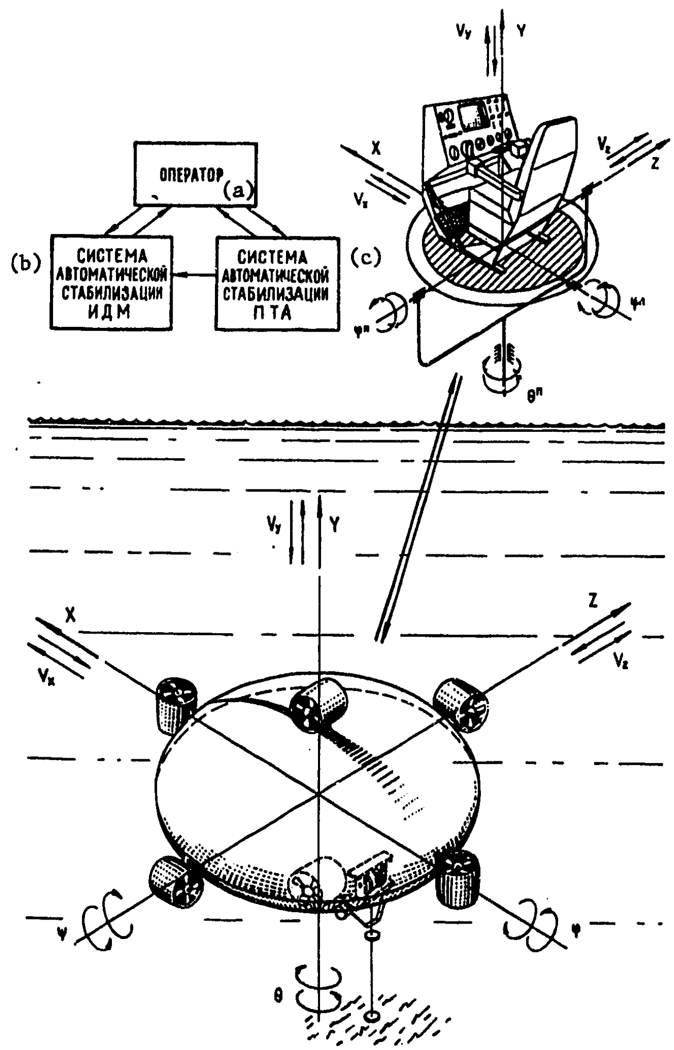

Figure 2. Diagram of the PTA control system shaping the "effect of being present."

Key: a. operator
b. IDM automatic stabilization system
c. PTA automatic stabilization system

information-dynamic model (IDM) has made it possible significantly to increase the effectiveness of the control process [3]. As a result of the moving control panel (see Figure 2), taking up its position in space corresponding to the position of the submersible, the volume of information coming to the operator was increased significantly.

When using the IDM, two of the operator's analyzers -- visual and vestibular -- participate actively in constructing the algorithm of this control input. The vestibular apparatus is the basic analyzer determining the position of a body and its displacement in the surrounding space. As has already been stated, the time of the latent period of reaction of the operator basically will depend on the effectiveness of the participation of the indicated analyzers in the construction of the control signal.

It is possible to achieve an increase in effectiveness by carrying out special training cycles that increase the stability of the vestibular apparatus. The most important event in this training is the formation of the functional relations of the vestibular analyzer to the others, especially the visual one.

When executing the program of operations, the NPA operates only in the dynamic or in the static mode. At low speeds and accelerations of the submersible, the operator does not experience G-loads that generate a change in sensitivity and the customary adjustment of the vestibular apparatus. The latter plays primarily the role of a corrector in the shaping of the control signal, and the main analyzer participating in the reception and transmission of the informative information is the visual analyzer. However, in individual cases (when visibility becomes worse) the vestibular analyzer can be predominant in the perception of the information about the spatial position of the submersible.

A number of experiments were performed, during the course of which a study was made of the quality of control of the NPA by the operator with the participation of two analyzers -- visual and vestibular -- simultaneously in the formation of the control signal.

A special stand was used which is a hinged suspended platform with the control panel and chair located on it equipped with the control arms. The platform had two degrees of freedom: rotation around the x and z axes corresponding to the axes of the effect of the vectors of the angular velocities of the trim and the heel of the submersible. The platform was rotated by power drives consisting of a pump, power cylinders and distributors of the slide valve type with electromagnetic regulator.

Special attention was given to monitoring the dynamic operating conditions of the test unit. It was necessary to insure correspondence of the angular velocities of the platform of the unit to the angular velocities of the submersible.

The experiments of the Institute of Oceanology demonstrated that the joint participation of the vestibular and visual analyzers significantly increases the reaction of the nervous system to the stimulant signal. This is explained by the fact that the change in sensitivity depends on the force of the side stimulant. With a low level of sensitivity, such stimulants increase it; with a high level, they decrease somewhat (curves, 1, 2 and 3 in Figure 3).

When investigating each of the analyzers individually the intensity of the stimulant (in the given case the angular velocity of the heel of the platform ω) does not insure a defined level of activity of the analyzers. Under the joint effect of two analyzers (curve 3 in Figure 3) it is possible to explain the increased sensitivity if we propose that one of the analyzers is a side stimulant with respect to the other, which at the same time stimulates the growth of its activity.

During the process of studying the joint effect of the analyzers, tests were adopted excluding one of the analyzers from participation in the control. In particular, it was proposed that the operator switch his attention from the television screen to other instruments on the panel. In this case, the reception and processing of the information about the spatial position of the submersible were wholly realized by his vestibular apparatus. In this case the nature of the process did not change. Independently of the structure of the effect and the mechanisms of psychological regulation of each operator individually in the final analysis adjustment of their nervous system and dynamic regrouping of the temporary nervous couplings takes place [1]. This is clearly illustrated in Figure 3.

After adjustment of the regulation system the latent period does not exceed 0.25 seconds for all three operators.

The remote control of the manipulator in the code of separate commands or in the code of motions leads to an increase in the time of performance of the missions by approximately an order by comparison with the time required for direct performance of the same missions by the operator without using the manipulator. The increase in time of performance of the mission is a significant deficiency of the autonomous deep water submersibles with limited power reserves and, consequently, time they can stay under water. In addition, such control of the manipulator with the existing possibilities of cable communications channels is a highly difficult operation both technically and functionally.

Automation of the process of performing the operations not requiring careful and continuous visual monitoring on the part of the operator and increasing the effectivness of utilizing the manipulators under poor visibility conditions or with low quality television image may turn out to be of significant help in such a situation.

The Institute of Oceanology of the USSR Academy of Sciences imeni P. P. Shirshov performed experimental studies to build an automatic underwater manipulator with comparatively simple functioning algorithm.

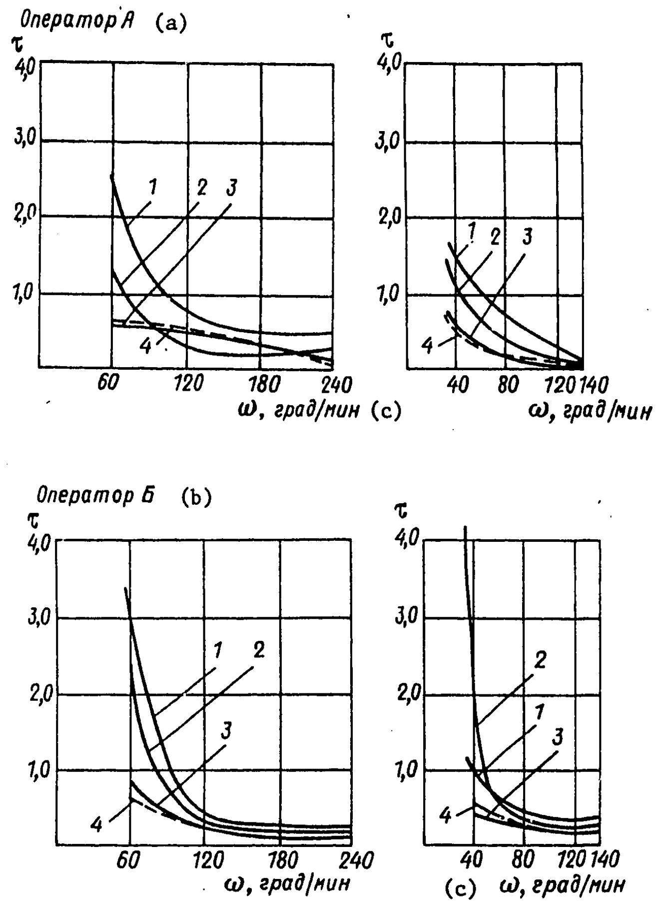

Figure 3. Latent period τ of the reaction of operators A and B as a function of the intensity of the stimulant. 1 -- visual analyzer; 2 -- vestibular; 3 -- visual and vestibular analyzers together; 4 -- monitoring the latter by navigational instruments.

Key: a. operator A
b. operator B
c. ω, deg/min

The mission of the automated control system included the search for geological objects of arbitrary shape in the range of the manipulator, determination of their sizes, grasping by the grappling element and transfer to the bin. The control of the manipulator with five degrees of freedom was realized from the onboard control computer module.

Five tactile sensors (see Figure 4) were installed in the grappling element; two sensors in the lower part of the grapple (they were designed for probing the search surface), and two on the lateral surfaces of the grapple (they served as indicators that the manipulator had touched an obstacle). Inside the grapple there was the fifth textile sensor which informed of the presence of an object inside the grapple.

Figure 4. Tactile sensors of the manipulator grapple.

The process of gathering geological samples was broken down into two steps: the search and the examination of the objects found. The search was carried out by the program using the method of grapple scanning over the examined area. The latter touched the surface with the tactile sensors, after which it was raised above it, and moved to the next scanning step. On encounter with an obstacle, the side tactile sensor informed of this. In order to be convinced of the mobility of the object, a trial movement of the grapple by one step was performed. After establishment of the fact of mobility of the obstacle the grapple probed the object with its lower tactile sensors to determine its size. Then if the size was smaller than its opening it grabbed the object and transferred it to the bin. The further search continued, beginning with the location where the object was taken.

The application of tactile sensors and the use of inertial elements in the drive control circuit made it possible to achieve gentleness of movement of the manipulator in spite of its significant power. The force with which the manipulator touched the probe surface turned out to be negligibly small.

The performed analysis of the existing NPA with manipulators demonstrated that further expansion of their functional possibilities and an increase in level of automation of the operator's work when controlling them is possible only in the case of a qualitative change in the environmental data gathering and processing system. The inclusion of the onboard control computer complex

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in the NPA system will permit qualitative changes in the structure of the submersible and, above all, the creation of a system in which the complex control of it is realized by a closed circuit without the direct participation of the operator. The NPA will become a submersible robot.

In such a robot provision must be made for multilevel construction, a control computer complex, a memory module, the possibility of constant correction to the model of the outside world and the internal state and teaching of elementary skills to it.

On the higher strategic and tactical levels it is necessary to provide for the possibility of operator intervention. Here the robot is structurally a set of systems combined by one behavior goal. None of the robot systems acts independently or uncontrolled, but it is subject to the general strategy assigned by the operator or the special strategy developed as a result of communication with the outside world.

The robot must consist of a carrier which insures its accurate displacement in space and the following systems: effector (systems for communication with the external environment); control computer; communication with the operator.

One of the main systems turns out to be the control computer system, the functions of which include the following:

Storage in memory and regular correction of the model of the external environment and the internal state of the robot;

Processing of the information coming from the receptor system in accordance with the subgoal assigned by the operator;

Use of the results of analyzing the information about the environment to shape the control signals into the effector system on the basis of the model of the external environment, the internal state of the robot and the given subgoal;

The efficient encoding of the information for transmission of it over the communications channel;

Control of the operation of the communications channel.

In the controlling information complex there are two levels of information processing: on the upper level the processing is carried out by a central computer; on the lower level, using specialized devices for processing and intermediate storage of the data. These devices are intermediate between the receptor system and the central computer (preprocessors) and simultaneously intermediate between the central computer and the effector system (postprocessor).

The functions of the central computer include the following:

Analysis of the noncontradictoriness and the possibility of executing commands coming from the operator;

Analysis of the commands on the strategic and tactical levels;

Output of commands of the tactical control level to the postprocessor;

Periodic interrogation of the buffered memory of each preprocessor and postprocessor;

Processing of the information from the receptor system on a higher level;

Storage and correction of the mathematical model of the external environment.

The preprocessor functions consist in the following:

Preliminary processing of the data coming from the receptor system;

Control of the postprocessors of the servoelements;

Storage of the information obtained as a result of preliminary processing in the buffered memory.

Finally, the postprocessor functions consist in the following:

Deciphering the commands on a tactical level coming from the central computer;

Direct control of the servodrives;

Monitoring of the processing of the commands by signals from the internal feedback sensors;

Storage of the information obtained as a result of monitoring the data processing in the buffered memory.

At the present time the majority of studies are concentrated on the creation of the supervisory control systems. With this type of control the operator working in the supervisor mode, located on the support vessel, first breaks down the initial problem into successive elementary operations. Each operation has a standard command assigned to it. The set of standard commands is determined by the nature of the performed operations and is actually a type of language for communication with the robot. In addition to the standard commands, this language also includes the auxiliary commands which, in particular, are used for more compact recording of the command phrases. This method of control provides the robot equipment with independence of action within the limits of the execution of the standard command.

It is obvious that the application of the supervisory control systems on the unmanned submersible robots will permit a significant increase in the efficiency of their use when performing the studies and underwater engineering operations at great depths.

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CONTROL SYSTEMS FOR ROBOT ENGINEERING COMPLEXES

[Article by Ye. P. Popov]

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In many branches of the national economy and fields of science, programmed automated manipulators (industrial robots) and also command and copying manipulators remotely controlled by a human operator are finding broad practical application. In particular, the command and the copying manipulators are used on manned and unmanned submersibles.

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However, the broad goals of the exploitation of the World Ocean cannot be solved using the existing simple manipulators. More universal, multipurpose robot engineering manipulation complexes with unmanned operating equipment controlled by a combined man-machine system are required.

The necessity for them is dictated by an entire series of arguments.

First, when executing a large volume of operations at depth the unmanned submersible can be at the object continuously for a long period of time, and the manned submersible or diving complex is forced to complete several diving and surfacing cycles as a result of the limited time of operation of the life support system. This essentially drags out and increases the cost of the entire operation.

Secondly, the mass of manned equipment will always be much greater than unmanned equipment designed for the same operations. This implies significant increase in weight of the lowering and raising devices on the above-water carrier vessel, which means an increase in the maximum admissible tonnage of the latter, which lowers the operativeness of the system and also increases the cost of the operation.

Thirdly, for the execution of an entire series of operation at depth universal manipulators are needed with no less than six degrees of freedom (similar to human arms not considering the wrists). They can be multipurpose with simple adjustment to different operating cycles. This is one of the advantages of the manipulation robots over traditional automated devices. In many cases they can completely replace the heavy, dangerous work of the divers.

Fourthly, the manipulation system must have a sufficiently "intelligent" control system adapted to the actual situation at the point of operation of the manipulators analogous to the human brain controlling the purposeful motion of the arms during the work process. For this purpose it is necessary for the manipulators to have the "sense of touch" and for a digital computer or specialized computer to be included in the control circuit. As a result of complexity of the operation and "unpredictability" of the underwater situation for complete automation of the operation of the manipulation robot it is necessary to create the elements of an artificial intellect. However, it is premature to talk about the solution of the latter problem on the modern level of development of science and engineering. Therefore the inclusion of the human operator onboard the above-water carrier vessel is unavoidable in the process of controlling the underwater manipulators. Here, it is necessary to transmit control signals from the ship to the submersible remotely over a cable and back from the submersible to the ship using television and other information to represent the underwater situation on a television screen (receiving panel).

Thus, the human operator intellect is used in recognition of the undefined and variable underwater situation and in the control of the movement of the manipulator. Various paths of constructing such a control system are possible.

In the simplest version the system is constructed so that the operator always controls every movement of the manipulators, acting with his hands on the control device and observing on a screen the underwater situation of the underwater object (see Figure 1). Such systems are called biotechnical. These biotechnical systems are divided into three basic types: command, copying and semiautomated.

In the command control systems the operator uses buttons, toggle switches or levers with buttons to move the manipulators corresponding to various degrees of freedom individually. In the given case there is simple remote inclusion of the individual drives on the manipulator (see Figure 2).

In the copying control systems, the operator station has a control mechanism which is kinematically similar to the underwater manipulator. The operator connects this control mechanism to his hand or simply moves only the end of the control mechanism with his hand. The manipulator will accurately repeat the movement of the control mechanism with respect to all degrees of freedom. This takes place as a result of the fact that each degree of freedom of the manipulator corresponds to the degree of freedom of the control mechanism by the servosystem principle (see Figure 3). Here the manipulator has the executing part of the servosystem, and the control mechanism is at the operator station. Thus, the total number of servosystems is equal to

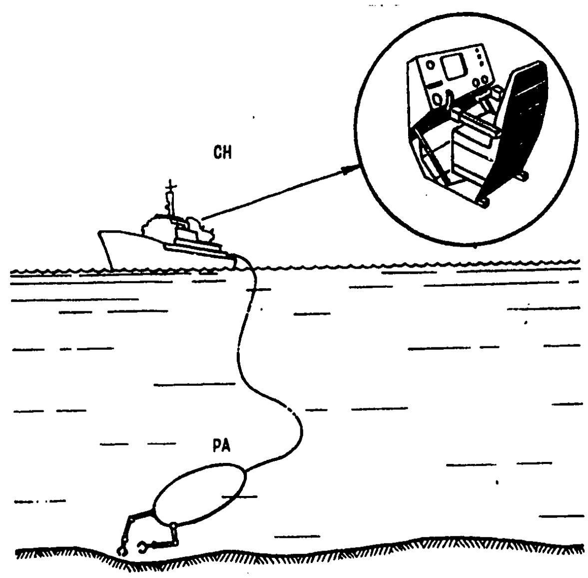

Figure 1. Biotechnical control system for manipulators with a carrier ship. CH -- carrier vessel; PA -- operating equipment.

the number of degrees of freedom of the manipulator. The servosystems are closed. Consequently, two signals each travel over each of them via the

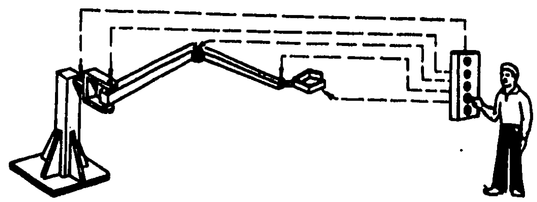

Figure 2. Diagram of the operation of a command control system.

ship-submersible communications channel: direct signal and feedback.

As is known, the two-way copying systems are still used. In them, at the control mechanism adjusted on the manipulator, engines are installed for transmission to the hands of the human operator in some force scale occurring during operation of the manipulator. Then the human as a link in the control system receives two feedback signals: visual with the television channel (on the screen) and tactile (reflection of the operating forces) which essentially increases the effectiveness of its operations.

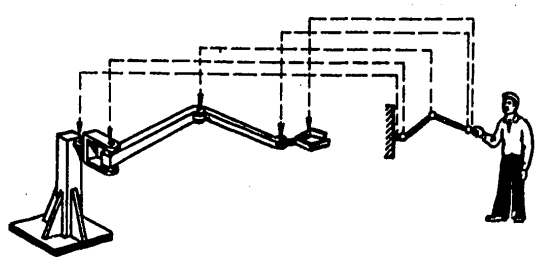

Figure 3. Diagram of the operation of the copying control system.

In the semiautomatic systems, there is a control handle at the operator control station which has several degrees of freedom (in the general case, six). Here the force with which the human operator presses on the handle with respect to each degree of freedom creates a displacement proportional to it which is converted to an electric signal.

Thus, the operator, pressing on the control handle and turning it, at the same time gives the desired motion to the end of the underwater manipulator (grapple or tool) with respect to six space coordinates (linear displacements and angular orientation) simultaneously. For realization of this, the signals picked up from the control arm with respect to all degrees of freedom go to the special computer CB (Figures 4 and 5). The latter recalculates them so that the control commands formed as a result for all drives will realize the combined movement of the drives under the effect of which the desired linear displacement and angular orientation at the end of the manipulator will be obtained.

The semiautomatic systems have a number of advantages; first, their control units are more compact and, secondly, the handle is convenient for operation, during the design of the kinematics of which, independently of the kinematics of the manipulator, it is possible to begin with convenience of working with it.

There are three basic methods of controlling such semiautomatic systems: speed, force and position and also combinations of them.

The speed method of semiautomatic control consists in the fact that when the operator presses on the control arm the special computer forms the control commands to the drives for which the speed of movement (linear or angular) at the end of the manipulator will be proportional to the magnitude of the displacement or the force of pressing on the control arm.

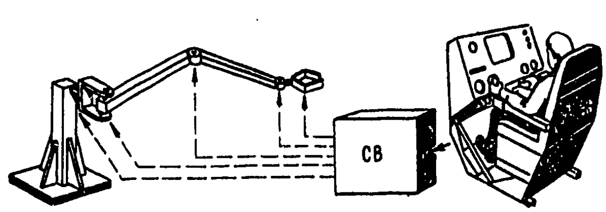

Figure 4. Diagram of the operation of the semiautomatic control system. CB -- special computer.

The force method of semiautomatic control consists in formation of the force (forces and moments) at the end of the manipulator proportional to the force of pressing on the handle. It is expediently used in the case where the grapple or the tool at the end of the manipulator is in contact with an object at the point of operations. The free movement of the manipulator by the force method using a specialized computer is formed as if its end point were pulled with a force proportional to the force that the operator pushes on the control handle. However, the force method of control of the free movement of the grapply is inexpedient, for the magnitude of the applied force does not determine the direction of movement directly.

Finally, the position method of semiautomatic control is distinguished by the fact that in it by using the control arm the human operator gives the current coordinates of the end point of the manipulator and the current angular position of the grapple, that is, the trajectory of motion and angular orientation of the grapple or tool at the end of the manipulator. Here the specialized computer shapes the control signals for the drives of all degrees of freedom of the manipulator so that the above indicated motion will be realized.

It is expedient to construct a combined semiautomatic control system in which for transport (transport displacements) of the end of the manipulator, the speed method of control is used; for local small displacements with exact positioning of the grapple or the tool, the positional method; and for performance of the work operations in contact with the objects, the force method of semiautomatic control. This combined system can be executed with a unified control arm and a unified special computer on addition of only a simple switch coupled to the arm. The efficiency of the operation of the entire system is increased if we "feel" the control arm by signals from sensors located on the underwater manipulator.

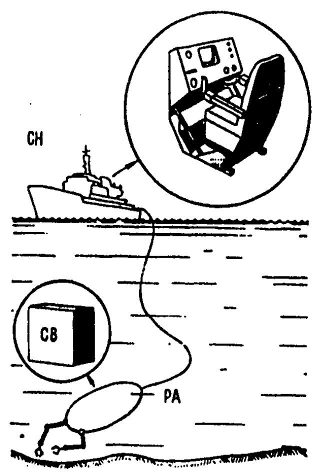

Figure 5. Automated system with specialized computer onboard the operating submersible.

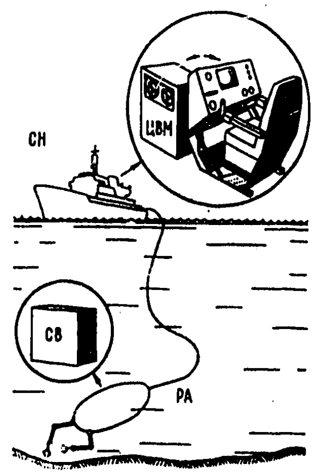

Figure 6. automated system with digital computer on the carrier vessel.

Thus, three basic types of remote control systems (command, copy and semiautomatic) are biotechnical, for in them the operator, by following the movement of the manipulator and the situation on a screen and by instruments, continuously feeds control signals by his hands. The hands of the man at all times direct the actions of the manipulator.

The operator cannot work for prolonged periods of time with this continuous load which creates tense operating conditions. In order to increase the effectiveness of the performance of the operation, it is necessary essentially to unload the operator and increase his work time by reducing fatigue. This can be achieved in part, it is true to an insufficient degree, by going from the copy control to semiautomatic control.

The effectiveness of the actions of the underwater manipulation robot increases if part of the operation subject to rigid programming or flexible programming with the simplest adaptation is performed in the automated mode. The control system for this part of the operation can be completely placed in the working submersible itself (PA); here it is possible to use either an onboard specialized computer on the PA (see Figure 5), that is, without loading the information channel of the cable or the ship's digital computer (see Figure 6).

The human operator observes on the screen and by instruments at his control station the situation and operations of the underwater manipulators in the automatic mode and, depending on it, switches certain automatic regimes on and off, and if necessary can take control in his hands (switch to one of the biotechnical regimes described above) (Figure 7).

This combination system which can be called automated is highly prospective. It permits a significant increase in productivity of operations (as a result of the automatic modes), it makes it possible to lighten the labor of the operator (free him of continuous manipulations by his hands) and at the same time to increase the duration of his efficient work.

The autonomous nature of the operation of the NPA can be increased without making it heavier if we introduce an additional "mother submersible" (AM) with the onboard digital computer installed on it (see Figure 8). Then the executive level of controlling the drives with the simplest computer is placed on the submersible, and the digital computer for subsequent hierarchical level of control system -- adaptive -- will be on the mother submersible. Let us note that two or several working NPA can work simultaneously with the mother submersible (see Figure 9).

It is expedient to use the mother craft for operations at great depths. First, the light working submersible cannot control the fluctuations of the long cable by means of its own propulsion devices (see Figure 6) if it is not attached. In the given case the mother submersible (see Figure 8) serves as an anchor from which a comparatively short cable runs to the working submersible.

Secondly, the mother submersible will serve as an intermediate power unit. Power is transmitted over the long cable from the carrier ship to the mother submersible in the most advantageous form for transmission. Current converters are installed on the mother submersible. The current is then fed to the users on the working submersible by a short cable. In addition, storage batteries can be installed on the mother submersible as spare sources of power.

Thirdly, the mother submersible can be equipped with measuring and recording equipment for recording the various properties of the environment along the entire line of descent from the carrier vessel and on the ocean floor.

The working submersible is lowered from the ship in stages; first it is lowered together with the mother submersible to the required depth, and then it goes from it to the given object of the operations.

The above-described automated control system including the automated and biotechnical regimes (see Figure 7) is the simplest form of systems with

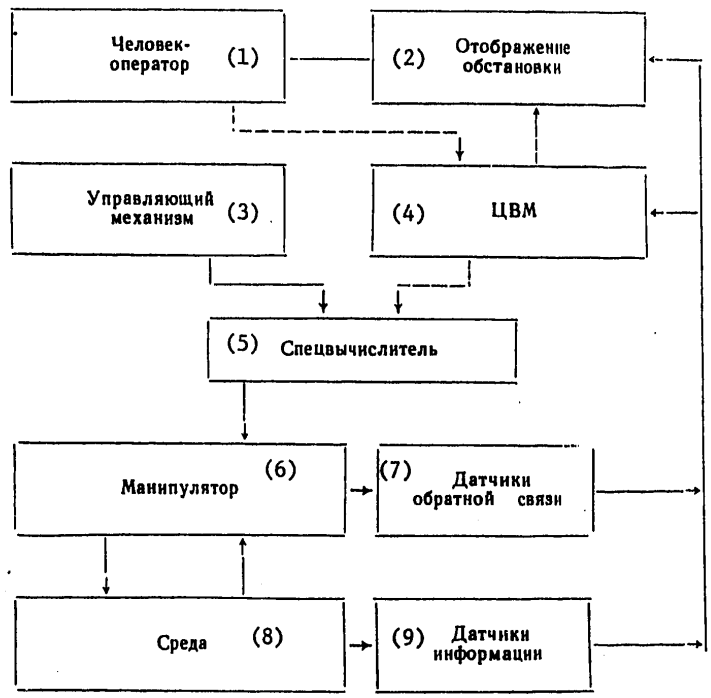

Figure 7. Functional diagram of the automated control system.

Key:
1. human operator
2. representation of the situation
3. control mechanism
4. digital computer
5. specialized computer
6. manipulator
7. feedback sensors
8. environment
9. information sensors

interactive control. The latter presupposes active interaction of man and machine. The controls in the supervisory mode and also the most improved dialog mode belong to interactive control.

With the supervisory control regime all of the individual elements of the operation are programmed. They are performed by manipulators each individually automatically under the control of the digital computer or specialized computer. By feeding a target area designation command (a light pencil on the screen, using the handle or another method) the human operator gives the machine the order to perform a defined element of the operation (see Figure 10). Thus, recognition of the situation and the strategy of the operations of the manipulation robot are worked out by the operator. Observing the situation on the screen and by instruments, he determines the sequence for inclusion of certain elements of the operations and their direction in the developed situation. Not only rigid programs, but also the simplest adaptation, for example, homing, search modes, are possible inside the elementary operations.

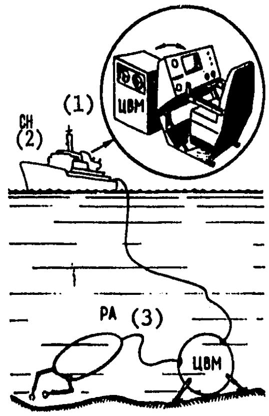

Figure 8. Robot engineering system with intermediate mother submersible.

Key: 1. digital computer
2. carrier vessel
3. working submersible

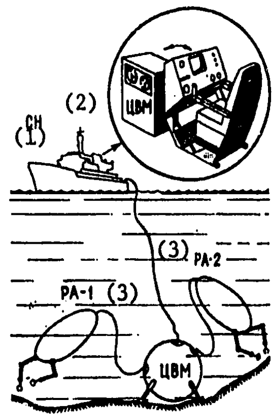

Figure 9. Robot engineering system with several working submersibles.

Key: 1. carrier vessel
2. digital computer
3. working submersible ...

For the dialog control mode in most complete form active interaction of the digital computer and the human operator takes place. The digital computer participates jointly with man in the recognition of the situation and the generation of a decision about further actions by the manipulation robot (see Figure 11). In the given case the digital computer is a "creative" partner of the operator in the processes of observation and control. For this purpose the manipulation robot must be equipped with the corresponding sensing (visual, tactile, sonic, and so on), that is a defined set of sensors of different information and perception apparatus and also primary processing of this information. The digital control computer must be equipped with the corresponding devices for the input of such initial data and also the equipment for visual representation to the human operator as a result of his perceptions and recommendations about further actions. It is also necessary to have the means of dialog communications, input of the control target and feed of the control commands by the human.

On the whole, the system will have a hierarchical structure with three levels separated with respect to missions and territorially:

a) the servosystem for controlling the drive with specialized computer onboard the working submersible (see Figure 8);

b) the digital computer on the mother submersible for primary data processing and adaptive control of the manipulators;

c) the digital computer and the operator stationed on the carrier vessel for interactive recognition of the situation, decision making and dialog control.

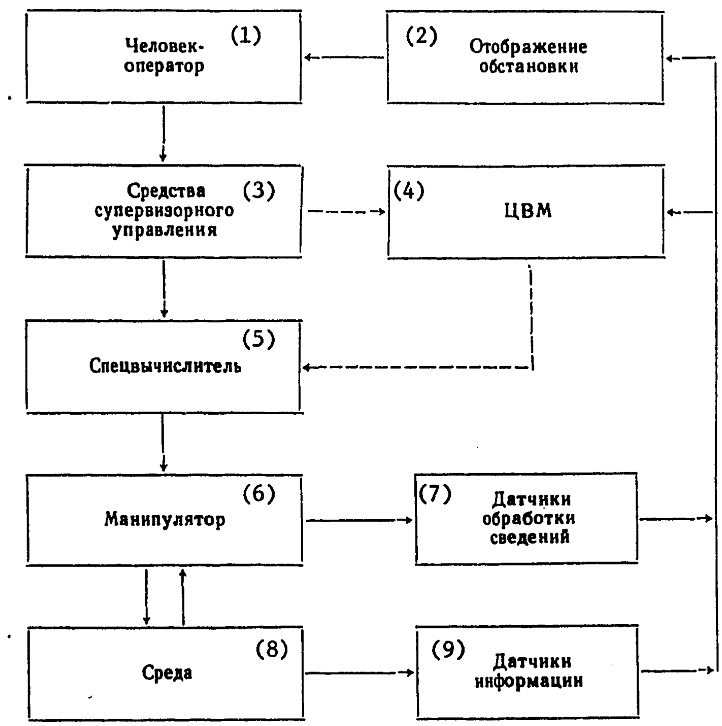

Figure 10. Functional diagram of the supervisory control system.

Key:
1. human operator
2. depiction of the situation
3. supervisory control means
4. digital computer
5. specialized computer
6. manipulator
7. information processing sensors
8. environment
9. information sensors

It is very important to solve the problem of expedient separation of the functions among these three levels considering the loading of the information channels of the cable in both sections (PA-AM and AM-CH). The observation and control equipment must be developed considering discreteness of the information transmission over the cable in a quite narrow frequency band.

Figure 11. Functional diagram of the dialog control system.

Key:
1. human operator
2. representation of the situation
3. dialog means
4. digital computer for generating a decision
5. control digital computer
6. digital computer for recognition of the situation
7. manipulator
8. feedback sensor
9. environment
10. information sensors

Then it is necessary to resolve the problem of visualizing the work area of the underwater robot at the operator station. The fact is that for underwater operations the water environment is turbid. The television operation turns out to be incomplete, and it must be supplemented by ultrasonic, laser and tactile information. Here all four types of information taken together must give a three-dimensional representation. Only the complex representation of these types of information with output to a common display will under the various conditions permit more satisfactory depiction of the underwater situations and when using each of them separately. However, this problem still remains unsolved.

A study was made above of the underwater remote control manipulation robots with combined man-machine control system. Now it is possible to talk about the creation of autonomous NPA with control systems based exclusively on the onboard digital computer, without cable communications with the carrier vessel. They can be used for the performance of simple manipulation operations and data gathering.

In this case the robot engineering complex (see Figure 12) consists of the mother submersible and the working submersible joined by a short cable. The basic control and processing information of the digital computer is placed on the mother submersible, and a simpler specialized computer, on the working submersible. The hierarchical principle of constructing the manipulator control system is retained, but with purely automated regimes, program and adaptive, and in the future, with elements of artificial intellect as was described above.

Let us consider the knotty problems of the design of the remote man-machine control system for unmanned underwater manipulation robots.

As we shall see, the system includes a large complex of technical devices which are varied with respect to content and scattered territorially, but at the same time make up a united whole. All of the elements of this system are interrelated in the work process. Therefore, not only a detailed projection of them as individual technical devices is needed, but also a systems projection with tying of the basic parameters of these elements together on the basis of the general requirements imposed on the effectiveness, quality, accuracy and the dynamic properties of the entire system.

The first step of this planning and design is determination of the executive level of the manipulator control system inside the working submersible. Beginning with analysis of the operations which must be completed, the basic requirements on the service zone, the kinematics of the manipulators, the power engineering and dynamic qualities of the drives, the algorithms for the operation of the specialized computer are determined. The required set of feeling sensors of the manipulator and the information pickups on the properties of the environment is determined.

The dynamics of the manipulator are described on the whole by a complex system of differential equations, the investigation of which for the synthesis of the control system is possible only using all-purpose digital computers. This investigation is complicated in the case where provision is made for the operation of the manipulators with a floating submersible (in the hovering mode without being fastened). Here all of the movements and the operating forces of the manipulator play the role of disturbances on the control system of the craft itself, which complicates its stabilization in the functioning of the manipulation system. For a solution of the problem, the investigation of the dynamics of the submersible jointly with the manipulators and sometimes the installation of an additional mechanical arm for fastening the submersible to the hull of the object are required. Possibly in this case the motion control system of the working submersible must be interconnected with the control system for the motion of the elements of the manipulator so that as a result of their joint actions the required manipulation operation will be performed. This introduces a defined specific nature into the work algorithms of the onboard specialized computer depending on the signals of the manipulator sensing sensors.

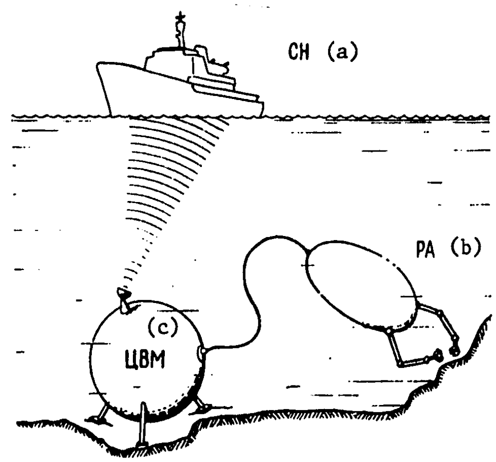

Figure 12. Diagram of the robot engineering complex.

Key: a. carrier vessel
b. working submersible
c. digital computer

Such are the basic problems of designing the servolevel of control onboard the working submersible.

Then the communications line between the working submersible, the mother submersible and the above-water carrier vessel appears as an element of the control system. The communications line is necessarily small-channel, and has a limited frequency band. The transmission of a significant number of information signals (including television signals) in one direction and also the command and control in the other leads to significant discreteness of the transmission of the signals as a result of which temporary delay of them is possible. This essentially influences first the effectiveness and the dynamic qualities of the adaptive automatic part of the manipulator control system including the digital computer of the mother submersible and secondly the quality of operation of the observation and control circuit running from the working submersible through the operator panel on the above-water ship.

Therefore in the second phase of the systems design it is necessary, on the one hand, to consider the characteristics of the communications line when determining the effectiveness and the dynamic qualities of the general control circuit and on the other hand, to impose requirements on the communications line (within the limits of the possible), beginning with the required effectiveness of the operation of the general control circuit. Here it is necessary to consider the interference and distortions of the information and command signals for which the corresponding statistical calculations of the control system are required both with respect to modules directly connected to the communication line and with respect to the overall effectiveness and dynamics of the entire control system as a whole.

For inclusion of such a communications line in the control circuit, it is also necessary to deal with serious development of the coupling devices of the outputs of this line with the basic control system modules. All of these devices must be minimized taken together with respect to the mass-dimensional characteristics and with respect to the power consumption, and it is necessary simultaneously to strive to achieve the maximum reliability. In the third phase of systems design it is necessary to construct the upper levels of the man-machine interactive control system using a digital computer, specialized computer and considering all of the peculiarities of the above-investigated servolevel, the communications line and the sensing system.

In the fourth step it is necessary to represent the information about the underwater situation in convenient form for man, and in the last, fifth step of the design, to perform the biotechnical development of the technical observation and control means, that is, match them with the physiological peculiarities of man. Here the control system as a whole as an interactive system must complete automatically the maximum possible number of elements of manipulation operations with minimum application of the manual labor of the human operator at the panel. For this purpose it is necessary to use all of the modern technical means and call on man for the control process only when his active participation is actually necessary. However, during the period of the entire operation of the underwater manipulation robot, including in the automatic modes, the human operator realizes continuous observation on the screen and the instruments of its operations and if necessary, at any point in time can take control in his hands.

Thus, it is necessary to consider the most prospective to be above-described automated, supervisory and dialog interactive control systems supplemented by the semiautomatic biotechnical systems with control handle and special computer.

Let us note that all of the above-investigated problems of systems design are closely related to each other and are solved in the final analysis jointly.

For successful realization of systems design of the remote control of underwater manipulation robots it is necessary to create special complex laboratory test stands for semifull scale simulation including the analog-digital computer complex, the rocking mockup of the working submersible with real manipulators, models of the targets of the operation, an operating mockup of the operator panel with equipment to display the situation and the control units (see Figure 13). The station mockup must be in an adjacent compartment outside the direct visibility of the manipulator operations location.

In the analog-digital complex the equations of motion of the submersible are simulated considering the hydrodynamics, the properties of the meters and

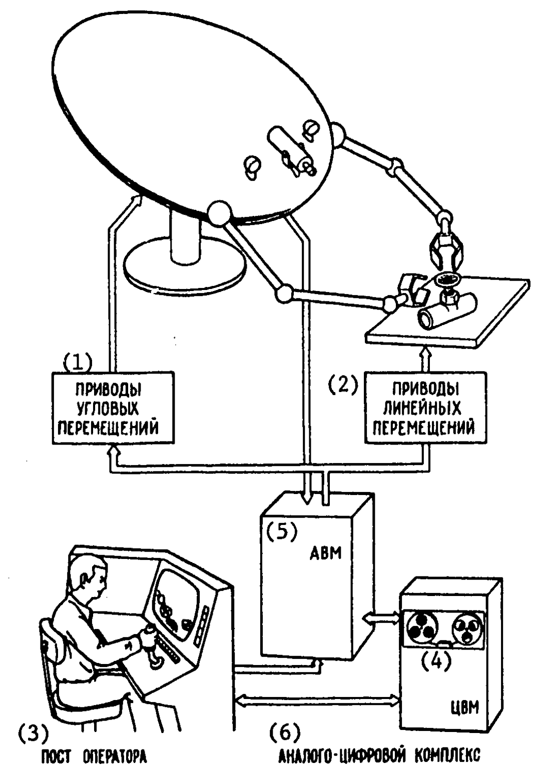

Figure 13. Diagram of the complex laboratory test unit for semifull scale simulation.

Key: 1. angular displacement drive
2. linear displacement drives
3. operator station
4. digital computer
5. analog computer
6. analog-digital complex

the steering-engine complex, the effect of the cable, and so on and also the algorithms for controlling the movement of the submersible and the manipulation system and considering the properties of the communications line and interference.

This test unit will under laboratory conditions, first of all, permit testing of how correctly the preceding calculations of the control system have been performed with respect to all of the systems design problems, including the results of the computer design with preliminary purely mathematical simulation. Secondly, it will permit the development of control algorithms considering the full-scale representation in the test unit of the manipulators and the human operator station, thirdly, introduction of the required changes into these full scale parts of the system to increase the effectiveness of the operation of the entire system as a whole; fourthly, work out the ergonomic and biotechnical characteristics of the system.

In addition, this test unit can be used for laboratory testing of various remote manipulation robot control systems and also become the basis of the trainer complex for training, selecting and conditioning the operators.

This type of semifull-scale simulation test unit is a powerful all-purpose planning and design means and means of laboratory development of a system permitting the holding of full scale marine trials in a well-prepared state.

It must be stated that it can be used for the development and testing in the laboratory of any other remotely controlled robot engineering complexes designed, for example, for unmanned operation of mines or unmanned operations under other extremal conditions, including in outer space.

In conclusion, let us state that it is possible analogously to plan and design and carry out the laboratory development of the manipulator remote control systems for the manned submersibles and spacecraft. In this case the human operator can be placed inside the rocking unit at the above-described test unit in order to approximate the conditions of his activity to actual ones, in particular, for putting his vestibular apparatus into operation.

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MANNED SUBMERSIBLES: STATE OF THE ART AND PROSPECTS FOR DEVELOPMENT

[Article by A. N. Dmitriyev]

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In the economic exploitation of the World Ocean, the manned submersibles (OPA) permitting man to perform various studies and operations underwater play a special role among the varied marine equipment.

A pressure-hull OPA protects man from external pressure; therefore in them, in contrast to the diving gear, any man, even one not having good health and driving skills can submerge to significant depths, to the maximum. It is considered that the work of the divers is effective at depths to 150 meters, and deeper it is more advantageous to use the OPA.

The first manned self-propelled submersibles had much in common with the first experimental submarines built in the last century by the designs of K. A. Shil'der, I. F. Aleksandrovskiy, S. K. Dzhevetskiy, and so on. They also have a pressure hull, power supplies, a propulsion complex, control system, navigation and life support systems. Their chief difference is their economic purpose, which determines the basic characteristics and the structural layout: for example, they can submerge to great depth, have low speed, but high maneuverability, and on them there are lights and manipulators.

The OPA are classified with respect to purpose and the most important technical characteristics.

The following submersibles are distinguished with respect to purpose:

Research, as a rule, multipurpose;

Production, design for underwater operations, basically specialized;

Cargo passenger, designed for transporting loads, hydronauts, scuba divers, rescue operations and underwater excursions;

Experimental for the development of individual types of systems and equipment.

With respect to method of delivery to the submersion points the following submersibles are distinguished:

Towed;

Transported onboard a carrier vessel;

Autonomous, based on shore.

With respect to method of holding at depths the following submersibles are distinguished:

Captive, supported on a cable;

Float, having light weight float (bathyscaphes);

Nonfloat, supported by the buoyancy of the pressure hull;

Bottom, moving along the bottom by means of mechanical devices.

With respect to depth of submersion the following submersibles are distinguished:

For shallow depths to 600 meters;

To medium depth — to 2000 meters;

For great depths, to 6000 meters;

For maximum depths to 12,000 meters.

The standard self-propelled submersibles transported onboard a carrier vessel are usually classified as a function of their technical specifications.

Depending on the displacement, the following submersibles are distinguished:

Light displacement -- to 20 tons;

Average -- from 20 to 60 tons;

High displacement, more than 60 tons.

Depending on the autonomous nature, three groups are distinguished:

Low autonomity operating 3 to 5 hours;

Average, within the limits of a 24 hour period;

High autonomity operating several days.

Depending on the speed of motion, the following submersibles are distinguished:

Low speed -- to 1.5 meters/sec;

Medium speed -- from 1.5 to 3 meters/sec;

High speed -- more than 3 meters/sec.

With respect to number of crew members the submersibles of the indicated type can be divided into single-place, two-place, three-place and multiplace.

The most numerous group is made up of the self-propelled scientific research OPA with a depth of submersion to 600 meters, a displacement to 15 tons, a speed of 1.0-2 m/sec and a crew of 2-3 people.

In spite of the variety of structural forms, these submersibles have common elements, the main ones of which are a pressure hull (a crew is placed in it), the life support system, control system, navigation and communications systems; the light hull (in it there is outboard equipment for achieving the best hydrodynamic qualities of the submersible); the power plant, the power and energy capacity of which are sufficient to insure the given speed, autonomity of navigation and operation of all systems and equipment.

The main elements also include the steering propulsion complex which provides travel and maneuvering for the submersible, the ship systems and devices usually beyond the limits of a pressure hull, the crew life support system which is located inside the pressure hull and consists of the air regeneration and conditioning systems, food and sanitary-hygienic modules and other devices.

A mandatory element of each underwater submersible is the ballast -- liquid and solid -- which is used for compensation of the variation in mass and buoyancy of submersible in the operating process, balancing of the buoyancy before submersion, for discharge when surfacing in an emergency and creation of the displacement reserve.

For the medium and great depth submersibles, the buoyancy of the pressure hull frequently turns out to be insufficient for equalizing its mass. In this case, the buoyancy deficiency is compensated for by the light weight floats executed from light solid materials or hollow tanks filled with liquid or gas.

The basic characteristics of the OPA determining its technical and operating properties are the operating depth of submersion, the mass, the displacement, the speed, the autonomity with respect to power and habitability reserves, the mass of the useful load, the number of crew members, the principal dimensions, the diameter of the pressure hull.

The pressure hull of the OPA provides for safety of submersion. Most frequently its shape is spherical. The hull is made up either of one sphere or two or three. The submersibles with cylindrical hull and semispherical end bulkheads are less widespread. The hull is basically made of high strength steel and more rarely of titanium. In recent years the pressure hulls of the shallow-depth submersibles are made of fiberglass, acrylic and silicate glass.

The outside hull is made of soft steel, aluminum and titanium alloys and fiberglass. Lead-acid storage batteries which are reliable in operation and simple to service and cheap are used as the power supplies.

In various countries searches have been made for new, more effective power supplies for submersibles which are small with respect to weight, but powerful.

The pressure hull together with the storage batteries, as a rule, makes up 30 to 70% of the weight of the entire submersible.

Outside the pressure hull are the steering-propulsion complex, the anchor-guiderope assembly permitting holding at one point under water or drifting at the bottom; the hydraulic system which provides for operation of the running, maneuvering and auxiliary hydraulic engines; the manipulators for taking soil and water samples, and so on; the device for discharging ballast; and the towing and mooring arrangements.

Beyond the pressure hull are, as a rule, the general ship systems:

The ballast system providing for taking on water in the ballast tanks before submersion and purging the ballast for surfacing to the above-water position;

the system is made up of ballast tanks with kingston valves and purge valves; the deep-water submersibles (bathyscaphes) also have a solid ballast system for which iron shot is used;

The high-pressure air system used primarily to purge the ballast tanks, the compressed air is also used for the hydraulic system, sealing the outboard engines and other auxiliary purposes;

The buoyancy control system serving to compensate for the positive or negative buoyancy occurring during submersion with variation in density of the water and volumetric displacement, with compression of the elements of the submersible under the effect of external pressure or temperature variation; the system is made up of pressure or elastic tanks, pumps and fittings;

The trim system designed to compensate for the trimming moments and create trim; water, mercury, ball fluid (steel balls with lubricating oil) are used as the working medium; on the simple shallow-depth submersibles the trimming is frequently realized by shifting the load.

All of the elements of the outboard units and systems must operate reliably in sea water with high external pressure; they must have small volume, mass and power consumption, and they must be adaptable for remote control and monitoring.

Analogous requirements have been imposed on the systems, the equipment and instruments located inside the pressure hull.

Usually the bathyspheres and hydrostats are considered the first OPA.

In 1953 the Swiss bathyscaphe "Triest" and the French FNRS-3 were built. In 1959 Jacques Cousteau began testing the "Denisa" submersible, the depth of submersion of which reached 300 meters.

In the Soviet Union during this time the GKS-6 hydrostat and the "Severyanka" submarine were used for fishing studies. In 1961, the "Sever-1" hydrostat was put into operation. All of them played an important role in ocean exploration, and they served as the basis for creating improved submersibles.

In 1961, France built the "Archimedes" bathyscaphe, and in the United States, the "Triest-2" was built. The Jacques Cousteau submersible "Denisa" became the prototype for designing the series "Deep Star" submersibles which reached depths of 600, 1200, 3600 and 6000 meters.

The design and the construction of the OPA and the laboratories has been carried out in the Soviet Union, Japan, Canada, England, the Federal Republic of Germany and other countries. Intensive preparation has been made for the storming of the ocean depths. The designers must build underwater manipulators, more accurate navigational systems, powerful power supplies, and the searches for superstrong materials have begun.

At the present time throughout the world there are about 200 different OPA with respect to type. They are primarily used for scientific studies in the field of oceanography, geology, biology, fishing and also for the servicing of the underwater oil fields.

In 1966 the Alvin OPA (United States) was used to find a hydrogen bomb lost by an American aircraft off the coast of Spain. In 1968 the Alvin was punctured from the deck during a descent and sank to a depth of 1540 meters. A year later it was raised by means of another OPA, the "Aluminaut" (United States) and other rescue means. The "Alvin" was rebuilt: the steel hull was replaced by titanium; improved equipment and instruments were installed on the submersible. The operating depth of submersion was almost doubled -- it now reaches 3600 meters.

In 1974-1976, studies were made in the rift valley of the midatlantic ridge at depths to 3650 meters using this rebuilt submersible. The submersible continues to operate successfully today in the ocean depths.

At the present time American companies are using other submersibles for underwater exploration and research: the "Star," "Deep Star," DSRV, TARTL, "Deep Quest" OPA and the series submersibles built by the Perry Cabmarine Company, submarines and remotely controlled submersibles. The DSRV type submersibles built in 1970, in addition to rescue operations, are also performing various studies by request from the Navy.

The basic supplier of the working submersibles on the world market has become the American company "Perry Oceanographic." It began with the construction of the recreational and sports OPA in the "Perry Cabmarine" series (PC) in 1956, and then it went to building the working OPA with a depth of submersion to 900 meters. The latter has a transparent bow hemisphere, modular execution of the pressure hull, which permits alteration of the hull depending on the purpose, and there is a diver's compartment with comings for joining to the deck decompression chambers and also manipulators and tools.

One of the latest apparatuses of the "Perry" Company -- the PK-16 -- can submerge to a depth of 915 meters. Its pressure hull is made up of three steel spheres. The submersible is designed to transport service personnel to the area of deep water operations at the bottom of the sea.

In 1969 the United States built the "Beaver-4" working submersible equipped with a system of manipulators, replaceable tools and the chamber for delivering the divers to the location of the underwater operations. The last version of this submersible was adopted for series construction.

An important role in the development of underwater engineering devices in the United States is played by the naval submarine center with its base in San Diego (California), where original submersibles are built.

In addition to the portable OPA, the USA Navy has built submarines, for example, the well-known "Dolphin" with a displacement of 950 tons with depth of submersion of 660 meters; the research vessel NR-1 with a displacement of 400 tons and a depth of submersion of 1000 meters and a compact nuclear power plant that has operated successfully for 8 years. The construction of the second NR-2 boats with increased depth of submersion is planned.

In France the study and the exploitation of the resources of the seas and oceans are being carried out in accordance with a large-scale program; an ocean exploitation center has been built (CNEXO). At the present time the French companies are operating the "Archimedes" bathyscaphe, the "Denisa" submersible, the "Siana" deep-water submersible, the "Shelf Diver" submersible and the recently built "Griffon," "Marco," "Globule," MOANA and "Nerey".

The three-place "Siana" with a displacement of 8.5 tons is designed for research and operations at depths to 3000 meters. It is equipped with the necessary control, navigation and communications systems. By using a manipulator which has five degrees of freedom it is possible to take soil samples, operate a wrench, cutting tool and other tools. As a result of application of high-strength materials, small-scale equipment and efficient design solutions, it has been possible to increase the payload and increase the depth of submersion with relatively small displacement.

The two-place "Globule" with a depth of submersion to 200 meters is designed to inspect underwater objects. It can also be used to control the underwater cable layer. In this case it is mounted on a special platform on the cable layer and it is connected to it by means of four magnetic locks.

After connection, the crew can control this "underwater plow" which is capable of bearing cable to a depth of up to 1 meter by using a hydromonitor.

The MOANA submersibles with 9 ton displacement can submerge to 450 meters (see Figure 1). In the two-sphere pressure hull there are 15 large windows which provide for all-around visibility. The pressure hull is connected to the frame on which all of the outboard units, systems and servoelements are attached. For performing underwater operations the OPA is equipped with manipulators which have five degrees of freedom and replaceable tools: soil samplers, grapples, cutting tools, attachments for screwing on nuts, and so on. They are designed to service underwater oil fields, but they can also be used for other purposes.

The French marine experts company (COMEX) is constructing an underwater scientific research boat "Argironet" with a depth of submersion to 600 meters. It is designed for a crew of ten. Provision has been made in it for a diving compartment for the researchers to exit into the ocean at depths to 300 meters. The "Argironet" will have the properties of a submersible and a laboratory with a high degree of autonomity, as a result of which its cost benefit will rise.

Canada has developed a large-scale program for exploration and exploitation of the resources of the World Ocean, including the Arctic regions. The Canadian company International Hydrodynamics is well known. It has built the "Pisces" submersibles with a displacement from 7 to 11 tons with depth

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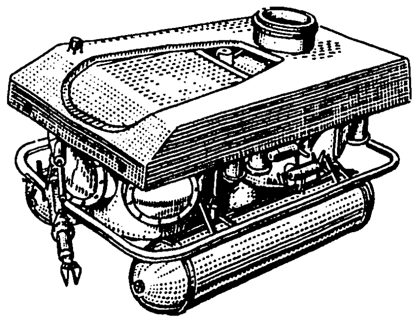

Figure 1. MOANA submersible.

of submersion from 1000 to 2000 meters and is placing them on the World Market. The submersibles have a spherical steel hull and an outer hull of fiberglass. The power supply is lead-acid storage batteries, the propulsion and the maneuvering of the submersible are accomplished by propellers. The submersibles are equipped with a set of scientific research instruments and manipulators in accordance with the customer requirements. The Pisces submersibles have high technical-operating characteristics and can be used for scientific research, rescue operations and underwater operations of laying cable and pipe on the seafloor and also for servicing marine oil and gas fields.

Two of the "Pisces" submersibles have been acquired by the Oceanology Institute of the USSR Academy of Sciences and are being successfully operated to study the depths of Lake Baykal and the oceans.

The same company is constructing a base ship for transportation and servicing of the "pisces" type submersibles. Their length is 27 meters, width is 12 meters, draft 2 meters, displacement 343 tons, a crew of 10 and autonomity of 30 days; these vessels are equipped with a launching assembly.

In addition to this company, in Canada the Ministry of Natural Resources and also the companies ARCh Marine Ltd. and Norton Maritime Exploration Ltd. are also working on the construction and operation of manned submersibles. The Norton Maritime Exploration Ltd. has acquired the August Picard mesoscaphe built in 1964 for recreational excursions and dives in Lake Geneva and the underwater laboratory "Ben Franklin." Now the modified mesoscaphe is used for geological exploration at depths to 700 meters, and the "Ben Franklin" laboratory, for studies at depths to 600 meters.

In England, in connection with the exploitation of the richest oil and gas deposits in the North Sea, the working of hard minerals and the development of aquaculture, a variety of underwater equipment has been built: submersibles, diving complexes and devices for extracting solid minerals. The oil fields in the North Sea were serviced by 11 OPA and several submersibles for transporting divers in 1977.

The "Intersab Ltd" company created in 1973 already had five OPA of the PK type in 1976 built by the American Perry Company. Special base ships were built to transport and service these OPA. In 1977 the company acquired two of the latest PK-18 submersibles for operations at depths to 300 meters. They have a transparent bow bulkhead, a three-place diving chamber with comings for docking with a decompression complex onboard the ship and a propulsion complex which provides high maneuverability. On the removable frame there are two manipulators with a set of interchangeable tools: drills, wrenches, grinding discs, and so on. One manipulator is used to fasten the submersible to any underwater stationary structure and the other, to perform working operations.

A still camera and movie camera, measuring instruments, sample takers and other equipment can be attached to the outer frame for performing scientific studies.

A broad program for the development of the oceanic industry was adopted in 1972 by the Federal Republic of Germany. The primary companies of the Federal Republic of Germany delivering OPA include "Brooker Physics AG" and "Engineer Kontor Lubeck." The first of them is building the widely known "Mermaid" type submersibles, and the second, the "Tours" type.

The "Mermaid" submersibles (Figure 2) of the latest structural design are analogous to the PK-18 type submersibles. The latest models with a displacement of 830 tons can descend to a depth of 500 meters. They have a diving compartment for four people; they are equipped with drills to drill wells 200 meters deep. The same company has developed an autonomous submersible, the "Tours 200/500," based on shore and designed for working in the coastal areas of the North Sea. It is a diesel electric submarine with a depth of submersion to 500 meters, speed above water 8 knots, underwater speed 11 knots, autonomity of 14 days. It has a crew of seven. The capacity of the storage batteries provides for underwater travel at a speed of three knots for 32 hours. The fuel reserve is sufficient for 2000 miles of travel.

This OPA does not need a base ship, and it does not depend on weather conditions. It has nine places to sleep, a common crew quarters, galley, sanitary and work facilities.

In Japan the first Kuroshio hydrostat was built in 1951. After 9 years the four-place scientific research submersible "Kuroshio-2" went into operation studying the shelf resources at depths to 200 meters. Recently Japanese researchers have obtained the "Iomiuri" submersibles with 35 tons displacement designed for six people with a depth of submersion to 305 meters; the "Sinkay" with a displacement of 85 tons and depth of submersion of 600 meters; the "Khakio" with displacement of about 7 tons with depth of submersion of 300 meters.

In 1973 Japan built the two-place OPA, the "Udzushio" with transparent pressure hull for operations at depths to 200 meters. Japan is leasing the French bathyscaphe "Archimedes" to study the ocean basins.

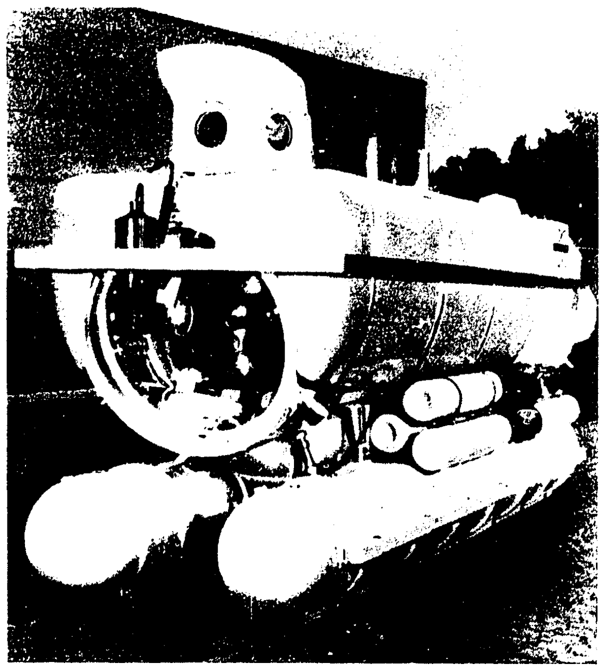

Figure 2. "Mermaid-3" submersible.

Sweden, just as a number of other countries, is participating in the building of submarines, undersea boats and submersibles and also other underwater equipment. Thus, the Swedish company "Kokums" is building the URF rescue submersible with a displacement of 80 tons, a depth of submersion of 450 meters, a crew of five, two of which are divers, on order from the Navy. The total weight of the set of tools on it is 2 tons. For delivery of the submersible to the operations locations at a depth of 120 meters, the SSV undersea carrier has been built with a displacement of 1600 tons and a length of 65 meters. It can go into the sea and take the URF submersible onboard without surfacing.

The company is also completing the construction of the 170 ton displacement OPA for inspection of underwater objects and a working submersible with a diving compartment.

In the Soviet Union, until the 1960's underwater research was conducted, as has already been stated, using the "Severyanka" submarine and the GKS-6 hydrostat.

In 1961 work was started on designing the towed "Atlant-1" OPA, the deep-water "Sever-2" OPA (see Figure 3) and other submersibles and laboratories for oceanographic and fishing studies.

At the beginning of the 1970's, the following OPA were built and put into operation: the four-place "Sever-2" with depth of submersion of 2000 meters; the two-place TINRO-2 with depth of submersion of 400 meters (Figure 4); the two-place towed "Atlant-2" (Figure 5). In 1976, the multiplace "Benthos" undersea laboratory was built with a depth of submersion of 300 meters (see Figure 6). Using these submersibles, broad information was obtained having extraordinary value for fishing. During the same years the Oceanology Institute of the USSR Academy of Sciences built the "Argus" submersible. The Far Eastern University will build a two-place "Shelf" submersible with a depth of submersion of 300 meters.

The towed "Atlant" submersibles and the "Sever-2" submersible have been operated under international programs.

The characteristics of some of the OPA are presented in Table 1.

By 1977, the number of OPA in the world increased by approximately 32% by comparison with 1976. Judging by the increase in volume of the undersea operations by approximately 30% per year, in 1979-1980 the rates of constructing the OPA will rise.

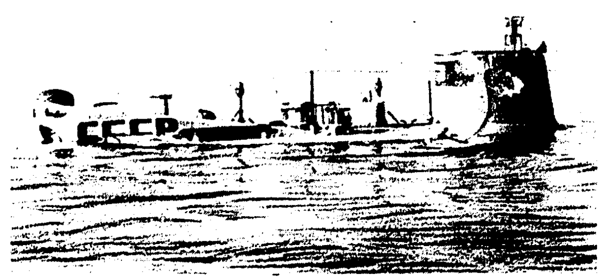

Figure 3. "Sever-2" in the above-water position.

Today 50% of all of the operating time of the submersibles is spent on servicing marine oil fields, inspecting underwater pipelines and cables; about 20% is spent on laying pipe and cables in the ground; 12% on underwater emergency rescue operation; the remainder of the time is spent on biological and geological studies, gathering coral and monitoring the pollution of the oceans.

A trend has been noted toward an increase in depth of submersion and displacement of the submersibles being built. Their seakeeping qualities are being improved. Thus, the "Pisces" OPA can operate in waves to force 6. The effectiveness of the operation of the submersibles will increase as a result of simultaneous use of several manned and remote controlled submersibles on one support vessel. Thus, for example, in the United States the "Trieste" bathyscaphe and an unmanned towed submersible are transported on the carrier ship "Point Loma."

The launching operations under stormy conditions present the greatest complexity. Frequently the weather conditions force a halt in operations. Accordingly, in recent years submersibles have designed simultaneously with the base ship which are considered as a unified complex designed for performance of specific underwater operations in the given part of the ocean. Usually several versions are developed, preference is given to the one which has the highest economic index.

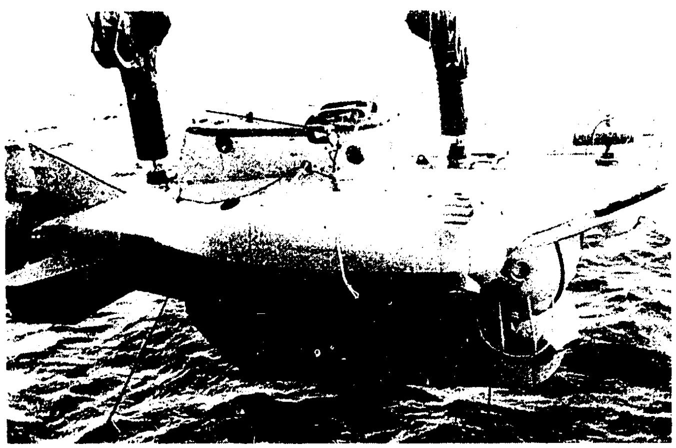

Figure 4. TINRO-2 before submersion.

In order to increase the efficiency of the underwater operations under any weather conditions, undersea base ships coupled with the OPA are beginning to be built. In the presence of nuclear power plants such bases can perform operations at great depths without surfacing.

One of the most important problems for further improvement of self-propelled OPA is the creation of theoretically new power supplies capable of operating without the oxygen of the air.

In spite of further improvement of the storage batteries there are no grounds for considering them a prospective power supply for submersibles. The most prospective are the power plants with piston and rotor propellers of various types, for example, th Ricardo type closed-cycle propulsion unit with recirculation of the exhaust gases and the Sterling type propulsion unit. Propane or hydrogen can be used as the fuel in them.

The power supply on submersibles can also be hydrogen-oxygen and hydrolysis-oxygen fuel elements, but as a result of their imperfection and high energy

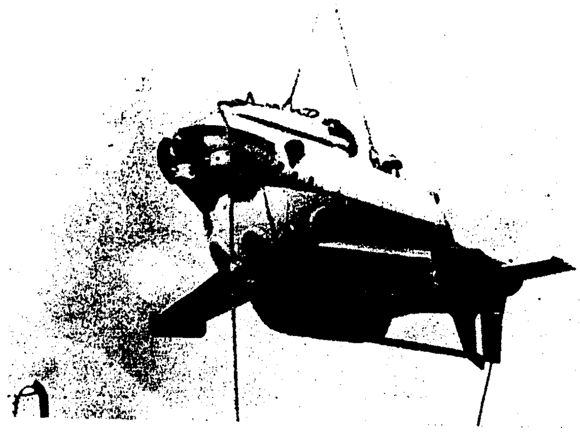

Figure 5. "Atlant-2" on the hook of the launching assembly.

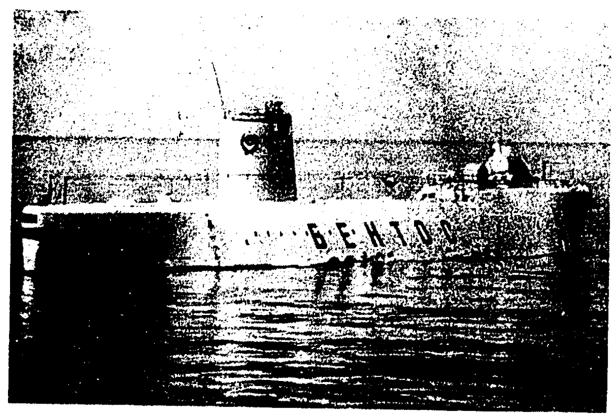

Figure 6. "Bentos-300" undersea laboratory.

Key: 1. BENTOS

lost they still have not found widespread application.

Nuclear gas turbine plants with radioisotopic heat source and reactors with liquid-metal coolants and also devices with direct thermal energy conversion to electric power are being developed abroad. The magneto-hydrodynamic, thermal emission and thermoelectric systems are the best known.

Thus, the development of the power systems for the submersibles will depend to a great extent on the development of reliable and economical power plants based on the achievements in space engineering.

Table 1. Characteristics of some OPA

Name of submersible	Operating depth, meters	Weight, kg·10³	Payload, kg·10³	Speed, m/sec	Autonomity with respect to energy reserves, hours	Crew	Principal dimensions, meters		
							L	B	H
"Mermaid-3" (Federal Republic of Germany)	300	10.5	0.50	2.31	4	4	6.2	1.80	2.7
"Atlant-2" (USSR)	300	3.0	0.24	3.0	--	2	4.3	3.2	1.8
"Bentos-300" (USSR)	300	510	2.5	0.75	240	12	30.4	6.6	11.3
PK-8B (USA)	250	5.5	0.45	2.06	2	4	6.0	3.0	3.2
TINRO-2 (USSR)	400	10.5	0.25	1.2	8	2	7.12	2.5	2.7
"Deep View" (USA)	460	6.0	0.36	2.5	4	2	5.1	1.8	--
"Sinkay" (Japan)	600	85.0	1.96	1.54	4	4	16.0	5.5	5.0
"Start-3" (USA)	600	8.30	0.68	2.06	3	3	7.5	1.8	2
"Beaver-4" (USA)	600	14.5	1.30	1.54	4	2+3	7.6	3.5	3.2
"Tours" (Federal Republic of Germany)	600	14.0	0.38	2.57	3	2	7.0	3.6	3.0
"Argus" (USSR)	600	9.0	0.60	2.0	7	3	6.0	2.6	3.6
"Argironet" (France)	600	300	3.00	3.5	10	10	28	6.8	8.5
NR-1 (USA)	1000	400	--	10.3	--	7	42.6	3.66	3.0
"Deep Star-4000" (USA)	1220	8.62	0.50	1.54	4	3	5.65	3.0	2.1
DSRV (USA)	1520	33.0	1.90	2.06	8.5	26	15.2	3.6	3.6
"Pisces-5" (Canada)	1980	11.0	0.86	2.06	3	3	6.1	3.1	3.7
"TARTL" (USA)	1980	20.0	1.60	2.06	4	3	9.9	3.4	3.7
"Sever-2" (USSR)	2000	38.6	0.8	0.75	8	4	12.0	26	4.0
"Deep Quest" (USA)	2440	52.0	4.7	2.57	10	4	12.0	5.8	4.1
"Alvin" (USA)	3500	13.5	0.70	2.06	4.5	2	6.7	2.4	2.7
"Aluminaut" (USA)	4570	81.0	2.5	2.06	18	6	15.5	3.0	4.4
"Archimedes" (France)	11000	196	1.8	1.54	6	2	21.3	4.0	7.8

The modern submersible type electric and hydraulic motors which operate in seawater at high outside pressure are still far from perfection; therefore it is necessary to develop small effective electric motors with a power from 5 to 50 kilowatts to drive the maneuvering and sustainer propulsion devices, and improved low-power hydraulic motors must also be developed for driving the outboard auxiliary machinery and devices.

Another less important problem must be considered to be the problem of reducing the weight of the pressure hull and, consequently, increasing the overall efficiency, depth of submersion and load-lifting capacity of the submersible. For the solution of these problems materials are needed with higher specific strength and anticorrosion properties. These prospective materials include high-strength steels, specialized titanium alloys, ceramic materials and plastics.

On the way to improvement of the OPA we also must:

Develop precision navigation and automated control systems, communications media, sonar and television for scanning the undersea space;

Improve the seakeeping qualities of the submersibles, create universal launching assemblies;

Create theoretically new manipulators capable of performing any installation and repair operations at great depths;

Develop improved instruments for studying the physio, chemical and biological fields of the ocean.

It is necessary to remember that today the study and exploitation of the ocean depths are of an international nature; therefore it is expedient to standardize certain characteristics and elements of the OPA. This will promote the creation of an international rescue system for submersibles and their crews that have gotten into trouble. The following must be standardized: the autonomity of the lifesupport systems (it must be no less than 70 hours per man), the operating frequencies of the underwater sound communications and emergency beacons. The standardization of the sizes of the hatches and the launching assemblies is also expedient.

As a result of expansion of the marine oil fields and an increase in depth, in the near future it is possible to expect an increase in the number of OPA.

With the development of agriculture, special OPA will be needed along with laboratories for biological studies and servicing of the submersibles.

Analyzing the modern trends in the exploitation of the resources of the World Ocean, it is possible to draw the folloing conclusions:

The OPA are an effective means of performing research, experiments and operations at any depth in the World Ocean; therefore the rates of their construction will increase with each year;

Continuous improvement of individual elements and the overall composition of the submersibles and also standardization of their assemblies will promote reduced cost of construction.

Probably the greatest demand will be enjoyed by the working submersibles used for underwater engineering operations and research. In order to perform long term and large-scale operations, the submersibles (underwater craft) based on shore are receiving more and more recognition, and underwater base craft will be used to transport and service the deep-water submersibles.

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PROBLEMS OF TRAINING UNDERWATER SPECIALISTS

[Article by P. A. Borovikov, M. I. Girs, A. Ye. Kovalenko, A. M. Podrazhanskiy]

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1. Training of Underwater Specialists

At the present time a serious problem in the training of a new type of specialist -- underwater specialist -- has arisen in connection with the

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stormy development of underwater equipment and rapid expansion of the scientific research and industrial-prospecting operations front.

The exploitation of the ocean is taking place in the research, experimental and industrial areas, which determine the basic principles of the training of the specialists working under the conditions of the hydrosphere. Depending on the peculiarities of the underwater work it is possible to isolate the following groups of specialists without analyzing their essence in detail:

1. Hydronauts -- captains (pilots) and crew members on the mobile manned submersibles (OPA). The primary quality is the capacity to insure fail-safe operation of the submersibles for research and industrial purposes.

2. Underwater researchers -- scientific co-workers or technical specialists directly performing underwater observations, experiments and work using underwater equipment.

Depending on the conditions of the performance of the operations and the specific nature of the use of the underwater equipment it is possible to divide the underwater researchers into two subgroups:

The hydronaut-researchers -- specialists working directly on the submersibles and in the underwater laboratories (PLB) using scientific research equipment in all of the depths accessible to the submersibles;

Aquanauts -- underwater specialists working directly in the water using the "wet" type submersibles, diving gear and diving complexes of submersibles.

3. Divers-deep-water experts performing underwater engineering operations at depths of more than 100 meters.

Since the next basic problem will be research and experimental prospecting operations underwater, a great deal of attention must be given to the training of hydronauts, underwater researchers and divers. It is possible to conduct the mass training of the technical specialist at a later time and conduct it by the measure of expansion of the production of underwater equipment.

Let us consider the peculiarities of training the above-enumerated groups of underwater specialists step-by-step.

As the accumulated experience in the operation and maintenance of the submersibles and underwater laboratories and also the experience in training their crews indicate, during the training process the hydronauts and the underwater researchers must acquire skills, practical knowledge required for effective operation underwater using especially complicated and not always fail-safe equipment.

Physical and psychological training is no less important for the hydronauts. They must have high moral qualities, fast reaction, be courageous and firm in decision making and carrying out decisions.

The hydronaut (captain or crew member of the OPA, PLB) must know the structure and the operating rules of the underwater equipment and all of its technical means; the principles of ship handling and navigation safety; the safety engineering rules and the rules for preserving the viability of the submersible and the carrier ship; diving within the program for diver training together with other professions; the principles of oceanology, hydrobiology, commercial ichthyology, hydrogeology, marine affairs, marine law and the organization of services on the submersible carrier ships.

He must know how to control the submersible or the mechanisms (in accordance with the job) under any surrounding conditions; if necessary he must know how to replace any crew member of the submersible; perform adjustment and preparatory operations and also repair and eliminate failures in the mechanisms, systems and instruments of the PA*; he must know how to fight for the viability of the submersible.

[* submersibles]

This is how a prominent American specialist in the field of the design and operation of submersibles, R. F. Busby characterized the hydronauts: "Captains of modern submersibles are equipped with exceptionally skillful enthusiasts moved by high incentives, filled with the desire to help a scientist or an engineer. The responsibility invested in the captain of the submersible is measured, on the one hand, by such values as human life and, on the other hand, capital investments reckoned in millions of dollars."

The hydronaut-researcher must know the scientific research equipment of the PA (submersibles) and the underwater technical observation means, the procedure and methods of underwater research, the principles of construction and control of the submersible: safety engineering rules and the rules of maintaining the viability of the submersible and the carrier ship, the structure and the rules for use of the individual rescue means, the principles of oceanology, hydrobiology, commercial ichthyology, and hydrogeology (in addition to its basic specialty).

He must not have to carry out the given underwater research program irreproachably using the technical means of the submersible, the gear and special equipment, to maneuver the submersible under simple conditions for the most complete use of the observation means, to use individual rescue equipment and to maintain viability of the submersible.

The acquanaut must have the same psychophysiological characteristics of the hydronaut, have the same training as the hydronaut-researcher and the diver qualifications of no less class 3, second group of specialization.

In addition to the above indicated requirements, he also must know how to use the diving complex and the gear of the underwater laboratory (submersible), how to perform underwater operations directly under water in various types of diving gear.

Let us discuss in omore detail the procedure for training the above-enumerated groups of underwater specialists, with the exception of the deep-water divers, for their work has many specific peculiarities.

As practice has demonstrated, the underwater specialists working with the OPA or the PLB must have skills in various areas of science and engineering. Thus, in order to be oriented under the conditions of the hydrosphere, they must know how at least in general form to classify the unknown underwater objects and discover their peculiarities.

Therefore, as a rule, underwater specialists already having higher or middle technical education, must obtain special technical training during the course of their education: they must become familiar with the structure and the rules for operating the submersibles, underwater equipment, scientific-research and industrial equipment. They must master the principles of ship-handling and navigational safety (only the hydronauts), marine affairs, and the theory and structure of ships and submersibles; the communication systems of the NPS and the OPA; safety engineering when working with the NPS and OPA; organization of servicing on the ships and the OPA and also marine law.

Oceanology, hydrogeology, hydrobiology and commercial ichthyology must be included in the training program.

In addition, as has already been stated, the underwater specialists must master diving affairs and be certified as a diver in addition to another professor or a diver third class.

Special attention must be given to the study of the underwater research procedures (only for underwater researchers).

Psychophysiological, physical and special medical training is no less important.

The volume and the contrent of the training program have been developed beginning with the requirements of the specific qualifications of the underwater specialists.

In order to set up the training of the underwater specialists on a scientific basic and create a clear cut system for training hydronauts, underwater researchers and technical specialists probably it is expedient to organize a special training center with training classes, test areas and trainers. Such a center must be equipped with underwater equipment. In it provision must be made for a dispensory for psychophysiological and physical training and recovery of the health of the specialists and also a diving complex.

The basic steps in the training of the hydronauts and the underwater researchers are the following:

1) selection of candidates for training in special courses;

2) practical sea training of the candidates not having navigational certification for the NPS, PA and PLB in the scientific groups or the technical servicing groups;

3) training of the candidates in a special center or in courses;

4) on the job training of candidates who have gone through the technical training course, on the submersibles and the PLB. On completion of this on the job training the candidates are awarded the initial qualification category;

5) the formation and the training of work crews for the OPA and the PLB.

It is necessary to train underwater specialists on leave from production jobs. The training course for the hydronauts is usually planned to last 10 to 12 months; the hydronauts-researchers, 3-4 months; aquanauts, 5-6 months.

Advanced training of these specialists is possible after they get the established navigational certification in the underwater situation, they check out their practical skill in the operation of OPA in accordance with the job held, taking exams with respect to primary disciplines: the structure and control of the OPA, the fundamentals of ship handling and navigational safety, diving affairs, safety engineering in underwater operations. The improvement of the training with respect to the basic specialty of underwater researchers and hydronauts can be realized in advanced training courses at the higher institutions of learning, scientific research institutes and industrial enterprises in established order under the direction of the mentor captains and leaders of scientific groups and also the training meetings during the training courses.

Let us consider the content of the basic steps of the training.

The required number of candidates for hydronauts and underwater researchers, the organization and the training time for the next year are determined beginning with the prospective plans and the requirements of the organization.

The contingent for selecting candidates can be the command group of the fleet ships (ship handlers, engineers) of the Ministry of Fishing and other ministries interested in underwater research, exploration, exploitation and extraction of marine products and minerals; co-workers of the scientific research institutions, design offices, planning and industrial organizations; scientific co-workers, postgraduates and graduates of the higher institutions of learning connected with solving the problems of exploitation of the ocean and environmental protection.

The candidates for hydronauts and aquanauts can be males up to 35 years of age having, as a rule, higher technical or middle specialized education, work experience in the specialty (diploma) of no less than two years and no less than a year of experience sailing on marine ships. With respect to state of health they must correspond to the requirements imposed on divers.

The candidates for the hydronaut-researchers can be specialists of any profile who with respect to the type of work perform underwater research, experiments or tests on the underwater equipment on the OPA. Their age and state of health must correspond to the requirements imposed on the merchant seamen.

In the absence of navigational qualification for candidates for hydronauts, hydronaut-researchers and aquanauts there is a possibility of working on fleet ships for no more than two years. Then they are admitted to their course training. The navigational certification must be obtained on one or two trips on scientific research vessels having submersibles or equipment corresponding to the future qualification of the candidate. During the trip the candidates are considered part of the crew or they are included in the technical service group of the submersible.

The training of the candidates is a complex process which is clearly divided into four steps;

1) theoretical exercises with respect to the items of the program during the entire training course;

2) practical exercises with respect to the program objects as the theoretical study of its individual sections proceeds, including the development of the operations of controlling the submersible on shore and in the sea;

3) the exams with respect to all of the subjects of the program -- on completion of the training course;

4) on the job training of the students who successfully passed the exams on the submersibles.

In the first step lectures are given on the program subjects. Special attention is given to the careful study of a OPA structure, all of its systems, units which can be divided into three groups: mechanical and hydraulic systems, electric power systems, electronic systems. In accordance with this division, a study is made of the technical documentation for the submersible.

Knowledge of the operating characteristics of the submersible and all of its systems is necessary for all of the hydronauts, for during dives and also during the prelaunch and postlaunch checks, and during performance of preventive and adjustment operations, interchangeability of the crew members is necessary.

Theoretically studying the structure of the OPA and all of its systems, their operating rules, the candidates must master the practical skills of operating the submersible and learn how to eliminate failures. Usually the latter is performed by a service group, but the candidates must know how to perform repairs, for each of them can be in the situation where there is no one to help during the course of operation of the craft.

Special lists of operations performed during the prelaunch and postlaunch checks are compiled in advance. It is expedient to use such lists as the bases for the practical training of the candidates. Repeating these operations a multiple number of times, the candidates can develop the necessary skills for operation of the PA.

It is more complicated to work out all of the repair operations. Naturally it is impossible in the training process to analyze all of the units and assemblies of the submersible. It is possible to achieve the required level of skills only in the operating process, during planned and preventive operations and also during repair after failure or breakdown.

After studying the structure of the submersible it is possible to proceed to the second step -- developing the control operations on shore. Finally, it is fastest of all to acquire control skills using trainers, but if there is no training center available, then the training is done on the "live" submersible. The numerous operations which the hydronaut must perform during submersion must first be worked out on land. In this step, all of the operations from closing the entry hatch to opening it must be "played out" to the point that they are performed automatically under the direction of the OPA captain-tutor. This automatic operations is needed to overcome the tension which unavoidably arises in the first submersions of the hydronaut.

Special attention must be given to working out the actions of the crew during emergencies, for which it is necessary to simulate such situations in the training process.

After strengthening the skills and working out the procedures for controlling the submersible on shore it is possible to proceed to practical training in the sea.

As has already been pointed out, the tension and constraint experienced by the hydronaut during the first submersion disappear after 25 to 30 hours of working in the submersible, for the load caused by the "effect of newness" is completely removed, and all of the skills acquired by him during preliminary training are reinforced.

During this period the candidate begins to adapt to the noise accompanying the operation of the submersible, to understand the origin and nature of each sound, to receive communications from the support service of the carrier ship, to learn how to transmit his own communications laconically and precisely, he becomes accustomed to the dynamic properties of the submersible, he becomes skilled in correctly evaluating the rate of submersion, surfacing and movement and understanding the peculiarities of the behavior of the submersible, and much else.

The importance of this training step is obvious. Naturallly not all 30 hours are spent at the "controls"; participation in the dives as an observer is no less important.

Accordingly, the following approximate time distribution of the training step can be recommended: participation in the dive as an observer 5 to 10 hours; hydronaut 15 hours; crew commander 5 hours.

These exercises are performed under the observation of the captain-tutor who has long work experience on the submersible.

During the last five hours of submersion, the captain-tutor is present in the OPA as an observer, recording errors. This final period called the "solo dive" must be considered to be an examination. In the absence of errors in the candidate's operations in some way influencing the safety of autonomous navigation of the submersible, he is considered to have passed the training course and is admitted for participation in the work dives as a hydronaut apprentice. After acquiring sufficient experience, he can be permitted to dive as assistant crew commander or crew commander. This problem is solved by the captain-tutor during the work process.

In the third step, the exams are passed with respect to all subjects of the program. A commission appointed by the owner of the OPA receives the exams. This commission must include the captain-tutor and experienced hydronauts who have worked under water for more than 300 hours.

After successful passing of the exams, the candidates for hydronauts are sent for on-the-job training on the OPA or the PLB.

The fourth step in the on-the-job training pursues the following goals:

- The reinforcing of the theoretical skills in the problems of the structure and the operation on the submersible and the equipment;

Obtaining practical skills in the servicing of the PA and the mechanisms when working under water under ordinary conditions;

Checking the personal qualities of the candidate and admission to independent work on the submersible.

During the on-the-job training process the hydronauts and the hydronaut researchers must work under water no less than 15 hours, the aquanauts must work no less than 15 hours and complete 10 dives with OPA and PLB.

After the on-the-job training and obtaining the positive characteristics of the captain-tutor of the OPA (the scientific group leader) the candidates are awarded the corresponding initial qualification category: third class hydronaut, third-class hydronaut researcher, and so on.

The hydronauts and the aquanauts are admitted to independent work after they work as backups. The OPA or PLB crews are formed by the captain-tutor only among the specialists having corresponding qualification categories for the given type (category of complexity) of submersible.

Many years of experience has demonstrated that for training a highly qualified captain (hydronaut first class), 3 to 5 years are needed.

Abroad, usually the PA [submersible] manufacturing companies train the hydronauts to control and service the submersibles, for example, the training course for working on the "Pisces" submersibles was developed by the International Hydrodynamics Company. It consists of two basic divisions: theoretical and practical. The job of the hydronauts is partial servicing of the submersible (only in the prelaunch and postlaunch periods and working on the submersible during dives). Current repairs required during operation are performed by the members of a special group.

In addition, the repair of the structures and modules after failure or breakdown during the course of operations is realized either by the manufacturing company or if the operations are very remote, company representatives. As a rule, the failed device (with the failure) is replaced locally and repaired later at the plant.

It is interesting that during the training period each hydronaut is issued a journal with a description of the structure of the various systems of the submersible, emergency situations, navigational conditions, servicing procedures, and so on and also the questions, the answers to which must be entered by the students independently.

The practical part of the course also consists of dives onboard the submersible. In accordance with the company rules the hydronaut must have 30 hours underwater, two-thirds of which are performed independently without any intervention by the instructor, but under his observation. During this period the hydronaut performs the jobs of the dive leader and communications specialist successfully.

2. Training the Deep-Water Divers

Let us especially discuss the problem of the training of deep-water divers, although on the whole it is not new. However, at the present time in connection with expansion of undersea operations, an increase in depth of performing these operations and, consequently, complication of the stated goals, the requirements on divcr training have changed. In connection with the industrial exploitation of the ocean, it is necessary to train the divers having various specialties in accordance with the requirements of the national economy. In practice, it is necessary to train thousands of fitters and riggers, repairmen, welders, flaw detection specialists for working under water under extraordinary extremal conditions.

Here, of course, special attention must be given to diver training, for an insufficient level of training with respect to specialty can lead only to breaking the assignment deadlines, then not knowing the rules for performing the underwater operations, to accidents and emergencies. Statistics show that the death rate of divers working in the marine oil fields fluctuates from 0.7% (in the Gulf of Mexico) to 1.0% (in the North Sea) out of the total number working per year. Such a high disaster rate, as analysis shows, is explained by the simultaneous effect of several factors: insufficient training of the diver himself and the service personnel, equipment failure, noncorrespondence of the equipment to the operating conditions, errors in the decompression regime, and complex hydrometeorological conditions.

Today, thousands of divers are engaged in underwater engineering operations. In the North Sea alone about 2000 divers are engaged in marine extraction of petroleum and gas. More than half of them regularly dive to depths of 120 meters or more. The main foreign diving companies of the COMEX type (France), "Taylor Diving and Salvage Company (United States), "Oceaneering International (United States) and so on have several hundreds of divers on their permanent staff and higher approximately a hundred divers each per year for temporary, seasonal work. All of these divers go through preliminary training and advanced training to the required level in the training centers that all of the foreign diving companies operate.

The training process in these companies, in spite of individual peculiarities and traditions, has much in common.

As a rule, provision is made for the training of divers of several certification levels.

The lowest certification is the diver working on compressed air. His working depths range up to 50 meters. A diver with this certification must know the rules for diving operations in the country in the waters of which he is working, the principles of physiology and medicine, he must master the individual diving gear and equipment (decompression chambers, compressors, and so on). He must know how to work underwater and competently operate the hose and autonomous individual air gear, diving platforms, manual mechanized tools and underwater power packs for them, soil washing media, devices for chopping, cutting, welding and pouring concrete under water, small boats used for supporting the dives (launches, power boats, and so on).

The next certification level is the diver permitted to work using artificial breathing mixtures (the deep-water diver). A diver with this certification must know and know how to do everything that the diver working on compressed air knows and knows how to do. In addition, he must know the rules for giving first aid in the work area, the theory of mixing gases, the gas-analytical equipment, gas mixers, tables of continuous and stepped decompression, he must master the individual diving gear with air and artificial breathing mixtures, he must study the structure of the deck diving complexes perfectly (the control stations, life support systems, and diving bells) and he must know how to control them. He must also competently and, observing the safety rules, dive from the surface on a diving platform or diving bell to depths to 180 meters, know how to exit from them into the water, perform blasting operations, photographic and remote surveys and also magnetic flaw detection.

The highest diving certification is the deep-sea diver permitted to spend several days under pressure. In addition to what has been enumerated above, he must know the operating rules in the regime of many days under pressure, special decompression tables, he must know how to dive competently and safely to depths of greater than 180 meters, and how to direct the dives of other divers.

In addition to special training, all the divers must have general industrial training on the technician and engineering level with respect to one of the required specialties.

The divers of all certification levels go through periodic retraining for familiarization with new equipment and new methods of working under water.

The large underwater engineering companies begin the hiring of their divering staff with preliminary selection of the candidates. The candidates can be people 20 to 22 years old having good health, having middle technical education with respect to one of the general industrial specialties and a certificate of completion of one of the recognized diving schools offering initial diver training. The candidates are subjected to a written examination encompassing a broad class of problems.

The students accepted for the diving school study the theory and practice of diving operations, including the deep-sea individual diving gear, including the water-heated gear, the assembly and servicing of the helmet cables, compressors and pumping stations. They acquire skills in performing underwater installation operations, the installation of grapples and lifts, performing underwater cutting, welding and blasting operations, the operation of underwater welding chambers and complexes for repairing pipe; they study the structure of dredges, barge pipe layers, and so on. In this initial training phase the students complete training dives in a deep-water simulator at the training center and they make practical dives in the sea.

On completion of training, the students undergo on-the-job training in underwater technical operations as support divers. Then the most prospective divers go through additional training and are admitted to simple independent operations.

On the whole, the diver training course, depending on the certification level, last 10 to 24 months. The independent activity of the "novice" begins only after several years of work in the sea on simple dives for auxiliary operations.

According to the data of the foreign companies, the diver who receives initial training at age 20 to 22, can begin to work independently only 3 to 5 years after training at the center, that is, at the age of 25 to 27), and at an age of 35 years old, he will be barred from diving because of his health. It is considered that after 7 to 10 years of active work in the sea the diver's organism ceases to respond to the imposed demands.

The training centers which train divers with higher certification have at their disposal shore simulators of deep sea dives and ships with deep-water diving complex onboard. The students perform dives to depths of 100 meters and more on them, they work out both the diving process and working under water (in the hydrotank of the simulator) and the individual underwater engineering operations, for example, underwater welding, flaw detection, and so on.

The training groups of the higher certification schools usually include about 10 people; about 25 people complete the school each year. This number of divers is entirely sufficient to fill out the company staff.

It is necessary to note that divers who have learned future operations in the simulator hydrotank perform them with maximum possible speed and good quality on real projects at sea. Therefore, it is expedient to work out the complex operations of an experimental nature in all their details in advance.

Undoubtedly, in connection with an increase in the demands of the national economy for underwater specialists, it is necessary to compile the rules of professional selection and create united training procedures and training centers.

This article contains a discussion of the basic problems of professional training of underwater specialists of different profile, and the paths of their solution are characterized in general features. It is obvious that these problems cannot be considered uniquely possible; they can turn out to be disputable to a high degree.

INHABITATION OF THE DEPTHS OF THE SEA BY MAN. LIFE-SUPPORT SYSTEMS

[Article by P. A. Borovikov]

The inhabitation of the depths of the sea by man can arise both from economic and social reasons. The former are primarily connected with finding new food, mineral and power resources, and the latter are connected with finding living room as a result of overpopulation of the land.

Today, considering the foreseeable future, it is only possible to talk about economic exploitation of the ocean, the conversion to a daily habitation environment, that is social expansion still cannot be discussed inasmuch as this problem has no real foundation. Therefore in the future the depths of the sea will be considered as an arena of human production activity. Thus, a human stay under water is limited today to weeks, and it can be no more than months.

Engineers and doctors working with the problem of inhabitation of the ocean depths must solve three interrelated problems successively: maintenance of life, health and fitness for work of a man under water. In order more clearly to understand the essence of the solved problems, their nature and volume, let us discuss the specific nature of the undersea environment.

First, water does not support the respiration of man formed as a biological species under the conditions of an air-gas environment. Therefore independently of all other other conditions it is necessary to use a gas mixture for breathing under water which will support the normal vital activity of the organism of man, that is, which, depending on the conditions of submersion will have a defined composition and parameters. When working under water it is necessary to use means of individual or collective protection of man as a whole or at least his respiratory tracts from the effects of water on them.

Secondly, the weight of the water exerts a pressure somewhat exceeding atmospheric on the organism. In this case all of the conditions of existence of man change charply, it is true that it has been demonstrated experimentally that the vital activity of a man uniformly subjected to increased pressure (from 0.3 to 60 atmospheres and more) is not disturbed with the corresponding composition of the breathing mixture. He experiences such pressure on submersion to a depth of 600 meters or more under water. However, on the whole, the problem of the life-support of man under hyperbaric conditions, frequently for many days and weeks is new and far from resolved.

At the present time there are two methods of performing underwater operations:

Method of Complete Isolation from the Surrounding Water. People are put in submarines, working submersibles, working chambers, and so on, that is, structures, the pressure hull of which takes the rising water pressure on itself. In such structures the conditions are the closest to ordinary land conditions. The pressure acting on the organism is kept equal to or very close to atmospheric, and the breathing mixture is air. The comfort zones are not deformed.

Method of Prolonged Stays of Many Days by Man under Pressure. This method is receiving ever greater recognition inasmuch as diver training in modern times is acquiring auxiliary significance; it is becoming the only means of adaptation to the water environment in which defined operations are performed. The primary goal of a man submerged under water is the performance of various operations with respect to the installation of equipment, its repair, underwater welding and also examinations, expert appraisals, and so on. The modern objects of underwater operations are at depths of 200-300 meters or more, and the volumes of operations reach tens and hundreds of man-hours of underwater time. Here it is necessary to be concerned with the safety of people, but also the efficiency of their work under water.

In order to deliver man under water, offer him the possibility of working under water on the object and returning to the surface alive and healthy, it is necessary to satisfy a number of requirements. Thus, strictly in accordance with the depth of submersion and the rhythm of submersion it is necessary to change the pressure of the breathing mixture, and in accordance with the pressure, the composition of the breathing mixture, its temperature and humidity. In addition, these characteristics also depend on the time spent under pressure under specific conditions and also the class of technical means used.

In modern diving engineering, there are three classes of equipment designed for the creation of the conditions needed for man to stay under pressure: ship barochambers, diving bells and individual diving gear. They are distinguished by the condition of allowable comfort and the times spent by man in them.

The divers live days and weeks in bell chambers installed on above-water ships or submersibles. Such prolonged staying of people in a closed space under pressure of tens of atmospheres requires maintenance of the necessary living conditions of the crew on a high level and in the most complete volume.

The diving bells are used during practical operations for several hours per day, and then the bell is either inactivated or a second, shift crew boards it. Of course, the life-support system is appreciably simpler in them, and the inhabitation conditions are less comfortable.

The individual diving gear is used continuously only for 2 or 3 hours; therefore it is possible with its help to create the minimum necessary conditions for man to stay under water.

On the whole, the life-support system must satisfy the following requirements.

First, it must maintain the working pressure of the breathing mixture with accuracy of ± 0.25 m H_2O.

Secondly, it must provide for changing the composition of the breathing mixture with an increase in working depths and, perhaps, pressure. Thus, for dives to 50 meters or more the inert component of air -- nitrogen -- must be replaced by helium. The presence of helium in the breathing mixture sharply changes all of its characteristics and the conditions imposed on the habitation conditions vary correspondingly.

Thirdly, exact regulation of the oxygen and carbon dioxide content is necessary, the presence of which in the breathing mixture is important for normal life support of the human organism.

At the present time researchers consider that the biological effect on the human organism comes not from the relative percentage content of the biologically active component, but its absolute mass content per unit of geometric space of the compartment. In addition, independently of the pressure of the breathing mixture the mass of the oxygen content and the carbon dioxide gas per unit geometric volume can remain approximately at "ground" level. The life-support systems are designed beginning with these two principles.

During the process of vital activity, the organism of man releases a number of gaseous products, so-called anthropotoxins, into the surrounding environment. The presence of these gases in the respiratory mixture in large quantities can lead to poisoning of the organism. Up to now physiologists have no clear picture of the nature of prolonged, many days effect of anthropotoxins on the organism of man under increased pressure conditions.

It is considered that their mass content per unit geometric volume of the compartment will be acceptable also for hyperbaric complexes.

Fourthly, it is necessary to keep the heat and moisture characteristics of the breathing mixture within the required limits. It is maintained using special equipment not connected externally to the systems for regulating the composition of the breathing mixture. By multiple experiments it has been demonstrated that with an increase in pressure of the breathing mixture, especially with replacement of nitrogen in the mixture by helium, the zones of heat and moisture comfort are deformed. Thus, at a depth of 200-300 meters, a temperature of 30-32° ($\pm 1°$) and humidity of 40-50% are considered comfortable. However, strictly speaking, for each breathing mixture, for each pressure and, the more so, for each life-support system the comfort zone will be different. This is caused by the fact that the concept of comfort is based on the heat exchange and moisture exchange processes of the organism with the external environment. It is natural that the given processes are also influenced by the thermophysical characteristics of the breathing mixture and moisture content, and the organization of its flows through the chamber and the velocity of these flows. The problem of heat and moisture balance of the organism of man under hyperbaric conditions is still in need of careful investigation, especially for introduction of new equipment and gear into the practice of diving operations.

The existing life-support systems usually carry out complex processing of the breathing mixture, removing the carbon dioxide and anthropotoxins from it, adding oxygen, maintaining the temperature and moisture of this mixture within the required limits.

However, this does not exhaust the problems facing the life-support system. It must purify the breathing mixture, removing the microflora continuously released by the crew members, which under the conditions of a closed space accumulate with very significant rate. The presence of microflora in the inhabited compartment is especially dangerous, for the resistance of the human organism under hyperbaric conditions is quite low. Usually before beginning operations the barochambers and equipment are carefully dininfected, and the crew members undergo disinfection. The disinfection is repeated periodically. In addition, special filters which stop not only the microflora, but also ordinary dust are installed in the system through which the breathing mixture circulates.

Finally, in the life-support system provision must be made for ways to feed the people under water or under pressure. Under normal pressure conditions -- in pressure hulls -- the feeding problem causes no special difficulties. When solving this problem for divers staying many days under pressure it is necessary to remember that their taste sensations differ from the sensations arising under ordinary land conditions. The researchers must discover how food is assimilated in the hyperbaric environments in order to develop the rations.

Thus, on the modern level of knowledge about the peculiarities of the life-support of the human organism under underwater hyperbaric conditions are of a semiempirical nature, and their volume is clearly insufficient. Obviously, the primary problem is maximal expansion of the volume of basic research with respect to diving and underwater physiology. Only then will the practical recommendations be based on the results of scientific work and not on trial and error.

Today the inhabitation of the depth of the sea by man is connected with the use of ship diving complexes: mobile modular and stationary. The deep-water versions of the various complexes are designed to support many days of work under pressure, and they are distinguished from each other with respect to number of divers taken into the compartments and, correspondingly, the volume of operations. The mobile complexes take on 2 or 3 divers and are used for the performance of random operations of small volume, for example, monitoring the state of the bottom equipment or small repairs. The stationary complexes can take on 8 to 12 divers simultaneously to perform the operations which are significant with respect to volume, for example, the installation of underwater devices, pipelines, and so on.

The requirements on the conditions of inhabitability in barochambers of the diving complexes of both classes are similar in general, and their technical solutions are identical.

The pressure of the breathing mixture is maintained in practice within the required limits as a result of feeding gas stored in bottoms in compressed form to the barochamber through lines or as a result of removal of the excess breathing mixture from the barochamber. Usually devices are included in the pressure regulation circuit for collecting the mixture discharged from the compartments, removal of the helium from it (if the mixture contains helium) in pure form and pumping the purified helium back into the tanks for repeated use. The pressure regulation circuits are controlled, as a rule, manually, especially in the pressure reduction stage -- decompression. A study is made of versions of the automated compression, pressure stabilization and decompression circuits, but they are still in the experimental testing stage.

The composition of the breathing mixture and maintenance of it within the given limits are monitored using circuits that regulate the parameter of the breathing medium or several media directly. Each circuit consists of a meter that measures the values of the regulated parameter (temperature, moisture or oxygen content) -- a module for shaping the control signal and servomechanism which regulates the magnitude of the given parameter.

It is very important that the measurements of the composition of the breathing mixture and its parameters -- temperature and moisture -- be highly accurate in the entire pressure range. We have already stated that with variation of the pressure, the composition of the breathing mixture changes: the relative, percentage content of the components (except the inert component) decreases proportionally to the increase in pressure. Thus, if the normal oxygen content in the air is 20%, at a depth of 100 meters a content of 1.8% will be normal, and at a depth of 300 meters, 0.65%, and at a depth of 500 meters, 0.39%.

Consequently, any gas analyzer measuring the relative volumetric content of the components of the breathing mixture must have fantastic accuracy, especially for large depths that are inadmissible today. Therefore, as has already been stated above, it is possible sufficiently precisely to analyze the composition of the breathing mixture only by the method of measuring the absolute content of the component per unit geometric volume of the compartment (the measurement must be performed directly in the compartment under the operating pressure of the analyzed medium). In this case the accuracy of the measurement can be comparatively low, but the main thing is it must not vary as the depth of submersion increases, for the mass content of the components of the breathing mixture (except the inert component) must not change. Thus, the problem of increasing the accuracy of the gas analysis in the ship barochambers and especially in the diving bells and also the breathing apparatus still has not been solved.

The measurement of the temperature and moisture of the breathing mixture is a somewhat simpler problem than analysis of the mixture composition, but even here the measurement technique used must be insensitive to variation of pressure and composition of the breathing mixture.

The module for shaping the control signal, comparing the readings of the measuring instrument -- sensor -- determines how much the monitored parameter has deviated from the given value and switches on (or off) the corresponding servoelement. In the automatic regulating systems this module is made in the form of a special instrument.

It must be noted that an increase in depth of submersion of the driver implies amplification of the intracircuit, cross relations between individual parameters that would appear not to be related to each other. It is difficult to consider all of these relations when converting the life-support system from one regime to another, and in recent years work has been started on complex automation of the diving descent and inclusion of a specialized control computer in the system as the control signal shaping module.

The servoelements themselves regulate the content of one component of the mixture or another or its parameter, operate by the commands from the control signal shaping module.

The oxygen for compensation of the oxygen consumed by the crew during respiration is supplied to the briefing mixture usually from an outside source through lines and a batching unit. The latter is the basic element of the oxygen feed circuit, for the quality of its operation to a significant degree determines the quality and reliability of the operation of the entire circuit. There are two versions of batches. In one the oxygen is fed to the compartment at a constant rate (for example, by batches), and the amount of supplied oxygen is regulated by the feed time; in the second version the oxygen is fed to the compartment in previously prepared batches. Both of these versions have their advantages and disadvantages, and they are used to an equal degree in the diving systems.

When creating the circuit for feeding oxygen to the compartment it is necessary to deal with the oxygen "flares" -- jets of pure oxygen escaping from the batcher. The speed of the escaping oxygen, its amount, the point of feeding it and the parameters of the mixer at the exit from the batcher must be selected so that the oxygen getting into the compartment will be already mixed with the breathing mixture and its concentration in the breathing mixture will not be fire-hazardous.

In practice usually several types of oxygen sources are used: tanks with compressed gaseous oxygen, vessels with liquid oxygen, electrolyzers that extract oxygen by decomposition of water into oxygen and hydrogen and, finally, solid chemical compounds which release excess oxygen during the process of one reaction or another.

All of the devices for purifying the breathing mixture to remove carbon dioxide and anthropotoxins released during the respiration of the crew usually are combined in one circuit which includes the modules for absorbing the impurities and the device which pumps the breathing mixture through these modules -- the so-called mixture flow booster.

The beathing mixture is purified of carbon dioxide usually either by chemical binding of it with some material — an absorber — or physical adsorption by materials such as zeolites or freezing it out using deep-cooling units. Most frequently quite simple, reliable and cheap chemical absorbers of carbon dioxide are used. The basic disadvantage of chemical purification of the breathing mixture to remove carbon dioxide is very high consumption of the absorber, reaching to 10 to 30 kg and more per man per day depending on the operating conditions. In the case of many days and even many weeks of exposure of a crew of four, six or more people, the absorber consumption reaches many tons. This amount must be delivered to the work area, stored, the cartridges charged, which presents defined difficulties. Therefore an intensive search is underway for regeneratable carbon dioxide absorbers of the adsorption type or nonconsuming means of purification of the type of cryogenic devices or molecular screens.

The breathing mixture is purified of the gaseous anthropotoxins also by special absorbers during the process of pumping the breathing mixture through them. The filter-absorbers of the harmful impurities, as a rule, are adsorbents of the activated charcoal type or compounds similar to it included in the same circulation circuit with the catalysts insuring oxidation of the products of the carbon monoxide type to carbon dioxide and subsequent removal of the products of oxidation on the corresponding absorber filters. The filters are quite capacious with respect to absorbing capacity. They have comparatively small size and, it is possible to state, satisfy the practical goals.

For creation of the heat flux which heats the breathing mixture, electrical, steam or water heaters are included in the mixture circulation circuit. Here it is necessary to maintain the mixture temperature within given, frequently very narrow limits. Practice shows that in the helium-oxygen hypobaric media the temperature fluctuations must not exceed fractions of a degree, and the maintenance of this magnitude of the fluctuations, especially in the automatic mode is a complex technical problem.

The regulation of the moisture of the breathing mixture consists in removal of the water vapor which gets into it with respiration, food, from the showers and the sanitary facilities from the mixture. The moisture is absorbed from the breathing mixture by various methods. One of the basic ones is condensation of the water vapor by cooling the breathing mixture to the dewpoint corresponding to the given regime and removal of the condensate from the chamber. For this purpose, the breathing mixture circuit includes a heat exchanger to which a coolant is fed with a temperature that provides for the necessary cooling. Then a module for heating the breathing mixture cooled in the exchanger to the initial temperature is placed behind the heat exchanger and the drop trap. The condensation method of moisture absorption is most widespread, for it is quite reliable and simple in operation. However, for implementation of it, refrigerators, heat exchangers, pumps for pumping the coolant through the heat exchangers, and so on are needed. In addition, this method is extremely power consuming -- double heat treatment of the breathing mixture is required: first cooling of it and then heating. It is necessary to know that the power expenditures on condensation absorption increase with an increase in the pressure of the breathing mixture.

A second method of moisture absorption used in diving practice is adsorption drying. The water vapor is removed from the breathing mixture by adsorbents of the silica gel, zeolite and other types. This method is more advantageous energywise inasmuch as heat treatment of the mixture is not required for implementation of it, and it is technically simpler. Its deficiency lies in the necessity for periodic regeneration of the adsorbent, which complicates the maintenance of the system and increases the operating losses of breathing mixture and this is also important considering the prices of helium. Adsorption drying is insensitive to a rise in pressure; therefore at the present time it is considered as the most prospective, especially for drying breathing mixtures under pressures of several tens of atmospheres.

Finally, it is necessary to talk about the necessity for careful organization of the flows of breathing mixture in the chamber. Usually the breathing mixture is collected for regeneration in one of the extremities of the compartment and the treated mixture is returned to the other extremity. Thus, constant movement of the breathing mixture from the "clean" end to the "dirty" end is realized, that is, the required mixing in the compartment itself. However, here, on the one hand, stagnant zones must not be formed in the compartment in which the constant exchange of the breathing mixture is absent and, on the other hand, the speeds of movement of the flow, the velocity, temperature and moisture gradients along the stream must be limited and cannot exceed comfortable values.

All of the living barochambers of the diving complexes have sanitation facilities. Usually hot and cold water are supplied to the sanitation facilities, and the sewage is discharged overboard from the chamber. Naturally, it is necessary to feed the water to a chamber experiencing, for example, a pressure of 30 atmospheres under a pressure exceeding the pressure in the chamber by several atmospheres. Usually this is done by using an intermediate pressure tank which is filled with water under normal pressure and then a counterpressure of defined magnitude is created in the tank which provides for our delivery of the water to the chamber. This system is structurally simple, but it creates certain additional operating difficulties -- it is necessary to watch the water level in the tank, the counterpressure in it, regulate the pressure when filling the tank, and so on.

In addition, the water reserve in the pressure tank is limited, and as a rule it runs out at a very inappropriate time. Recently, high-pressure water pumps have begun to be included in the water feed lines by means of which it is possible to fill the pressure tank with water and thus create an unlimited supply.

The sewage is connected by special units (the bottom of the shower, the lavatories, the toilet), it is removed from the chamber through a pipeline to another storage tank, and from it, to the general ship system. The stop valves installed along the discharge line must reliably block the line even on passage of foreign objects through it.

Considering the habitability of the hyperbaric compartments, it is impossible not to mention sound communications. The high speed of sound in helium, the different density in the breathing mixture lead to a shift of the resonance frequencies of the vocal chords of man to the higher frequency range. This shift increases with an increase in pressure, and at depths of 200 to 300 meters or more the voice of man is made understandable only after it is processed in special electronic devices -- speech correctors. The creation of them is a still unsolved problem.

Up to now we have investigated problems occurring when insuring normal life-support of the crew in the living barochamber of the diving complex on the above-water or underwater ship. Approximately the same problems must be solved also when providing for exit of the diver into the water in individual gear. As a result of the short stay of the diver in the water (to several hours) a number of problems are removed such as observation of the comfort zone with respect to humidity, eating and provision for the natural necessities and control of microflora. The result of the problems become more acute. First, direct contact of many with water creates an additional load on the physiological systems of the organism. Secondly, the individual gear of the diver is a much more dynamic object than the living barochamber.

In case of failure of the devices for purifying the breathing mixture, supplying oxygen, heating, the diver has minutes to eliminate the failure. In practice any failure can be eliminated only in the diving bell or even on the surface. All of this imposes very rigid requirements on the reliability of the individual diving gear.

Thus, the breathing apparatus must supply the diver with a breathing mixture exactly in accordance with the ambient pressure.

Equality of the pressures of the breathing mixture and the environment of the diver is reached by including a highly sensitive element in the breathing channel of the gear in the form of a rubber bag from which the diver breathes or a precision rubber diaphragm which drives the gas feed mechanism.

The regulation of the composition of the breathing mixture in the individual gear is provided by two methods. In the first method the diver receives the fresh breathing mixture over a hose from the surface or from a diving bell, and the mixture exhaled by him is returned through another hose to the surface or to the bell for regeneration and repeated use. In the second procedure the diver uses an autonomous breathing apparatus that is not connected to the surface with a bell. This apparatus automatically replenishes the oxygen breathed by the diver and removes carbon dioxide from the mixture.

In diving practice most frequently the hose type breathing apparatuses are used as more reliable operation, lighter and less awkward than autonomous cnes. The determination of the composition of the breathing mixture in the apparatus presents a basic difficulty. Up to now, no industrial model of sensors that gage the oxygen and carbon dioxide content in the breathing mixture of an autonomous apparatus has been created although individual developments have already appeared.

It is necessary to consider the problem of keeping the diver warm under water a more acute one. In the barochamber the diver is in a gas environment with a comfortable temperature, and he breathes it; in the water he is surrounded by the water environment with a temperature reaching -2°, and he inhales the gas mixture from the apparatus which has a temperature close to the water temperature. Thus, the normal feeling of well-being of the diver can be insured if his body is heated to the comfortable temperature and the gas mixture which he inhales is simultaneously heated to avoid respiratory heat losses. Thechnically the problem of maintaining thermal comfort of the diver still has not been satisfactorily solved, for the available gear either does not provide for the necessary supply of heat or it is awkward and restricts the actions of the diver. The most widespread at the present time is a gear with hot water heating fed along a hose from the surface or from the diving bell, but it is far from perfection.

A separate, but important problem of supporting the normal vital activity of a diver in the water at a depth of hundreds of meters is to monitor his sense of well-being. Practice has demonstrated that self-monitoring of the diver is insufficient, for not all symptoms of growing disturbances can be felt by him, and, the more so, he cannot properly evaluate the degree of danger they represent.

Several models of systems have been created to monitor the state of the basic indexes of the well-being of the divers such as respiration rate, cardiac contraction rate, body temperature, but they are still in the experimental testing stage.

Considering the problem of inhabitation of the depths of the sea by man, it is especially necessary to discuss the problems of giving a stricken diver (sick or injured) the necessary medical aid.

First, "purely" diving sicknesses are possible: various types of compression and decompression disorders, consequences of deviations in the composition of the breathing mixture, and so on. These sicknesses in general have been quite well studied, and procedures have been developed to prevent and treat them.

Secondly, when working under water injuries are not excluded. Even a small injury, absolutely safe for human life on dry land can lead to a fatal outcome under water. Thus, whereas a man who loses consciousness on dry land has a hundred to one chances that he will survive, for a diver the ratio drops to four to one.

Thirdly during prolonged work under water and under pressure (to several weeks or more) any diver can fall ill from ordinary, "everyday," diseases, catch a cold, appendicitis is possible, acute ulcers, and so on. It is impossible to remove the stricken diver from the pressure immediately -- he must undergo decompression with an average rate of decrease in pressure of 1 meter/hour, that is, from a depth of 300 meters, depending on the seriousness of his condition, a man can be brought up only after 300 hours or 12.5 days.

The treatment of the patient under pressure is complicated also by the fact that the diagnosis must be stated remotely -- the doctor is not sent to a chamber at great depths -- while the nature of the effect of medicines and the consequences of surgery on the organism under pressure are unclear. Up to now it is even unknown how to decompress a man who has undergone surgery.

While the volume of diving operations in a given region is low, correspondingly the number of diseases or injured divers is low, and the problem of rendering specialized medical aid is not so acute as when performing mass diving operations in a limited region. A model of such exacerbation of the situation is the oil and gas fields of the North Sea in which about 2000 divers are working at the present time, the death rate among which reaches 1% per year[1].

In the North Sea basin at the present time a specialized hospital is being built with a barrel operating room (a pressure of 30 atmospheres) designed for therapeutic or surgical treatment of sick divers. In the given region there are about 2000 people employed in diving operations. The patients will be delivered from the work location to the hospital by helicopters in one-man portable barochambers, that is, under the same pressure at which they were when they suffered the injury or came down with the disease.

The depth of submersion is becoming more and more significant. Under laboratory conditions depths of 610 meters have been reached; on actual dives at sea people have been at a depth of 501 meters. The practical operations of servicing a marine oil field are performed at depths of about 300 meters, and the average working depth today for divers is 100 meters. Researchers expect that soon depths of 600-800 meters will become realistic working depths, and perhaps even 1000 meters. The length of stay of the diving crew under pressure will increase. The maximum work by the divers under prolonged pressure will be 100 days a year or more according to the data of foreign diving companies.

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[1] S. A. Warner, "Diving Fataliges ledd to correck ve achion," OCEAN INUSTRY, Vol 12, No 4, 1977, pp 124-126.

Increasing the depth and work time of man under water will depend on the quality of the life-support systems creating comfortable and safe conditions for him.

As we see, the basic medical-physiological study of the behavior of the organism under the extremal conditions of the hydrosphere, obtaining information about remote consequences of the effect of increased pressure constitute an urgent problem, for the process of inhabitation of the World Ocean by man is becoming more and more intense with every day.

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