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**THE GEOLOGICAL-GEOPHYSICAL
ATLAS OF THE INDIAN OCEAN**

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The Geological-Geophysical Atlas of the Indian Ocean was compiled as a result of the International Indian Ocean Expedition (IIOE) which was held from September, 1, 1959 to December, 31, 1965.

The Indian Ocean has been one of the least investigated areas of the World Ocean by that time. That is why Scientific Committee on the Ocean study under UNESCO sponsorship took decision to hold the International Indian Ocean Expedition in 1958. Practically, the Indian Ocean exploration had begun much earlier.

The Soviet ship "Ob'" carried out complex study in the Indian Ocean in 1955 - 1958 including geological, physical-chemical, meteorological and biological works. During International Geophysical Year (IGY, 1957 - 1959) American and French ships conducted researches in the Indian Ocean.

In accordance with international collaboration 13 countries took part in the Expedition on 46 research vessels, some of them repeated investigations in different years. Whole the Ocean was covered with scientific observations according the IIOE oceanographic program. The Red Sea, Persian Gulf and seas adjacent to the Sunda Island Arc, and Ocean areas up to Antarctic Continent on the South were covered with investigations. Meridians with 20° East longitude and 147° East longitude were adopted as marginal at South-West and South-East.

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There were several aspects of the Indian Ocean Study: physical oceanography, sea biology, meteorology and geology-geophysics:

Research vessels of the USSR carried out investigations in the Indian Ocean due to IIOE program. Geological-geophysical works were conducted by scientific-research ship "Vitijaz" in 1960 - 1962 and were advanced in 1964-1965 within the most part of the Indian Ocean; the Soviet vessels "A.I. Voeikov" and "Yu.M. Shokalsky" made physical-chemical explorations.

At Northern-Western part of the Indian Ocean the Great Britain ships carried out both recognizing and detail study (Murray Ridge survey, separate regions of Adon and Arabian-Indian ridges study, water mass distribution, mountain rocks from the Ocean floor storage and so on).

The USA oceanographic vessels made significant researches in accordance to IIOE program and took contribution into geology and geophysics of the Ocean floor data accumulation. Most part of the ships performed echosounding, seismoprofiling, photosurveying of the bottom. The "Anton Braun" ship made biological explorations. In geological-geophysical studies of the IIOE the vessels of some other countries took part too. (Detailed scetch of the ship routes due to IIOE program is shown on 2-3 pages of the Atlas).

Many ships made echosounding measurements along with their traversing. Data obtained were used for compiling new bathymetric charts, quite necessary for different kinds of oceanographic researches. Almost all the research ships taking part in geological-geophysical strips of the IIOE are shown on the

photos, p.p. V and VIII.

Volume of oceanographic information stored according the IIOE program was rather huge. Final result of the IIOE complex study was a set of atlases published in different countries. They are as following:

Geological-geophysical Atlas - the USSR,
Oceanographic Atlas - the USA,
Meteorological Atlas - the USA,
Plankton Atlas - India.

Oceanographic Atlas of the International Indian Ocean Expedition was published at USA in 1971. It contains 531 pages with text and charts.

All the charts in the Atlas were made on iniform base in the same scale, data of measurements for temperature are given in degrees of C; saltness, chemical elements were shown with isolines, the main ones being outlined on the chart; a number of measurements was marked with the help of geometric picture. The Atlas was issued in the four printing inks; both sides of a sheet were printed.

Meteorological Atlas of the International Indian Ocean Expedition was issued at USA in 1972. Meteorological Atlas was published in two volumes and contains data on pressure, winds, temperature, evaporation and sediments, cloudness.

Plankton Atlas of the International Indian Ocean Expedition was published at India in 1968.

When a plan of the IIOE atlases edition was under consideration it was supposed to perform compiling in the same scales and projections to provide direct comparing data in the

different branches of science. But it became impossible due to discrepant requirements from different specialists. That is why all the atlases were compiled in various scales and projections, and it is rather difficult to compare represented data. Different methods of cartographic representation of the ocean floor were applied in the Atlases.

Each of the Atlases has made an essential contribution into the Indian Ocean study.

Geological-geophysical Atlas of the Indian Ocean was compiled and edited in the USSR in 1975 by Academy of Sciences and Chief Administration of Geodesy and Cartography under the Council of Ministers of the USSR. Geological-geophysical Atlas was made on the base of the International Indian Ocean Expedition data. An important stage for preparation period was International Edition Staff election, scientists representing different fields of the Earth sciences took part in the Edition Staff. Data shown in the Atlas has been obtained either during IIOE or earlier. Results of the more later observations were included too.

Project of the Atlas was developed by Oceanological Institute of the Academy of Sciences and by Scientific Editorial Map Compiling Division GUGK under the Council of Ministers of the USSR under total sponsorship of the International Edition Staff.

The Atlas has 84 sheets (168 pages). It contains more 200 charts and schemes, photos, and text. Printing is two-side and two languages are used for the texts: Russian and English. There are many multicolor charts printed in 6 - 18 printing

inks. Principal task of the Atlas is to portray real data obtained during IIOE with a minimum of interpretation necessary to make this data visible and understandable. Much of the data have been published firstly.

Besides the conventional cartographic techniques of imagery the Atlas has texts, tables, photos which help to show more completely the corresponding sections of the Atlas. The geological and geophysical data are presented in nine sections under the titles of:

1. Status of knowledge.
2. Bottom topography.
3. Bottom photos.
4. Magnetic anomalies.
5. Gravity field.
6. Heat flow.
7. Seismicity and active volcanoes. Deep structure of the ocean floor.
8. Sedimentary cover and baring of the bottom rocks.
9. Bottom sediments and suspended matter.

Each section of the Atlas is introduced with explanatory notes describing the nature of data, method of compiling, and some details of the charts and diagrams in this sections. The charts of the ocean exploration opening most of the Atlas sections carry much volume of information. On the all the charts research vessels routes and oceanographic stations are shown with different colors according to their country.

Mercator projection and Lambert equal area azimuthal one are used for the Atlas charts. The Mercator projection is

used for the bottom topography charts and gravity charts at a scale of 1:5 000 000 at 45° latitude and for magnetic anomalies charts at a scale of 1:12 233 000 on equator. The same projection was applied for large-scale charts on detailly studied regions in the same sections of the Atlas.

All the charts comprised in the Atlas may be divided into several groups depend on a scale:

- a) the charts of the World Ocean as a whole-scales of 1:20 000 000, 1:40 000 000, 1:70 000 000;
- b) the bottom topography charts (14 sheets) and gravity anomaly ones in free air (7 sheets) at a scale of 1:5 000 000;
- c) large region charts - at a scale of 1:2 000 000 - 1:6 000 000;
- d) charts on the areas of active exploration - scales from 1:50 000 to 1:500 000 and from 1:750 000 to 1:1 000 000.

Expedition routes charts placed in "Status of knowledge" section expose range of scientific researches during IIOE and in the years some earlier or later. The 36 scientific-research vessel routes are shown on the chart titled "The routes of the International Indian Ocean Expedition" (p.p. 2-3 of the Atlas), various kinds of scientific observation were carried out when traversing: geological-geophysical, hydrological, meteorological, biological, bottom sedimentary measurements. A map under title "The Routes of the Other Expeditions Provided Data Used for the Atlas" is present in this section too.

Data for compiling were taken from published reports and articles on the IIOE results.

The section of the bottom topography charts is the prin-

cipal section of the Atlas, the greatest as to the chart number ($1/3$ of the Atlas). The picture of underwater topography is given on the bathymetric and physiographic maps and profiles. Images of the ocean floor as a whole and its separate parts are shown on the bathymetric charts. Ocean floor as a whole is represented on the review map at the scale of 1:20 000 000 with contours spaced in 1000 m; this map has been compiled by the Soviet scientists, it shows uniform generalized picture of the underwater topography. For the continents adjacent to the Indian Ocean ground relief is shown with isohypses and multilayer painting according to elevation steps. The chart at such or smaller scale forms a base for many other charts of the Atlas.

Underwater topography chart at a scale of 1:5 000 000 contains 14 sheets (which may be connected into a big wall map); the charts for separate vast regions have different scales. For the most interesting areas from morphological point of view large-scale charts were produced based on detail investigation of the ocean floor.

Bathymetric charts have been made with the help of oceanographic expeditions observations and depths taken from GEBKO measuring plates and marine navigation charts prepared by Hydrographic Services of different countries.

A chart "The Indian Ocean Underwater Topography" at a scale of 1:5 000 000 covers all area of the Indian Ocean.

Relief drawing has been done in conventional manner with the contours spaced in 500 m, that enables to have clear perception about bottom areas difference and their morphological

features. A contour with 200 m altitude is drawn to outline the continent shelf more detailly.

A new method of the bottom development exposing has been applied on the bathymetric charts: reference data along measuring tracks of the research vessels are marked with a dashed line and singular measurements - with singular dots. The same technique is used on the gravity maps too. The depth altitudes are given for the most specific forms of bottom relief. The depth marks along measuring tracks are shown with an increased dot.

The bathymetric chart of 1:5 000 000 scale was compiled by Great Britain, the USSR, the USA, South African Republic (see a scheme on p. 5 of the Atlas). The chart sheets made by the different authors for their own area were put into the Atlas without any corrections, except for isobaths adjustment along marginal bends.

The bathymetric charts have different contour intervals due to area being mapped and its morphologic features: for review map of 1:20 000 000 scale in 1000 m with additional isobaths in 500 m at the bottom of the hollows and in 200 m at the shelf; for 1:5 000 000 map in 500 m, for the charts with detailed investigations in 10 - 100 m.

Special color grades were developed for underwater topography representation:

a) for the ocean as a whole with the continent shelf and continental slope image - olive-green colors, for the ocean bed - light blue and dark-blue colors (the

1:5 000 000 sheets, p.p. 14-15, 18-19).

b) for the areas with detailed investigation - light-blue and dark-blue colors (p.p. 25, 29, 33);

c) for the shelf bend - yellow-green-turquoise colors (p.p. 24, 101).

The method widely used in the Atlas - various color scales application for the different map types.

Geographical names of underwater relief forms are often differ from one another in Russian and in English. The Edition Staff has spent significant efforts to make up agreed Russian names for mountains, hollows, canyons, some of the ridges with according foreign ones. However, it was failed for some relief forms (for the Mid-Ocean Ridges). That is why there are the names conventional in the USSR in Russian and those conventional abroad - in English for the same features.

The survey profiles of the bottom floor and separate topographic forms which have been obtained with echo sound measurements are located in the same section. These profiles represent underwater topography for the ocean as a whole (p. 8) and its main geomorphological provinces (continental slopes - p. 93, middle ocean ridges - p. 9).

The physiographic charts are given in the Atlas with two maps: a) at the scale of 1:8 000 000 which has been compiled at the first stage of the International Indian Ocean Expedition, and b) at the scale of 1:20 000 000 based upon IIOE data and further investigations. In spite of different scales the variance in underwater topography drawing reflects evolution in morphology concept during sixties.

To provide more complete show of the ocean floor in the Atlas a section titled "Bottom photos" exists, which gives the image of different bottom kinds in the Indian Ocean and some areas with detail underwater photography, and show variety and complicity of the processes taking place at the ocean floor.

For the first time the Indian Ocean Geophysics has been shown most completely. The second part of the Atlas equal one-to-third of the total map number is devoted to this theme. Geophysics is portrayed with the map series of magnetic field, gravity field; seismicity and active volcanoes, heat flow, deep Earth crust structure, sedimentary cover thickness.

In the section devoted to magnetic field the charts are obtained with the help of data stored by research ships which conducted magnetic survey by means of towed proton magnetometer in 1960 - 1965-th and partly based upon 1965 - 1967-th surveying data. Along with the chart of knowledge status named "The Routes of Magnetic Survey" (p.p.66-67) the maps of magnetic field of the whole ocean (4 sheets) and the maps of the separate areas with detailed magnetic survey are included in the section.

The whole ocean maps (p.p. 70-71, 72, 73, 74-75) are drawn with the help of magnetic anomalies profiles which have been built along the ship tracks and are compiled in Mercator projection in the scale of 1:12 233 000.

On the detailed study charts magnetic surveying data are shown with isolines, positive and negative anomalies are marked with red and blue inks respectively. To make easy comparison of the isolines they are assigned in millioersteds. The

contour interval is the same as in the authors' manuscripts. All the magnetic field charts are matched with underwater topography maps taken from the section "The bottom relief". In several charts for detailed study areas the bottom relief is translated from published articles.

A section "Gravity Field of the Indian Ocean" is introduced with the chart "The Routes of Gravity Survey" (p. 85) where the tracks of the expeditions for surface marine gravimetric measurements and the stations with underwater pendulum measurements made in the USA, Great Britain and the FRG are exposed.

A map of free-air gravity anomalies in the scale of 1:5 000 000 is similar to bathymetric one of the Ocean in the same scale but contains less sheets (6 sheets) and represents gravity field through the most part of the Indian Ocean. The charts from the Atlas "The Indian Ocean Bottom relief" of 1:5 000 000 scale has been used as a base. A map of free-air gravity anomalies has been produced with gravimetric measurements data obtained during IIOE mainly. All the measurements have been converted into common system. Reference data availability is marked with dashed points along observation strips of the research vessels. The enhanced point on the strip outlines peculiar stations of gravity acceleration and determined values are written in milligals. Pendulum stations are signed with special symbol. Gravity field is drawn with contour interval of 25 mgal.

The section contains also the map "Averaged gravity field anomalies expressed in the Bouguer reductions", the free-air

anomalies calculated as a mean within $1^{\circ} \times 1^{\circ}$ squares in the Indian Ocean were used for the map compilation. The other data as more than 200 pendulum observations from submarines and above 3.400 gravimetric measurements from the ships and allied published data were included in the processing. To make the contents more understandable schematic sections of the Earth crust resulted from gravimetric measurements and a table with technical characteristics on the used unstruments are placed in the section .

A chart of heat flow from the Earth interior in the Indian Ocean and a chart of the mean heat flow values (p.p. 106-107 and 108) present power of a heat flow in different parts of the Ocean and reflect degree of the study, give knowledge about expeditions aimed for necessary measurements. To express heat flow picture more evident the heat flow profiles passing through the Indian Ocean and the Middle Ocean Ridge are shown (p. 108).

The charts of seismicity and active volcanoes within the whole Indian Ocean, Aden bay and Vitijaz Chute, a chart of deep structure of the Earth crust, and sections of the Earth crust obtained with seismic sounding data are comprised into section "Seismicity and Active Volcanoes" and "Deep Structure of the Underwater Earth Crust".

A map "Seismicity and Active Volcanoes" (p.p. 110-111) shows geographical propagation of the earthquakes, volcanoes, and underwater eruptions epicentres. All the earthquakes which took place during 1900 - 1966 and were determined with instrumental observations are drawn on the map. All the

earthquakes are classified depending on their intensity (magnitude) and epicentre depth. The catastrophical earthquakes for hystoric period (obtained from describing non-instrumental observations) are outlined with particular mark. The active volcanoes on the ground and underwater eruption places which are known for history of mankind are displayed with sufficient completeness. The seismic stations are plotted and the World net of standardized seismic stations is emphasized on the map.

A chart "Deep Structure of the Earth crust and the Upper Mantle" compiled with seismic sounding data (p.p. 114-115) is a complex of the seismic researches results obtained by means of broken wave method. The map includes both published and unpublished data. Various layer velocities expressed in km/sec and the layer thickness values in km are drawn with different ways.

The Earth crust sections built with seismic sounding results and a table displaying practical results of velocity measurement in km/sec and the layer thickness in km for various rock kinds at each observation station are included into the Atlas for more exhaustive topical explanation.

The part "Sedimentary Cover and Solid Rocks of the Indian Ocean Floor" comprises a chart "Sedimentary Cover Thickness and Solid Rocks of the Indian Ocean Floor" (p.p. 118-119), a chart of knowledge degree, and sedimentary cover profiles. The map gives the unconsolidated sediment cover structure with the help of isopachyts (lines with uniform thickness of

equal-aged sediments) in 0,5^s (about 100 m) interval; it enables us to consider sediment cover thickness at different regions of the ocean floor. The map have been compiled, mainly, on the base of continuous seismic profiling, however, the other data have been used too. Distribution and petrography of solid rocks for the islands and ocean floors have been indicated. Data have been stored when dredging and sweeping during marine expeditions in 1950 - 1973 and from ocean mining works.

The third part of the Atlas as to volume is a section under title "Bottom Sediments and Suspended Matters". The charts indicate composition, distribution and rates of sedimentation on the bottom of the Indian Ocean, as well as composition and distribution of suspended matter as a source of recent sediments formation. A map where geological stations with obtained bottom sediment probes have been indicated affords huge volume of information on the Ocean knowledge during various country expeditions (p.r. 126-127).

A chart "The Types of the Bottom Sediments of the Indian Ocean" (p.p. 130-131) - general chart of the section shows distribution of the main types of recent sediments as to their substance-genetic and granulometric compound and sedimentation zoning processes. There are several kinds of cartographic imagery: material compound of sediments is represented by color, granulometric one - by means of dashed lines, some elements (tested outputs of different kinds of magmatic rocks, different age sediments under Quaternary Period, and some other) are shown with the help of out-of-scale symbols.

The next charts of the section reflect the contents of different chemical components in the bottom sediments as following: ores, calcium carbonate distribution (CaCO_3), amorphous silica and organic carbon, granulometric fractions penetration, ferromanganese concretions distribution and composition; foraminifer and diatome distribution. Relief is drawn with isobathes in 1000 m interval and additional contours at shelf and hollow bottom areas. According to the bottom relief and actual data the isolines for any component of the bottom sediments have been drawn. Actual measurement results are indicated for oceanographic station.

A part of the Atlas section is devoted to the charts and vertical sections showing distribution of suspended matter in the Indian Ocean waters. The charts depict quantitative distribution of suspended matter at different layers (compiled by means of measured concentration at different levels) and granulometric, mineralogical, and chemical composition.

The last chart of the Atlas is the chart of the preliminary results from deep-water mining (p. 144), produced with the help of research ship "Glomar Challenger" measurements with the well positions and the main data on the sediment cover and foundation sections.

Collaboration of various countries during the International Indian Ocean Expedition has proved in fact economical benefits of such an approach to complex study of the Indian Ocean. Multiside development, wide and exhaustive exchange of information on any branch of oceanography, joint analyzing data have enlarged scientific knowledge on the Indian Ocean

and have created a base for producing a set of the atlases with data obtained during the IIOE.

The main part of the maps, presented in the Geological-Geophysical Atlas of the Indian Ocean have been compiled by the members of International Edition Staff and by many other authors. Some charts and schemes have been taken from published works.

Mutually profitable platform for collaboration from economical point of view has been found in the course of editing the Geological-Geographical Atlas of the Indian Ocean. The Oceanographic and Meteorological Atlases published in the USA have been compiled by American authors only with the help of the IIOE data.

The Geological-Geophysical Atlas of the Indian Ocean can be regarded as the first successful experience of international collaboration of a great many Soviet and foreign authors. Numerous scientific offices of Australia, Great Britain, the USSR, the USA, the FRG, the SAR (the South African Republic) and many other took part in compiling charts for the Atlas. That is why the charts carry much information and deep contents.

Many of the charts have been compiled on the basis of the firstly summarized data: the charts of the Earth crust deep structure with the help of DSS information, the nepheloid distribution charts, thickness of sedimentary cover and the bottom solid rocks, preliminary results of deep-water drilling and so on.

Some of the charts employ many-sided image: the chart

of the bottom sediments types (p.p. 130-131), granulometric, mineralogical, and chemical compound of the suspended matter (p. 141). The use of multicolor background inks makes the chart very expressive and original.

Comprehensive bibliographic list of the works devoted to geological-geophysical results of the Expedition and to the later researches of the Ocean is a characteristic property of the Atlas.

An important feature of the Atlas is reference data indication on the charts with isolines, it enables to user to give his own interpretation of the data. Uniform scale for the charts placed in different sections of the Atlas and uniform chart control give the possibility to reveal mutual ties and regularities resulted from geological-geophysical researches for any region of the ocean floor.

However, rigorous documentation of the facts being published, dissimilar availability of actual data for map making, and different points of view of the authors made it impossible to perform total contents correlation of the charts, in particular, if these charts are placed in different sections of the Atlas.

As the ocean exploration being performed actively there are some new facts yielding to the chart correction, but the International Staff has decided to abandon this procedure, that is why all the materials having been stored after 1972 are omitted from the use in compiling.

The Geological-Geophysical Atlas is the first experience in the matter of Atlas making for vast region of the

World Ocean based on international collaboration. The Atlas is helpful reference-book for future ocean researches. The Geological-Geophysical Atlas of the Indian Ocean is of interest for numerous specialists on marine geology, geophysics, and geomorphology. The experience gained in the process of works on international atlas based upon close connection and cooperation between particular scientists and cartographers, and between various state organizations as well may be used for further procedures in the field of the atlases making in the other parts of the World Ocean (for example, The Black Sea - by member states of CMEA) and for compiling many other prominent scientific-cartographic arts. A number of the atlases of the Indian Ocean have summed up valuable information about the Ocean having been stored during the International Indian Ocean complex exploration.