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BASIC FEATURES OF THE GEOLOGICAL STRUCTURE
OF THE HYDROLOGIC REGIME AND BIOLOGY
OF THE MEDITERRANEAN SEA

(pages 1-224)

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SOVIET MARINE GEOLOGIC PROJECTS
IN THE MEDITERRANEAN SEA

V. P. Goncharov

The history of the oceanographic study of the Mediterranean Sea, starting in 1870, includes a total of about 200 scientific research expeditions. During this time 30-40 expeditions were engaged in geological projects (including individual depth soundings), approximately 10 expeditions specially studied sediments or conducted geophysical research. The first geological projects deserving of attention appeared at the end of the 19th century. Among them may be included the corresponding sheet of the Monaco Bathymetric Chart and the first descriptions of the deepwater sediments of the sea, made by the Frenchman Pruveau in 1894 (Bourcart, 1953). — ~~P~~

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A number of works on sediments in the first half of the 20th century were produced by Tule, Chevalier, Andre, Boggil'd, Buen, Arrigo. In the postwar years, extensive materials on the soil of the Mediterranean Sea were obtained in expeditions on the ships "Skagerrak" and "Albatross" (approximately 40 long cores of ground), the "Atlantis" (approximately 70 samples from the ground surface), the "Calypso", etc. The results of these projects have been described in numerous articles by Peterson, Norin, Olausson, Bourcart, Blanc, Custeau, Gennesso, Douglas, Parker, Todd, etc. The sediments of the Adriatic have been described in the works of Alfirevic (1958) and Ercegovic (1958), the sediments of the African shelf have been described in the work Hilmy (1950). The majority of the abovementioned investigators, however, whose works are of undoubted interest, consider either individual narrow questions connected with the study of sediments, or limited regions of the sea. These works are not infrequently based on a nonuniform and not always justified classification,

and do not give a complete conception of the sediments of the entire sea and the rules governing their formation.

At the same time we do not have up to now a sufficiently complete general map of the sediments of the Mediterranean Sea. An exception is to be found in the survey map of silts in the Marine Atlas (1950), prepared by M. V. Klenova. It is also possible to mention the Atlas of silts of the Mediterranean Sea, primarily for the coastal regions, which was published during the war in Germany.

Geophysical research, mainly seismic determinations of the thickness of the sedimentary layer in the upper part of the earth's crust (14 small profiles and 28 point-sounding stations), is known to us from the works of M. Ewing and J. Ewing, Gaskell, Hill, Swallow, etc. A gravimetric map of Europe and North Africa, including the Mediterranean Sea, with isoanomalies in the Bouge reduction every 25 mgal, was published in 1855 (sic) (Bruyn, 1955).

In spite of the fact that soundings in the Mediterranean Sea have been made since the middle of the 19th century, up to 1950 there have been no good bathymetric charts of the sea. Thus, in his work "The Relief of Oceans and Seas," Bourcart (1953) writes that the relief of the Mediterranean sea bottom is known only in its general features. In 1955 was published the Soviet Marine Atlas, containing several sheets of maps of the Mediterranean Sea basin, although on a small scale. /4 However, on these maps it is also impossible to distinguish many of the largest forms of the relief of the sea bottom.

Only in the most recent years have sufficiently detailed bathymetric maps appeared, made on the basis of postwar echo sounding materials. At that time the ships "Albatross" (1947-1948), "Challenger" (1952), "Calypso" (several times since 1955), "Vema" (1956), and "Atlantis" (1948, 1958), were working here as well as the hydrographic services of France, Italy and several other countries. Of the bathymetric maps

that have appeared, note should be taken of the large-scale ones and the 1:1,000,000 scale map of the western part of the sea, published by the Monaco Oceanographic Museum and edited by J. Bourcart (1958-1959), the map of the continental slop of Algiers by A. Rosfelder, the maps of the northern parts of the Tyrrhenian and the Adriatic seas edited by A. Segre (1959), the map of the Strait of Gibraltar by G. Giermann (1961) (Bourcart, 1960; Carte..., 1960; Giermann, 1961). For the eastern Mediterranean region, a bathymetric map was compiled under the leadership of M. Pfannenstiel (1960) with the principal isobaths every 500 m, between which isobaths every hundred meters are given in dotted lines. This map contains considerable inaccuracies and is insufficiently well produced cartographically.

Interesting geological results have been obtained by means of underwater still and motion-picture photography and with the lowering of bathyscaphs.

All this indicates a constantly increasing attention to the geological study of the Mediterranean Sea.

From the geological point of view the Mediterranean Sea is located in an extremely interesting zone. The tectonic development of this zone is closely linked to the development of the enormous Alpine geosynclinal belt in the Mesozoic-Cenozoic period. Many of the greatest structures are now either cut off or completely covered by the sea. These include first of all: the northern edge of the African-Arabian platform, the Crete-Rhodes island arc and the belt of deep troughs connected with it, the structures of the young Aegean Sea, the peripheral regions of the Tyrrhenian Sea, characterized by contemporary volcanism, the regions of closure of the Pyrennees and the structures of the Balearic islands, the northern wing of Atlas.

Considerable interest is afforded by study of the sediments of the Mediterranean Sea, which is located in the region of

transition between an arid climatic zone and a humid one. In addition, the uniqueness of the sediments of the sea is determined by the features of its hydrologic-hydrochemical regime, as well as by the distribution of the terrigenous, volcanic and volcanogenic materials.

Soviet geological projects in the Mediterranean Sea started in 1957, when two sounding tracks were made on the vessel "Ob'" and an aqueous and atmospheric suspension was collected. An echometric sounding was made during the 31st and the 33rd trips of the expeditionary ship "Vityaz'" (1960); in addition, in the 33rd trip a silt core was collected in a large-diameter tube. Since 1958, projects have been carried out in the Mediterranean Sea by the expeditionary ship of the Sevastopol Biological Station "Academician A. Kovalevskiy," in five trips of which dredging samples were collected. These ships performed the following scope of operations, the materials of which may be used for purposes of marine geology: over 15,000 km of continuous echo sounding, 22 dredging samples, one silt core, more than 250 samples of aqueous and atmospheric suspension (Lisitsyn, 1961).

The geological research of the Black Sea Experimental Scientific Research Station of the Institute of Oceanography, Academy of Sciences, USSR in the Mediterranean Sea was started in 1959 during the first trip and continued during the second-fourth trips of the expeditionary ships "Academician S. Vavilov" (Petelin, 1961; Kovylin, 1961; Neglyad, 1962; Ochakovskiy, 1963). These projects encompass a rather extensive complex of investigations and may be divided according to the following trends: 1) geomorphology and tectonics; 2) the study of sediments, including the distribution of contemporary sediments, 5 their stratigraphy and mineralogy, water suspension, sediment water; 3) seismoacoustic operations carried out by the reflected wave method. Underwater photography was carried out in a limited scope, and projects were carried out with a

deep-water television installation (Yemel'yanov, Marakuyev, 1962).

By 1962, expeditions on the expeditionary ship "Academician S. Vavilov" carried a large scope of geological operations (see Appendix). Over 46,000 km were travelled with continuous echo sounding (the total length of the routes was about 62,000 km), 301 geological stations were made. At these stations 153 samples were taken from the surface by a dredger, 74 cores were taken by silt tubes, including two cores by a piston tube (the length of these cores was 8.3 and 11.1 m). The total length of the silt tubes was over 150 m. Approximately 300 samples of water suspension were collected by the membrane filtration method, including 123 samples from deep-water levels. A total of more than 4,000 samples was selected from the silt tubes and the bottom dredgers for various types of analysis and for study of the water suspension. In the second to fourth trips five seismic reflected-wave-method profiles were made in the eastern part of the sea, in the Ionic and Tyrrhenian Seas. Their total length is about 180 km. A total of 35 point seismo-acoustic soundings in all the basins of the sea were made, except in the Aegean Sea and the Sea of Marmara. Under observations with a television installation were carried out at three stations, the bottom was photographed at 6 stations. The illustration shows the results of Soviet marine geological projects, including the projects carried out by the expeditionary ship "Academician S. Vavilov."

A rather large amount of factual material, collected in the four trips of the expeditionary ship "Academician S. Vavilov" and obtained from other organizations, is at present being processed and will be generalized in the corresponding sections of the combined work "A General Oceanographic Characterization of the Mediterranean Sea."

On the basis of echo sounding data, with account taken of available domestic and foreign materials, sheets of the bathymetric map of the Mediterranean Sea in a scale of 1:1,000,000,000 are being compiled. A bathymetric map with isobaths every 500 m and a tectonic diagram of the sea (all in a scale of 1:3,000,000) have already been compiled and transmitted for the Tectonic Map of Eurasia."

On the basis of the new bathymetric chart it has become possible to carry out regional geomorphological zoning, to delineate the largest shapes of the relief of the bottom, either unknown up to now, or such to which the proper attention had not been paid, and to unify into one entity the entire system of deep troughs extending along the Balkan peninsula and the islands of Crete - Rhodes into a single trough, which has been given the name of Hellenic trough. This trough apparently constitutes a contemporary geosyncline in the initial stage of its development, forming along an abyssal fracture with a length of approximately 1500 km. Within the limits of the trough is located the maximum depth known in the Mediterranean Sea (5121 m), discovered by the expeditionary ship "Academician S. Vavilov" in 1962. Considerable interest is afforded by the wide arched uplift -- the Central Mediterranean Bar, which has definite features of similarity with oceanic bars. In addition, attention is drawn to the special features of the distribution of the forms of the mesorelief within the limits of the largest basin of the sea, which characterize similarity or difference in the history of the formation of their relief.

Material dealing with the sediments of the Mediterranean Sea are processed principally at the Black Sea Station of the Institute of Oceanography, Academy of Sciences, USSR. Here analyses are carried: granulometric, mineralogical (both of sediments and of suspension), chemical -- for carbonate content

and Corg, for iron, manganese, titanium, amorphous silica, phosphorus, and some other elements; a study is made of the foraminifera. A part of the analysis is made, upon the order of the Black Sea station, in other organizations -- in the University of Rostov and in various laboratories in Moscow. At these places are made certain mineralogical analyses, a full spectral and thermal analysis, a study is made of the sediments with x-rays and under an electron microscope. /7

Generalization of all the data (the number of various analyses have already exceeded 2,500) is carried out at the Black Sea station of the Institute of Oceanography, Academy of Sciences, USSR. On the basis of these materials are compiled charts of the distribution of individual fractions of sediments, a summary diagram of present-day sediments, based on a classification of silts worked out in the Institute of Oceanography, Academy of Sciences, USSR, and a diagram of sediment distribution on the basis of carbonate content; diagrams of the location of other elements are compiled. Individual results of the first investigations have been published in the press.

On the basis of seismoacoustic operations, several sections have been constructed which characterize the thickness of the unconsolidated sediments in the western basin, in the Adriatic, and in the regions of the troughs of the eastern part of the Mediterranean Sea.

Some basic results of the projects of the Black Sea Experimental Scientific Research Station on marine geomorphology, tectonics, sediments, and seismo-acoustic research are being published in the present collection.

It can be seen that in recent years extensive, variegated and rich material has been collected in the Mediterranean Sea; this has made it possible to undertake the solution of many general problems of the geology of the Mediterranean Sea. Nevertheless, the data obtained in Soviet expeditions have

some very substantial inadequacies. A large number of these inadequacies are due to the fact that all the geological operations were carried out as a sideline, and sometimes optionally. Thus, up to now we still know very little considering the geomorphology of the most interesting zone of the Hellenic trough and the structures connected with it.

There is absolutely no information concerning the depth structure of the earth's crust and its thickness; little is known about the velocity section even of the upper sedimentary series, not to speak of the "granite" and "basalt" layers. The rules governing the replacement of sediment types in the transition from shallow shelf zones to deep-water zones have been insufficiently studied, as well as the variability of the sediments within the limits of each zone. It is necessary to develop methods for studying the variability of sediments, without which serious charting to the contemporary sediments of any reservoir is impossible (Yemel'yanov, Shimkus, 1962). There are very few long cores of silts (only 3), therefore it is not yet possible to carry out a correlation of the basic stratigraphic horizons between regions that differ substantially with respect to conditions of sediment formation in the present epoch and in earlier ones.

Further geological study of the Mediterranean Sea urgently requires the carrying out of special geological trips, which must be charged with the following basic tasks:

1. to study in detail the geomorphology of the Hellenic trough and the Cretan Sea, and to follow through the eastern and western continuations of the Central Mediterranean bank;
2. to carry out, by means of buoy setups, a detailed traverse echometric survey of the bottom in the open regions of the sea with subsequent selection of series of soil samples at these polygons;
3. to obtain long (up to 15-20 m) cores of soil by means of heavy tubes in the principal basins of the sea;

4. to select soil samples with tubes and dredgers for several detailed sections from the shoreline to the seashore, being guided in the sampling not only by the depths, but also by the shapes of the bottom relief;

5. to carry out seismic operations by the refracted wave method for several cross-sections to determine the structure of the earth's crust of various parts of the Mediterranean Sea;

6. to collect data for the distribution and composition of the aqueous and atmospheric suspension.

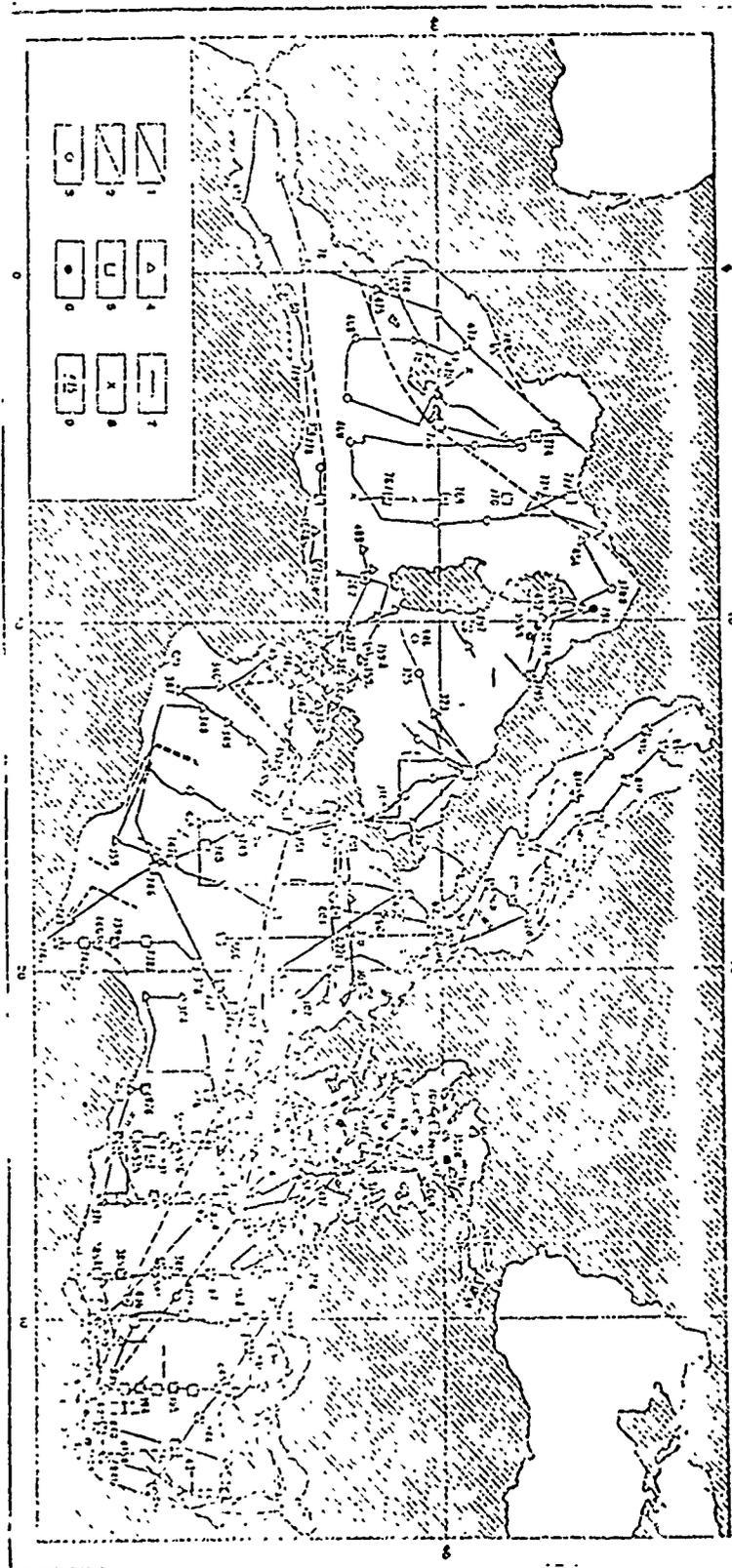


Figure 1. Marine geological research of Soviet expeditionary ships in 1957-1962.

- 1 - Soundings by the expeditionary ship "Academician S. Vavilov";
- 2 - Soundings of other Soviet ships;
- 3 - Samples taken by silt pipes;
- 4 - Samples taken by dredger;
- 5 - Samples of water suspension;
- 6 - Soil samples taken by other Soviet ships;
- 7 - Seismic profiles of the expeditionary ship "Academician S. Vavilov";
- 8 - Point seismic soundings of the expeditionary ship "Academician S. Vavilov";
- 9 - Underwater photography.

Appendix:

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Scope of geologic operations in the Mediterranean trips of the expeditionary ship "Academician S. Vavilov" in 1959-1962.

	Trips				Total
	1st	2nd	3rd	4th	
Echo sounding, km	13 490	11 420	8 550	12 680	46 240
Number of stations	99	36	57	107	301
Dredgers	50	15	36	51	151
Silt tubes	35	9	16	13	74
Total length of cores, m	82	23	28	23	156
Samples from dredgers					
moist	150	43	118	217	518
dry	85	10	83	109	292
Samples from tubes					
moist	774	249	213	218	1450
dry	800	247	260	285	1592
Water suspension	96	—	43	151	290
including deep-water	31	—	20	72	123
Submarine photo, series	3	3	—	—	6
Submarine television, series	—	—	3	—	3
Seismic reflected-wave-method profiles, km	—	66	95	17	178
Point seismo-acoustic soundings	—	—	3	32	35

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THE RELIEF OF THE MEDITERRANEAN SEA BOTTOM

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O. V. Mikhaylov

Information of the relief of the Mediterranean Sea bottom can at present be reduced to numerous, frequently insufficiently reliable data of cable depth soundings and a considerable number of echo soundings carried out (primarily during the postwar years) by various research vessels of various countries. Attempts at generalization of the accumulated data have been expressed in several bathymetric charts, compiled by foreign oceanographic and marine institutes for individual regions and parts of the sea.

Among the most reliable bathymetric charts of the Mediterranean Sea are the charts of the Algiers-Provence basin, published under the editorship of J. Bourcart (1960), maps of the northern part of the Tyrrhenian Sea and the Adriatic Sea under the editorship of A. Segre (Carte..., 1960) and the map of the Strait of Gibraltar compiled by Giermann (1961). The bathymetric chart of the eastern part of the Mediterranean Sea, published under the editorship of M. Pfannenstiel (1960), contains many inaccuracies connected, in our opinion, with inadequate compilation methods, the absence of thorough analysis, and subsequent geomorphological interpolation of the data of continuous echo sounding and an insufficiently critical approach to the marks of navigation charts. On the whole, this chart does not correspond to the present-day level of sea-bottom cartography.

Due to the absence of a reliable bathymetric chart of the entire sea, it is impossible to tie the numerous separate data concerning the geology and the geophysics of the basin into a central whole, and to interpret them with sufficient justification. Study of the relief of the Mediterranean Sea bottom is of great interest, since this sea is located in a zone with a transitional type of earth crust, and is characterized

by a very complex tectonic structure, high seismicity, and contemporary volcanism, and its geomorphology casts light upon the processes of the formation of the Alpine folding.

In 1959 the Marine Geology Laboratory of the Black Sea Scientific Research Station of the Institute of Oceanography, Academy of Sciences, USSR started a systematic investigation of the Mediterranean Sea with the aim of detailed geological study of this most interesting region. The material accumulated by the expeditions of the expeditionary ship "Academician S. Vavilov," the sounding data of other Soviet and foreign ships, as well as numerous domestic and foreign navigational charts and some bathymetric charts, made it possible to start the preparation of a new detailed bathymetric chart. The preliminary bathymetric chart of the Mediterranean Sea shown in Figure 1, with isobath sections every 500 m, and a supplemental 200 m isobath, is based on most of the available echo sounding data and navigational charts, all of the marks of which have been taken into account by us in plotting the isobaths, with the exception of individual obviously erroneous depth values which crudely fail to coincide with the echo sounding data. The preliminary chart, made to a scale of 1:1,000,000, was then converted into a scale of 1:3,000,000 with the necessary generalization. The Algiers-Provence basin was plotted almost entirely according to the data of the maps of J. Bourcart; however, we have introduced some changes and additions based upon material from the soundings of the expeditionary ship "Academician S. Vavilov." In processing the material and in compiling the chart, use was made of the method developed in the Institute of Oceanography, Academy of Sciences, USSR (Udintsev, 1951, 1954, 1956, 1957, 1959; Budanova, 1958; Marova, 1958 d; Budanova et al., 1960). As a result of the work done, it was possible to distinguish important and characteristic features and the

largest shapes of the bottom relief, particularly in the eastern part of the sea, and to carry out the geomorphological zoning of the entire sea in a new manner.

The morphological diagram (Figure 2.) has been compiled by the author jointly with V. P. Goncharov. The diagram shows only the largest forms of the relief, and the very most general division of the sea bottom into regions is given, with the basic genetic types of the small forms. The morphological characteristic of the shelf is not given in the diagram in order to avoid overloading the drawing.

It is customary to divide the entire basin of the Mediterranean Sea into two extensive regions: the western and the eastern. The morphology of the two regions, determined first of all by the tectonics, differs sharply. The western part, including the Algiers-Provence basin, the Tyrrhenian Sea, and the African-Sicilian sill, is characterized by a relief formed entirely under the influence of the processes of the development of the Alpine folding. The relief of the bottom of the eastern part is determined by a complex inter-relationship between the rigid massifs of the African-Arabian platform in the south and young folding in the north.

The outer boundary of the Algiers-Provence basin corresponds on the map approximately to an isobath of 2500 m. It closely approaches the feet of the continental slope of Corsica and Sardinia, the eastern and southern slopes of the Balearic projection and the slope of Algiers, but remains far away from the French and Spanish coastline. The bottom of the basin is extremely even, with depths everywhere close to 2800 m (Figure 2; Figure 3, profile A). The region of the greatest depths (2850-2870 m) is located in the southern part of the basin. The maximum depth, according to sounding data of the expeditionary ship "Academician S. Vavilov," is 2877 m (38° 36.0' N, 6° 56.1' E).

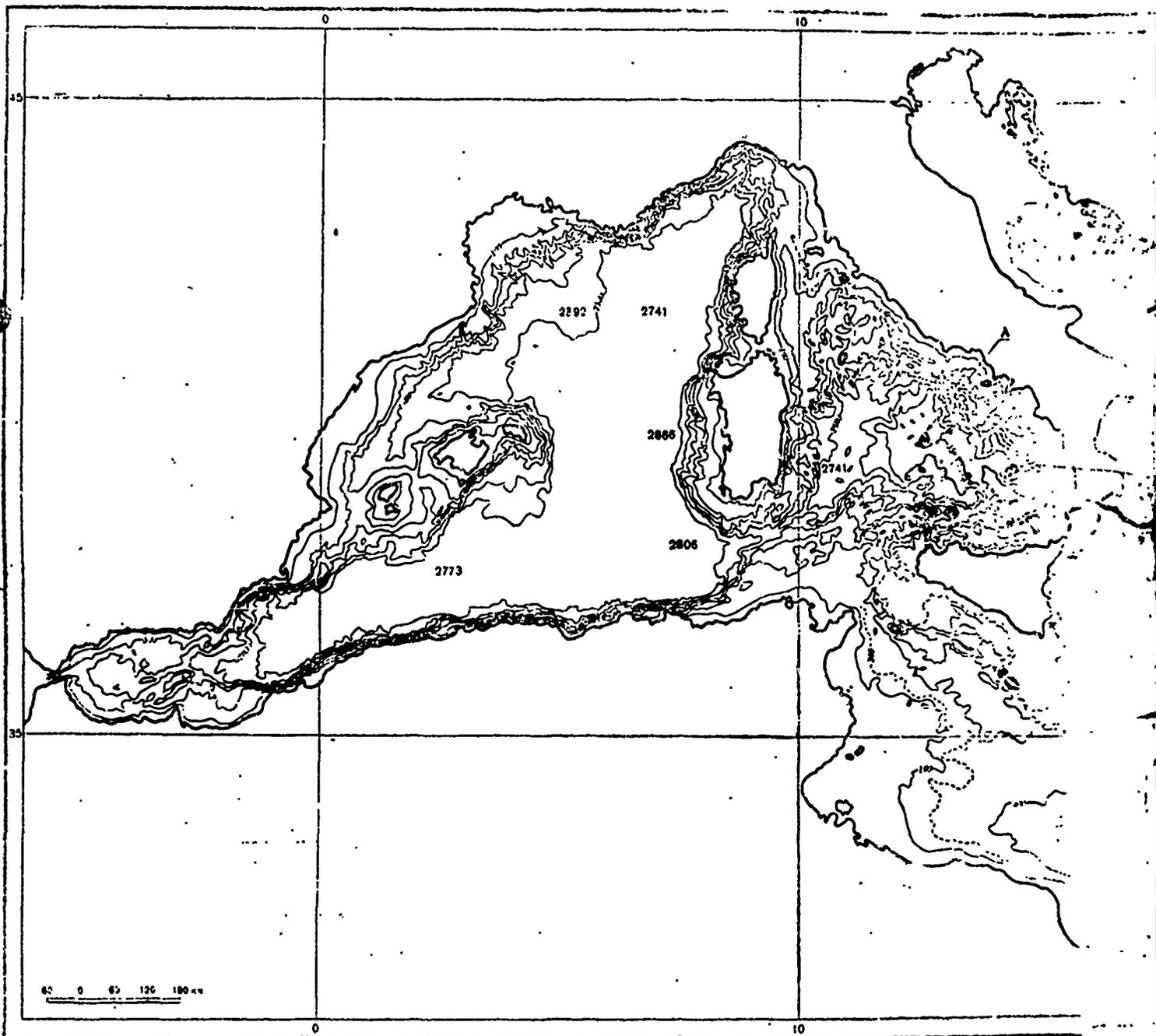


Figure 1 - Bathymetric map [remainder illegible].

A - underwater volcano of Vavilov. [B - (remainder illegible)]

A.



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B

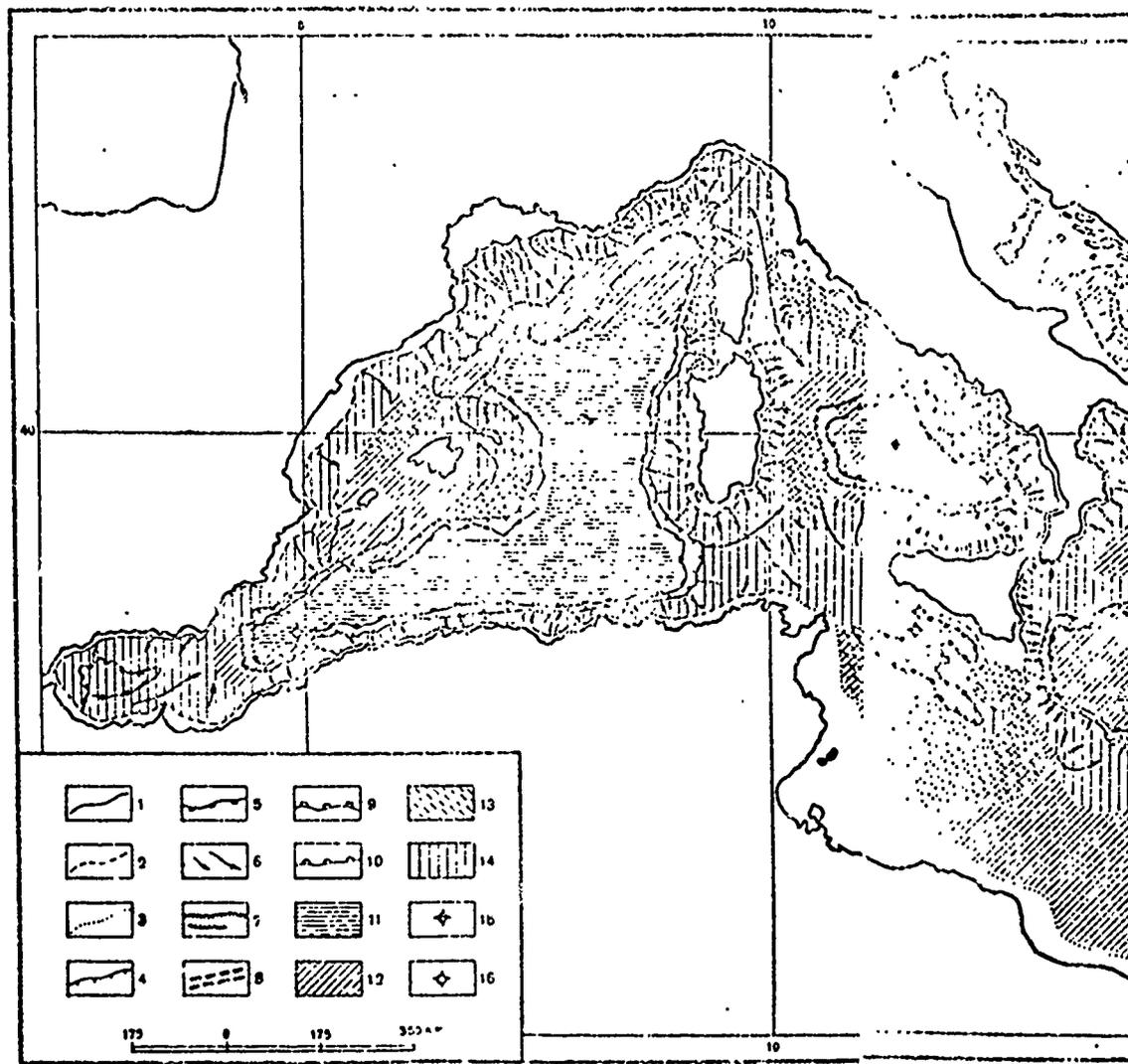
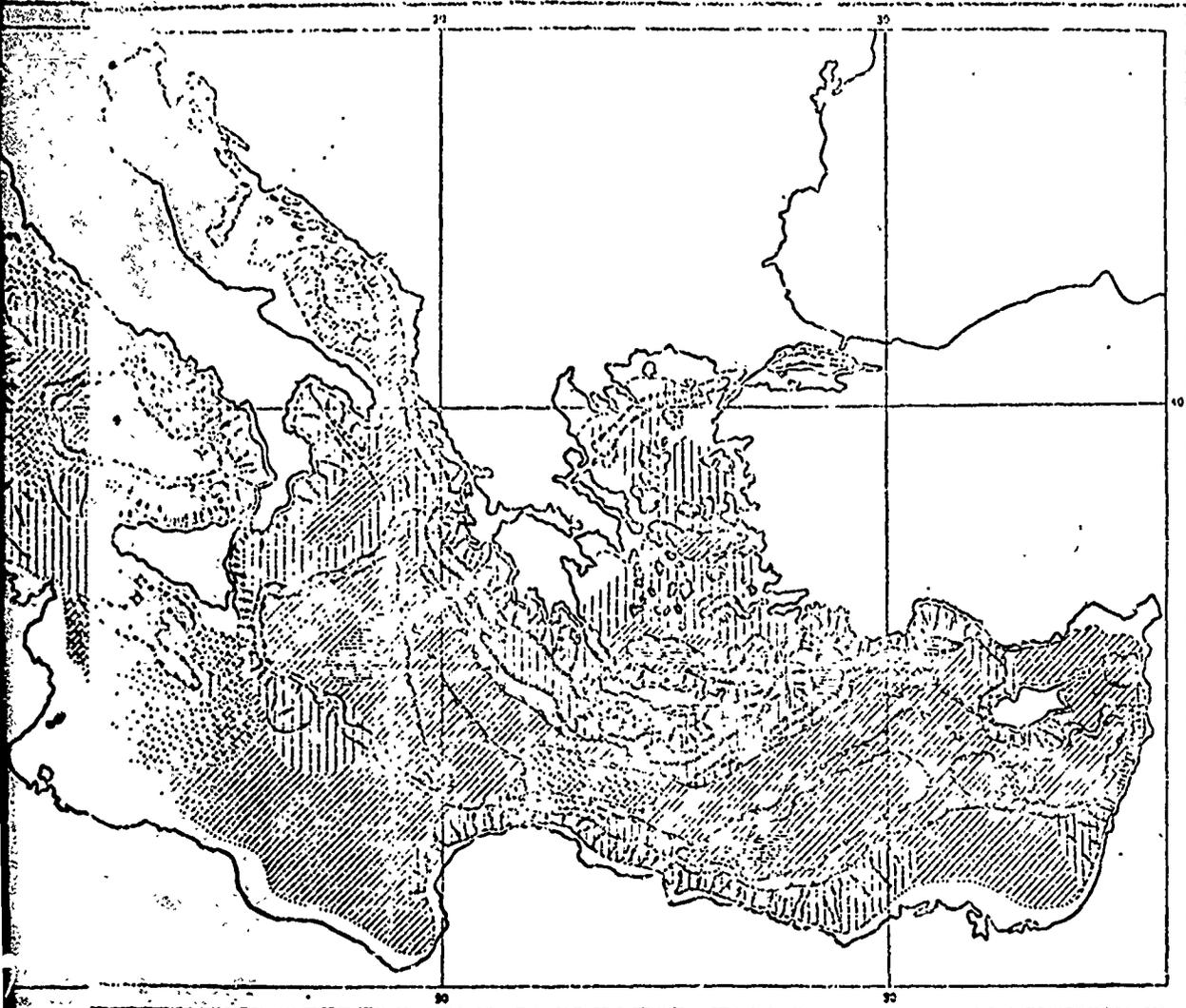


Figure 2 - Morphological diagram of the Mediterranean

- 1 - edge of the shelf, with a sharp transition to a continental slope;
- 2 - the same, with a gentle transition to a continental slope;
- 3 - the same, with a smooth transition to a continental slope;
- 4 - foot of the continental slope;
- 5 - contours of the deep-water depressions and basins;
- 6 - valleys within the limits of the continental slopes;
- 7 - Hellenic deep-water troughs;
- 8 - other troughs;
- 9 - contours of underwater elevations and plateaus;
- 10 - contours of the Central Mediterranean bar;
- 11 - limit plains of non-wave accumulation;
- 12 - sectors with accumulative planation of primary roughness;
- 13 - ancient planation surfaces;
- 14 - sections of bottom with retention of primary roughness;
- 15 - individual submarine mountains and volcanoes;
- 16 - presumed submarine mountains and volcanoes.



the Mediterranean Sea.

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The bottom of the Algiers-Provence basin genetically constitutes a limit plain of non-wave accumulation. Its analogs are, for instance, the Black Sea, the South-Okhotsk, and the Japanese deep-water basins. Therefore individual depressions (deeper than 2900 m) or elevations, to be found on the bathymetric charts of J. Bourcart, are not shown on our bathymetric chart within the limits of the Algiers-Provence basin. The origination of individual marks on some navigational charts, which formally confirm the existence of these unevennesses, is most probably of all connected with errors inherent in cable sounding.

The continental slope of the Algiers-Provence basin is complexly dissected and steep, with numerous underwater valleys. The greatest steepness and complexity of its structure usually corresponds to sectors attached to regions of young mountain structures and regions of structure closure of the Pyrenees and the Maritime Alps. However, not a single one of these structures is followed through in the relief of the bottom for any distance out to sea. In these places the slope frequently has scarps, and its steepness changes from 5 to 15-20°. Thus, a steep scarp between isobaths of 1000 and 2000 m is expressed in the northern part of the slope of Costa de Ponente, scarps between isobaths of 500 and 1000 m, as well as between 500 and 1500 m are marked on the slope of the northwestern islands of Asinar and on the slopes of southern Sardinia, where still another scarp corresponds to a depth of 200-500 m. The western slope of Corsica abounds in short trenches, which attain 1000 m in depth. Some underwater valleys are continuations of terrestrial valleys, such as, for instance, the Ajaccio valley, which retains its contours /12 down to 2450 m. The coast of Algiers has a rather steep continental slope, on which can be traced small structures, connected with the Atlas mountain chains which are perpendicular

to its strike. The steepest part of the slope is contained between the isobaths of 200 and 1500 m. The valleys descend almost to the foot to depths of 2000-2500 m.

The submarine elevation of the Pityusae Islands and the Balearic Islands is clearly contoured by the 1000 m isobath. The horst structure of the Balearic projection is well expressed in the relief of its continental slope by precipitous scarps between 500 and 1500 m (south of the island of Majorca) and 500-2000 m (east of the island of Minorca). On the whole, the relief of the slopes is rather moderate, with the exception of a small sector in the east and northeast. South of the island of Minorca and north of the Island of Ibiza, ancient planation surfaces are encountered on the slope.

The continental slope of the bay of Lyons is the most gently sloping in the Algiers-Provence basin. The valleys within its limits can be traced to 2200 m, and disappear at these depths under the cover of contemporary sediments. A characteristic feature of the morphology of these valleys is the development of lateral scarps along the thalweg. The first scarp usually corresponds to a depth of 300-600 m, the second corresponds to approximately 1000 m.

North of the Balearic projection and from the Bay of Lyons eastwards to the Ligurian Sea, the transition from a steep continental slope to a peneplain is characterized by a wide zone of hilly, gently sloping relief, located at depth between 2200 and 2700 m. The gradient of the bottom here is not great -- less than 1° (usually the continental slope of the Algerian-Provence basin abruptly passes directly into the basin bed).

The boundary of the shelf of the seas of the Algiers-Provence basin is rather well indicated on the map by the 200 m isobath. The coastal shoal usually constitutes a narrow, 2-5 mile strip. Only in some regions (the bays of Valencia and Lyons, the coastline of Sardinia) does it extend for 10-30

miles. The edge of the coastal shoal basically corresponds to depths of 110-130 m.

Located entirely within the bounds of the continental slope zones, the Sea of Alboran has a dissected topography, represented by a series of depressions extended in a latitudinal and a sublatitudinal direction, and individual elevations, which include, for example, the volcanic projection of the island of Alboran. The depths of the sea in the depressions vary from 1000 to 1500 m. The maximum depth shown on the navigation charts is 2000 m, but, according to our data, there is little probability of the existence here of any depth greater than 1600 m.

The Tyrrhenian deep-water basin is outlined on the bathymetric chart by the 3000 m isobaths. The most greatly levelled sector of the basin bottom is located deeper -- at 3550-3600 m. It occupies a rather extensive area and, with respect to relief type, is similar to the basin of the Algerian-Provence basin. Apparently there are no depths here greater than 3650, and the maximum sea depths drawn on the map of A. Segre (3840 m) is not likely to be reliable.

The zone of the continental slope of the Tyrrhenian depression may be divided into several morphological non-uniform parts.

The shallow north Tyrrhenian region, containing the area of the Tuscan islands, has a very uneven bottom, shallow (up to 500 m) sectors of which alternate with deep grooves and wide valleys. The gradient of the bottom gradually increases southwards, and with increasing depth the relief acquires a sloping and hilly character, not infrequently with peneplanation planes. The region is separated from Corsica and northern Sardinia by the flat-bottomed Corsican-Tuscan trough.

The upper part of the continental slope of the Italian coastline from Naples to Calabria (to 1000 m) is gently

sloping and hilly, not infrequently complicated by volcanic upheavals. Peneplanation planes are encountered here almost everywhere. The lower part of the continental slope is considerably steeper. Most of the valleys end at depths from /13 1000 to 1500 m and only south of the Bay of Policastro are

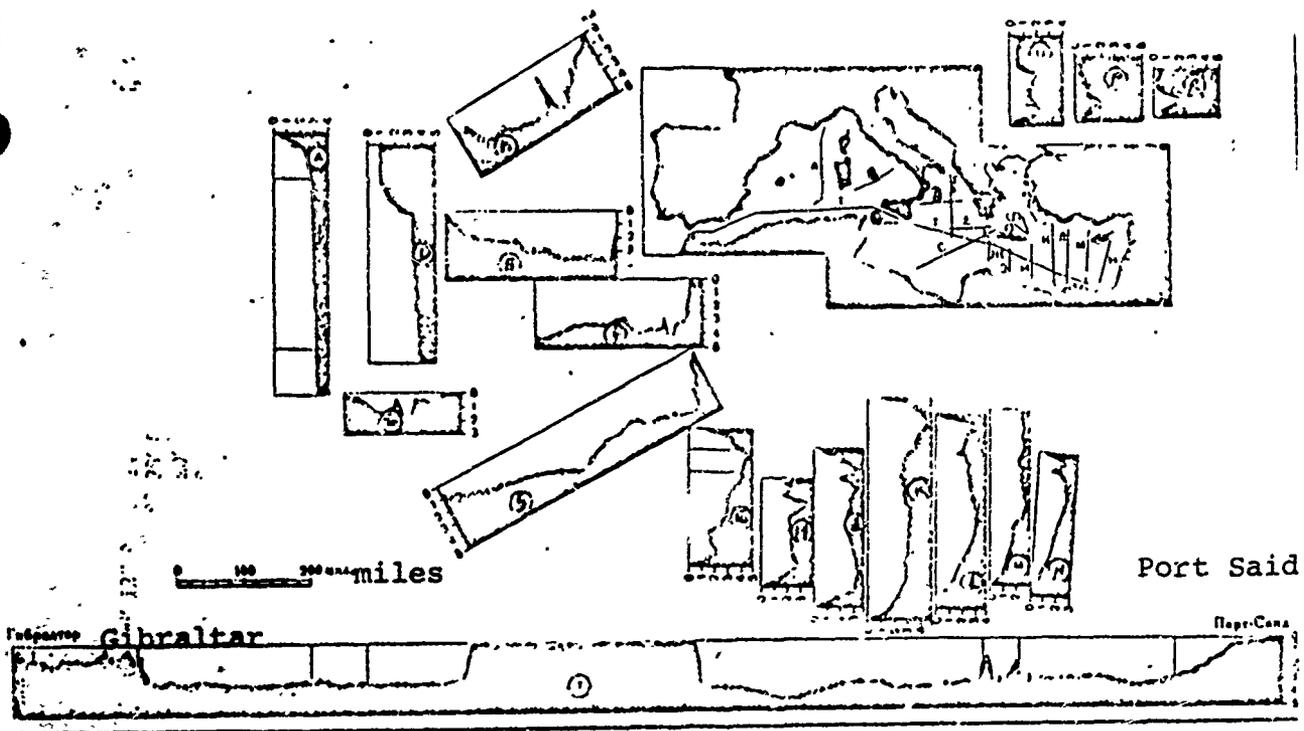


Figure 3. Profiles of the bottom of the Mediterranean Sea. (Ratio of the horizontal and vertical scales 1:37).

some of them traceable to the foot of the slope. /14

The region adjoining northern Sicily includes numerous protrusions of volcanic islands -- the Lipari Islands, Ustica Island. Between prolonged depression with depths of 1000 to 1500 m. Its Sicilian slope is cut up by numerous short valleys. The continental slope of the Lipari Islands descends by a steep scarp to the bed of the basin. It is very steep in the region of the island of Stromboli (up to 47°), but becomes less steep towards the west.

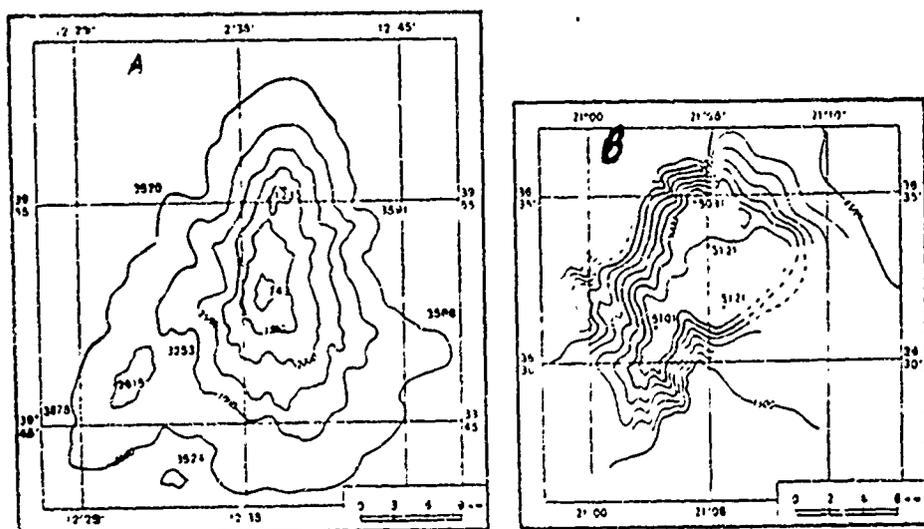


Figure 4. Bathymetric charts of the submarine volcano of Vavilov (A) and the region of the maximum depth of the Mediterranean Sea (B).

The south Tyrrhenian region is characterized by a comparatively wide continental shoal (up to 25 miles). The continental slope is gentle, with numerous banks, islands, and ranges of hills with a northeast strike. The continental shoal of the eastern coast of Sardinia and Corsica is narrow (2-4 miles) with the exception of a sector north of Orsey Bay and the Strait of Bonifacio, where its width is on the average 10-15 miles. Small valleys have developed within the bounds of the slope, which end at a depth of 1000-1500 m. On the continental slope of South Sardinia three scarps are noted: to 1450, 1450-2800, and 2800-3000 m.

Of interest is the existence, in the center of the Tyrrhenian deep-water basin, of a solitary volcano, investigated by the expeditionary ship "Academician S. Vavilov" in 1959 (Figure 1; Figure 3, profile B; Figure 4, A). The least depth of its peak is 731 m ($39^{\circ} 51.2' N, 12^{\circ} 36' E$). It rises above the bottom at 2850 m, the width of its base is about 30 km, the steepness of its slope is up to $11-15^{\circ}$.

Of interest in the relief of the African-Sicilian sill are three parallel depressions with a northwest strike,

separated by low connecting links (Figure 3, profile B). The bottom relief of the remaining regions of the African-Sicilian sill is complicated by small elevations, possibly of volcanic origin, similar to the Island of Pantelleria. Just as in the other bases of the western part of the Mediterranean Sea, it is possible to distinguish peneplanation planes here, particularly along the African coast. The greatest depth measured in the center depression of the sill is 1730 m ($36^{\circ} 25.5' N$, $13^{\circ} 25.3' E$).

Of greatest interest in the extremely dissected topography /15 of the eastern part of the Mediterranean Sea, in our opinion, is the complex of the Crete-Rhodes island arc. It includes the mountain range passing from Peloponnesus through the islands of Crete, Karpathos, and Rhodes into Turkey, the system of narrow deep-water troughs extending along the arc from the Ionic Islands to the Gulf of Antalya, and the depression of the Cretan Sea. The troughs of the exterior (southern) side of the arc can be clearly traced on the echo sounding tracks of the expeditionary ship "Academician S. Vavilov" (Figure 3, profiles E-L). South of the Strait of Kasos there exist three parallel troughs, separated by mountain ranges. Sometimes the troughs are separated by low connecting links or arcs situated echelonwise, but everywhere they retain their principal direction and form a single system, which girdles the Crete-Rhodes island arc from the south. The profile of the trough usually has a V-shaped form, although here and there are also encountered sections of bottom levelled due to the accumulation of sediments. The width of the troughs is from 5 to 20 miles. Sometimes they pass into wider valleys with more gentle slopes.

For this system there is proposed a single name -- the Hellenic trough. Its origin is apparently brought about by a regional abyssal fracture with a length of over 1500 km.

The depth of the Hellenic trough (according to the enveloping isobath) almost everywhere exceeds 1000 m. We cite the values of the maximum depths measured in its depressions on the expeditionary ship "Academician S. Vavilov": at the Ionic Islands -- about 4000 m, at Strophades Island -- 4224 m ($35^{\circ} 28.2' N$, $22^{\circ} 41.9' E$), west of Peloponnesus -- 5121 m ($36^{\circ} 33' N$, $21^{\circ} 05.4' E$), at the Strait of Cerigo -- 5015 m ($35^{\circ} 52.5' N$, $22^{\circ} 18' E$)*, at the Strait of Antikythera -- 4490 m ($35^{\circ} 32.7' N$, $22^{\circ} 37' E$), south of the western end of the island of Crete -- 3591 m ($34^{\circ} 46.2' N$, $23^{\circ} 40.2' E$), south of the island of Gavdos -- 3590 m ($34^{\circ} 35' N$, $24^{\circ} 10.6' E$), south of Cape Lithinon on the island of Crete -- 3530 m ($34^{\circ} 07.3' N$, $24^{\circ} 46' E$), at the Strait of Kasos -- 4034 m ($34^{\circ} 49.9' N$, $26^{\circ} 31.5' E$), southeast of the island of Rhodes -- 4486 m ($35^{\circ} 55' N$, $28^{\circ} 38.2' E$), south of Lycia -- 3054 m ($35^{\circ} 58.7' N$, $29^{\circ} 58' E$), at the Gulf of Antalya -- 2671 m ($35^{\circ} 58' N$, $30^{\circ} 59' E$).

The cited depths are the greatest of those measured by us, but possibly are not the maximum depths. Individual depressions of the trough have a strike cross-wise to the general axis, and are apparently connected with transverse faults. Precisely in such regions are encountered the greatest depressions. The greatest of the presently known depths of the Mediterranean Sea -- 5121 m (Figure 4, B), was discovered in the fourth trip of the expeditionary ship "Academician S. Vavilov." The slopes of the Hellenic trough, particularly the northern one, are very steep ($15-20^{\circ}$), and are sometimes precipitous.

The depression of the Cretan sea, which belongs to the complex of the Crete-Rhodes island arc, has a complicated configuration and structure. A large part of it is well outlined on the bathymetric chart by the 1000 m isobath (Figure 1). A wide bucket-shaped depression, passing along the northern slope of Crete, passes at the island of Kasos into a narrow

* Sounding of the expeditionary ship "Calypso," 1955-1956 (Lacombe, 1960).

parallel trough having a V-shaped profile (Figure 2; Figure 3, profiles O-R). This trough is probably connected with a tectonic seam. Its depth varies from 1000 to 1500 m. The maximum depth of the sea in one of the depressions of the trough west of the island of Karpathos is 3591 m. The greatest of the depths measured by us here is 2480 m (36° 04.8' N, 27° 05.7' E). The small depression passing along the northeast slope of the islands of Cerigo and Antikythera is apparently a tectonic continuation of the basin of the Cretan Sea; its maximum depth of 2167 m (36° 13.9' N, 23° 31.2' E) is doubtful. According to our data, there are unlikely to be any depths here which exceed 1400-1500 m.

The southern continental slope of the island arc from the Gulf of Antalya to the Ionic Islands is characterized by an extremely complicated structure. Its steepness varies within rather wide limits, but even at the most gently sloping /16 sections the average gradient of the bottom is not less than 5°. The steepest slope adjoins the region of the northwest extremity of Crete (Cape Krios). Here, between 150 and 2000 m, is clearly expressed a scarp with a gradient of about 40". The mean steepness of the continental slope is apparently about 20°. Within the limit of the slope, scarps are developed almost everywhere. Only the Turkish slope of the basin between Rhodes and Lycia has a comparatively simple (for this zone) structure. South of the islands of Rhodes, Karpathos and the eastern part of Crete, on the continental slope can be traced mountain ranges with high peaks, parallel to the Hellenides, as well as ranges of hills and elevations of varying height and orientation. Numerous valleys and canyons cut through the continental slope in various directions, frequently descending to the foot. Below 2500-3000 m the continental slope passes directly into the slope of the Hellenic trough. The coastal shoal along the southern shores of the Crete-Rhodes arc is very feebly developed. It extends into the sea usually

not further than 2 miles, and in places is completely absent.

The complex of the Crete-Rhodes island is, in the morphological respect, the most complex one in the entire Mediterranean region, and requires detailed study.

The system of depressions of the Hellenic deep-water trough is contoured from the south by a large arched uplift, rising over the level of the bottom to the extent of 500-800 m. This uplift, called by us the Central Mediterranean Arch, extends along an arc from the Ionic islands to the Sea of Levant. The arc is clearly distinguished on the sounding profile (Figure 3, profiles F, S, G-L), and on the bathymetric chart is well outlined by the 2500 m isobath (Figure 1). South of Lycia, on the arch, there is located a small plateau with depth of 1200-1400 m and a minimum depth, according to our data, of 1156 m (35° 35' N, 30° 34.8' E). North of Cyrenaica the arch joins the extensive Mediterranean Plateau (Figures 1 and 2, Figure 3, profile G), the depths of which are less than 2000 m and which has minimum depths of about 1350 m. The least depth, according to our sounding data, is 1318 m (33° 45.3' N, 22° 49.2' E). The western and the eastern ends of the arch have not yet been determined by us; however, it may be assumed that in the east it turns from the Lycian plateau to southern Cyprus, and west of Peloponnesus gradually flattens out. The middle plateau is separated from the continental slope of Cyrenaica by a narrow trough with depths greater than 2300 m. The depth of the trough is on the average 250 m. The mesoforms of the relief of the arch and of the middle plateau have been insufficiently studied. According to our data, the relief of the arch is hilly, with individual low hills and small depressions.

The central plateau divides the deep-water regions of the eastern part of the Mediterranean Sea into two basins: the Central Basin in the west and the Levantine Basin in the east (Figure 2).

The bed of the Central Basin is contoured on the map by the 3500 m isobath. Considerable areas within the limits of the basin are located at depths of over 4000-4100 m, the topography of the bottom flattening out only in these sectors. The main area of the central basin is characterized by a dissected, rolling topography with depth variations of 100-150 m. The width of the feet of the hills is approximately 1-2 miles, the steepness of the slopes if on the average close to 7°. Several small depressions are located along the foot of the continental slope of Sicily. Possibly a shallow, flat trough extends here. The greatest depth measured by us in the central basin is 4116 m (36° 10.3' N, 18° 30' E). The maximum depth according to navigation-chart data is 4297 m. Most of the individual high mountains (volcanoes) shown within the limits of the bed of the basin on the map of M. Pfannenstiel are very doubtful, since they have been entered on the map only on the basis of single depth soundings.

The Levantine basin, bounded on the north by the central Mediterranean arch, is well outlined from the east and south by the 2500 m isobath (Figures 1 and 2). The extensive area /17 in the center of the basin has depths in excess of 3000 m. The topography of the bottom is here more restrained than in the central basin. Comparatively gently sloping hills (up to 2°) within its limits attain heights of 200-250 m. Within the region of the maximum depth of the basin -- 3174 m (32° 23.8' N, 26° 40' E) -- a small area of the bottom is peneplained.

South of the island of Cyprus is located a local plateau with depths of less than 1000 m above some of its peaks. Two small troughs separate the plateau from the underwater base of the island of Cyprus on the north and from the continental slope of Africa on the south. East and west of the plateau are located two basins, of which the deepest one is the western one (its depths are 2400-2600 m). The eastern, Phintian basin is characterized by a rather flat topography and depths of not

more than 2200 m.

The underwater base of the island of Cyprus has outlines which differ considerably from the shape of the island above the water. The western and southern slopes of Cyprus are cut up by deep valleys and are complicated by individual elevations and mountains. The steepest slope is the western one (18-20°).

Of interest is the link (bridge) connecting the eastern underwater continuation of the island with the projection of the continental slope of Syria. The depth above this link is less than 1000 m. At depths of 1500-1700 m, within the limits of the southern slope, a bend is to be noted, the slope becomes considerably more gentle (2.5-3° instead of 10-15°). The western and the southern slopes of the islands pass rather steeply into the bed of the basin.

The continental shoal of the western coast of the Ionic Sea constitutes a strip 2-5 miles wide. In the gulf of Taranto it is wider -- about 10 miles. The transition from the continental slope is rather smooth and corresponds to a depth of 100-110 m. The continental slope may be divided into two sectors: the southeast slope of Calabria and the sector from the Strait of Messina to the latitude of the island of Malta. The slope of the first sector is gentle, smoothly passing into the bed of the basin at depths of 2700-3000 m. Outstanding among the largest of the valleys located within its limits is a wide, trough-type, bucket-shaped valley, passing from the Gulf of Taranto to the foot of the continental slope (Figure 2). The slope of the second sector is characterized by considerably greater steepness (up to 10-15°) and acute ruggedness. Thus, one of the valleys of the continental slope at Cape Isola delle Correnti (Sicily) has a depth of over 1500 m. The transition to the bed of the basin is very sharp along the entire sector and corresponds to depths of 3000-3500 m. Somewhat south of Sicily (at the latitude of Malta) the continental slope turns east, includes within itself individual elevations and separate uplifts, and as it moves

east gradually passes into the calm and even slope of the Sidra Sea.

The continental slope of the African-Arabian platform may be divided into two types: a steep and rugged slope, probably connected with faults, and a quiet slope of submerged edged sectors of the platform (Figures 1 and 2). The slope of the first type extends along the coast of Syria and Lebanon and from the Arabian Gulf westwards to the Gulf of Syrtis Major. Its steepness varies between 4 and 10°. Most of the valleys are well developed and can be traced to the foot. The slope of the second type is located at the shores of Egypt, where its mesoforms are overlaid with mud deposits, and in the Sea of Sidra. The gradient of the bottom at the sectors is equal to only 40" - 1° 30'. The length of the continental shoal at all these sectors varies. Its average width is of the order of 5 miles. It attains considerable size only in the Sea of Sidra (about 15 miles) and in the region from Alexandria to El-Arish (30-40 miles). The narrowest continental shoal is at the coast of Syria, between Latakia and Ras-El-Bast.

The Gulf of Iskenderun and the shoal from Cape Karatash to Cape Ovjik are broad and shallow. The topography of the bottom is most even of all in this region. The continental slope is almost not traced at all, although between 100 and 500 m a comparatively steep scarp is noted. In the central part of the region the depths increase gradually from east to west; this is probably explained by intensive filling of the synclinal bend between the Cilician Gates and Cyprus with deposits. From Cape Ovjik to Cape Anamur the scarp of the continental slope is more clearly expressed. /18

In the topography of the Adriatic Sea bottom are to be distinguished a northwest shallow-water region and a southeastern basin. The mesoforms of the topography of the northwestern part of the sea have been buried by a thickness of sediments carried in by numerous rivers. The depths of the shallow-water region increase gradually from northwest to

southeast, reaching 170 m at the Palagruza islands. There apparently exists an insignificant gradient of the bottom surface from the Apennine coast to the Dalmatian islands. The southern slopes of some of these islands are precipitous and deep. A small transverse depression with depths of up to 270 m intersects the shoal from Cape Ferruccio to the island of Girier, and probably constitutes a very young graben. The gently sloping banks located north and northwest of Gargano peninsula, as well as the islands of Tremiti, Pianosa, and Palagruza apparently constitute a submarine extension of the Gargano massif.

Layering data obtained in soundings show that the bedrock here is covered with an insignificant thickness, only a few meters, of unconsolidated sediments. The rock lies at the most various angles to the surface of the bottom. The southeast deep basin of the sea constitute a wide depression with a well levelled bottom and comparatively gentle slopes. On the northwest slope two terracelike surfaces are to be distinguished -- at a depth of 200 and 300-350 m. The maximum depth in the basin is unlikely to exceed 1300 m.

The structure of the basin of the sea of Marmara, which is small in area, is connected with the fault which continues on its bottom the north Anatolian fault. The trough passing also: the northern deep slope consists of 3 depressions (to 1225 m), separated by low connecting links. At the foot of the northern continental slope passes a shallow trough, which is well expressed only in the easternmost part of the sea. At the south, an extensive part of the body of the sea constitutes a shoal with depths of the order of 60-80 m.

Two faults are well expressed in the relief of the northern part of the Aegean Sea. The first of these, passing from the Gulf of Saros to the Magnesia Peninsula, is a continuation of the north Anatolian fault. It has the shape of

a wide, flat trough. The deepest part of the trough starts approximately at the Akte Peninsula. The depths here are everywhere greater than 100-1200 m. The second fault is less clearly expressed by a system of narrow depressions, extending from the Bay of Edimit to the island of Skyros. The depths increase from east to west, reaching 1000 m at the foot of the island of Skyros. The comparatively shallow elevation contained between these faults, with the islands of Imiroz, Lemnos, and Agios-Evstratios is characterized by precipitous slopes. The central and the southern parts of the Aegean Sea have been little studied. In the topography of the bottom it is difficult to trace the expression of any tectonic lines. The numerous basins and the elevation separating them have a most variegated configuration and orientation and, on the whole, have the features of a block structure. The greatest depth in this region is 1262 m ($37^{\circ} 49' 09''$ N, $26^{\circ} 20' 02''$ E), and is located in one of the basins near the isle of Samos. A second deep basin (over 1000 m) is located 10 miles southwest of the isle of Antiparos.

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SOME SPECIAL FEATURES OF THE GEOMORPHOLOGICAL STRUCTURE AND
TECTONIC DEVELOPMENT OF THE MEDITERRANEAN SEA

/20

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The problems of the tectonic structure of the Alpine geosynclinal zone of Europe, covered by the waters of the Mediterranean Sea, have already for centuries been the center of attention of the greatest tectonics specialists of the world (Suess, Stille, Staub, Argan, etc.). In spite of this, the contemporary conceptions of the tectonics of the Mediterranean basin are still far from complete.

As a result of oceanographic research in seas and oceans, in the last few decades a large amount of new material has been obtained concerning also the structure of the Mediterranean Sea bottom. The greatest contribution in this has been made by French, Soviet, Italian, and English scientists. The principal items of this research are the following: 1. bathymetric charts of individual basins and sectors of the sea (Bourcart, 1960; Pfannenstiel, 1960; Segre, 1960; Giermann, 1961); a bathymetric chart of the entire basin, compiled in the marine geology laboratory of the Black Sea Experimental Scientific Research Station of the Institute of Oceanography, Academy of Sciences, USSR (Goncharov, Mikhaylov, 1963; Mikhaylov, 1963); 2. valuable data of direct observations by means of descents in bathyscaphs (Peres, 1958, 1959); 3. samples of bedrock from the sea bottom (Bourcart, 1953, 1959; Segre, 1958); 4. data concerning the structure of the sedimentary series on the basis of seismic research (Moskalenko, the present collection); gravimetric charts (Bruyn, 1955; Morreli, 1961); 6. data concerning submarine volcanism (Neymayr, 1902; Pfannenstiel, 1960); 7. data concerning submarine earthquake epicenters (Caloi, 1937; Griland, 1955; Galanopoulos, 1960, 1961).

The correctness of the tectonic interpretation of the enumerated data depends to a great extent upon the trustworthiness of the concepts concerning the tectonic structure of the dry land surrounding the Mediterranean Sea. In this respect there is great value in the new international tectonic map of Europe (Shatskiy, Bogdanov, 1961). In this map is reflected the more or less coordinated latest opinion of various schools concerning the most complex theoretical problems of the geology of Europe. In the opinion of the compilers, the map possesses also many substantial drawbacks, since "some of the problems formulated in the process of compilation of the map are in by no means all of the cases solved in a sufficiently satisfactory manner" (p. 24). This, for example, can explain the appearance of the work of M. V. Muratov (1962), in which the tectonic structure of Sicily and the southern Apennines is represented in a different form than in the tectonic map of Europe.

In connection with the fact that the Mediterranean Sea is located in the folded belt of Europe (Figure 1), let us briefly recollect the basic features of the structure and development of Alpine structures that have been described in a number of works (Shatskiy, Bogdanov, 1957, 1961; Salvin, Yaranov, 1960; Muratov, 1960; A. A. Bogdanov, 1961, 1962, etc.).

The Alpine folded structures of Europe, North Africa, and Asia Minor constitute a superposed geosynclinal system which has originated on the site of previously formed ancient systems (the Caledonian, the Hercynian). The possible breakup of the Alpine region into individual closed geosynclines may be linked to the general tapering out of the alpides to the west. Within the limits of the regions of Alpine folding, there are clearly to be distinguished myosynclinal and eusynclinal belts, the eusynclinal systems being principally developed in the east, and the myosynclinal systems being principally developed

in the west. On the boundaries of the alpine folded regions foredeeps are well developed, filled with neogenic mollases.

Some of these features of the structure of the alpine folding zone of Europe unquestionably put their mark also on the structure of the Mediterranean Sea, which extends across this entire zone. The most general analysis of the topography of the bottom, the structure of the sedimentary layer, and of the results of geophysical research has confirmed the correctness of such a conclusion. There has been brought out a sharp heterogeneity of the tectonic structure of this basin; in compressed form this is also shown on the tectonic diagram of the Mediterranean Sea compiled by us (Ye. M. Yemel'yanov, K. M. Shimkus) (Figure 1). The basic principles and premises of the construction of such a diagram and its brief characterization have been given in another work (Yemel'yanov, Mikhaylov, Moskalenko, Shimkus, 1964). But due to the restricted scope of the previous article, a number of questions touched upon in it has been very incompletely treated. The aim of the present work is to fill some of these gaps. In connection with this it is necessary to examine additionally the features of the morphological structure of the Mediterranean Sea; this will make it possible to determine to some extent the basic trends of the tectonic development of this basin.

Already upon first acquaintance with the topography of the Mediterranean Sea bottom, attention is drawn to sharp distinctions in the morphological structure of its individual basins. They differ from one another with respect to depth, the nature of the structure of large forms of bottom topography (continental shoal, zone of continental slope, deep-water basin), and configuration.

In spite of the differing structure of the continental shoal (variable width, the character of its gradient and bend) and of the continental slope (steepness, ruggedness,

scalariformity), the interbasin differences are most sharply manifested in the structure of their central regions. Thus, for instance, the central part of the sea of Marmara is taken up by several depressions, separated by low connecting links, which in their totality form the deep-water basin of the sea. The central region of the Aegean Sea consists of a large number of shallow depressions of varying configuration. Deeper depressions of a sublatitudinal direction extend along the northern and the southern parts of the sea. In the Adriatic Sea a comparatively deep region occupies only one quarter of the body of water (in the south), and is represented by a cup-shaped depression of rather simple structure. The central part of the Tyrrhenian Sea is a deep basin of round shape with volcanic cones.

The morphological differences are most sharply manifested when the Algiers-Provence basin is compared with the eastern part of the Mediterranean Sea. Thus, the central deep-water region of the Algiers-Provence basin is represented by a flat-bottom basin, most of it being cumulatively levelled. Mesoforms and microforms of the bottom topography are developed only on a small sector in its northern half. The increase of depths in the basin is gradual; the maximum depths are observed in the central part of the basin.

An entirely different pattern is observed in the eastern part of the Mediterranean Sea. In the region of the bed of the bottom, here are developed three very large morphological structures, predominantly with a latitudinal strike: the Central Mediterranean Arch, the system of deep-water depressions of the Hellenic trough, and the southern chain of gently sloping extensive basins (Goncharov, Mikhaylov, 1963). The overwhelmingly greatest part of the bottom is perceptibly or or sharply dissected, the elevations are usually more sharp-peaked than in the western part of the sea. The maximum

depths are to be found at the edge parts of the bottom bed.

A notable characteristic of the morphology of the Mediterranean basin is its complex configuration. It is morphologically determined by the strike of the principal basins in a latitudinal direction (the Sea of Marmara and the Cretan Sea, the eastern part of the Mediterranean Sea, the western half of the Algiers-Provence basin, the Sea of Alboran) and by their intersection with some depressions of submeridional and meridional strike (the Aegean, and the Tyrrhenian Seas, the eastern part of the Algiers-Provence basin).

Besides the large interbasin morphological differences, in the Mediterranean Sea there also exist intrabasin difference. They are most sharply manifested in the structure of the shoal and the slope. Thus, for instance, in the eastern part of the Mediterranean Sea, within the limits of the continental shoal and slope two large zones can be distinguished, which differ with respect to their structure: the zone along the coast of the southern Apennines and Africa and the zone of the Balkan-Anatolian coastline.

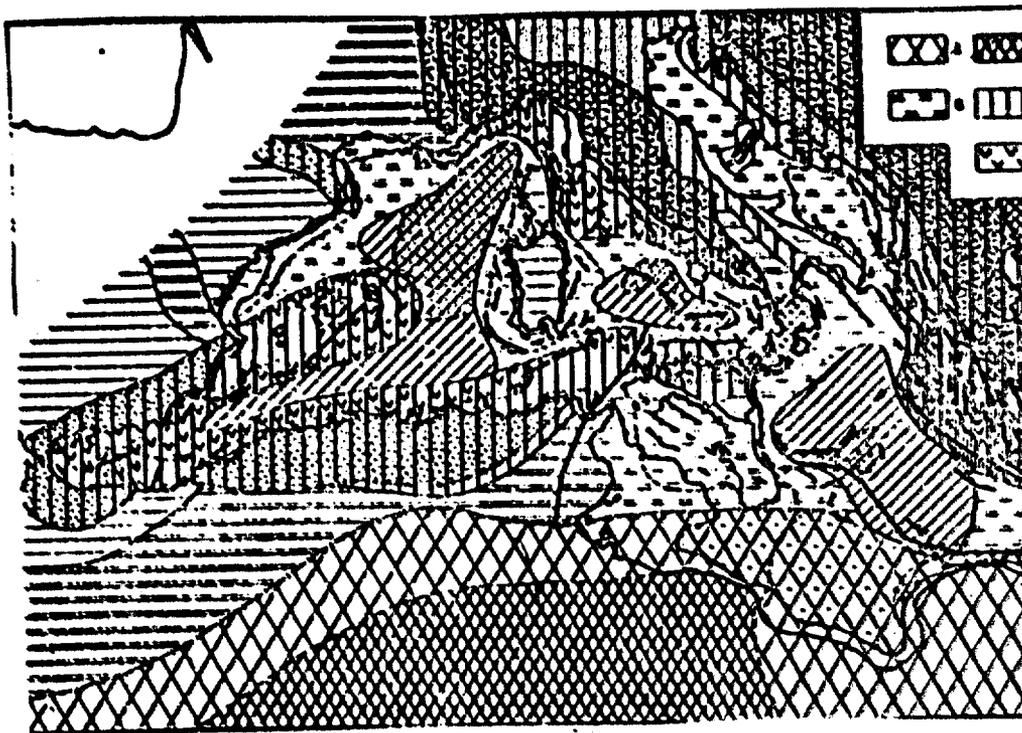
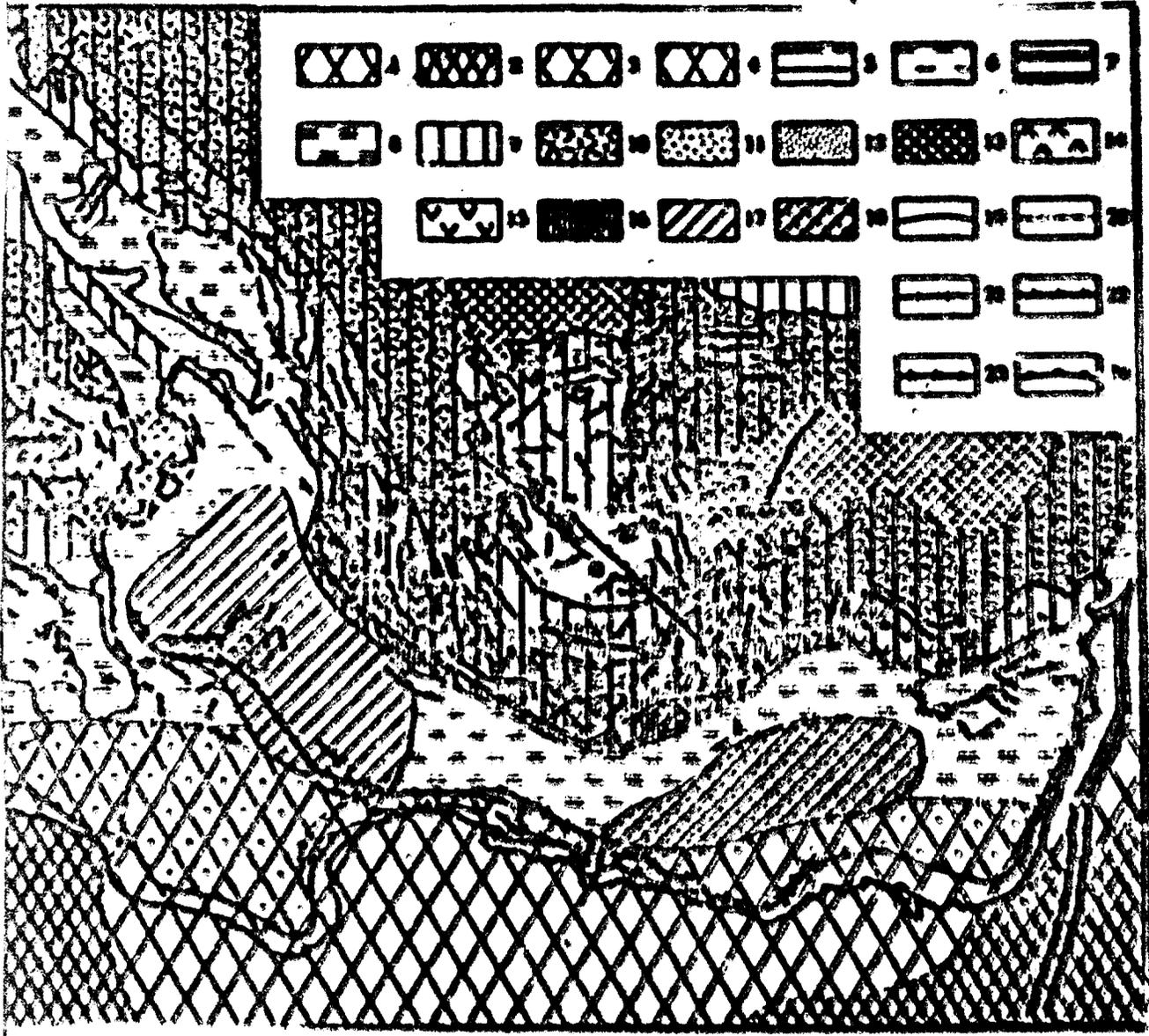


Figure 1. - Tectonic diagram of the Mediterranean Sea.
(see legend on following page).

A.



1-4 Region of Pre-Cambrian folding: 1. regions with deep bedding of the foundation (synclises); 2. regions with shallow bedding of the foundation (underground slopes of shields, and anteklises); 3. regions of Pre-Cambrian folding, submerged under water; 4. latest bends in the regions of Pre-Cambrian folding, submerged under water; 5-8 regions of pre-Cenozoic foldings; 5. sections of epihercynian platform with outcrops of folded base (on dry land); 6. the same sectors in the region of the sea, covered with a sedimentary layer; 7. sections of epihercynian platform covered with a sedimentary mantle (on dry land); 8. the same sections in the region of the sea, covered with a thick (more than 2 cm) sedimentary mantle; 9. regions of Cenozoic folding; 10. alpine eugeosynclinal zones; 11. alpine myogeosynclinal zones; 12. foredeeps and internal depressions; 13. central massifs; 14. projections of foundation within the limits of alpine folding systems, submerged under water; 15. latest bends within the limits of alpine folding systems submerged under water; 16. deep troughs; 17-18 areas of earth crust without a "granite" layer: 17. without a thick (less than 0.8 km) thickness of unconsolidated deposits; 19. boundary contours; 20. presumed boundary contours; 21. boundary of the African platform; 22. fractures; 23. fractures along axes of deep-water depressions; 24. edge of continental shoal.

In spite of the relatively inhomogeneous structure (steep sectors of continental slope with a narrow shoal alternate with sections characterized by a gentle slope and a broad shoal), the first zone has the simple structure of a continental slope and a simple system of submarine valleys. The continental slope in the upper part is steeper than in the lower part.

In the Balkan-Anatolian zone the structure of the continental slope is characterized by complex dissection, with almost everywhere a high steepness, the development of individual elevations, situated in the form of arcs, etc. (Mikhaylov, the present collection).

In the Tyrrhenian Sea the gentle continental slope with ranges of hills on it is typical for its northern and southern parts, and a step-wise slope of complex structure with strongly dissected gently sloping steps and steep scarps is typical for regions adjacent to the western and the southeastern coasts of this basin.

In the Algiers-Provence basin the zone of the continental shoal and slope, extending along the Algerian coast, consists of alternating steep and relatively gently sloping sectors.

The steepest sectors lack morphologically well defined valleys. There is noted a block structure of the slope and a frequent absence of shoal.

The Balearic-Catalonian zone is characterized by a wide shoal and a slope of simple structure, having sectors with greater steepness and weak dissection. The region of Lyons, /24 in addition to an extensive shoal, has a gentle continental slope with strong dissection. The zone at the coast of Provence is characterized by the presence of a continental and an island shoal, and a very steep continental slope cut up in a complex manner by submarine valleys.

In the region surrounding Corsica, hardly any continental shoal exists. The slope is for the most part cut up by short trenches; long deep valleys are seldom encountered. The Sardinian coast shoal is broad, and the slope is much more gentle and less cut up than in the vicinity of Corsica.

A more detailed description of the topography of the bottom is given in the article of O. V. Mikhaylov, "Topography of the Mediterranean Sea Bottom" (see the present collection).

In the general analysis of the present-day morphology of the Mediterranean Sea bottom, note is taken only of certain features of the ancient relief which "peeks" through a series of loose sediments ($V=1.7-2.1$ km/sec.). Determination of the masking role of these deposits makes it possible to judge the extent to which the features of the ancient relief, buried under a series of sediments in the Neogenic-Quaternary period, have been preserved in the present-day morphology of the bottom.

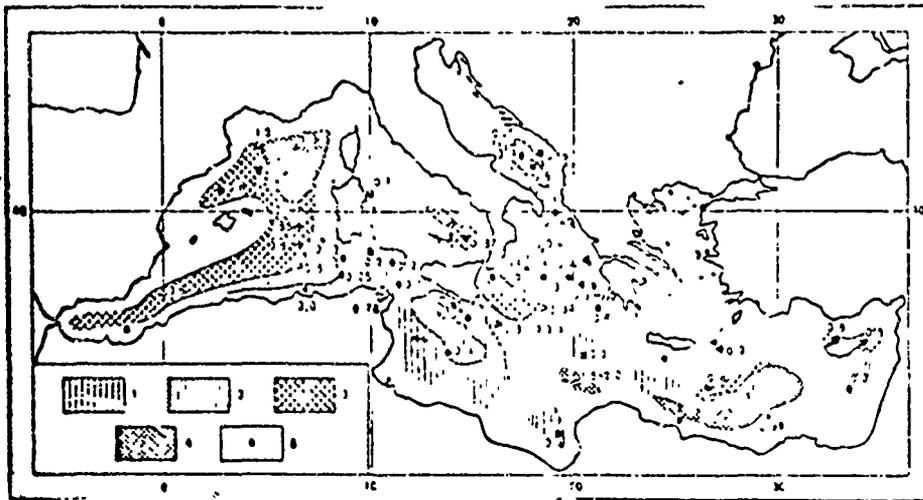


Figure 2. Diagram of the distribution of loose ($V=1.7-2.1$ km/sec.) sediments on the bottom of the Mediterranean Sea. 1. less than 0.25 km; 2. 0.25-0.50 km; 3. 0.50-1.00 km; 4. more than 1.00 km; 5. point of seismic sounding.

In Figure 2, compiled by V. N. Moskalenko (see the present collection), it can be seen that the most intensive sediment accumulation in the last stages of the tectonic development of the Mediterranean Sea took place in the Algiers-Provence basin and in the Levantine Sea. It is natural that the primary relief is smoothed to the greatest extent particularly in these regions. Feeble changes in the thicknesses of the sediment series in the Algiers-Provence basin may serve as testimony to the rather evened-out character of the underlying relief. Great variations of thicknesses of the eastern part of the sea characterize the more acute dissection of the primary bottom. The character of the increase of the thicknesses of the loose sediments permits the assumption to be made that one of the basic sources of sedimentary material in the Neogenic-Quaternary period in the western Mediterranean Sea region was the region north of the Bay of Lyons, and the Alps, and in the eastern Mediterranean Sea region -- the elevated parts of Cirenaica and Marmarica and the Nile River. The possibility is not excluded that the greater part of the Nile sediments then went not in the direction of the Israel-Lebanon coast, as is observed at the present time, but was carried

away in a northwest direction from its delta.

The following features may be noted in the distribution of the loose sediments with respect to area: 1) a decrease in the thickness of the sediments (to 0.2 km) is observed in the regions of the continental slope, at submarine elevations and 25 on their slopes; 2) a gradual increase in the thicknesses of the sediments takes place in the direction towards the foot of the continental slope and the basin adjacent to the slope; 3) in the central parts of the sea basins, the thicknesses of the loose sedimentary series are somewhat less than on their edges; thus, the thickness of these deposits depends both on the distance from the sources of detrital material and on the dissectedness of the topography of the bottom.

The character of the distribution of loose sediments in the Mediterranean Sea permits the conclusion to be made that the pre-Quaternary relief of the bottom in its eastern part, with the exception of the regions of the Hellenic trough and the Aegean Sea, was considerably more complex than its present topography, whereas for the western part such differences were far less pronounced. From what had been said, it also follows that the basic features of the pre-Quaternary relief are not masked by sediments, since their thicknesses are comparatively small, particularly in the zone of the continental slope and within the limits of the elevations.

The last stages of the tectonic development of the Mediterranean region are integrally connected with the development of the Alpine geosynclinal belt in Europe, Africa, and Asia Minor. It is natural that the movement of the Alpine tectonic cycle should be in some manner reflected also in the structure of the bottom relief of this basin, and, in particular, in its morphology. Therefore we assume that the previously enumerated most general morphological differences between the individual basins of the Mediterranean Sea have a definite tectonic

meaning. For example, they confirm the superposed character of the Alpine structures. Thus, in places where the Alpine tectonic plan coincided with a more ancient one, there originated meridional depressions of simple structure, and where it intersected the more ancient plan (the eastern part of the Mediterranean Sea), there arose very complex morphostructures with a latitudinal strike. Furthermore, the enumerated morphological features constitute a partial proof of the fact that the Alpine tectonic movements developed with unequal force in various parts of the Mediterranean Basin.

The comparatively monotonous and simple structure of the western part of the Mediterranean Sea is the result of weak influence of the Alpine tectonic cycle (the myogeosynclinal zone). The available data indicate that at the bottom of the bed of this part of the sea there are no morphological signs of underwater continuations of the Balearic projections and the Pyrenees. This is also substantiated by the result of geophysical research: in this regions are observed persistent thicknesses of the sedimentary series (Moskalenko, the present collection). The small thickness of the sedimentary series (3-4 km; Muraour et al., 1962) in the region of the Bay of Lyons rules out the continuation of the Pyrenees in the north-east direction as well. Consequently, these morphological features may serve as a confirmation of the assumption concerning the disintegration of the Alpine geosynclinal belt of Europe in the western direction into individual closed geosynclines and the development, in the same direction, of a weakened myogeosynclinal regime. The simple structure of the Adriatic Sea may be explained by the fact that it has for the most part developed at the commissure of the foredeep of the Apennines and the myogeosynclinal zone of the Dinaric Alps which tapers out to the west (an intermontane trough).

In the eastern part of the Mediterranean basin, the Alpine tectonic cycle has manifested itself in an entirely different

manner. In this stage, at the site of Peloponnesus and Asia Minor there developed a thick, tectonically very active eugeosynclinal zone. The action of the alpine orogenic movements on the area now submerged under the waters of the Mediterranean Sea manifested itself in the formation there of enormous depressions linked to the tectonically weakened commissure belts. Such structures can be the Hellenic trough, which constitutes as it were a foredeep, and the southern chain of depressions (along Africa) which has developed at the site of the commissure of the Hercynian (central arch) and pre-Cambrian platform structures (Africa).

In connection with the fact that the eastern part of the Mediterranean Sea is not an intra-Alpine, but a pre-Alpine basin, formed along the edge of the Alpine folded zone, there must be reflected in it many features of the tectonic structure and development inherent in the commissure zones of young and ancient regions which has been rather well studied by Soviet scientists (Peyve, 1945, 1960; Shatskiy, 1947; Pushcharovskiy, 1960, 1961; Chekunov, 1961, et al.).

It seems to us that according to its morphological features, the Hellenic trough fully corresponds to the definitions of Alpine longitudinal troughs which, for example, are given by Yu. M. Pushcharovskiy. It apparently originated in the region of the jointing of Alpine folded structures with the Epi-hercynian platform (Figure 1). In all probability, this depression is the western continuation of the Alpine foredeep, which extends on dry land along the Alpine zone from the Pacific Ocean, interrupted only in the region of Siberia by a young transverse elevation.

A perceptible similarity is noted between the structure of the Hellenic trough and the system of depressions (troughs) developed along the Indonesian Island arc. These troughs also developed in a zone of abyssal fractures, and are characterized

by high seismicity, low gravity anomalies (of the order of 20-50 mgl, sometimes up to 100 mgl; Umbgrov, 1952). A noteworthy feature is also the fact that the Indonesian troughs, similarly to the Hellenic trough, are located on the continuation of an Alpine foredeep (see "Map of the structure of the earth's crust" in the book of Kropotkin, Lyustikh, Povaloshveykovskaya, 1958). In this connection it is interesting to note that attempt have already been made to compare the Indonesian deep-water depression with basins of ancient accumulation (Kuynen, 1952).

The which has been set forth bears witness to the fact that in the eastern part of the Mediterranean Sea there are features of the manifestation of young tectonics, whereas the western part of the sea is characterized by a more conservative tectonic state.

Unquestionably the alpine tectonic influence on the structures of the eastern Mediterranean region was much more varied than has been shown here. It has, for example, given the impetus for the renewal of shoves along ancient disjunctive lines. There are grounds for assuming that the combination of granulation with the resumption of movements along ancient disjunctive lines brought about the origin of a large number of depressions and elevations of the Aegean Sea, the eastern part of the Mediterranean Sea, etc.

From a morphotectonic analysis of the underwater and above-water coastal strip of the Mediterranean basin it follows that comparison of the morphological features of individual sectors of the bottom with the geological and tectonic structure of the adjacent dry land makes it possible to determine to some degree the possible continuations of continental structures under water, and thereby to bring out the features of the geological structure and the formation of small bottom sections of individual basins, as well as of the zones of continental shoal and the slope as a whole. For example, the region

adjoining the Sea of Marmara on the east consists of several zones of tertiary uplifts and depressions that are latitudinally oriented (Kopp, 1961).

It appears that the deep-water basin of the Sea of Marmara also originated on the site of a similar depression. This is also proved by the fact that across the bed of the sea there extends the basic North Anatolian Fault (Pazoni, 1961, and others), which extends along similar depressions on the dry land in the vicinity of this sea. According to the morphological signs, this fault can also be extended across the northern graben-like bed of the Aegean Sea to the Magnesia peninsula. The central part of the Aegean Sea was formed on the site of submerged rigid Hercynian structures cropping out on numerous islands (Pinar, Lahn, 1952; Makhachek, 1959). This region is separated from the alpine structures on the south by a continuation of the zone of tectonic seams extending from the Gulf of Kerme (Turkey) across the volcanoes Nisiros, Santorin, 27 Milos, and others, which testify to the existence there of a belt of abyssal fractures. A deeply depressed continuation of gigantic alpine latitudinal Myocene folds, with the disjunctive structures accompanying them, noted in Anatolia (Pinar, Lahn, 1952) may be the Cretan Sea.

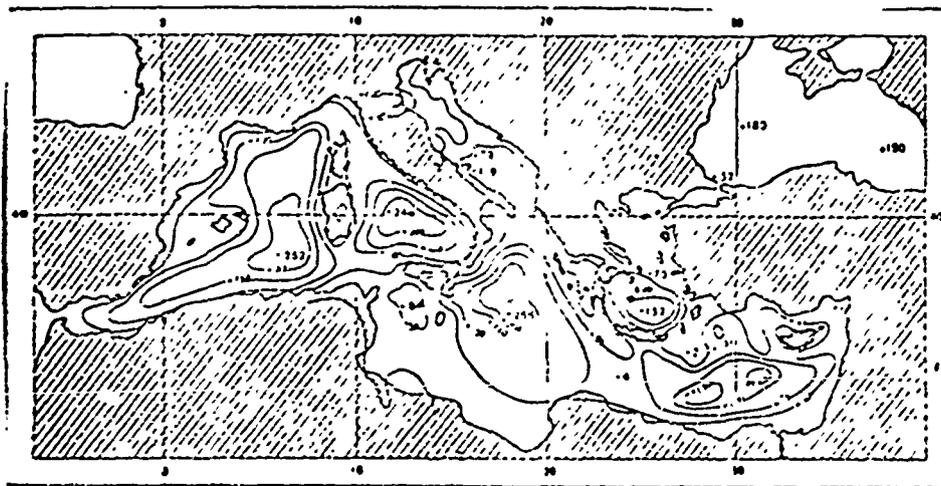


Figure 3. Gravimetric diagram of the Mediterranean Sea (according to the data of Bruyn, 1955).

In the eastern part of the Mediterranean Sea, in the region of southeast Italy, it is possible to trace an underwater continuation (to a depth of 3000 m) of the Apulian plate (the Salentine peninsula), which is characterized by positive gravity anomalies both under water and on dry land (Morreli, 1961). In the region of the Bay of Taranto there is a continuation of the intermontane depression of Bradano in the form of Quaternary deposits. This is confirmed by morphological and gravimetric data (Figure 3). Judging by the high (up to +100 milligal) gravity anomalies (Bruyn, 1955) and the morphological signs, the vicinity of the Bay of Malta and the region east of it can be a continuation of the structures of the Iberian plateau (the southeast of Sicily). The morphological stages in the limits of the continental slope east of the Bay of Malta, with individual elevations developing on them, are represented by limestone massifs, depressed along the faults, with ancient volcanic cones (by analogy with the Iberian plateau). The region of Syrtus Major is a continuation of an enormous belt of depression, extending in a latitudinal direction, south of Cyrenaica-Marmarica from Egypt.

The character of the morphology of the underwater region in the vicinity of the Nile is to a great extent determined by the influence of the efflux of the sedimentary material of the Nile River, which started at the end of the Myocene, when the Nile valley was formed in Egypt in the process of the formation of large Myocene folds (Makhachek, 1961). The region of the continental slope of the Arabian Near East Phoenician Sea is apparently a continuation of one of the branches of the great East African Fractures, which determined the fault character of the continental slope at the coast of Israel-Lebanon. The island of Cyprus, being a fragment of the land of Syria (Henson, and others, 1949), constitutes a young horst elevation (Shmidt, 1960). Only its northern mountain chain (Cyrene) is the

southern extremity of the arc of alpine structures of the Cilician Gates. The complex morphology of the bottom in the vicinity of central Greece is determined by the influence of fractures which intersects the folding structures of the continent and of its underwater portion. The central group of Ionian islands constitutes sectors of land broken up by faults, separated by sea passages (Makhachek, 1961).

According to gravimetric data, the northern part of the /28 Adriatic Sea is a continuation of a thick Neogene-Quaternary depression of the Po River. In the remaining part of the sea are developed the rigid structures of the massifs of the Gargano and of the Apulian plate, this being proved by almost analogous gravitational anomalies in the above-water and underwater regions (Morelli, 1961). The possibility is not excluded that these structures also continue into the northern part of the sea, but there they are covered by a very thick sedimentary series. It is interesting that the zone of the depression in the northern part of the sea undergoes strong subsidences at the present time as well (Salvioni, 1957; Puppo, 1957).

In the opinion of a number of researchers (Beneo, 1950; Castany, 1955, 1959; Caire, Mattauer, 1960), geological and tectonic links exist between Tunis and Sicily. The connecting link for them are the structures of the African-Sicilian sill. This region is characterized by considerable gravitational anomalies and a small (about 1 km) total thickness of the sedimentary series (Moskalenko, the present collection), this testifies to the shallow occurrence of the crystalline foundation.

The southwest region of the Tyrrhenian Sea is, in the tectonic sense, a continuation shoal (the banks of Eskerki, Frer, Estafet, the island of Galit; Castany, 1955, 1959), and in the vicinity of the continental slope, all the way to its foot. A confirmation of what has been said above may be the morphological similarity of the Bizerte hills with the relief

of the continental slope of this region. Such viewpoints have been expressed by a number of foreign researchers (Segre, Castany, 1955; Segre, 1958). Thus it appears that this region is a submerged zone of the Atlas structures. Its eastern boundary is disjunctive, and possibly coincides with the underwater continuation of the Zagran fracture.

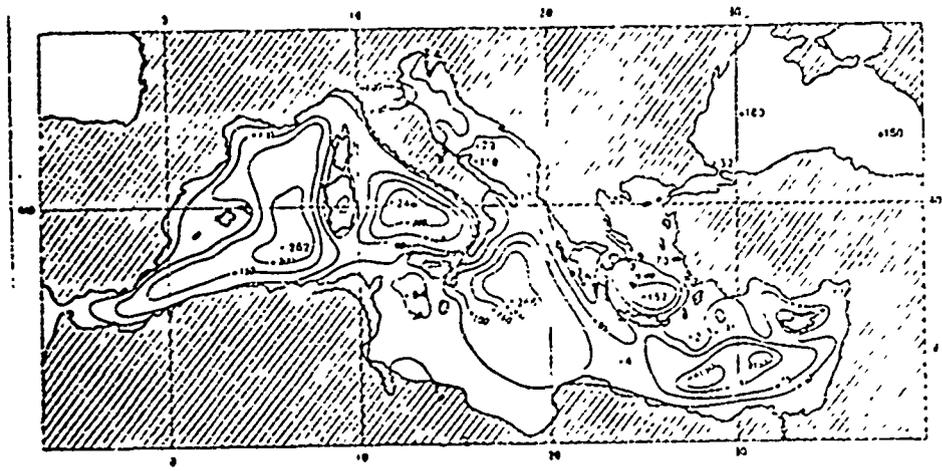


Figure 3. Gravimetric diagram of the Mediterranean Sea (according to the data of Bruyn, 1955).

A morphological similarity is observed between the exterior hilly zone of the Tuscan Apennines and the partially hilly north Tyrrhenian region. The Tuscan islands, which include granite and trachyte ones (Elba, Capraia), constitute fragments of a submerged isthmus between Corsica and the Apennines (Collet, 1938). An analysis of the geological structure of the islands and of the geological material obtained in dredging the bottom confirms the existence in this area of a submerged zone of the Alps (Segre, 1958; Shatskiy, Bogdanov, 1961; Belousov, 1962). The presence of young intrusive bodies in the Ligurian region and in the area between Corsica and the Apennines characterizes this zone as eugeosyncline. The gently sloping character of the continental slope testifies to the smooth tectonic curve in connection with the closure of this zone in the Tyrrhenian Sea. There is a number of indications (Trevisin, Tongiorgi, 1957) concerning the recent existence (Myocene-Pliocene) of dry land at the site of the entire Tyrrhenian Sea.

The Atlas mountain ranges, which extend in a latitudinal direction along the Algerian coast, are separated by structures of a meridional direction and a northeast direction. These perpendicular structures have submarine continuations which determine to a considerable extent the transverse undulation of the continental slope (Bourcart, Glangeaud, 1954). In the coastal part they form the sides of many bays (Bugi, the Bay of Oran, etc.). The inhomogeneity of the submarine slope of the Tunis-Morocco coast is also brought about to a considerable extent by the underwater projections of ancient (Paleozoic) coastal massifs (Shenua, Bu-Zarea, Buzegza, Great Kabilia, Kabilia-Kolo, Btuk, etc.). The gentle character of the slope at the site of the western submergence of the Tell Atlas ranges is caused by the underwater continuation of the Tertiary Taza depression, which in the Pre-Pliocene period connected the Mediterranean Sea with the Atlantic Ocean. At present the portion of it in the vicinity of the Mediterranean Sea is occupied by the Oued-Moulouya River valley. The underwater continuation of the meridional zone of land faults (Makhachek, 1959), which approach the sea in the vicinity of the river, apparently separates the Algerian zone of the continental slope from the Moroccan zone.

The region of the sea of Alboran is the site of the commissure of the Riphean and the Baethan cordilleras, the underwater continuations of which are detected by morphological signs (underwater ranges) in the region of the Strait of Gibraltar (Hernandez, 1961; Giemann, 1961).

The region of the Bay of Lyons is a sector of the flooded zone of the Hercynian depression of the Rhone and Saone rivers. Study of the bottom by means of dredging (Denizot, 1958; Bourcart, 1959) shows that this region continued to become depressed in the mouth of the Rhone river with rock obtained in dredging the continental slope, Bourcart considers that the underwater valleys in the region of the bay are of dry-land origin.

The Maures massif (between the mouth of the Rhone river and Nice) constitutes a sector of the submerged massif of the Hyeres islands, broken up by meridional faults. This is responsible for the extremely great ruggedness of the continental slope of this region. The underwater continuation of this massif have been detected between Marseilles and Carnes (Bourcart, 1960). East of Marseilles the sea bottom is composed of Paleozoic rock of sedimentary origin (Sisier shales), and opposite the Maures massif is composed of very much broken-up granite, probably of pre-Cambrian age. On the basis of study of the volcanic products at the Capes of Antibes and Aix, and in the Var valley (Bourcart, 1959), it is assumed that the deepwater region between the capes of Antibes and Maillot is represented by an ancient Paleozoic foundation. According to dredging data, the continuation of the Provence Alps may be assumed to be in the zone of the continental slope (Bourcart, 1959, 1960), and the continuation of the serpentinite-ophiolite massif of Voltri (Segre, 1938) may be assumed to be in the region of the gulf of Genoa. On the continental slope of Voltri massif is bounded by two underwater valleys, which are a continuation of the above-water valleys of Bisagna and Poltsevera Teler. On the slope of the Bay of Genoa, in addition, Triassic limestones have been detected, greatly cut up by underwater valleys. The enumerated continuations of the various structures along the Provence coast may also be distinguished on the basis of a somewhat different morphology of its individual sectors.

Underwater continuations of the ground-level structures (valleys are observed also at the western coast of the granite massif of Corsica).

The acute difference in the character of the underwater relief of Sardinia and Corsica is, in all probability, due to the various geological structure of their underwater parts. Judging by the geological structure of the east coast of Sardinia and the result of bottom dredging, it may be assumed that in

distinction from Corsica, the underwater part of Sardinia is covered by a sedimentary series and constitutes the edge of the zone of continuous submersion of the Alger-Provence basin. Evidence for this can be found, for example, in the periodic volcanic outpourings in western Sardinia during the Oligocene-Pliocene period.

A survey of the possible continuations of continental structures under water in the Mediterranean Sea has shown that the morphological heterogeneity of the continental slope is for the most part caused by an inhomogeneous geological structure and insufficient tectonic development of individual sectors of the coast. It becomes obvious that the unequal dissection of the continental slope may be due not only to an unequal degree of ground-level and underwater erosion, but also to non-tectonic movement. Judging by the tectonic conditions, the first alternative is most likely for the African coast of Egypt-Libya, the Gulf of Lyons, the west coast of Sardinia, and the northern and southern regions of the Tyrrhenian sea, while the second alternative is more likely to apply to the Balkan-Anatolian coast of the Aegean Sea. The remaining regions have been subjected to the action of both factors to an equal extent.

As far as the time of submergence of the indicated continental structures is concerned, on the basis of an analysis of the tectonic development of the coastal land, it may be assumed that in the regions of the sea of Marmara and the Cretan Sea they were laid down in the Myocene-Pliocene period, and in the region of the Aegean Sea they were laid down at the end of the Pliocene, when shoves along ancient faults were resumed. Simultaneously with uplifts and subsidences on land and block breakup in the Pliocene-Quaternary period, there took place subsidences of regions adjoining the Apulian plateau and Calabria.

Cenozoic warping in the zone of the depression of Africa began probably in the Paleogenic period, when the arched uplift of Cyrenaica and Marmarica were formed. Then they were renewed in the Pliocene, when well-defined vertical movements developed in the entire region, bringing about the formation of erosion-fault latitudinal scarps on land. Thus, new sectors of the platform became involved in the subsidence. Regions adjacent to the Arabian Near East formed as a result of flexure-fault subsidence in the upper Pliocene simultaneously with the uplift of the continental plateaus. The Balkan zone of the sea could have become involved in the subsidence in the Post-Pliocene period, when the Peloponesus underwent an enormous arched uplift (Makhachek, 1959). As a result of Post-Pliocene breakups of the Crete-Rhodes arc, within its limits individual depressions and straits were formed. The formation of the depressions of the Hellenic trough, which developed at the site of the Myocene foredeep, may be linked to this movement.

The present-day structural plan of the Adriatic Sea was also determined by Pliocene-Quaternary movements (Grdzlov, 1962).

Of a similar age is also the graven of the African-Sicilian sill, the Tyrrhenian Sea (Trevisa, Tongiorgi, 1957; Sigogneau, 1960), the African zone of the Algerian-Provence basin, the Balearic zone, and the Gulf of Lyons.

The subsidence of the enumerated regions most likely of all took place in stages. Morphological signs of this may be steps on the continental slope, part of which, in all probability, are peneplanation plains. The periodicity of the volcanic outpourings also speak in favor of such a character of the subsidence. Thus, in the Cenozoic in the region of the Mediterranean Sea, the first volcanic outpourings were manifested in the Upper Oligocene, and then in the Pliocene-Quaternary period (Glangeaud, 1952). This is also testified by the eruptions of volcanoes in west Sardinia (Makhachek, 1959).

The question of the time of subsidence of the central parts of individual basins of the Mediterranean Sea is less clear. A number of opinions exists with regard to this question. Some researchers (Caire, Glangeaud, Grandjacquet, 1960) consider, for example, that certain parts of the Mediterranean basin (the Tyrrhenian) Sea are a residual basin of the Paleolithic ocean. Others (Mazarovich, 1951; Bourcart, Glangeaud, 1954; Glangeaud, 1956; Berhmann, 1958; Kuenen, 1959; Muratov, 1960; Belousov, 1962) retain the opinion that the basin of the Mediterranean Sea is a recent (Myocene-Pliocene) formation.

It seems to us that the formation of the deepwater part of the Mediterranean Sea continued for a long time, and proceeded at unequal rates in the various parts.

In some cases, the formation of deepwater regions probably took place simultaneously with subsidences of coastal regions (the Sea of Marmara, the Aegean Sea, the Cretan Sea, the Sea of Alboran). But quite evidently the subsidences of the coastal and central parts sometimes did not coincide, and the growth of the depressions was gradual or periodic (accelerated during strong orogenic movements). An example of such an expansion of a basin may be the Algerian-Provence basin.

Signs of young uneven subsidence of the basin of the Tyrrhenian Sea can be seen both in the morphology of the bottom (the graduated character of the slope) and in the nature of submarine volcanic manifestations. The most extensive steps have developed along the coast of the Apennine peninsula and Sicily. They are not infrequently composed of land (Sicily) /31 and underwater volcanic cones. Products of volcanic outflows on the steps have also been discovered on the basis of gravimetric data (Segre, 1958); they encircle the entire deepwater part of the sea in individual spots. This testifies to the

disjunctive nature of the boundaries of the trough of this basin. High and sharp-peaked volcanic cones in the central part of the Tyrrhenian basin compensate, as it were for the subsidences of the broken-up rigid base of the sea bottom. Manifestations of present-day volcanism on the boundaries of this sea testify to its continuing subsidences at the present time as well.

The formation of the central part of the eastern half of the Mediterranean Sea is rather complicated. The region of the Hellenic trough consists of the Myocene foredeep of the Alpine zone of the Dinaric and Anatolian Alps, complicated by Pliocene-Quaternary vertical movements. The chain of depressions off the coast of Africa has formed on the site of an ancient depression which has been rejuvenated during the Oligocene period and later. The central part is in all probability a continental structure, involved in the subsidence by the Alpine foredeep and the African depression. True, this arch has some external similarities with the central oceanic ranges (relative height up to 1 km, long length -- about 1300 km, a relatively flat and broad upper part, small, up to 0.2 km, thickness of loose sediments). But this is only an apparent similarity. As yet there is no basis to consider the Central Mediterranean Arch to be analogous in its internal structure and origin to, for example, the East Pacific Central Elevation (inflation of the oceanic earth crust). It is known (Shor, Raitt, 1959; Menard, 1960), that this elevation is composed of normal and even thinned-out (to 3.7 km) oceanic troughs.

The features of the tectonic development of the Mediterranean Sea that has been set forth make it possible to provide an explanation for the rather variagated structure of the earth crust underneath this basin. In Figure 1 it is shown that in the Algiers-Provence basin and in the Tyrrhenian basin the central

parts consists entirely of a transitional type of earth crust, similar to the oceanic type. In the eastern part of the Mediterranean Sea such an earth crust is developed only in the form of extensive spots. Since it has become apparent that the eastern part of the Mediterranean Sea is tectonically younger than the Algiers-Provence basin, it is possible to state hypothetically that in the western part of the Mediterranean Sea the process of oceanization is in the stage of completion, whereas in the eastern part it is in the development stage. It can be seen from Figure 1 that these processes have already encompassed also the ancient rejuvenated regions (the chain of depressions of the coastal Africa), and younger ones (the Cretan Sea).

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STUDY OF THE SEDIMENTARY SERIES OF THE MEDITERRANEAN

/34

SEA BY SEISMIC METHODS

V.N. Moskalenko

The Institute of Oceanography started to carry out seismic research in the Mediterranean Sea in 1960 on the expeditionary ship "Academician S. Vavilov." The principal task faced by the seismic group was to carry out reconnaissance seismoacoustic operations in order to investigate the structure and the acoustic characteristics of the sedimentary series in the most interesting, in the geologic-tectonic sense, regions of the Mediterranean Sea through which the ship's course passed. Figure 1 shows a map with the location of the seismic profiles and stations worked by Soviet and foreign expeditions.

In 1960 M.S. Mikhno and G.N. Shchiptetsov worked out two seismic profiles by the reflected wave method: profile 1 in the Ionic Sea and profile 2 in the Tyrrhenian Sea. In the 1960-1961 period V.M. Kovylin and G.N. Shchiptetsov completed two more profiles by the reflected wave method: profile 3 in the eastern part of the Mediterranean Sea and profile 4 in the Ionic Sea. In 1962 V.M. Moskalenko worked out a profile by the reflected wave method southwest of the strait of Kasos, and carried out point observations -- seismic soundings by the reflected wave method -- in the Algiers-Provence basin, the Ionic Sea, the Syrtus Sea, in the Tyrrhenian Sea, in the eastern part of the Mediterranean Sea, and in the straits between Tunis and the islands of Sicily and Sardinia -- at a total of 35 stations. In the course of 3 expeditions, seismic profiles were worked out with a total length of 180 km.

In addition, seismic projects with the reflected wave method and the refracted wave method (with the use of seismic radio buoys) were carried out by scientists from England, the USA, France, and Sweden. They worked out 14 profiles by the refracted

wave method with a total length of 320 km, and 28 point seismic sounding stations, in all basins of the sea and on the islands of Malta and Cyprus. Scientific research on islands was carried out with the aim of tying in and comparing the seismic data for deep bodies of water with the geology of these islands.

It can be seen that seismic research was carried out in almost all the seas of the Mediterranean basin. Unquestionably the scope of seismic operations carried out up to the present is not great for such an extensive sea with such a complex geological and tectonic structures, even for the first, most general characterization of the structure of the sedimentary series. All the seismic research in the Mediterranean Sea has to do principally with the sedimentary series. Out of 82 stations, only at 10 stations were waves from a crystalline foundation registered. It was impossible to isolate waves from deeper seismic boundaries.

The Institute of Oceanography carried out seismic research in the Mediterranean Sea by reflected wave method. The seismic profiles were worked out by a piezo scythe, 9-channel in the second trip, 3-channel in the third trip, four-channel in the 35 fourth trip. The hydrophones in the scythe were located every 100 m at a depth of 15 m. Observations along the profile were carried out every two km at profiles 1 and 2, every 3-7 km at profiles 3 and 4, and every 1.0-1.3 km at profile 5. The methods used in carrying out the seismic projects were selected directly on the spot, depending upon the complexity of the topography of the bottom and the capacity for correlation of the principal groups of waves. Point seismic soundings were carried out in addition to the principal oceanographic operations. The recording of seismic waves took place on two hydrophones situated 1 below the other at a depth of 12-15 and 25-30 m. The distances between stations varied greatly -- up to 75-110 km and more.

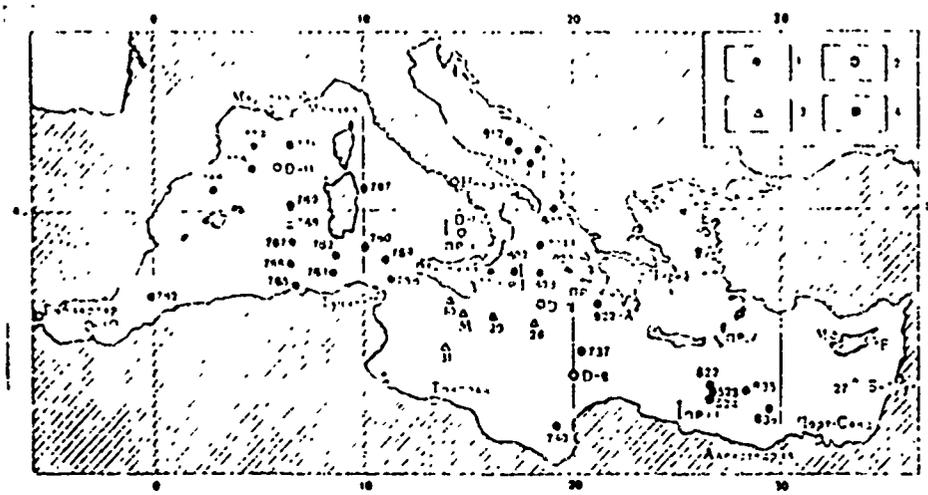


Figure 1. Location and seismic profiles and stations.

- 1 - seismic profile and stations worked out by the Institute of Oceanography, Academy of Sciences, USSR in 1960-1962;
- 2 - seismic profile worked out by an American expedition in 1951-1953;
- 3 - seismic profile worked out by an English expedition in 1950-1952;
- 4 - seismic stations of a French expedition in 1959 (Maroaur, 1959).

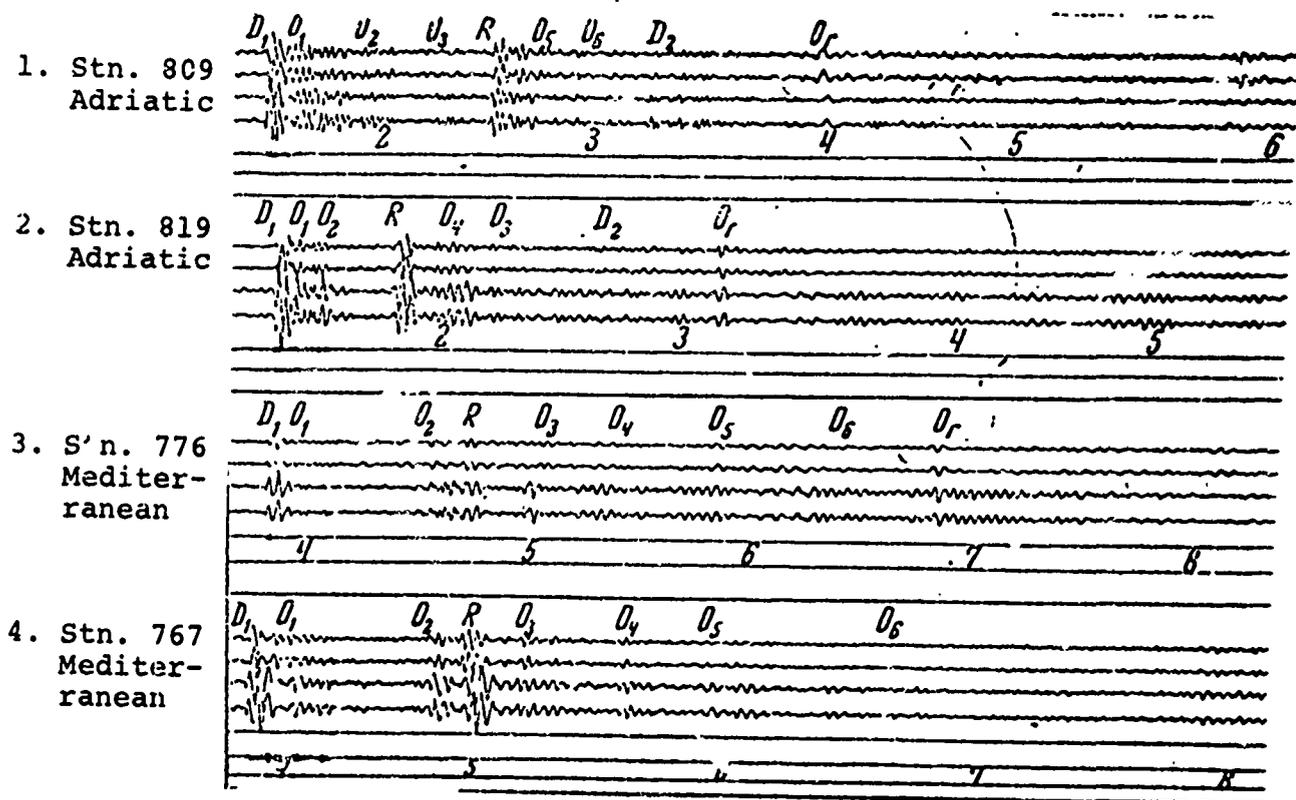
According to the character of the seismic information, all seismograms may be subdivided into 3 groups. On seismograms of the first group are registered reflections from the boundaries of the division of the upper unconsolidated sedimentary series (stations 737, 740, 765, 774, 802, etc.). On seismograms of second group are registered reflections from the boundaries of the division of the upper and the lower sedimentary series with recording of the intensive R wave from the boundary of the division between them (Figure 2). It is assumed that the lower sedimentary series is represented by denser consolidated sediments. Sediments of the second group were obtained in all regions of the Mediterranean Sea (stations 767, 769, 807, 809, etc.). In the third group are seismograms on which a series of reflections from the bottom sedimentary series is ended by recording of the multiphase

and lower-frequency O_{bdry} wave, which is characterized by an amplitude of the same order as the preceding waves (stations 766, 775, 788). Apparently this wave is a reflection from the base of the sedimentary series. The dynamic expressiveness of the R and O_{bdry} waves (with respect to the other reflections), and the values of the thicknesses computed prior to these reflections, permit these waves to be taken for reflections from the root and base of the bottom sedimentary series of consolidated sediments. The values of the thicknesses here agree well with the data obtained by American and English researchers (Baskell, Swallow, 1953; Gaskell et al., 1958; J.I. and M. Ewing, 1959).

In all regions of the Mediterranean Sea, a large number of reflecting horizons is observed in the sedimentary series. Up to 5-7 groups of reflected waves are recorded on the seismograms, and in individual regions their number reaches 9-10 and more (Station 803).

For calculating the thickness of the sediments an average 37 was used, calculated on the basis of thicknesses and average velocities determined by foreign expeditions (see above), with account taken of the gradient of the average velocity: for unconsolidated sediments $\alpha = 0.33$, for the bottom sedimentary series $\alpha = 0.75 \text{ sec}^{-1}$.

(See Figure 2 on following page)



The Algiers-Provence Basin

In the Algiers-Provence basin, seismic research was carried out in the form of point seismic soundings along the meridian of 6° E in the seas of Gallo and Alboran -- a total of 10 stations. Two seismic profiles (D-7 in the Sea of Alboran; D-11 in the Sea of Gallo) were made by an American expedition (J.L. and M. Ewing, 1959). Profile B-11 lies almost in line with the profile along the meridian of 6° E.

On the profile along the meridian of 6° E are distinguished reflections from the upper and the lower sedimentary series (Figure 3a). The boundaries between them are well correlated by the characteristic group recording of two intensive waves. The second wave is 1.2-1.3 times greater in amplitude than the first.

The time interval between them is retained on all seismograms. On stations 766 and profile D-11 are registered waves from the foot of the sedimentary series.

The total thickness of the sedimentary series gradually increases in a northward direction from 4.5 km (station 766) to 5.8 km (profile D-11). The thickness of the upper sedimentary series of unconsolidated sediments amounts to 0.5 km at station 766 and also gradually increases northwards to 1.35 km (profile D-11, station 771).

In the series of unconsolidated sediments in the northern part of the profile, considerably more reflecting boundaries are recorded than at the shores of Africa, but simultaneously with this there is observed a considerable weakening of the intensity of the reflections from the boundary of the division of the lower sedimentary series. Thus, at station 771 it was not possible to distinguish reliably a single reflection from the lower sedimentary series. The gentle, almost horizontal occurrence of the layers of the sedimentary series, their persistence with respect to thickness along the profile (particularly in its southern part) -- all these data indicate that this region, located between the Hercynides of the island of Sardinia and the Alpides of the Balearic Islands, is a rigid, stabilized sector of earth crust with intensive sediment accumulation.

On the profile across the Sea of Gallo are also distinguished the upper and lower sedimentary series, the thickness of which decreases considerably in the southwestern part of the profile. In the region of station 788 the total thickness of the sedimentary series is 3.5 km, the thickness of the upper sedimentary series of unconsolidated sediments is equal to 0.6-0.8 km.

In the Sea of Alboran the thickness of the unconsolidated series is 0.7 km (station 782). The thickness of the entire sedimentary series on profile D-7 is 2.0 km.

The Tyrrhenian Sea. In the Tyrrhenian Sea the principal seismic projects were carried out in the southeast border of the deepwater basin; a 42-km profile was worked out in a meridional direction. Two groups of waves stand out clearly on all seismograms. The first group includes reflections from the upper sedimentary series, the second group contains reflections from the lower sedimentary series. In each group of waves it is possible to distinguish up to 3-4 and more reflections. It was, however, possible to correlate only the reference reflections, the most intensive ones, with a clearly distinguished axis of coherency and a characteristic group recording of several waves.

The reflecting boundaries lie horizontally along the profile. The thickness of the unconsolidated sediments is about 0.5 km, and only at the northern segment of the profile (stations 24-29) is its increase to 0.8 km observed. Obviously, the increase of thickness of the unconsolidated sediments is connected with the fact that the profile passes into a region of continental slope with a higher sediment-accumulation intensity. On seismograms /38 6-16 a deeper reflection is to be traced, very apparently from the base of the lower sedimentary series of lithified sediments. The thickness of the lithified sediments up to the boundary is 1.6-1.7 km. The total thickness of the entire sedimentary series in this region is 2.2-2.5 km.

(See Figure 3 on following page)

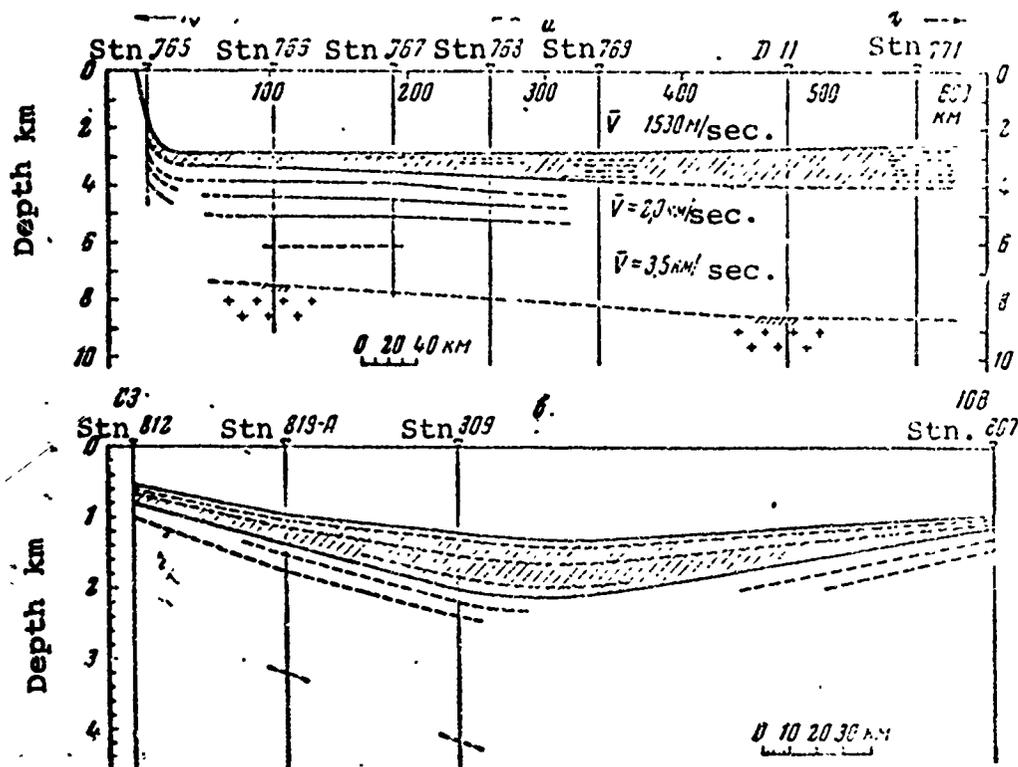


Figure 3. Seismic cross-section.

- a - along the meridian of 6° E, Algiers-Provence basin;
- b - across the southern basin of the Adriatic Sea.

According to the data of the American expedition (J.L. and M. Ewing, 1959), 20 km east of profile 2 the thickness of the non-lithified sediment is 0.87 km. Underneath occurs a series with a boundary velocity of $V_{bdry} = 4.9 - 5.7$ km/sec.

East of the island of Sardinia, at station 797, according to point seismic sounding data, the thickness of the loose sediments is very insignificant, apparently up to 0.1 km. Of the same order are the thicknesses of the upper sedimentary series in the region of the straits between the islands of Sicily and Sardinia and the Tunisian coast. Only in the central part of the bay of Tunis is the thickness 0.7 km.

The Adriatic Sea. The southern basin of the Adriatic Sea is squeezed in between the Hercynian massifs of the southern part of the Apennine peninsula on the west and Alpine structures on the east and northeast. The southern basin of the Adriatic Sea is a region of heavy accumulation.

According to point seismic sounding data, up to 4-6 reflecting horizons can be traced in the southern basin. At all stations there is to be clearly distinguished an intensive wave, which apparently is a reflection from the roof of the lower, more consolidated sedimentary series. This boundary can be /39 traced from the Strait of Otranto (station 807) northwest on station 809, 819-A to station 812 (Figure 3b).

The maximum thickness of the nonlithified sediments has been registered at the station with the deepest water, number 809, and is equal to 0.8 km. At the periphery of the basin the thickness of the upper sedimentary series gradually decreases to 0.5 km at station 807 (the Strait of Otranto) and to 0.25 km at the northwest boundary of the basin (station 812). At station 809 and 819-A a depth wave has been recorded with a time difference of entry with respect to the bottom reflection $\Delta t_1 = 1.81$ sec (station 819-A) and $\Delta t_2 = 2.30$ sec (station 809). The total thickness of the sedimentary series up to this boundary is approximately 3-4 km.

The Ionian Sea. In the Ionian Sea almost the entire scope of seismic operations was performed in the northern and partly in the central parts of the sea. In this region the sedimentary series has a very complex structure. The sharply dissected bottom topography, with large gradients with respect to height, the presence of a system of deepwater troughs bordering the Ionic Islands on the west, southwest and on the south, all this has undoubtedly reflected to a considerable extent upon the formation and structure of the sedimentary series.

Seismograms of all three groups were obtained in the Ionian Sea. It was possible to carry out a partial correlation of the reflected waves only at profiles 1 and 4, and it was not possible to do this for the point seismic sounding stations, each of which differs from the other with respect to cinematics, dynamics, and the number of reflections. The greatest number of waves (more

than 10) was recorded at station 803. The deepest boundary at this station and in profile 1 occurs at a depth of approximately 2.5 km, and at station 804 at a depth of 3.2 km. The thickness of the upper sedimentary series in this region changes sharply from station to station and varies within the limits of 0.3-0.7 km. Only in the central part of the sea is the series of unconsolidated sediments persistent with respect to thickness; at stations 28 and 29, and in profile B-9 their thickness is 0.3-0.4 km. At profile 1 the thickness of the nonlithified sediments divides clearly into two layers with a total thickness of 0.5 km.

The Sea of Sirte and the eastern part of the Mediterranean Sea. Seismic projects of limited scope were carried out in the Sea of Sirte and in the eastern part of the Mediterranean Sea. For this entire region there are only 3 seismic profiles (one of them was worked out by the English; Gaskell, Swallow, 1953) and several point seismic sounding stations.

From these scant data it is very difficult to draw any conclusions concerning the structures of the sedimentary series of this region. In profile 3 the reflections of the upper sedimentary series are represented by a series of intensive waves, the number of which in individual seismograms comprises 7-9 and more (station 534). The thickness of the upper sedimentary series is more than 1-1.2 km. At stations 522, 523, 835, and 836 the thicknesses of the upper sedimentary series are respectively equal to 0.8, 1.5, 1.3, and 1 km. The deepest reflection is recorded at station 835 at a depth of 4.0 km. In the eastern part of the Sea of Levant, in profile 27 the thickness of the nonlithified sediments is 0.3 km. Underneath lies a layer in which the boundary velocity comprises 4.3 km/sec. Possibly this layer consists of Miocene limestones which, according to seismic observation data in the Bay of Famagusta, underlie the deposits of the upper series of unconsolidated sediments.

Interesting results have been obtained in profile 5, south-east of the Strait of Kasos, in the zone of deepwater troughs. This profile passes through the crest of the uplift with a mark of 640 m, and passes further along its steep slope (to 25°) to a depth of 2700 m. In spite of the fact that the observation interval was not more than 1.0-1.3 km, it was possible to carry out only a partial correlation of the waves at small segments of the profile. It can, however, be clearly seen that the wave pattern gradually increases in complexity in the direction of the crest of the uplift. The number of intensive waves with distinct arrivals increases; these are apparently reflections of the acoustically rigid boundaries of the division in the sedimentary series. The layer at the bottom of the slopes of this elevation is most apparently composed of rather consolidated sediments, and only in the hollow of the northern slope, judging by the reduction in the reflecting power of the bottom, does it consist of semiliquid or very loose sediments. This is fully explainable: loose and semiliquid sediments creep down from the steep slopes under the influence of the force of gravity, and accumulate at more levelled-out sectors of the relief. /40

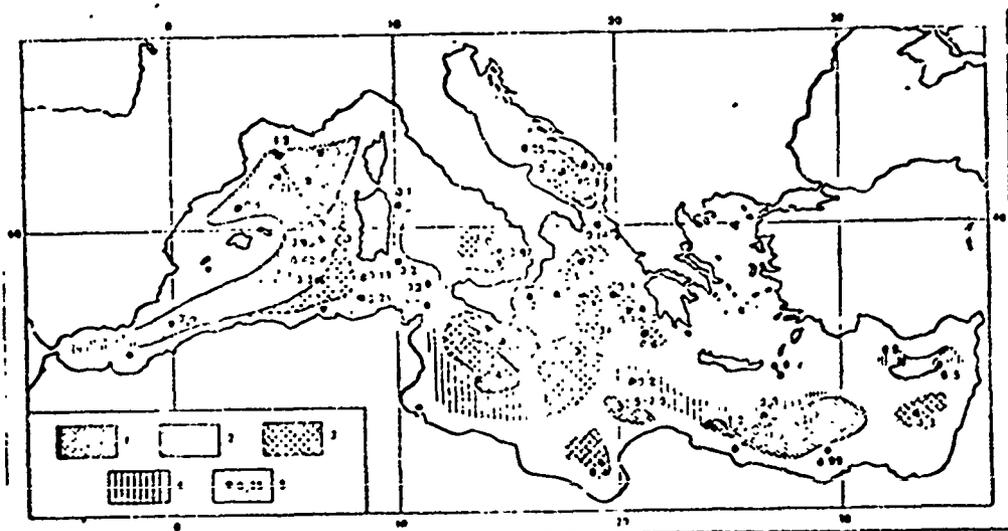


Figure 4. Map of the thicknesses of the upper sedimentary series of unconsolidated sediments.

(key on next page)

(key to Figure 4)

- 1 - thickness greater than 1 km;
- 2 - thickness 0.5-1.0 km;
- 3 - thickness 0.25-0.5 km;
- 4 - thickness less than 0.25 km;
- 5 - thickness (in km) at the given station

All the conclusions concerning the geological and geophysical structure of the sedimentary series of the examined regions of thicknesses and the rate of propagation of seismic waves, are preliminary and very general. This is connected with the fact that, in the first place, not all the available materials on the Mediterranean Sea have as yet been thoroughly processed all the way through; in the second place, very little seismic research has as yet been conducted in the Mediterranean Sea. Seismic stations and profiles are scattered over the entire sea, essentially without a system. Very few profiles have been worked out by the refracted wave method. Of all the seismic observations, about 83% have been conducted by the reflected wave method, but due to the small base of the piezo sickle it was not possible to effect a single determination of the effective velocities with sufficient accuracy.

The principal value of the seismic research carried out in the Mediterranean Sea lies in the fact that it encompasses almost all the regions of the Mediterranean Sea. On the basis of the materials of Soviet and foreign expeditions it is already now possible to make even though preliminary, but nevertheless definite conclusions concerning the character of the structure of the sedimentary series for many regions of the Mediterranean Sea. On the basis of the materials of these expeditions, a map has been compiled of the thicknesses of the upper sedimentary series of unconsolidated sediments (Figure 4), which, in spite of the

large number of blank areas in it, can be used for solving a number of geological and tectonic problems of the Mediterranean Sea, its geological structure and history.

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THE GRANULOMETRIC COMPOSITION OF CONTEMPORARY SEDIMENTS /42
AND SOME FEATURES OF THEIR FORMATION
IN THE MEDITERRANEAN SEA

Ye. M. Yemel'yanov

The coastal bottom deposits of the Mediterranean Sea have been studied since ancient times, whereas mention of deepwater deposits was first made only at the end of the 19th century. In 1894 the Frenchman Pruvo first described the sediments of the continental slope of the French coast (Bourcart, 1953). In the beginning of the 20th century the deepwater sediments of the Mediterranean Sea were described by Tule, Chevalier, Andree, Boggild, and others (Boggild, 1912; Chevalier, 1914; Andree, 1920). Two types of deep water sediments were distinguished -- blue oozes with a CaCO_3 content of less than 30%, and globigerine oozes with a CaCO_3 content greater than 30%. In the postwar years, deepwater and coastal sediments were studied and continue to be studied by French scientists in expeditions on the ship "Calypso" (Bourcart, 1954 a,b, 1959, 1960, 1962; Blanc, 1957, 1958, 1959a,b; Duplaix, Cailleaux, 1957; Nesteroff, 1959; Bourcart et al, 1960).

The materials of the Swedish deepwater expedition, collected in 1947-1948 on the ships "Skargerrak" and "Albatross," published in the report of the expedition also contain some data concerning present-day deepwater deposits (Pettersson, 1958; Norin, 1958; Olausson, 1960).

In the last ten years, the present-day sediments of the Adriatic Sea have been described and studied by numerous Yugoslave scientists, among whom should be mentioned the works of Alfirevic (1959) and Morovic (1951).

With respect to the coastal and shelf sediments of the Mediterranean Sea, some data available for the foredelta parts of large rivers, the coasts of Morocco, Egypt, Israel, Lebanon, (Buen, 1931; D'Arrigo, 1936, Hilmy, 1950; Emery, Neav, 1960;

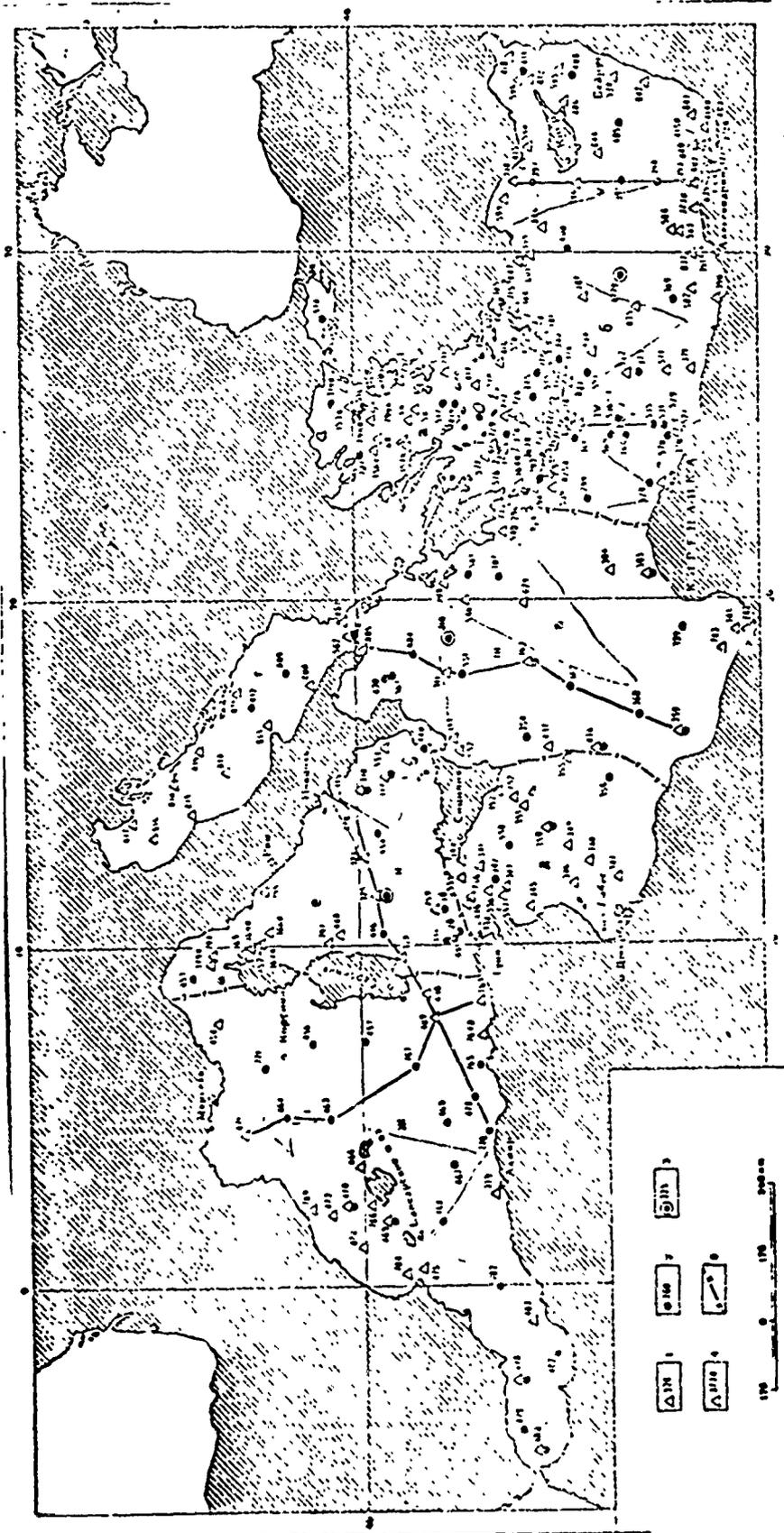


Figure 1. Diagram of the location of stations completed on the expeditionary ship

"Academician S. Vavilov", "Academician A. Kovalevskiy," and the "Vityaz'."

- 1 - samples taken by dredger, 2 - samples taken by direct flow tubes,
- 3 - samples taken by piston tubes; 4 - boundaries of the sectors of the Mediterranean Sea (A-G) noted in Tables 2-8; 5 - position of the lithological profiles; I-V-- profiles.

Ismat, 1962) and others. During the second World War, for the needs of the German navy there were compiled detailed lithological charts of the majority of the coastal, tactically important shallow regions of the shelf of the Mediterranean Sea (Atlas....). The Turkish and Greek coasts of the Mediterranean Sea have been almost completely not encompassed by such projects, and at present we do not have at our disposal any at all reliable data on the shallow sectors of these regions of the reservoir.

The granulometric composition of the sediments of the Mediterranean Sea has been studied far too little. We have at our disposal only some scant data (Blanc, 1958, 1958 a, b) for shallow (5-105 m) sediments of the Bay of Genoa, the French coast, the African-Sicilian sill, and the southern part of the Aegean Sea. For the sediments of the regions, in addition to quartiles, M_d , and the sorting coefficient, 3 types of cumulative curves have been selected; parabolic, logarithmic, and hyperbolic curves. The first of these characterize unsorted sediments, the granulometric composition of which does not change during transportation, the second characterizes sediments, the granulometric composition of which changes in the process of transporta- /44 tion, the third type of curve characterizes elutriated (fine-grained) sediments. Determination of these curves (facies) helps to a considerable degree in determining the genesis of the sediments. But, unfortunately, deepwater sediments have remained almost untouched by such research.

For the Mediterranean Sea, up to the present neither general diagrams of the distribution of individual fractions with respect to area, nor summary charts of sediments has been compiled. The rules governing the arrival and accumulation of sediments have also not yet been determined. The soil diagrams published in the Marine Atlas (1950) and in the Atlas of Physical Geography

Data (1957) are very schematic and imprecise, while the works of foreign scientists dealing with the distribution of present-day sediments do not go beyond the limits of individual regions of the Mediterranean Sea. The first diagram of the distribution of sediments along the entire area of the eastern part of the sea was compiled by the author only in 1960 (1961), but due to lack of data it does not reflect many features in the distribution of sediments.

Soviet geological research in the Mediterranean Sea started in 1959. As a result of four expeditions of the Black Sea Experimental Scientific Research Station of the Institute of Oceanography, Academy of Sciences USSR (1959-1962) on the expeditionary ship "Academician S. Vavilov," samples were collected from 250 stations (Figure 1). In the same period, other Soviet ships of the Academy of Sciences, USSR ("Academician A. Kovalevskiy" and "Vityaz'") collected additional samples at 30 stations (see article by V. P. Goncharov in the present collection). The sediment samples were obtained according to the procedure adopted at the Institute of Oceanography, Academy of Sciences, USSR and were taken by the "Okean-50" dredger (Lisitsyn, Udintsev, 1952), a direct flow tube and a piston tube (Sysoyev, 1956), and a piston tube of large diameter (180 mm) with a length of up to 11 m. The granulometric analysis was carried out by staff members of the Lithology Laboratory of the Black Sea Experimental Scientific Research Station of the Institute of Oceanography, Academy of Sciences, USSR under the leadership of N. G. Prokoptsev by the screen and combined water method (Petelin, 1961; Prokoptsev, the present collection). The graphic treatment of the granulometric analysis data and the classification in connection with differentiation of the sediment types were carried out according to the procedure adopted in the Institute of Oceanography, Academy of Sciences, USSR (Lisitsyn, 1956; Bezrukov, Lisitsyn, 1960).

On the basis of the obtained material were determined the principal features of the arrival and accumulation of sediments in the Mediterranean Sea. A special part in obtaining knowledge of the mechanism of sediment formation was played by study of the granulometric composition of the deposits. . . Granulometric analysis, along with other forms of research, made it possible to trace the sources and the paths of arrival of sedimentary material from land. With detailed granulometric charting it is possible to determine the classes and conditions of the formation of a given sediment type, to expose the part played by various factors (biogenic, atmo-genic, volcanogenic, river runoff) in sediment formation. It is specifically the granulometric composition of the sediments and their sorting that make it possible to determine more fully the complex pattern of the hydrodynamic regime of the basin and of the residence of various benthonic organisms.

On the basis of what has been said, the author considers the study of the granulometry of deposits as a first-priority initial stage in the integrated study of the sediments of marine reservoirs.

The Mediterranean Sea evokes great interest among geologists due to its special geographic and tectonic position. It is located between young, tectonically active mountain structures on the north and southwest, and the African, tectonically little active platform on the southeast. It is known that with respect to the area of its body of water, the Mediterranean Sea is the largest marine reservoir in the world. The area of the water-collecting basin (B) of the Mediterranean Sea is approximately 3,700,000 km², while the area of the reservoir itself (I) is 2,855,000 km². The ratio of B:L=1.3, which but little exceeds such a ratio for oceans and is considerably lower than in the Black Sea (3.7). /45

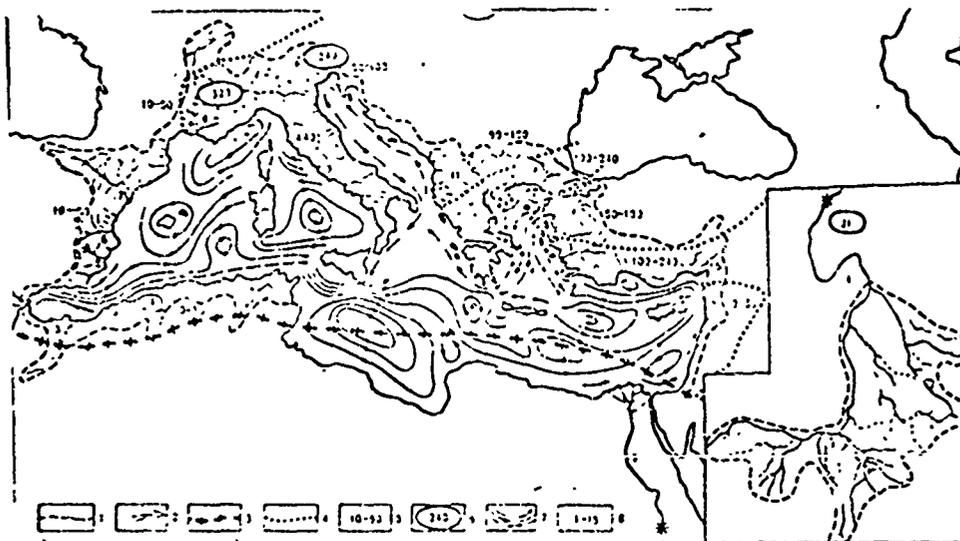


Figure 2. The water-collecting area of the Mediterranean Sea.

- 1 - boundaries of the water-collecting basins;
- 2 - hydrographic network
- 3 - boundaries of the humid and the arid zones;
- 4 - boundaries of different intensities of mechanical denudation in the water-collecting basin;
- 5 - washout of products of mechanical denudation in tons per 1 km² (according to Strakhov, 1961);
- 6 - mechanical denudation in the basis of the largest rivers (1, 8, and 10, see Table 1) in tons per 1 km²;
- 7 - directions of surface currents of the sea;
- 8 - names of rivers designated in Table 1 by numbers (1-15).

The northern and the western parts of the basin are in a humid climatic zone, while the southeastern part is in an arid zone. The water-collection basin of the Mediterranean Sea (Figure 2) belongs to the belt of intensive mechanical denudation (Strakhov, 1961). The intensity of washout from 1 km² of surface of water-collection basin varies within the limits of 10 to 440 m and depends on the dissection of the region and the hydrographic network.

Along the coast of the Mediterranean Sea it is possible to distinguish a number of regions with signs of young (Alpine) tectonic and morphological regimes (The Algiers-Morocco, the West Apennine, the Balkan-Anatolian regions, etc.), as well as regions that are tectonically rather stable (platform regions) with a weakly broken-up relief (the African platform the Pyrenean peninsula, the eastern coast of the Apennine peninsula, etc.).

In places where the regions of a young tectonic regime coincide with regions of high humidity, maximum values of the volume of washed-out materials are observed. This, for example, may explain the high-wash-out modulus (50-240 t per 1 km²) of the Alpine, the Apennine, the Dinaric-Balkan and the Anatolian zones. These zones are usually drained with a dense network of mountain rivers (Figure 2), whereas in the other regions there is considerably less of them, while the region of the African platform (from Tunis to Israel) is entirely drainless. The only exception is the Nile River. Some data concerning the areas of the basins of the largest rivers and their runoffs are cited in Table 1, compiled according to the data of G.F. Lopatin (1950), N.M. Strakhov (1961), and the Great Soviet encyclopedia (1952).

Another very important supplier of detrital material is shore abrasion. The quantitative characteristic of this factor has not yet been accounted for, but since the majority of the /46 shores of the Mediterranean Sea are abrasional (Marine Atlas, 1950), with the exception of the shores of the large gulfs, its high value is obvious.

A considerable part in supplying some of the regions of the Mediterranean Sea with sedimentary material is played by land and underwater volcanism. Volcanic eruptions took place in historical times and are taking place in the contemporary period in the regions of the Apennine peninsula and Sicily, the African-Sicilian sill, the Ionic Sea, and the Aegean Sea (Neumaier, 1902; Pfannenstiel, 1960). The principal masses of pyroclastic material arrive in the southeastern part of the Tyrrhenian Sea and in the southern part of the Aegean Sea. But it is known that ashes are also carried out beyond the bounds of these regions. Thus, ash from erupting Vesuvius has more than once fallen on the decks of ships in the Aegean Sea, and has reached Syria and Africa (Neumaier, 1902). According to our

observations, the regions of the bottom adjoining the cone of the volcano Stromboli are completely covered with ash material. A certain amount of pumice ejected by volcanoes into the sea is also carried out over its entire body of water; this has more than once been observed by us in various regions of the sea, within the water layer, and on the surface of the bottom.

Table 1
Largest rivers of the water-collecting basin
of the Mediterranean Sea

River	Length of river km	Area of river basin, km ²	Average annual water discharge, m ³ /sec.	Solid runoff, million m ³ /yr.
African part of the basin.				
1. Nile	6500	2 867 000	2600*	62-88*
2. Oued-Medjerda	460	22 000	--	--
3. Oued-Moulouya	520	--	1000-1	--
4. Oued Sheliff	700	35 000	4000-1	--
European part of the basin.				
5. Segura	341	14 400	--	--
6. Khukar	498	22 400	--	--
7. Ebro	928	86 800	615	--
8. Rhone	812	90 000	1 700	up to 31.5
9. Riber	405	17 170	210	--
10. Po	658	75 000	1 500	18-300
11. Vardar	368	--	--	--
12. Struma	392	16 800	--	--
13. Maritsa	530	53 800	--	--
Asiatic part of the basin.				
14. Great Menderes	380	--	--	--
15. Dzheykhan	350	--	--	--

* At Aswan

A definite part of the terrigenous material is supplied by atmogetic activity. The greatest quantity of aeolian material arrives in the eastern part of the Mediterranean Sea and in the southern part of the Algiers-Provence basin (Arrenius, 1961). In this respect, some figures cited by Bernard (1959) are indicative. It has been calculated that the number of particles of corroded aeolian sand up to 30 μ in size reaches in certain places in the eastern part of the Mediterranean Sea, 170,000 per 1 ml of water, which exceeds many hundred- and thousandfold the content of particles suspended in water at Monaco and in the region of Algiers. The maximum quantity of suspended particles was observed north of Cyrenaica.

In spite of the obvious part played by the aeolian factor in the delivery of terrigenous material to the Mediterranean Sea, its significance in sediment formation is not infrequently undervalued. This is connected with the fact that aeolian material arrives in the sea primarily in the pelitic fraction, and it is not always possible to distinguish the aeolian particles from the terrigenous material.

The granulometric composition of a sedimentary substance brought into a reservoir becomes strongly distorted as a result of the transformation of solid particles in the reservoir itself. The first place in this process is occupied by the biogenic factor. From the works in the present collection it can be seen that in spite of the extensive development of the specific composition both of the benthos and the plankton, which exceeds by a factor of 2-5 the specific composition in the Black Sea, their biological mass in the Mediterranean Sea is rather insignificant -- several dozen times less than the biological mass in the Black Sea. Thus, the biological mass of the benthos is smaller by a factor of 10-100 and more, and fluctuates in various types of sediments from 0.3 to 18.9 g/m², whereas at the southern

coast of Crimea it reaches on the average from 54.6 to 326.5 g/m² (see the article by Kiselev and Chukhchin in the present collection). The benthos, as has been shown by our research, resides principally at small depths within the limits of the continental slope and is but rarely encountered in the region of the bed bottom.

The biological mass of the phytoplankton in the Mediterranean Sea is also much smaller than in the Black Sea (2-10 times). Thus, the net biological mass in various sections of the reservoir fluctuates within the limits of 3.3-159.0 mg/m³ of water (see the article by Kondrat'yeva in the present collection), whereas in the Black Sea it is equal to 30.5-201.0 mg/m³. Numerically predominant in the Mediterranean Sea, among the phytoplankton, are the small flagellates and dinoflagellates; with respect to biological mass, the dinoflagellates and the diatoms predominate. The biological mass of the coccolithophorids, small flagellates, and other phytoplankton is rather insignificant. According to the data of Bernard and Lecalschlauder (1953), the part played by the coccolithophorids in sediment formation should be considerably greater. In the western part of the sea, at the shores of Tunis, their biological mass, according to Bernard, is so great that the coccoliths alone could form 57 cm of sediment in one thousand years. But these data appear exaggerated.

The biological mass of the zooplankton in the waters of the Mediterranean Sea is also comparatively small. According to the data of V.N. Greze (1963), the upper layers of the waters of the Ionic Sea contain up to 57.3 mg/m³ of zooplankton. But already at a depth of 1000 m it falls to 1.4 g/m³. Under 1 m² in a column of water at a depth of up to 2500 m, there are approximately 9,860 mg of zooplanktons.

A certain quantity of solid sedimentary particles is formed in the reservoir itself by chemical means. Thus, in suspension and in the pelitic part of the sediment we have several times noted well defined crystals of calcite 1-5 μ in size, formed, in our opinion, by chemogenic means. The granulometric composition of those parts of the sediment which have been deposited from the water layer is sometimes distorted by diagenetically formed solid particles on the bottom. Such a phenomenon, more precisely -- the formation of calcareo-argillaceous concretions, has been observed by us in the eastern part of the sea. The size of the concretions is 1-5 mm, but sometimes they attain 5 cm and more in diameter. An insignificant part of the solid particles within the limits of the African shelf are formed within the water layer and on the surface of the bottom in the form of oolites, which have been observed by us in present-day sediments.

The total quantity of material contained in the water in the form of solid particles (suspension) in the Mediterranean Sea is not great: 0.5-0.8 g/m³ of water (Yemelyanov, 1962), sometimes rises to 1.0-2.0 g/m³ (the Algiers-Provence basin). Mineralogical research of the suspension under a microscope has shown that the sandy-aleuritic part consists primarily of biogenic material. Consequently, sandy-aleuritic particles /48 are not carried into the central parts of the sea, or are carried there in insignificant quantities (fine-aleuritic fractions).

Of the physicochemical features of the waters of the Mediterranean Sea, indicated in article on the hydrology of the sea, let us note only the good miscibility of the water to the very bottom, its saturation with the oxygen, the particularly high temperature of the water at the bottom (13-14°), and the salinity (up to 39.5‰, in the eastern part of the sea).

Arriving material and material formed in the reservoir itself is subjected to processing in the coastal part of the sea, undergoes the effect of wave activity, and is carried about by sea currents. The velocities of these currents depend upon the season and upon the meteorological conditions. The mean values for August, according to the Dutch oceanographic and meteorological atlas for the Mediterranean Sea (Middellandse Zee, 1957), in the open parts of the sea fluctuate within the limits of 8-20 cm/sec, i.e., they are capable of transporting not only pelitic but also sandy-aleuritic particles. In the straits of the Aegean Sea the velocities of the currents sometimes exceed 60 cm/sec. In the strait of Gibraltar, the marine constant (compensational currents attain a velocity of 125 cm/sec, but already at the traverse of the Cape of Oran (Algeria) they fall to 25 cm/sec (Shlyamin, 1949). Tidal currents, in spite of insignificant fluctuations of the sea level (on the average 0.5 m, rarely more than 1.0 m), reach considerable velocities in the Strait of Messina (up to 25 cm/sec; Shlyamin, 1949) and are capable of carrying away not only sand, but also gravel. In other straits the velocities of the current are also quite considerable and reach 5-75 cm/sec (for example, in the strait of Tunis, where pelite is almost totally absent at depths of up to 200 m). As a consequence of such strong currents, which do not attenuate even at the very surface of the bottom, in some places there is not only observed a so-called zero rate of sediment accumulation, but even a washout of already formed sediments is possible.

Landslide phenomena have been observed by us in the Mediterranean Sea only in one case -- at the steep underwater slope of Crete (station 539, depth 2,750 m). The great steepness of the slopes of the sea basin, the active tectonic life as well as constant and strong earthquakes in the northern, mountainous

part of the water-collection basin and in the reservoir itself (Galanopoulos, 1960; Yemel'yanov, Mikhaylov, Shimkus, see the present collection) make it possible to assume that landslide phenomena should take place in the Mediterranean Sea rather extensively, and thus should facilitate the redistribution of already deposited sediments. Particularly active phenomena of this kind are observed in the northern part of the Algiers-Provence basin, where the continental slope, greatly dissected by canyons, almost completely lacks present-day sediments (Bourcart, 1957).

II

The deep water sediments of the Mediterranean Sea consist, in the majority of case, of argillaceous and aleuritic-argillaceous oozes, usually of a light brownish-yellow color, sometimes with pink and gray shades. The oozes are plastic, viscous and very viscous, of soft, less frequently -- of semiliquid consistency. The moisture of the sediments of the Mediterranean Sea, in comparison to the sediments of the northern or far eastern seas of the USSR, is not high and varies within the limits of 37-63%.

The content of some of the components in the sediments is shown in Table 2.

In the Mediterranean Sea, it is possible only in a few cases to distinguish weakly ferrigenous and weakly manganous sediments. A content of organic carbon higher than 1% is also rarely encountered. Thus, the sediments are either ferrigenous, or weakly calcareous, calcareous, and strongly calcareous. The distribution of the total content of carbonates with respect to the area of the sea may be seen in Figure 1 of the article of Ye. M. Yemel'yanov (see the present collection). Among the carbonates are also to be distinguished ferrigenous, biogenic, chemogenic, (and diagenetic), and pelitomorphic (cryptogenic) ones.

Table 2

Composition of Sediments

	No. of Samples	Fluctuation limit	Mean Content
CaCO ₃	215	3,6-92,3	40-50
C _{org}	215	0,2-1,6	0,6
SiO ₂ ^{auth}	126	0,2-1,9	0,3
Fe	150	0,4-6,1	3,1
Ti	150	Traces -0,93	0,2
Mn	143	Traces 0,24	0,07
P	91	Traces 0,11	0,01

Ferrigenous carbonate: do not differ in dimensions from other ferrigenous minerals. Biogenic carbonates consist of shell material of benthic and plankton organisms. The dimensions of benthos shells (as well as pteropoda shells) and their detritus corresponds primarily to the gravel-sandy fraction. Foraminifera are most often of all encountered in sandy and aleuritic fractions, coccolithophorids are most frequently of all encountered in the medium pelitic (0.005-0.001 mm) fraction. Ground-up shell material (organogenic slime) is observed in the entire granulometric spectrum of the sediment, all the way to the colloidal fraction.

Calcareo-argillaceous concretions and crusts are usually greater in size than 10-1 mm and are encountered at various depths. Oolites and pseudoolites constitute fine and medium-grain sand, which occurs on the shelf from Alexandria to Tunis.

Chemogenic and cruptogenic calcite enters into the composition of pelite (pelitomorph carbonate).

Although volcanogenic material is frequently encountered in the sediments of the Mediterranean Sea, it comprises only fractions of 1%. The only exception is the southeast part of the Tyrrhenian Sea and the southern part of the Aegean Sea

(the region of the island of Santorin). The pyroclastic material consists of rather coarse ash (sand and aleurite), more infrequently, pumice fragments and glass.

Due to the small dimensions of its particles, aeolian material (pelita) cannot as yet be separated from the rest of the ferrigenous material. Comparatively coarse aeolian particles (they differ from the others in that they are well-rounded and has a yellow-brown film) are encountered in deep-water sediments only as individual grains, rarely in large quantities.

On the basis of the obtained data, the first attempt was made to distinguish in the Mediterranean Sea the fundamental, genetically different types of contemporary sediments.

Type 1. Sediments with an acute predominance of terrigenous material (terrigenous and weakly calcareous, $\text{CaCO}_3 < 30\%$).

Type 2. Sediments with a considerable content of CaCO_3 (30-50%). These are mainly organogenic-detrital shell and cryptogenic pelitomorphie muds.

Type 3. Sediments with a predominance of calcareous materials (CaCO_3 usually 50-70%). These are mainly pteropod-foraminiferous, organogenic-detrital shell and cryptogenic pelitomorphie deposits.

Type 4. Sediments with an acute predominance (over 70%) of calcareous materials. These are organogenic-detrital shell sands.

Type 5. Chemogenic sediments (oolites, pseudoolites, calcareous concretions and crusts).

Type 6. Volcanogenic sediments.

The sediments of Types 2-4 may be consolidated into a single type -- organogenic sediments (biogenic material predominates /51 over chemogenic material). Thus terrigenous, biogenic, chemogenic, and volcanogenic sediments have been noted in the Mediterranean Sea.

The formation of genetically different types of sediments is a result of the interaction of all the factors enumerated above, which take part in sediment formation and in the supply of sedimentary material to the reservoir. It is natural that all the features of the water-collecting area and of the basin itself must to some degree reflect on the granulometric composition of the bottom deposits. This is proved first of all by the distribution of individual fractions with respect to depths and with respect to sea area.

The gravel fraction (>1.0 mm) is not widely distributed in the Mediterranean Sea. It is encountered most frequently of all in carbonate organogenic-detrital sands which occur at depths of up to 200 m in the form of shell detritus and entire mollusk shells. Rock fragments and individual minerals of the gravel fraction have been observed by us almost not at all. In terrigenous sands there is, as a rule, very little gravel -- up to 7.8% (in shell sands -- up to 43.7%). In large aleurites the fraction >1.0mm has been distinguished only once (19.1%), in fine-aleuritic oozes it has been distinguished several times. In deep aleuritic-argillaceous and argillaceous oozes the gravel fraction neither of terrigenous nor of organogenic origin is encountered. The only exception is a small admixture of plankton pteropod shells, the quantity of which rarely exceeds 2-3%. In the Aegean Sea, south of Peloponnesus-Crete to the gulf of Syrtis Major, in the gravel fraction are frequently observed argillaceous concretions, the dimensions of which not infrequently exceed 3-5 cm in diameter. Sometimes in deepwater muds are observed large pieces of round pumice, scattered over the entire body of the sea.

Thus, it is obvious that terrigenous detrital material of gravel size is not carried into the deepwater parts of the sea. In its formation, part is taken only by biogenic, chemogenic-diagenetic and, to a lesser degree, volcanogenic material.

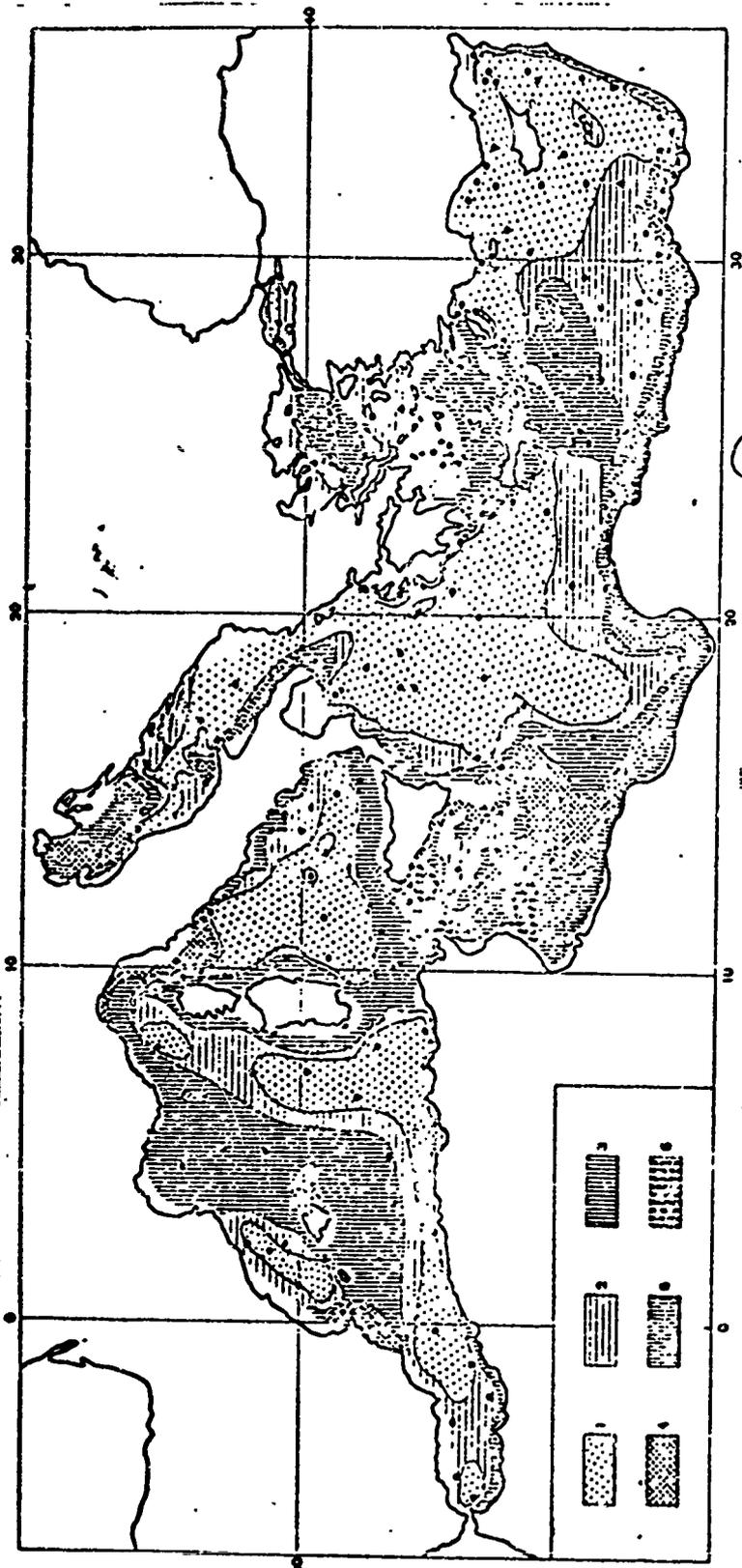


Figure 3. Diagram of the distribution of fractions with respect to area.

1 - < 2, 2 - 2-5, 3 - 5-10, 4 - 10-50, 5 - 50-90, 6 - >90.

The sand fraction (the total of fractions >0.1 mm) is distributed unevenly with respect to area (Figure 3). The relationship of its content to the depth and distance from shore is shown in Figure 4 (1a, 1b). It can be seen that as the depth increases and as the distance from shore increases, the content of the sand fraction rapidly decreases, and it appears again only at a depth of approximately 200 m and at a distance of 10-40 km from the shore. Below the depth of 200 m there is already 50-10% of the sand fraction, and deeper than 700 m its quantity does not exceed 10% and on the average fluctuates within the limits of 2-5%. The relationship of the content of the sand fraction to the distance from shore is not entirely clear, since its maximum values are contained in regions which are at a distance of more than 100 km from the nearest shore. Some increase in the content of the sand fraction at a distance of 50-200 km from the shore in deepwater oozes is explained by the abundant presence here of shell foraminiferous and pteropod material, and its maximum values at a far distance from the shore are explained by features of the relief (shallow projections, covered by shallow material), the residence of benthos at small depths remote from land (the African Sicilian sill), and some washout of aleuritic-pelitic particles from the sediment, which also to a considerable extent enriches the sediments with the sand fraction. On the whole, in the eastern part of the sea the content of the sand fraction in sediments is somewhat higher than in the western part of the sea.

The large-aleuritic fraction (0.1-0.005 mm) is less uniformly distributed in the sediments than is the sand fraction. In its placement there is observed some shift of the maximum to depths of 200-500 m, i.e., the large-aleuritic fraction accumulates in the upper part of the continental slope. In the coastal part its quantity fluctuates within the limits of

0.1-19.8%, below 500-700 m the mean values are equal to 8.5-8.0%, and only in one place do they read 44.7% (large aleurites south of the Strait of Messina). The minimum values of the large-aleuritic fractions in deepwater argillaceous oozes /52 reach trace values, i.e., this fraction is practically entirely missing here. Some concept of the content of large aleurite in various types of sediments is given by Tables 2-8 and by histograms of the sediments (Figure 5). The large aleuritic fraction, as has been shown by mineralogical analysis, consists of organogenic detritus, quartz, plagioclasm and, to a lesser degree, of heavy terrigenous minerals and, in the Tyrrhenian Sea, also of pyroclastic materials. Consequently, part is taken in the formation of this fraction principally by two factors -- the biogenic and the terrigenous (arrival from shore).

The fine aleuritic fraction (0.05-0.01 mm) is shifted still farther into the sea than the large aleuritic fraction. Its maximum quantity is observed at depths of 300-700 m, i.e., also in the upper part of the continental slope, at a distance of 3-50 km from the shore (on the average, 10-30 km). The fine aleuritic fraction occurs most extensively of all in the regions of the eastern part of the Tunisian sill and in the Gulf of Syrtis Major, as well as in the Aegean Sea. Here its quantity reaches 48-59%, and sediments containing maximum quantities of this fraction are at a distance of 75-160 km from the shore. In other regions of the sea the aleuritic fraction accumulates in a narrow strip in the upper part of the continental slope several kilometers from the shore. In the shelf deposits the fine aleuritic fraction plays a subordinate part, and its quantity does not on the average exceed 10%. In the deepwater oozes, on the contrary, the part played by this fraction increases. Thus, in the aleuritic-argillaceous oozes its content is on the average 20-27%, with a maximum of 37%.

Argillaceous muds contain a little bit less of the fine aleuritic fractions -- on the average 15-20%, but in spite of this it always forms one of the peaks in histograms.

The fine aleuritic fraction consists primarily of detrital terrigenous and shell material (foraminifera and pteropods), and in the Tyrrhenian Sea -- also of pyroclastic materials.

The pelitic fraction (<0.1 mm) in the Mediterranean Sea has the most extensive distribution, it predominates on an enormous area of sea bottom. Its distribution with respect to area is shown in Figure 6. The minimum content (up to 10%) of the pelitic fraction is noted only in the coastal sediments (sands). As the distance from the shore increases and as the depth increases (Figure 4, IIA, IIB), the content of pelite in the sediments increases very rapidly. Thus, already at a depth of 500 m more than 45% of pelite was detected at 97% of all stations, and deeper than 700-800 m the pelitic fractions predominate. Starting approximately with the 1000 m isobath its quantity does not change with depth and is equal on the average to 72-75%. As the distance from the shore increases, the content of pelite increases sharply at a distance of 10-25 km. Farther from shore its quantity remains almost constant -- approximately 72-75%. Such a distribution of the pelitic fraction may be explained by features of the bottom relief, with which it is in close relationship (at elevations there is less pelite, in depressions there is more pelite).

Since large depths reach close to the shore almost everywhere except for the southeast part of the sea, the fine fractions are also located at a short distance from the shore, i.e., the average curves of the distribution of the pelitic fraction as a function of the depth and the distance from the shore are very closely related to the hypsometric curve of the sea. Some deviations from this rule are the result of special features

of the supply of sedimentary material to the reservoir. Thus, in the regions of the foredelta of large rivers (the Nile, the Po, the Rhone) a large content of pelitic particles (50-85%) is observed at a distance of only 5-10 km from the shore at depths of 20-60 m. On the other hand, the somewhat lower content of pelite in the open parts of the sea (the eastern part) at depths of 2000-3000 m is due to the deposition here of a large amount of organogenic-shell material of aleuritic and sandy dimensions. The high content of the pelitic fraction in the sediments of northern districts of the sea which adjoin mountainous regions is apparently connected with the fine pulverization of the material washed out from land to pelitic dimensions (the conditions of the warm moist /54 climate of the humid zone of the lithogenesis).

The content of the large pelitic (0.01-0.005 mm) fraction in almost all of the ooze sediments is considerably less than that of the other pelitic and fine-aleuritic fractions, and in fine-aleuritic oozes there is even less of it than of the sand fraction. The content of the large pelitic fraction in oozes fluctuates within the limits of 1.6-15.4%, and in Aleuritic-argillaceous oozes its content is 10-12%. The distribution of this fraction is an exception for all the fractions, since it depends almost not at all upon the depth, distance from shore, and sediment type.

The minimum-content values of the large-pelitic fraction in the granulometric spectrum of sediments are due above all to the biogenic factor of sediment formation. As is known, foraminiferous shell material has larger dimensions than does large pelite, and the dimensions of coccolite shells are usually less than 0.005 mm. Thus, this fraction includes only fragments of foraminifera and pteropods and large coccolites.

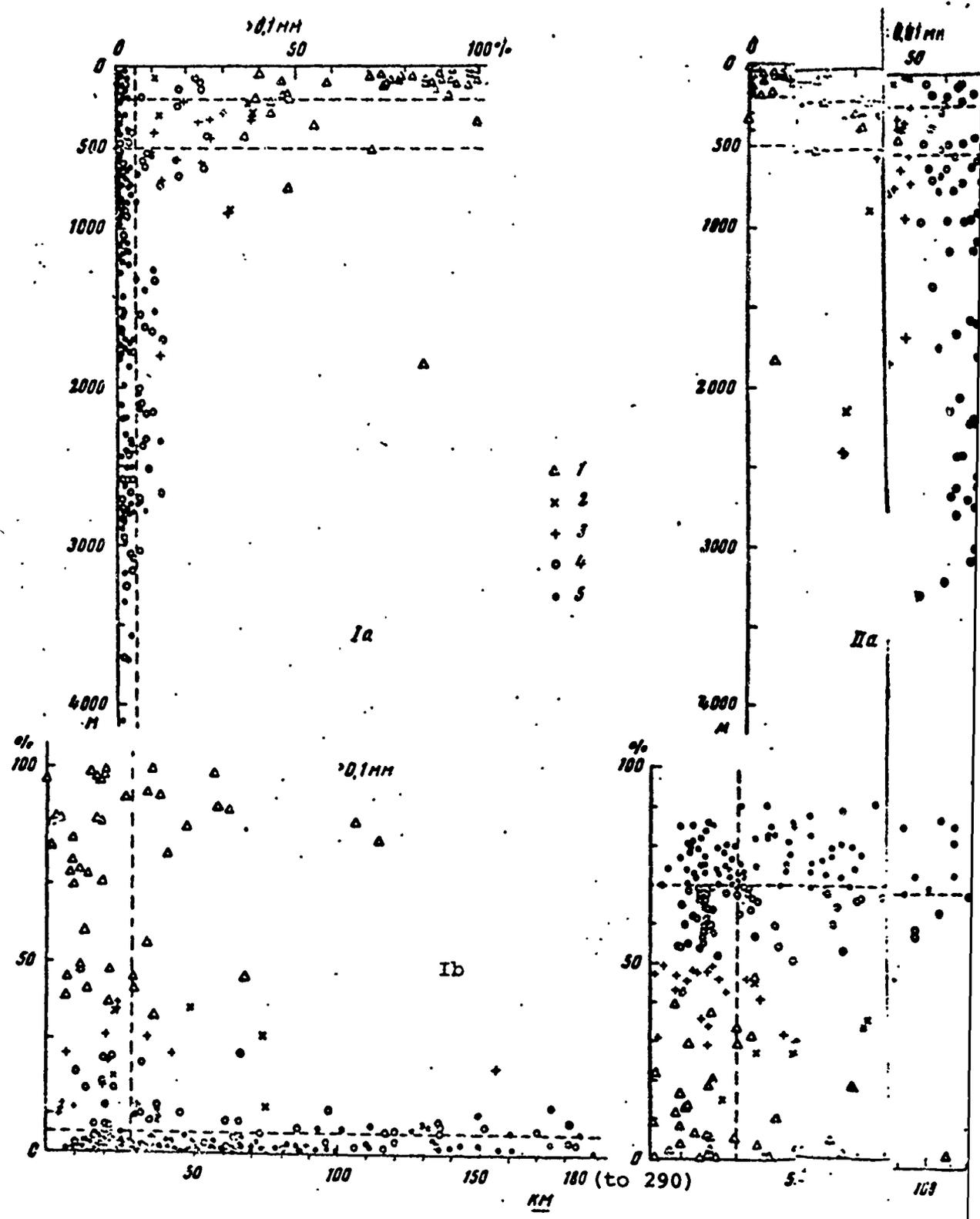
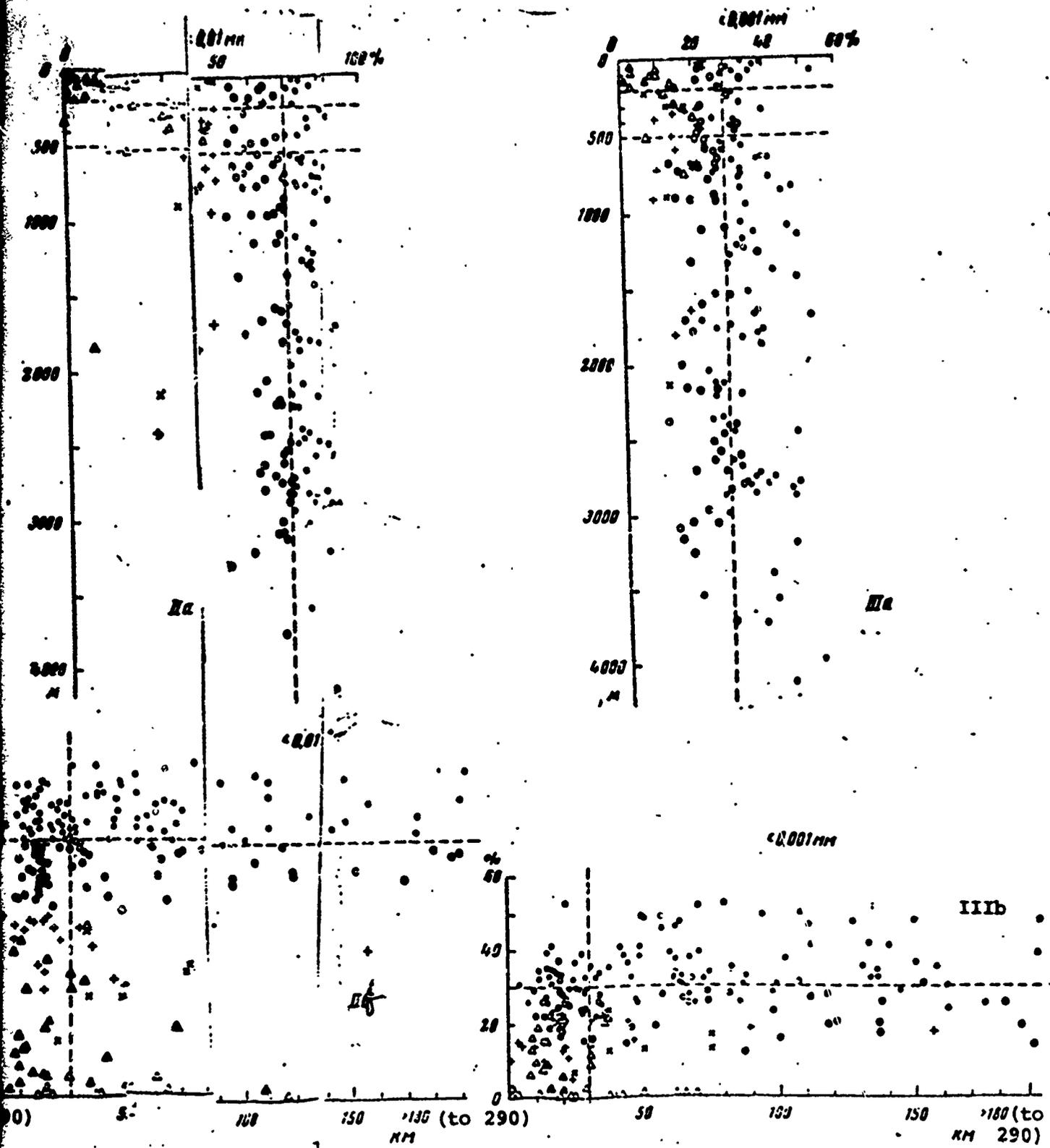


Figure 4. Relationship of the distribution of various fractions to depth (a) and distance from the shore (b).

- I -- for the fraction > 0.1 mm.
- II -- for the fraction < 0.01 mm;
- III -- for the fraction < 0.001 mm;

- 1 - in sand samples; 2 - in samples of large aleurites;
- 3 - in samples of fine-aleuritic oozes; 4 - in samples of aleuritic-argillaceous oozes; 5 - in samples of argillaceous oozes.

A.



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B.

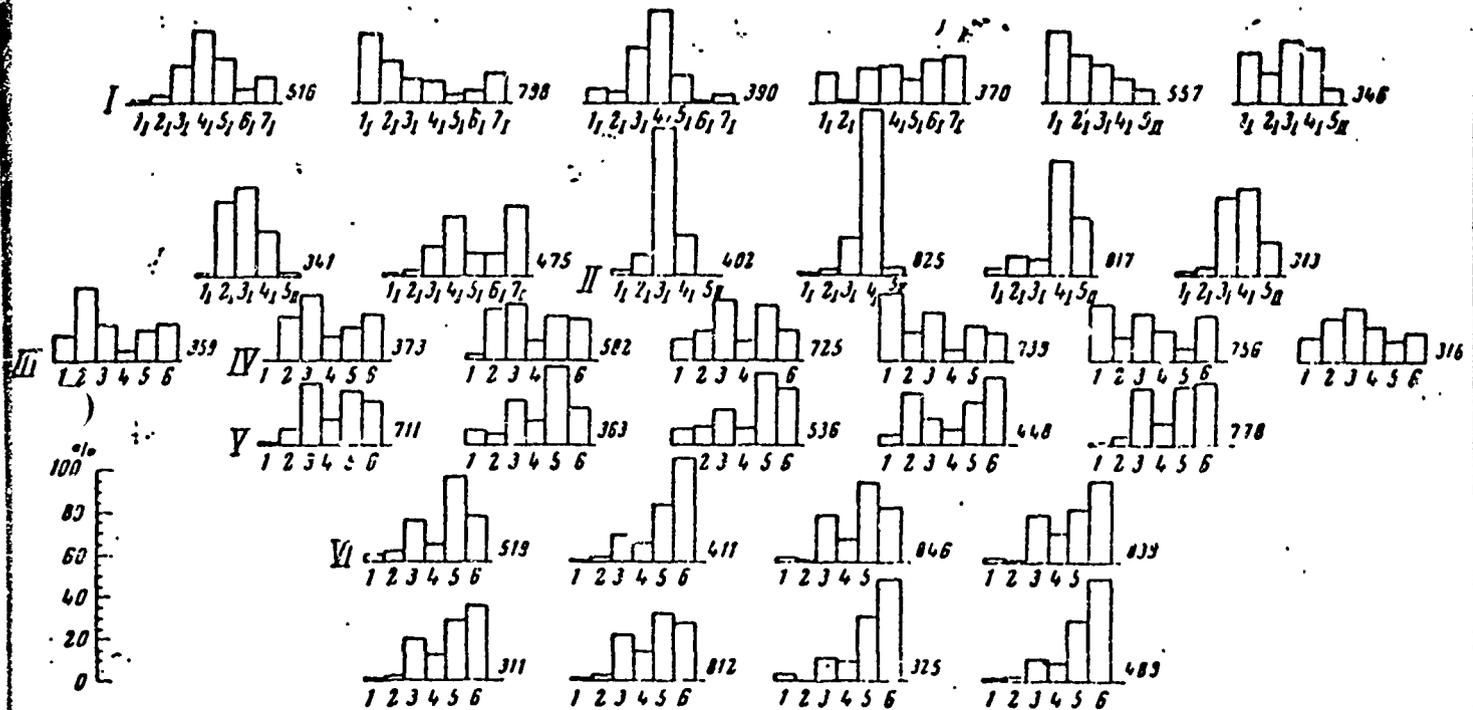


Figure 5. Typical histograms characterizing individual seas, basins, or sectors thereof.

I -- sands predominantly large- and medium-range (organogenic-detrital);
 II -- sand predominantly fine-grain (terrigenous).

Content of fractions (in %): 1_I - >mm; 2_I - 1.0-0.5 mm; 3_I - 0.5-0.25 mm;
 4_I - 0.25-0.1 mm; 5_I - 0.1-0.05 mm; 5_{II} - < 0.1 mm; 6_I - 0.05-0.01 mm;
 7_I - < 0.01 mm;

III -- large aleurites

IV -- fine aleuritic oozes;

V -- aleuritic-argillaceous zoos,

VI -- argillaceous oozes. Content of fractions (in %):

1 - >0.1; 2 - 0.1-0.05; 3 - 0.05-0.01; 4 - 0.01-0.0005; 5 - 0.0005-0.0001;
 6 - < 0.0001 mm. The numbers to the right of the histogram (516, 798,
 etc.) are numbers of stations.

D

The content of the medium-pelitic (0.005-0.001 mm) fraction in deepwater aleuritic-argillaceous and argillaceous oozes is 1.5-3.0 times greater than the content of the large-aleuritic fraction, and in sand their quantities are approximately equal. In aleuritic argillaceous oozes the content of the medium-pelitic fraction is on the average 25%, and in argillaceous oozes it is somewhat more (Tables 3-8). The greatest limit of fluctuation (14-41%) are observed in the eastern part of the sea (on the average 33%), in the western part of the sea the limits of variation

are comparatively small (25-32%), on the average 30% in argillaceous oozes and 22% in aleuritic-argillaceous oozes. Similar fluctuations in the content of the medium-pelitic fraction have been noted in the Adriatic Sea and in the Sea of Marmara.

Thus, we see that the average content values of the medium-pelitic fraction are more constant and are lower in those regions of the sea which adjoin mountainous water-collecting areas. In districts remote from such regions (the eastern part of the sea), sharp fluctuations in the distribution of this fraction with respect to area and comparatively high content values of this fraction are observed; this is possibly also due to the precipitation of biogenic and chemogenic components in these regions. Mineralogical analysis has shown that in the medium-pelitic part of the sediment, there are observed considerable accumulations of coccolite shells and foraminifera fragments, as well as large accumulations of carbonate grains, possibly of chemogenic origin. The possibility is not excluded that sharp fluctuations in the content of the medium-pelitic fraction in the eastern part of the sea are also brought about by the abundant arrival of aeolian material from the arid zone of the African platform, since the dimensionality of the aeolian particles corresponds to the dimensionality of the pelite.

The content of the colloid and the subcolloid (< 0.001 mm) fraction in all types of sediments with the exception of sand is very considerable. The relationship of its distribution to the depth and the distance from shore and to the granulometric type of the sediment is shown in Figure 4 (IIIa, IIIb). It can be seen that its quantity sharply increases to a depth of 500-1000 m and an offshore distance of up to 40 km. Deeper and farther out, the average curves of the content of the colloid fraction remain practically constant. In the Aegean Sea and the Adriatic Sea,

and in the region of the Hellenic troughs (south of the Peloponnesus-Crete Turkey) this curve is in second place after the medium-pelitic curve, and at Cyprus, in the regions of the Nile foredelta, in the Sea of Marmara, the Tyrrhenian and in the Algiers-Provence basin, it is predominant among all the remaining fractions. The content of the colloid fraction in the Sea of Marmara reaches 52%, in the Tyrrhenian Sea it is equal to 28-48%, in the depression of the Tunisian sill it is 37-47%, in the Algiers-Provence basin it is 26-50%. The total mass of the colloid fraction in sediments predominates among all the other fractions. It comprises the principal mass of the argillaceous and aleuritic-argillaceous oozes which cover about 80-90% of the entire area of the sea bottom.

Some conception of the overall distribution of the various fractions with respect to cross-sections through the principal basins of the Mediterranean Sea (see Figure 1) is yielded by the lithological cross-sections represented in Figure 7 (I-V). The sand fraction on them is represented in the upper part (by dots), and the colloid fraction is represented at the bottom of the cross section. Above the cross section, the diagrams show a schematic curve of the depth at the stations. The cross sections are convenient by virtue of the fact that they make it possible rapidly to measure the content of individual fractions at each of the stations, and show the relationship of the content of a fraction to the depth and forms of the relief.

Study of the distribution of fractions with respect to area, their relationship to the depth and to the forms of the relief makes it possible quickly and reliably to distinguish the granulometric types of the bottom deposits, which are the final result of all the sediment-formation processes and mixing of the above-mentioned fractions. Distinguishing the sediment type on the basis of the classification of the Institute of Oceanography, Academy of Sciences, USSR sometimes brought about difficulties.

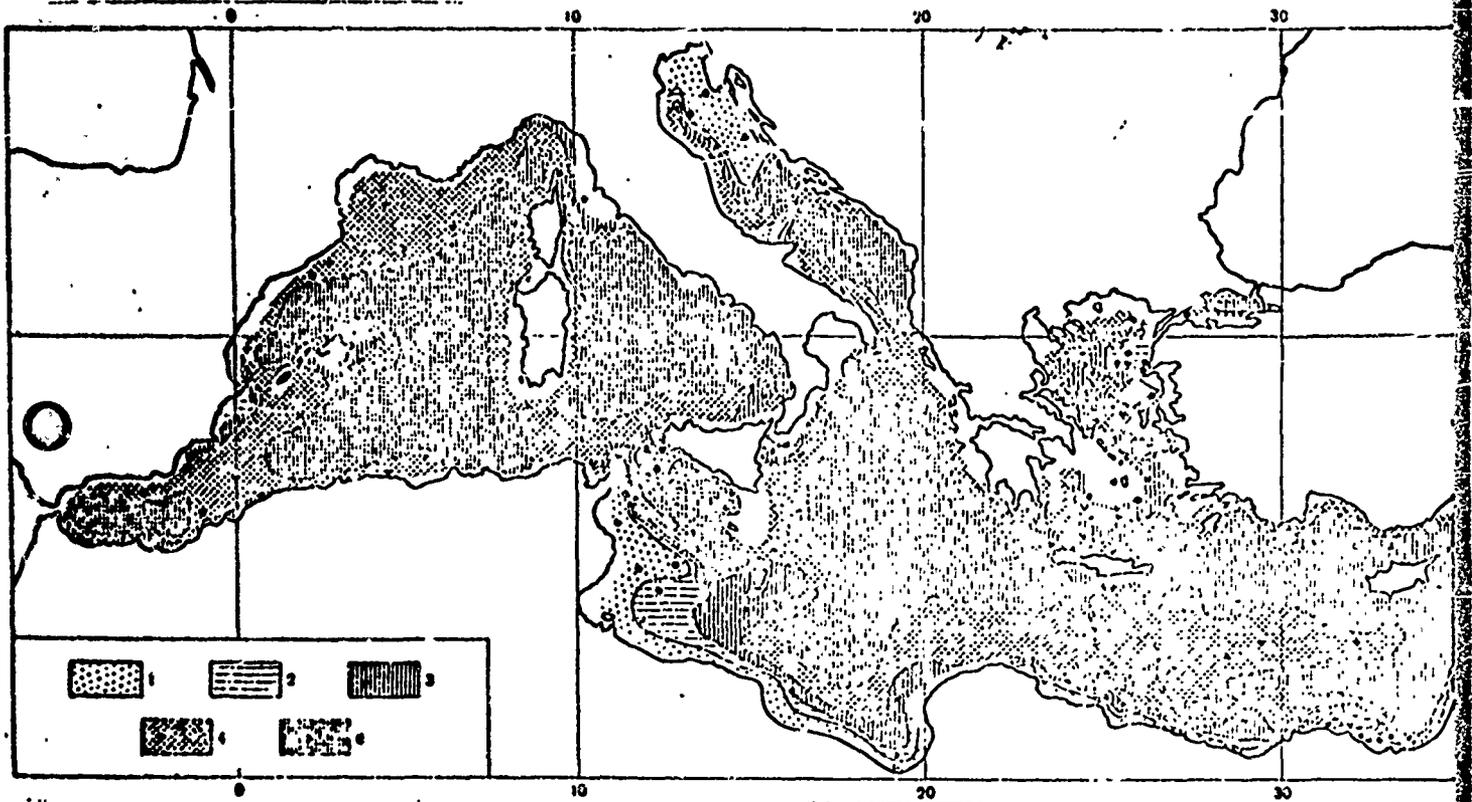


Figure 6. Diagram of the distribution of fractions < 0.01 mm (in percent) with respect to area.

1 - < 10 ; 2 - 10-30; 3 - 30-50; 4 - 50-70; 5 - > 70 (to 91%).

Thus, large aleurites, fine aleuritic ooze and sand were not always clearly distinguished, and in distinguishing of aleuritic-argillaceous and argillaceous oozes, their M_d was almost not taken into account. In the sediments of the Mediterranean Sea the M_d is, as a rule, lower than is indicated in the classification, and fluctuates within the following limits (in mm): sands, 0.023-0.85 (on the average 0.33), large aleurites 0.17-0.54 (on the average 0.37), fine-aleuritic oozes 0.010-0.33 (on the average 0.018), aleuritic-argillaceous oozes 0.0020-0.0095 (on the average 0.0048), argillaceous ooze 0.0009-0.0045 (on the average 0.0022). Some data on sediment types are available in the article of V.P. Petelin (1961).

Outcrops of bedrock (Figure 8) have been shown by us only in several cases (in regions remote from the shore), since it is not possible to represent numerous outcrops within the limits of a shelf in a diagram of the adopted scale. Boulder and gravel

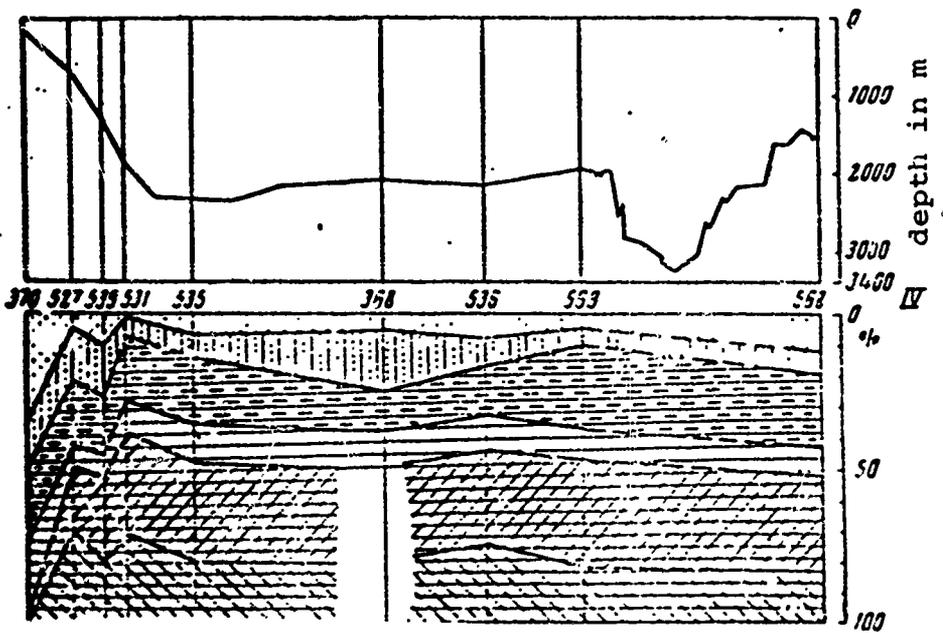
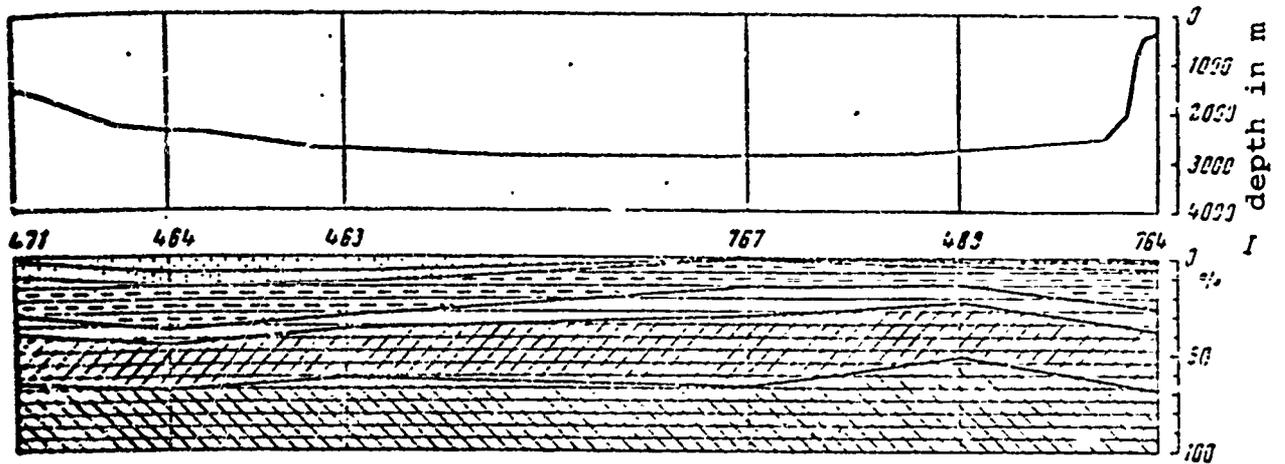
Table 3

Composition of predominantly fine-grain (terrigenous) and medium-grain sands according to fractions

Particle size, (in mm), sorting coefficients	b* Nile foredelta		Crete		c. Ionian Sea		d. Adriatic Sea		
	Fluctuation limits, %.	Average, %.	No. of Samples	Average, %.	No. of Samples	Average, %.	Fluctuation limits, %.	Average, %.	No. of Samples
>1.0	2.14-7.83	4.90	2	Traces	1	Traces	Traces	Traces	1
1.0-0.5	9.31-13.52	11.43	2	3.0	1	3.42	2.22-12.46**	9.01	3
0.5-0.25	35.83-63.00	63.37	2	17.25	1	35.10	7.20-40.06	20.73	3
0.25-0.10	19.05-49.41	19.25	2	76.65	1	41.15	36.63-63.84	52.91	3
0.10-0.05	0.12	0.12	1	1.25	1	4.62	6.43-16.13	9.86	3
0.05-0.01	Traces	Traces	1	0.42	1	4.62	1.27-4.05	2.16	3
<0.01	1.86	1.86	1	1.35	1	6.02	2.50-5.53	6.51	3
Md	0.35-0.35	0.35	2	0.19	1	0.23	0.14-0.25	0.20	3
So	1.3-1.3	1.3	2	1.2	1	1.7	1.3-1.7	1.4	3

* In Tables 3-8, the letters a-g indicate sectors of the Mediterranean Sea (See Figure 1).

** The sum of the fractions is 0.5.



(continued next page)

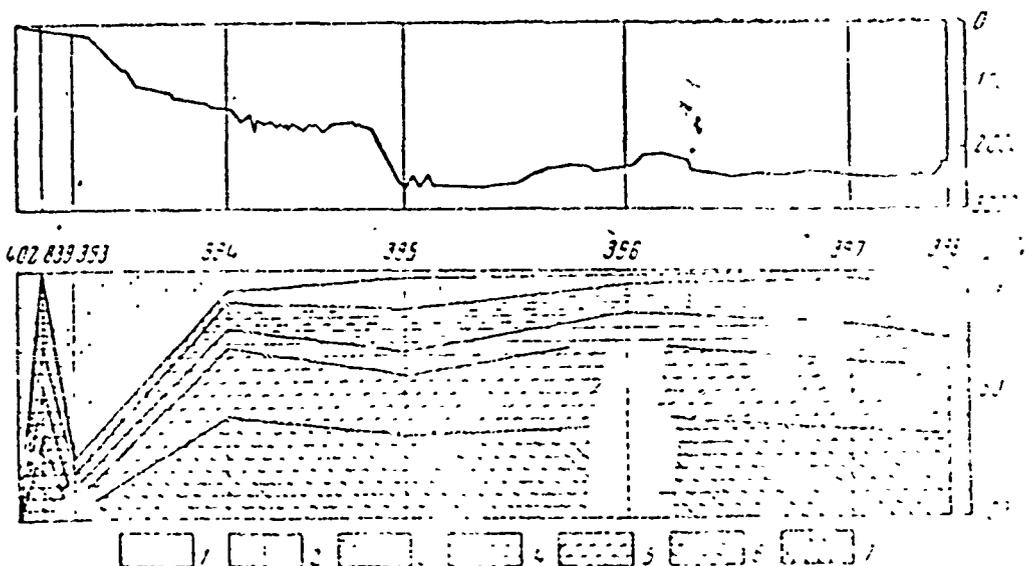
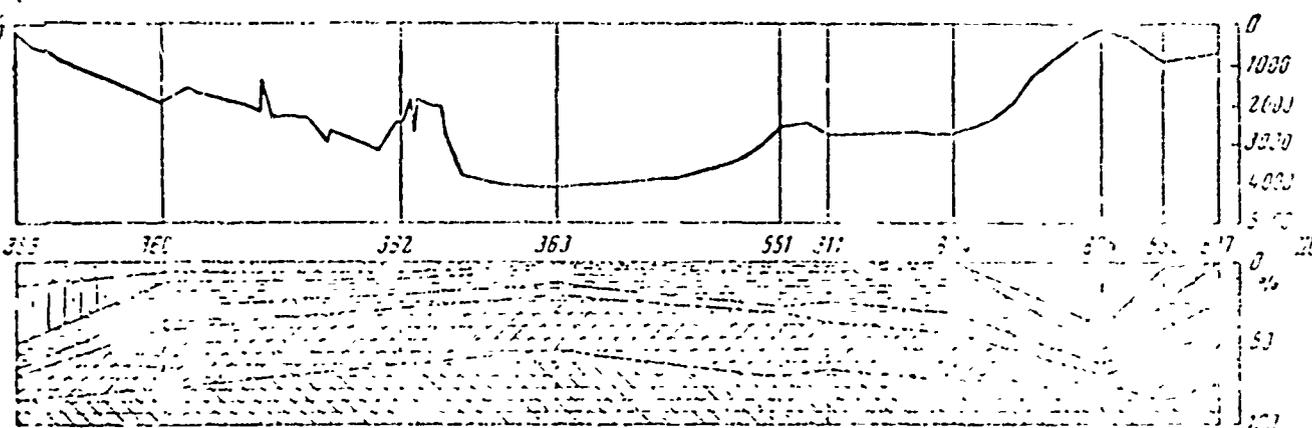
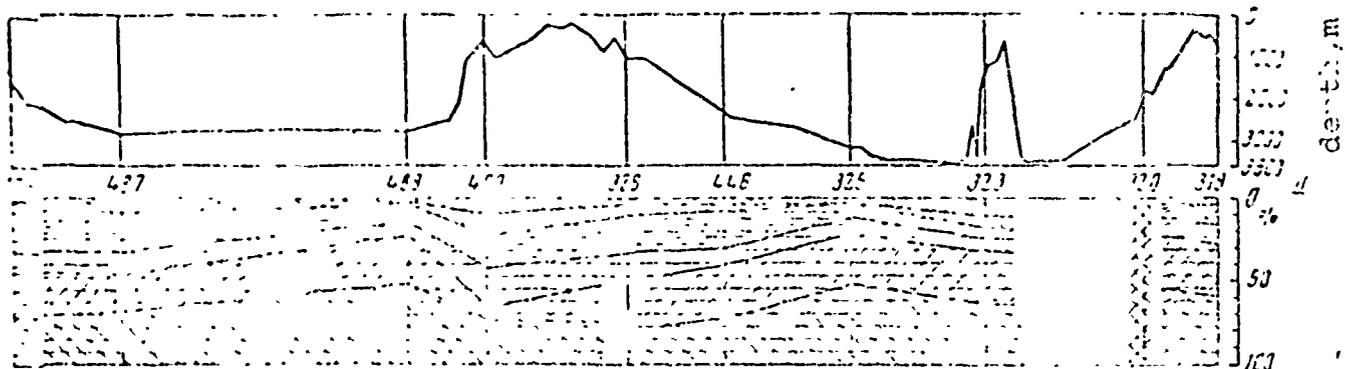


Figure 7. Lithological cross section (I-IV) of the upper layer (10-2 and 0-10 cm) of the bottom deposits of the Mediterranean Sea (the position of the cross sections, see Figure 1). The upper cross sections show the depth at stations (in m), the bottom cross sections show the content of fractions (in %): 1 - >0.1 ; 2 - $0.1-0.05$; 3 - $0.05-0.01$; 4 - $0.01-0.005$; 5 - $0.005-0.001$; 6 - < 0.001 ; 7 - accumulation of pumice piece.

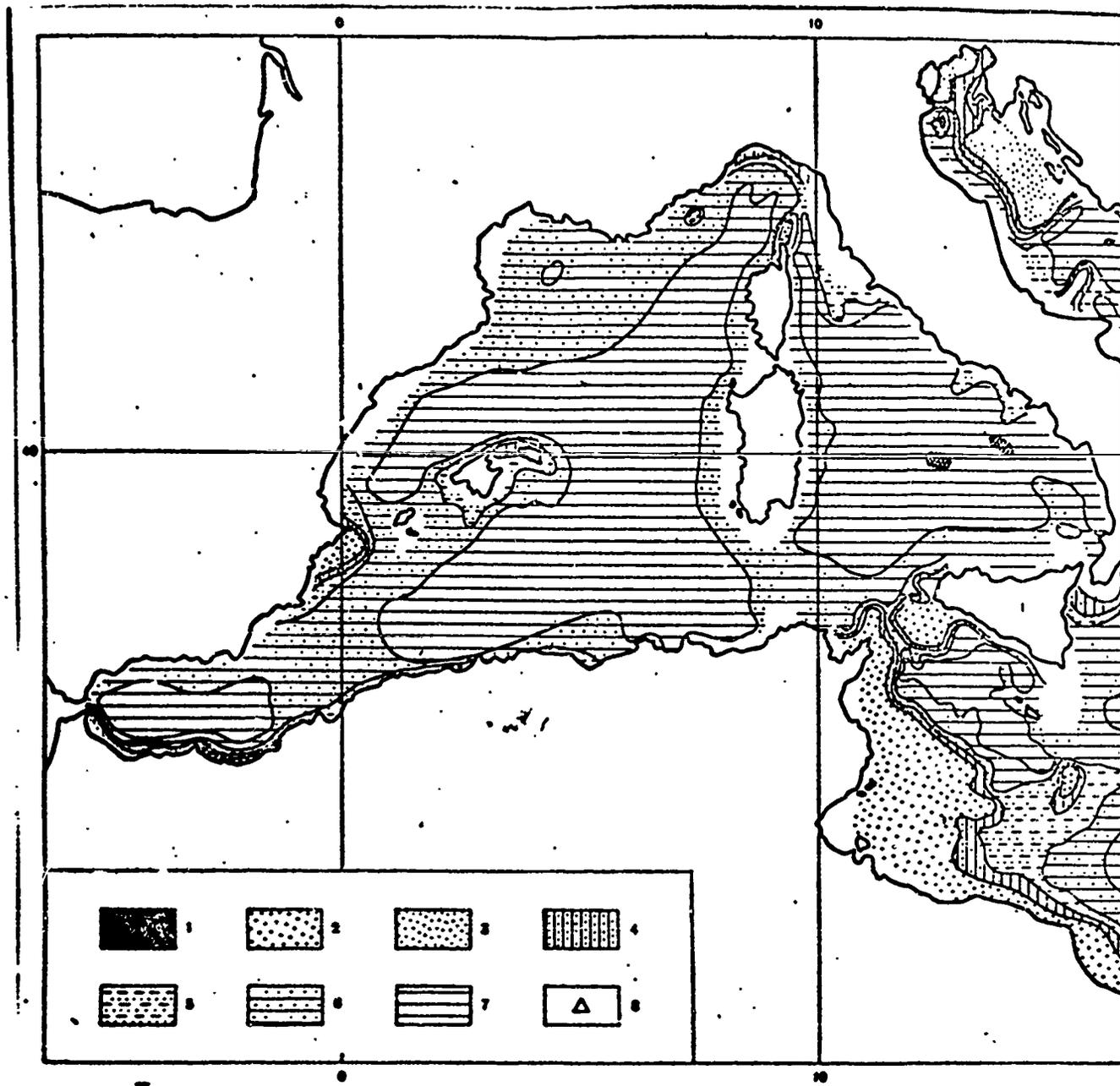
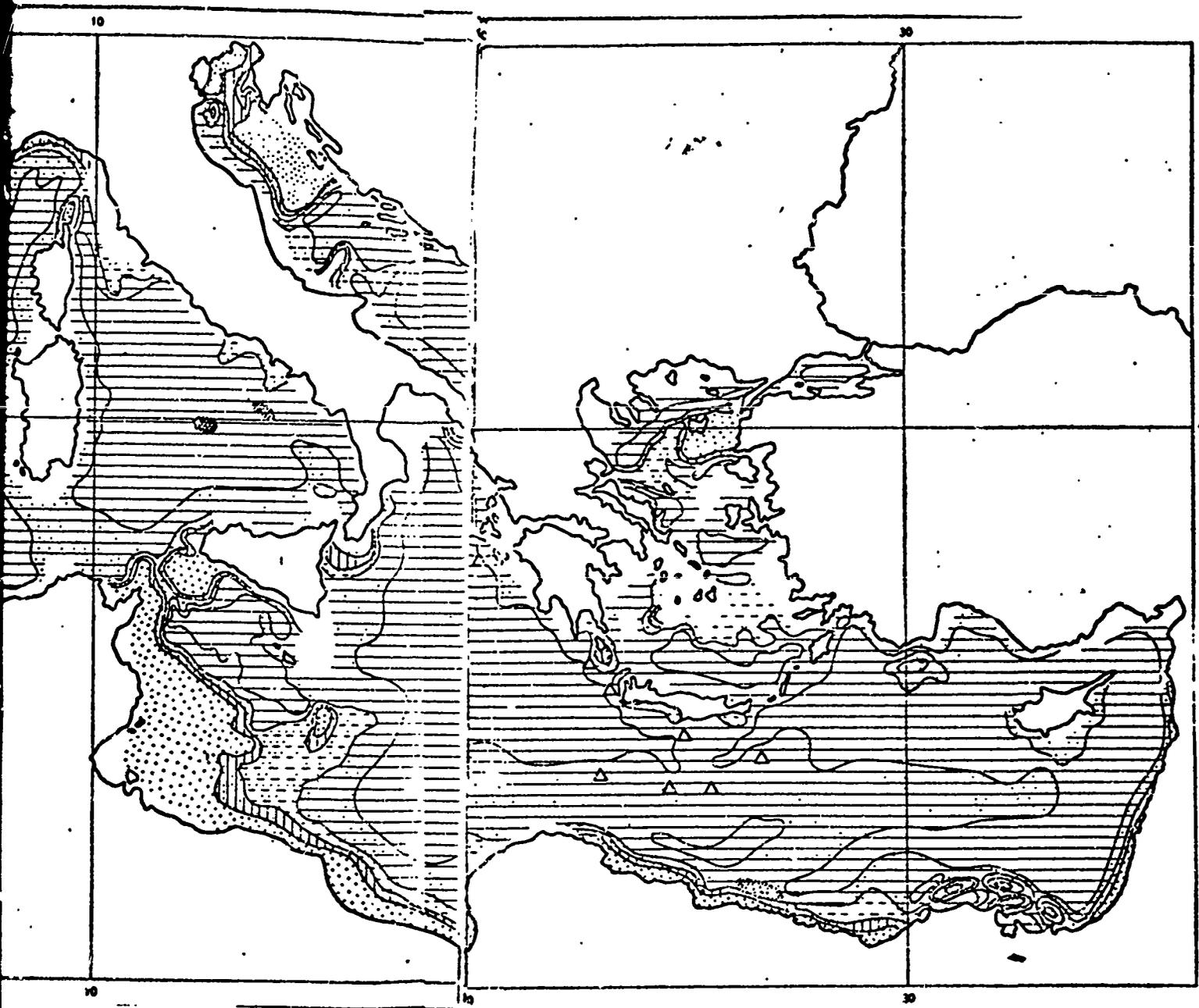


Figure 8 -- Diagram of the distribution of the principal granulometric types (2-7) of the present day-bottom deposits of the Mediterranean Sea.

- 1 - outcrops of bedrock (established and presumed);
- 2 - sands, predominantly large-and medium grain;
- 3 - sand, predominantly fine-grain;
- 4 - large aleurite;
- 5 - fine-aleuritic oozes;
- 6 - aleuritic-argillaceous oozes;
- 7 - argillaceous oozes;
- 8 - accumulation of calcareous-argillaceous concretions.

A.



principal granulometric
of the Mediterranean Sea.

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cretions.

B,

deposits are not shown, since in the regions of our operation they were almost never encountered. Such deposits are observed only in the immediate vicinity of the shore, and this is also difficult to show in our diagram. Gravel deposits at one of the Aegean Sea stations, consisting of shell detritus, are shown as sand.

Sands are indicated by two signs: as large-grain sands and as small-grain sands.

Sands usually occupy a narrow strip along the coast. Only in shallow-water regions, projecting far out into the sea, do sands come out from the shore to considerable distances. The granulometric composition of the sands is shown in Tables 3 and 4 and is represented on histograms (Figure 5), and on the fields of cumulative curves (Figure 9, IA and Ib) obtained by combining cumulative curves plotted for each available specimen. It can be seen that the granulometric composition of terrigenous sand is rather monotonous: principally they are medium- and fine-grained, well sorted ($S_o = 1-2$), and yield single-peak histograms (see Figure 4, II). Such sands have been encountered by us in the foredeltas of the Nile and Po Rivers, south of Crete and at depths of up to 30-40 m, in the Adriatic Sea at depths of up to 70-100 m, and south of the Strait of Messina at a depth of 1,833 m.

Shell sands have been sorted medium well ($S_o = 2-4$) and poorly ($S_o = 4$), the content of various fractions fluctuate within wide limits; this greatly hindered the distinguishing of sands as sediment types. Shell sands are medium- and well sorted only within the limits of the African-Sicilian sill, where, as has been noted, there takes place a total or partial wash-out of the pelitic fraction, or a zero speed of its deposition is observed due to the presence here of high marine current.

velocities. Histograms of shell sands usually have two or three peaks. On the diagram, the sign for organogenic-shell sands is also used to indicate the so-called pseudoolitic and oolitic sands which occur on the shelf from Alexandria to the Gulf of Syrtis Minor. Their granulometric composition is shown on the histogram of station 390 (see Figure 5).

Large aleurites have been encountered by us only at 6 stations. Such rare occurrence of sediments of this type is explained by the narrow strip of their occurrence in the upper part of the continental slope, on the average between the 200-500 m isobaths. On the sediment type diagram the large aleurites are shown by a narrow strip separating sands from fine-aleuritic oozes. The granulometric composition of large aleurites is shown in Table 5, and is represented on the histogram of station 359 and on the field of cumulative curves (Figure 9, IIa). The fluctuation limits of individual fractions are large, the histograms have two peaks. Consequently the sorting is also poor (with the exception of large aleurites in the western part of the sea, where $\sigma = 1.9$).

Table 4

Composition of predominantly large-grain and medium-grain shell sands according to fractions

Particle sizes (in mm), sorting coefficients	a. Aegean Sea.			e. Bay of Tunis.		
	Fluctuation limits, %	Average, %	No. of Samples	Fluctuation limits, %	Average, %	No. of Samples
>1.0	6.35-32.22	20.84	7	0.73-42.78	19.75	6
1.0-0.5	3.40-19.75	12.16	8	8.56-35.56	20.90	6
0.5-0.25	8.20-16.06	11.90	8	12.10-41.50	25.24	6
0.25-0.10	9.20-23.07	14.43	8	8.35-16.52	12.60	6
0.10-0.05	5.37-19.77	12.08	10	1.57-16.07	8.52	1
0.05-0.01	2.39-22.23	7.59	10	0.94-18.85	7.55	1
0.01-0.005	14.60	4.78	8	1.70	1.70	1
0.005-0.001	Tra- ces 19.02	6.21	3	9.13	9.13	6
<0.001	15.20	10.95	8	20.73	20.73	6
<0.01	0.92-15.20	19.31	10	3.85-31.56	13.68	6
Δd	0.075-0.650	0.460	10	0.090-0.850	0.430	6
ΔS_0	3.5-5.6	4.2	10	1.7-4.0	2.3	6
σ	27.43-85.58	42.59	8	36.15-99.82	67.82	6

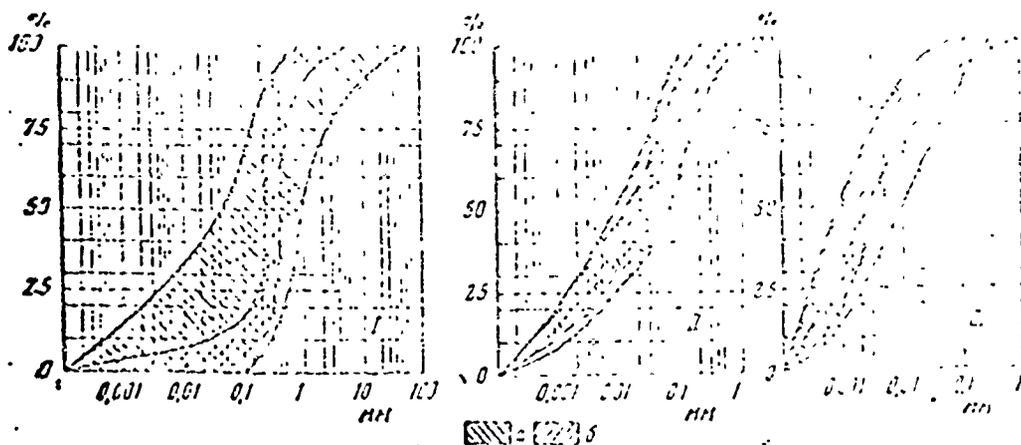


Figure 9. Fields of cumulative curves, compiled on the basis of station 390 (see Figure 5).

- Ia - primarily large- and medium-grain sands;
- Ib - predominantly fine-grain (terrigenous) sands;
- IIa - large aleurites;
- IIb - fine-aleuritic oozes;
- IIIa - aleuritic-argillaceous oozes;
- IIIb - argillaceous oozes.

Table 5

Composition of large aleurites according to fractions

Particle sizes (in mm), sorting coefficients	c. Ionian Sea			g. Western part of the Mediterranean Sea		
	Fluctuation limits, %.	Average, %.	No. of Samples	Fluctuation limits, %.	Average, %.	No. of Samples
>1,0	8,87--38,04	19,65	3	1,64--36,93	15,61	3
0,1--0,05	12,74--44,44	30,59	3	33,42--72,53	51,63	3
0,05--0,01	16,65--22,00	19,54	3	9,15--37,40	20,31	3
0,01--0,005	4,58--5,35	4,83	2	2,86--5,65	4,27	3
0,005--0,001	8,73--13,93	10,65	3	1,64--2,87	2,27	3
<0,001	12,61--17,27	14,42	3	6,87--7,79	7,33	3
<0,01	26,69--35,95	29,95	3	6,61--15,42	11,11	3
3/2	0,044--0,054	0,049	2	0,035--0,045	0,068	3
So	3,0--10,0	6,3	3	1,8--1,5	1,0	3

Fine-aleuritic muds are distributed more extensively than are the large aleurites, but they too occupy a narrow strip in the upper and middle parts of the continental slope, rarely descending to its foot or rising to the shelf. The granulometric composition of fine-aleuritic muds is shown in Table 6 and is represented in histograms (see Figure 5, IV) and on the field of cumulative curves (Figure 9, IIB). The composition of the fine-aleuritic oozes is quite varied, the fluctuation limits of the individual fractions are large; as a result of this the histograms have two or three peaks and the oozes are poorly sorted. Such a composition of the oozes did not always make it possible to separate fine-aleuritic oozes from large aleurites or even from sand. In separating sediments of these types we were guided by the value of the median diameter.

Aleuritic-argillaceous oozes (containing 50-70% pelitic fraction) also occupy a narrow strip within the bounds of the continental slope far into the sea. The bottom of the sea bed (up to depths of 3,000m) is covered by aleuritic-argillaceous oozes only in regions where active precipitation of shell material takes place on the bottom (the eastern part of the sea). The granulometric composition of the oozes is shown in Table 7, and is represented on histograms (Figure 5, V) and in the field of cumulative curves (Figure 9, IIIa). Histograms of oozes, /59 as a rule, have two peaks: one of the peaks almost in all cases is for the shallow-aleuritic fraction, while the second peak (the maximum) is for the medium-pelitic muds, and more rarely for the colloid fraction.

The sorting of the oozes is usually poor, this being explained by the effect of shell material upon the terrigenous part of the sediment (this has been mentioned above). The Md of oozes in the western part of the sea is usually less (0.0020-0.0044 mm) than in the eastern part (0.0026-0.0080 mm).

Table 6
Fine-aleuritic mud

Particle sizes (in mm), sorting coefficients	a. Aegean Sea		b. Eastern part of the Mediterranean Sea.		g. Western part of the Mediterranean Sea.				
	Fluctuation limits, %	Average %	No. of Samples	Fluctuation limits, %	Average %	No. of Samples			
>1,0	1,59-46,41	21,33	8	0,14-39,22	11,54	7	0,18-13,93	10,13	5
0,1-0,05	2,34-23,00	19,19	8	2,63-24,05	13,84	7	1,90-19,63	17,12	5
0,05-0,01	13,08-30,57	29,34	8	12,17-62,65	30,04	7	20,65-53,59	32,15	5
0,01-0,005	2,22-17,13	6,49	8	7,28-34,92	13,70	7	5,34-7,13	6,42	5
0,005-0,001	12,74-30,70	18,77	8	5,63-23,11	16,56	7	7,52-31,85	15,50	5
<0,001	9,21-21,86	13,44	8	5,43-21,86	17,36	7	10,91-24,89	14,74	5
<0,01	32,48-48,68	40,91	8	26,15-49,58	11,59	7	24,18-49,89	36,67	5
Nd	0,011-0,020	0,014	8	0,011-0,015	0,013	7	0,010-0,017	0,0135	5
Σ	1,8-7,2	4,2	8	1,8-7,0	5,3	7	1,7-5,0	3,3	5

Argillaceous oozes (containing more than 70% of the pelitic fraction) occur on extensive areas of the sea bottom, frequently rising up along the slope all the way to the very shelf. Such phenomena are observed in the Tyrrhenian Sea, the Adriatic Sea, the Aegean Sea, and the Sea of Marmara, where they occur not only in the basins of the sea, but also on the shelf, at a distance of 10-15 km from the shore. In regions of the foredeltas of large rivers, argillaceous oozes rise to 20 m and occur at a distance of 4 km from the shore. In these regions the argillaceous oozes usually occur in spots, rapidly tapering out along the horizontal. Individual spots of oozes are noted in portions of the sea near river mouths and in several bays (the Bay of Lyons and others). They are not shown due to the small scale of the diagram.

The granulometric composition of argillaceous oozes in individual regions of the sea is shown in Table 8 and is represented in histograms (Figure 5, VI) and in the field of cumulative curves (Figure 9, IIIb). The thinnest oozes occur in the western part of the sea ($Md = 0.0019$) (the histogram of station 489 is typical for the entire deepwater part of the Algiers-Provence basin), the coarsest oozes ($Md = 0.0029$) occur in the eastern part of the sea. The oozes are best sorted of all in the Adriatic Sea and in the basin of the Tunisian sill. Histograms of argillaceous oozes as a rule have two peaks. but the maximum is not always in the same place. Thus, on histograms of the oozes of the Nile foredelta, the western part of the Mediterranean Sea, the Tyrrhenian Sea and the Sea of Marmara, and at some stations of the Ionic Sea, the maximum is situated in the colloid fraction, whereas in the Adriatic Sea and in the Aegean Sea and at several stations of the sea of Levant and the Ionic Sea, the maximum is situated in the medium-pelitic fraction.

(See Figures 7 and 8 on following pages)

Table 7

Composition of aleuritic-argillaceous ooze acco

Particle size, (in mm), sort- ing coeffi- cients	a. Aegean Sea			b. Eastern part of t erranean Sea.	
	Fluctua- tion move- ments, %.	Average, %.	No. of Samples	Fluctua- tion move- ments, %.	Average, %.
>0,1	0,64-16,70	9,33	10	0,15-23,78	15,70
0,1-0,05	3,62-34,92	9,88	10	1,55-44,72	7,54
0,05-0,01	9,01-37,39	24,48	10	12,07-36,48	26,85
0,01-0,005	6,04-13,21	10,39	10	7,28-27,91	11,04
0,005-0,001	20,24-37,91	29,38	10	14,95-41,83	31,68
<0,001	14,95-30,83	21,93	10	12,06-33,21	20,75
<0,01	54,17-67,15	61,50	10	51,55-69,08	13,75
<i>Ald</i>	0,003-0,008	0,044	10	0,0026-0,008	0,0045
<i>Σ</i>	3,4-8,3	4,7	10	3,0-6,8	3,9

Particle size, (in mm), sort- ing coeffi- cients	e. Tunisian Strait			f. Tyrrhenian Sea	
	Fluctua- tion move- ments, %.	Average, %.	No. of Samples	Fluctua- tion move- ments, %.	Average, %.
>0,1	7,30-17,72	12,51	2	1,61-26,30	7,89
0,1-0,05	12,03-18,98	15,50	2	6,32-24,30	11,34
0,05-0,01	15,14-15,54	15,34	2	9,72-34,13	21,28
0,01-0,005	—	4,70	1	3,91-11,98	8,51
0,005-0,001	—	17,29	1	17,09-24,52	20,28
<0,001	—	32,71	1	19,28-33,65	29,16
<0,01	54,70-58,58	56,63	2	50,93-68,14	59,47
<i>Ald</i>	—	0,005	1	0,001-0,0035	0,0035
<i>Σ</i>	—	10,0	1	4,3-9,4	7,1

A.

ooze according to fractions.

Eastern part of the Mediterranean Sea.		c. Ionian Sea		d. Adriatic Sea.				
No.	Average, %.	No. of Samples	Fluctuation movements, %.	Average, %.	No. of Samples	Fluctuation movements, %.	Average, %.	No. of Samples
78	15,70	28	1,11-2,11	1,55	6	0,14-23,51	8,65	3
72	7,54	28	0,44-17,40	5,66	6	0,43-6,52	3,56	3
48	26,85	28	21,22-29,69	27,53	6	12,33-35,24	23,99	3
91	11,04	28	10,81-17,39	13,61	6	11,22-18,48	14,91	3
83	31,68	28	13,10-33,79	27,20	6	23,92-30,02	26,36	3
21	20,75	28	15,10-31,05	25,03	6	20,85-25,07	22,50	3
08	13,75	28	59,74-69,72	65,28	6	60,39-66,81	63,79	3
08	0,0045	28	0,0035-0,0066	0,0045	6	0,0045-0,0066	0,0053	3
	3,9	28	3,6-5,0	4,2	6	3,2-3,5	5,1	3

Table 7. (Continuation).

e. Aegean Sea		g. Western part of the Mediterranean Sea.			
No.	Average, %.	No. of Samples	Fluctuation movements, %.	Average, %.	No. of Samples
	7,89	8	0,40-11,60	4,79	9
	11,34	8	2,25-13,26	6,06	9
	21,28	8	14,27-31,90	24,47	9
	8,51	8	6,50-25,00	12,05	9
	20,28	8	8,44-29,45	21,35	9
	29,16	8	23,01-37,58	29,11	9
	59,47	8	52,97-68,46	64,69	9
	0,0055	8	0,0020-0,0080	0,0040	9
	7,1	8	4,0-7,0	5,2	9

B.

Table 8

Argillaceous ooze.

Particle size, (in mm), sorting coefficients	a. Aegean Sea			b. Eastern part of the terranean Sea.		
	Fluctuation movements, %.	Average, %.	No. of Samples	Fluctuation movements, %.	Average, %.	No. of Samples
> 0,1	0,33-9,58	3,40	10	0,14-11,62	0,77	36
0,1-0,05	1,63-5,45	3,53	10	0,18-15,77	3,60	36
0,05-0,01	10,34-23,61	16,91	10	9,09-34,49	17,98	36
0,01-0,005	7,02-12,84	9,99	10	1,25-22,67	11,11	36
0,005-0,001	32,30-42,81	36,23	10	23,00-41,54	30,81	36
< 0,001	19,13-34,75	29,03	10	25,08-52,93	34,05	36
< 0,01	71,81-81,62	76,00	10	70,06-90,01	77,20	36
Mid	0,0019-0,0027	0,0025	10	0,0009-0,0037	0,0029	36
So	2,5-3,8	3,2	10	2,4-6,2	3,5	36

Particle size, (in mm), sorting coefficients	e. Tunisian Strait			f. Tyrrhenian Sea		
	Fluctuation movements, %.	Average, %.	No. of Samples	Fluctuation movements, %.	Average, %.	No. of Samples
> 0,1	1,56-3,51	2,38	5	0,25-9,63	2,93	
0,1-0,05	1,70-4,31	2,37	5	0,38-7,90	3,75	
0,05-0,01	5,58-17,76	9,95	5	6,08-22,79	15,17	
0,01-0,005	5,87-8,57	7,22	5	6,84-13,52	10,20	
0,005-0,001	33,02-34,58	33,80	5	23,21-37,63	11,84	
< 0,001	37,38-46,74	42,06	5	27,71-48,26	35,66	
< 0,01	81,99-89,79	85,98	5	70,00-90,08	75,53	
Mid	0,0011-0,0015	0,0013	5	0,0011-0,0028	0,0021	
So	2,7-3,5	3,1	5	3,0-4,6	3,7	

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A.

oze.

n part of the Medi- ean Sea.		c. Ionian Sea				d. Adriatic Sea.		
Average, %	No. of Samples	Fluctua- tion move- ments, %.	Average, %	No. of Samples	Fluctua- tion move- ments, %.	Average, %	No. of Samples	
0,77	36	0,13-4,98	2,23	11	0,27-2,60	0,99	6	
3,60	36	0,52-9,66	3,62	11	0,69-2,61	1,66	6	
17,98	36	9,36-24,31	15,61	11	13,52-25,07	20,32	6	
13,11	36	3,93-13,81	9,31	11	11,31-17,92	15,42	6	
30,81	36	27,10-39,26	33,65	11	30,90-40,03	32,96	6	
34,05	36	24,22-47,91	34,91	11	29,21-32,51	28,51	6	
77,20	36	73,42-89,40	78,78	11	72,91-83,98	76,57	6	
0,0029	36	0,0013-0,0045	0,0022	11	0,0017-0,0035	0,0028	6	
3,5	36	3,2-4,5	3,8	11	2,7-3,4	3,1	6	

Table 8. (Continuation).

henian Sea		g. Western part of the Mediterranean Sea.			
Average, %	No. of Samples	Fluctua- tion move- ments, %.	Average, %	No. of Samples	
2,93	15	0,15-7,39	2,31	16	
3,78	15	0,17-6,91	2,68	16	
15,17	15	10,60-25,61	16,48	16	
10,20	15	4,34-15,57	9,81	16	
31,81	15	21,51-33,28	29,82	16	
35,66	15	30,03-49,52	38,77	16	
75,53	15	70,10-88,98	78,55	16	
0,0021	15	0,0011-0,0030	0,0019	16	
3,7	15	3,0-5,5	4,0	16	

B.

Granulometric analysis has shown that the distribution of the fractions with respect to area and in individual granulometric types of sediment is quite varied. In each type are sediments with a different spectrum, a different profile, a different median diameter and different sorting. This can be seen particularly well in the histograms. If, however, the histograms are examined within the limits of a single genetic type of sediment, a rather clear link is observed between the granulometric composition and the material composition of the sediments.

Oozes of the first type (terrigenous and weakly calcareous deposits) are represented by histograms with two peaks: one peak with a sharply expressed maximum in the colloid fraction, the other peak (a small one) in fine-aleuritic material. Histograms of sands and of large aleurites are usually single-peaked (two winged), more infrequent. (in the deepwater part) they have two peaks with a small peaklet in pelite.

Common for all histograms of the first type of sediments is the presence of a sharply expressed maximum, good for (large-grain sediments) and medium (sometimes poor) sorting (Figure 10 II). Such an arrangement of peaks on the histograms of ooze sediments is determined by the granulometric composition of the terrigenous material washed out from land, pulverized to colloidal dimensionality under the conditions of the moist and warm climate of the Mediterranean Sea region, with a well developed crust of weathering. The second (smaller) peak is obtained due to terrigenous and, to a lesser degree, biogenic material. The fine-aleuritic fraction serves as a kind of limit in the pulverization of clastic (light and heavy) minerals. Argillaceous minerals are the most developed in the fraction < 0.005 mm (Strakhov, 1954).

Thus, the medium-pelitic fraction remains in an intermediate position and, as a rule, forms one of the minima in the histograms.

Oozes of sediments of the second type (calcareous) are also characterized by two-peak histograms, but the maximum is shifted from the colloid fraction to the medium-pelitic fraction, and if it is not shifted, which is observed regularly (in the northern part of the Algiers-Provence basin) is in any case expressed considerably more weakly than in histograms of the first type. The second peak retains its position.

The shift of the maximum is the result of a considerable quantity of admixture of calcareous material (pelitomorphous calcite and coccolithophorids). In the Adriatic Sea, due to the presence there of shallower depths and a strongly dissected water-collecting area, the shift of the maximum is possibly brought about by the washout of material with a dimensionality coarser than colloidal.

Characteristics of strongly calcareous sediments (the third type) are two- and three-peak histograms without sharply defined maxima (the sediments do not have sharply predominating fractions). The peaks are usually situated in the medium-pelitic, fine-aleuritic and sand fractions. The content of coarse fractions in the sediments increases perceptibly and that of pelitic fractions decreases. The variety and the large number of peaks of the histograms is obtained due to the admixture of benthic and foraminiferous material and pelitomorphous calcite. Due to the presence of a large amount of admixtures with various granulometric spectra, sediments of the third type are worse sorted than are the sediments of all the other types.

Histograms of carbonate organogenic-detrital shell sands (the fourth type) have a single peak, are one- and two-winged, with an unclearly expressed maximum in one of the sand fractions.

More infrequently (at great depths) are observed two-peaked histograms with a weakly expressed peak in pelite. The shift of the maximum into one of the sand fractions is brought about by the deposition, in such regions, of a large amount of shell material (detritus). The sorting of sediments of the fourth type is good or medium.

Chemogenic sediments are characterized by histograms with a single peak in the fine- or medium- sand fractions. More infrequently, at depths greater than 15 m, the single-peak histograms become 2- or 3-peaked ones due to the admixture of shell and pelitic materials. The sorting of chemogenic sediments is good. /63

Histograms of volcanogenic sediments usually have two peaks: the ash material forms a peak in one of the aleuritic fractions, the terrigenous material forms a peak in the pelite.

It can be seen that in the formation of one shape or another of the granulometric profile, the principal part is played by various admixtures to the terrigenous material. The quantity of the admixture, its spectrum, and its profile determine the granulometric composition of the sediments. These observations are confirmed by the conclusion of N.M. Strakhov (1954, p. 415) concerning the fact that the presence of two peaks cannot serve as a reliable indication of the washout of sediments, as is sometimes considered to be the case (Klenova, 1948).

Knowledge of the rules governing the changes of the granulometric profiles of the sediments is helpful in distinguishing without detailed study of the material composition, the principal regions of the formation of this or that type of sediment, and this has been done by us for the Mediterranean Sea (Figure 10).

Terrigenous and weakly calcareous sediments accumulate in regions adjacent to large river arteries or mountainous sectors of the water-collecting area -- to sources of terrigenous material. Naturally there are numerous deviations from this system. Thus, on the banks of the western Mediterranean region, the Aegean Sea, calcareous and strongly calcareous sediments accumulate and calcareous crusts form (Blanc, 1958, 1959b). But these deviations do not change the fundamental pattern.

Calcareous sediments are pushed away from the shore by terrigenous sediments to considerable distances and to great depths. Only in the northern part of the Algiers-Provence basin and in the Adriatic Sea do they come close to the shore or even all the way to the shore. Within regions of the deposition of calcareous sediments are also noted numerous cases of the formation of terrigenous or weakly calcareous deposits (for example, in the region of the continental slope of the French coast, where landslide processes and sludge flows are actively manifested in numerous canyons). Their granulometric profile must differ substantially from the profile of the surrounding sediments.

In the diagram (Figure 10) it can be seen that the first and second types of sediments with the granulometric composition characteristic of them accumulate in the humid zone of lithogenesis (under the conditions of a warm and humid climate) with the active arrival of detrital material and weak carbonate formation.

Strongly calcareous sediments (pteropod-foraminiferous, organogenic-detrital shell, oolitic sediments, etc.), i.e., sediments of the third-fifth types, are formed principally within the limits of the arid zone adjacent to the drainless African region. In the deepwater part of the sea (mainly at

uplifts) and within the limits of the continental slopes there takes place an active deposition of biogenic material and pelitomorphic calcite. Organogenic-detrital shell sands are deposited on the edge of the shelf or on underwater banks, oolites and pseudoolites are deposited in the shore region mainly to a depth of 50-70 m. Almost everywhere within the region of the deposition of strongly calcareous deposits there takes place the active formation of calcareous crusts and concretions, the precipitation of chemogenic calcite.

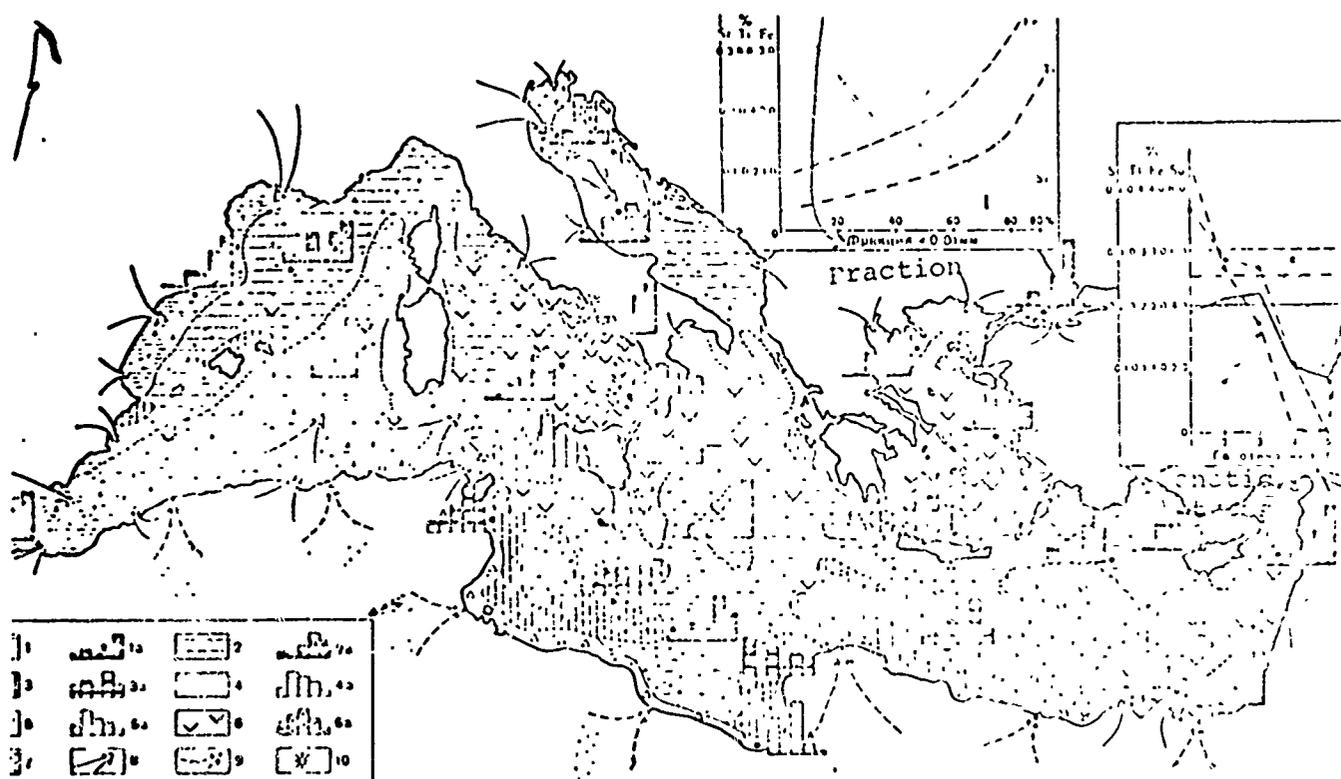


Diagram 10. Diagram of the accumulation of genetically different contemporary sediments of the Mediterranean Sea.

- 1 - terrigenous sediments sharply predominate the (index "a" indicates histograms characteristic of the given sediment type);
- 2 - terrigenous sediments with a large admixture (30-50%) of calcareous materials;
- 3 - strongly calcareous sediments (containing 50-70% CaCO₃);
- 4 - strongly calcareous sediments (organogenic -detrital shell sands, containing over 70% CaCO₃);
- 5- chemogenic (calcareous) sediments.
- 6- volcanic sediments
- 7- regions of the occurrence of aeolian material;
- 8 - main arteries of the arrival of terrigenous materials;
- 9 - arteries of the arrival of aeolian materials;
- 10 - sources of pyroclastic materials;

(continued next page)

- I - Example of the dependence of some components on the content of the fraction smaller than 0.01 mm (average for the entire sea);
- II - graph of the dependence of sorting (S_o) and some components on the sediment type (horizontal lines are average values for sediments of the entire sea);

A - sand histograms.

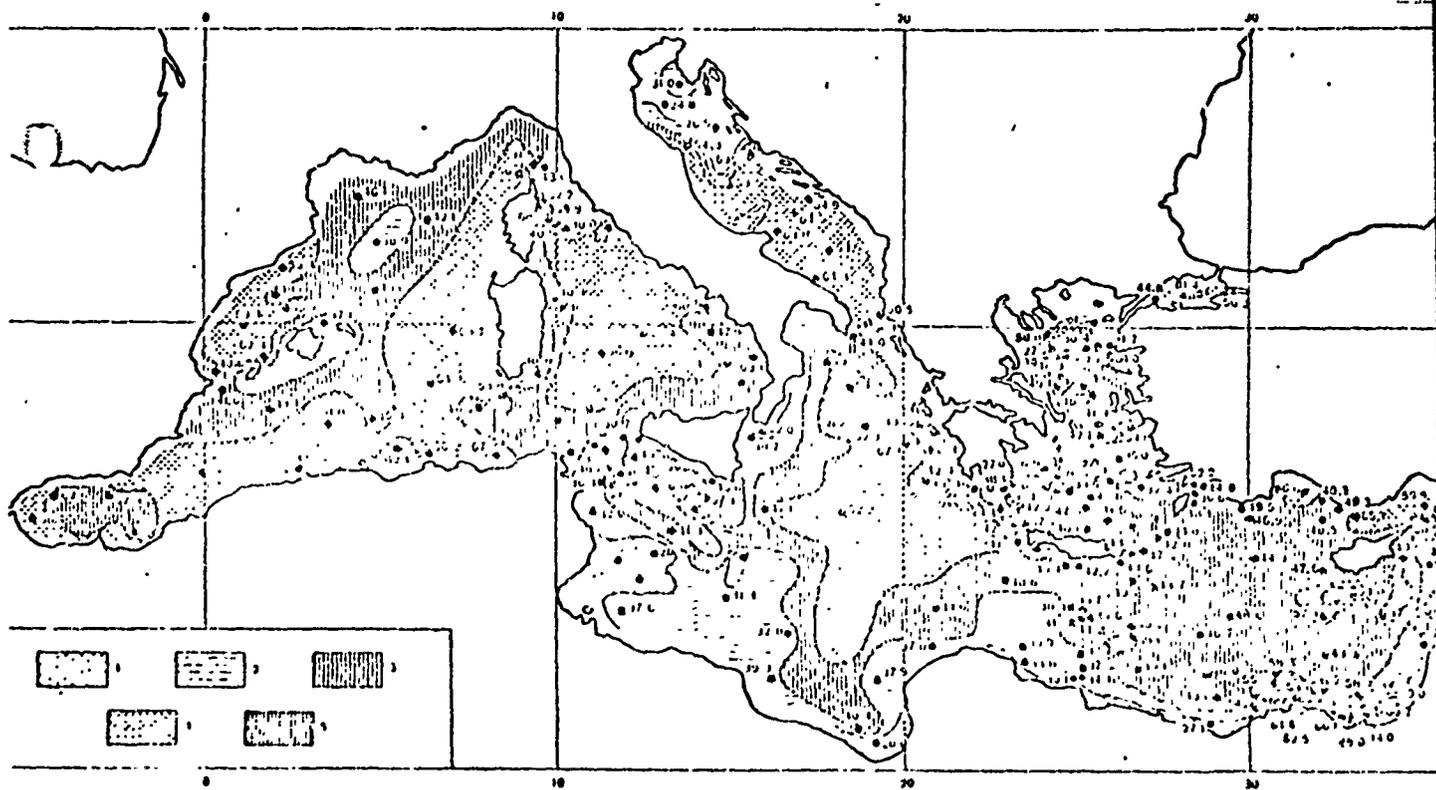


Figure 11. Diagram of the distribution of moisture of the sediments of the Mediterranean Sea (i, %).

1 - < 30; 2 - 30-40; 3 - 40-50; 4 - 50-60; 5 - >60.

The different granulometric composition of the sediments of the humid and the arid zones determines their different physical and mechanical properties. The moisture of the sediments of the arid zone is considerably lower than the moisture in this humid region (Figure 11). A close relationship has been established not only between the humidity and the pelitic fraction, but also between the humidity and the carbonate content (Figure 12): when the content of the fraction < 0.01 mm is decreased to 10%, the moisture in the sands and aleuritic-argillaceous oozes increases on the average by 3%, in argillaceous oozes by up to 5%. An increase in the carbonate content

of oozes to 2.5% reduces humidity by 1%. The deepwater sediments of the arid zone are considerably dense, more viscous, /66 and more clastic than are the sediments of the humid zone. In these differences are manifested some features of geographic (climatic) zonality and sediment accumulation of the Mediterranean Sea.

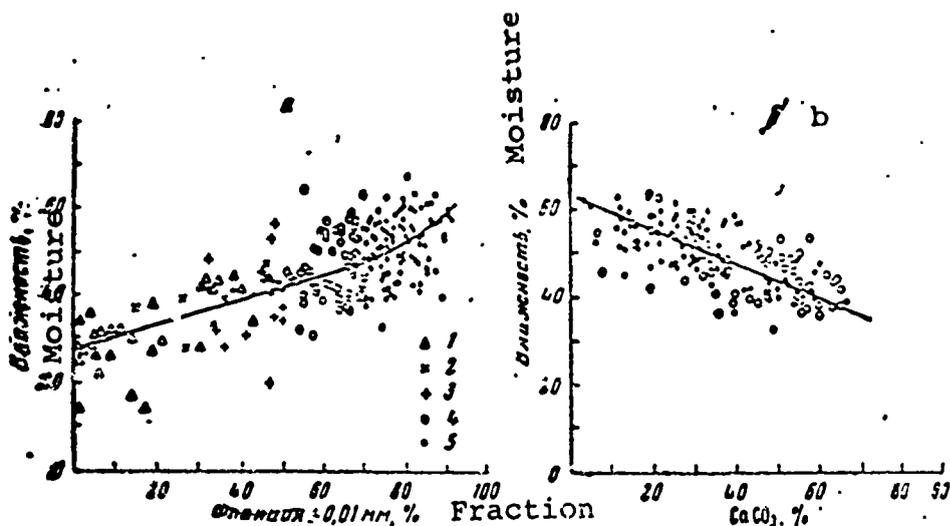


Figure 12. Graph of the relationship of moisture of the content of the pelitic fraction in sediments (a) and to the carbonate content of oozes (b).

- 1 .. in sand samples;
- 2 - in samples of large aleurites;
- 3 - in samples of fine-aleuritic oozes;
- 4 - in samples of aleuritic-argillaceous oozes;
- 5 - in samples of argillaceous oozes.

The volcanogenic sediments are azonal. They are formed in regions directly adjacent to active volcanoes, although pyroclastic material is encountered at all depths and at various distances from the shores.

Thus, it can be seen that sediments of different material composition are characterized by a definite granulometric profile or, on the contrary, the granulometric profiles helps in distinguishing the material content of the sediments. A similar relationship should be observed in other water reservoirs that are similar to the Mediterranean Sea.

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The mechanical composition of silt samples of present-day marine sediments as collected by the expeditionary ship "Academician S. Vavilov" was determined in the lithology laboratory of the Black Sea Experimental Scientific Research Station of the Institute of Oceanography, Academy of Sciences, USSR by various methods of aqueous analysis. In the first stages of the organization and setting up of aqueous mechanical analysis at the Black Sea Experimental Scientific Research Station in 1959, it was carried out in the lithology laboratory according to the methods developed in the Institute of Oceanography, Academy of Sciences, USSR, by S.I. Malinin, (1952). This method, based on "elutriation" and subsequent separation of the aleuritic fractions in a calm water column, makes it possible to obtain free particle fractions of the sample undergoing analysis: a fine-aleuritic fraction, a large-aleuritic fraction and a fraction with particles greater than 0.1 mm; the latter is separated in a sieve with 0.1 mm apertures, through which the silt fraction that has been prepared for analysis is passed in a moist state. The residue on the sieve is washed, dried, weighed, etc. The large- and fine-aleuritic fractions are separated by settling in cylinders with water. The dimensions of the poured-off particles, as well as the purity of the obtained fractions, are controlled under a microscope in the process of analysis. In addition to the three indicated fractions obtained directly, there is determined the quantity of pelitic material (particles smaller than 0.01 mm in size) through calculation according to the deficit in the sum of the weights of the obtained fractions in comparison with the total weight of the sample going into analysis (in terms of dry materials).

It is obvious that such an overall characterization of the mechanical composition of the pelitic material of present-day sediments of the Mediterranean Sea, consisting to a considerable extent of ooze, cannot be accepted as satisfactory.

It was necessary to subject to supplementary analysis the pelitic fractions (particles less than 0.01 mm). For this purpose we used the pipette method, first class, by means of a Vasil'yev pipette (Vasil'yev, 1953). For installation of the pipette, use was made of a carriage especially designed for this purpose, which was mounted on a rail track installed above the apparatus for aqueous analysis according to the method of S.I. Malinin.

Analysis of the pelitic material was carried out before its elutriation from a silt sample prepared for analysis by the Malinin method. Thus, the indicated methods were combined by us into a single integrated method (Prokoptsev, Stel'makh, 1963).

This made it possible not only to increase the precision of the analyses (cross check of the two methods) and the productivity of the analytical laboratory, but also to diminish the consumption of the analyzed material. The latter factor is of considerable importance in laboratory investigations of samples collected by direct-flow and piston tubes of small diameter.

At present, a method for analysis of the mechanical composition of pelitic fractions by means of suspension scales has been developed in the laboratory (Prokoptsev, 1964). In the opinion of the author, the use of such cables, in addition to considerably accelerating the completion of the analysis and increasing the productivity of the laboratory, will make it possible to obtain fundamentally more precise data concerning 70 the relationship of the argillaceous and the colloid fractions of the sediments. This opinion is based upon the fact that in the course of analysis by the pipette method, during the drying

of samples selected by the pipette, the natural state and the composition of the colloid and partly of the argillaceous fractions are disturbed (at a temperature of 105° partial dehydration can take place), whereas analysis by means of suspension scales, based on change of the concentration of the pelitic material-water suspension, is obviously free from the indicated drawback. At the same time, in the designing of suspension scales, the precision of whose measurements can in individual cases be less than the precision of the pipette method, some drawbacks still remain. This indicates the necessity of additional improvement in the design of suspension scales.

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THE CARBONATE CONTENT OF THE PRESENT-DAY BOTTOM
DEPOSITS OF THE MEDITERRANEAN SEA

Ye. M. Yemel'yanov

The distribution of carbonates over the area of the Mediterranean Sea has been studied comparatively little. The first references to the content of carbonates in deep-water oozes are encountered in the beginning of the 20th century. In 1920 Andree (1920) described the calcareous oozes of the Tyrrhenian Sea and noted that they reach to the shore of the Bay of Naples. Boggild (1912) named the oozes collected by the Dutch expedition on the ship "Tor" in the western part of the sea, globigerine oozes. In the eastern part of the sea the Danish expedition on the ship "Pola" discovered calcareous oozes and argillaceous-calcareous concretions occurring in the Strait of Cythera and between Crete and Africa at a depth of 30-3130 m. Two types of oozes were distinguished -- blue with CaCO_3 less than 30% and globigerine (with CaCO_3 more than 30%).

French scientists (Bourcart, 1954; Blanc, 1956, 1959; Bourcart, Boillot, 1958) indicate that deepwater oozes can contain from 20-34 to 75-93% CaCO_3 . Oozes with a CaCO_3 content of up to 50% occur at the French coast at a depth of 50-60 to 2,000 m, and even 2,500 m. The accumulation of carbonate shell material within the limits of the Mediterranean shelf has not infrequently been written about by Bourcart (1957), Blanc (1956, 1958) and other French scientists. Some questions dealing with the accumulation and transformation of carbonates in the sediments of the western part of the Mediterranean Sea have been studied by Blanc and Molinier (Blanc, Molinier, 1955; Blanc, 1958) and Lalou (1957). Bernard and Lecat-Schlauder (1953) have pointed out the active part played by coccolithophorides in the carbonate formation of the Mediterranean Sea, and have

indicated that their significance in the sediment of oolites on the shelf of the African coast from Alexandria to Tunis has been studied by Hilmy (1950) and Lucas (1955). Lucas has proved that oolite formation in the Mediterranean Sea is taking place very actively. Oolites have a concentric structure, and various mineral grains can serve as centers of crystallization for them.

Consequently, in the Mediterranean Sea there has been noted the presence of terrigenous calcareous, and strongly calcareous sediments; terrigenous, biogenic, and chemogenic carbonates have been established.

In spite of the large number of the enumerated works, up to now there is not yet any work that summarizes the distribution of carbonates along the area of the entire Mediterranean Sea. The works of foreign scientists deal either with one of the aspects of carbonate formation, or with the distribution of carbonates on a small sector of the sea bottom.

During the four Soviet oceanographic expeditions on the expeditionary ship "Academician S. Vavilov" (1959-1962; see the article by V. Goncharov in the present collection), about 250 samples of bottom sediments were collected which encompass the entire body of the Mediterranean Sea. In almost all samples, under laboratory conditions (the analyses were carried out in the analytical chemistry laboratory of the Black Sea Experimental Scientific Research Station under the supervision of V. S. 72 Sevast'yanov) CO_2 was determined, which was then recalculated in terms of the total content of CaCO_3 . The analyses were carried out on the basis of air-dry samples by the Fresenius-Knopp method.

The Mediterranean Sea is located at the boundary of two zones of lithogenesis with different conditions of supply of the reservoir with sedimentary material and of the formation of sediments in the reservoir itself. The northern and the western parts of the

basin, located in a humid zone, are surrounded by mountainous regions with the active arrival of detrital terrigenous material. The southern part of the sea, located in an arid zone, adjoins the tectonically calm platform part of Africa and lacks this material. The conditions of supply of the Mediterranean Sea with detrital material, the topography of the bottom, and the hydrologic features of the basin have been dealt with by other authors (see the article of Ye. M. Yemel'yanov, O. M. Mikhaylov, and I. M. Ovchinnikov in the present collection). We shall touch only upon some features of the hydrochemical conditions of the basin.

We do not as yet have in our possession precise data concerning the supply of carbonate materials to the Mediterranean Sea, but it is known that in the loess of the Mediterranean red beds, within the limits of the water-collection basin, calcareous crusts are formed (Bouline, 1961), which indicate considerable accumulations of calcareous material in silt waters. However, the degree of saturation of the river waters of the Mediterranean region with dissolved carbonates has not as yet been clearly established. It may be assumed that the rivers of the humid zone of this region, due to the strongly dissected relief of the water-collecting area, should supply the carbonate predominantly in the form of detrital material. Its arrival in the northern regions should be more considerable than in the southern regions, also because active abrasion processes take place there (Marine Atlas, 1950). Thus, in the region of the Rhone delta, terrigenous carbonates are a product of the disintegration of underwater limestone outcroppings (Duboul-Razavet, Kruit, 1957). The carbonate content of the oozes of the delta increases as the particles become finer, and may attain 39%.

From the arid water-collection area of the sea, a certain amount of carbonate detrital material should arrive in the form of eolian material (Hilmy, 1950). The Nile River does not carry out a perceptible quantity of detrital carbonate, since the calcareousness of the river detritus within the limits of the delta rarely exceeds 2%.

() Arriving in a marine medium, the detrital and dissolved carbonate material undergoes a number of complex changes. The processes of the dissolution, its behavior in aqueous solutions, as well as the processes of the precipitation of carbonates are determined by a combination of four basic factors: 1) the pressure of carbon dioxide in the air and its masses in the solution itself; 2) the temperature of the solution; 3) the influence of salts which enter into the composition of the solution, particularly sulphates and chlorides of sodium, potassium, calcium, and magnesium; 4) the influence of "living substance" in natural waters (Strakhov, 1951 a, b; Teodorovich, 1960). When any one of the factors changes, the equilibrium of the carbonate compounds is disrupted; this leads to their precipitation or to their additional dissolution.

() The carbonate regime of the Mediterranean Sea differs from the regimes of the Black Sea and the Atlantic Ocean (Table 1). The temperature and the salinity of the waters of the Mediterranean Sea are considerably higher than in other reservoirs. Here, even in the water layers adjoining the bottom, the temperature does not sink below +13°. The specific alkalinity of the waters is approximately equal to the alkalinity of the equatorial waters of the Atlantic Ocean, but in the Mediterranean Sea no increase of this specific alkalinity is observed at greater depths. On the contrary, it is sometimes even lower there than on the surface of the sea. The waters of the Mediterranean Sea are also distinguished

by a comparatively high pH and a low $p\text{CO}_2$. These values hardly change at all with depth (according to the data of V.A. Yegorova - approximately to depths of 2000-3000 m).

It is known that the solubility of calcium carbonate increases with an increase of small $p\text{CO}_2$ and decreases with an increase in the temperature, salinity and pH, and conversely. Knowing the solubility at a specific temperature and the $p\text{CO}_2$, it can be computed that in the case of fluctuations of the temperatures of the waters of the Mediterranean Sea, it is 1.5 times higher in winter than in summer, and equals approximately 1.08-1.55 mg x equiv/liter.

It has been established that a close relationship exists between the $p\text{CO}_2$ and the pH: when the $p\text{CO}_2$ increases the pH decreases. But since the two factors are almost constant in the Mediterranean Sea, and the $p\text{CO}_2$ indicates the quantity of carbonate dissolved in the water, it follows (with a negligible $p\text{CO}_2$) that the reserve of carbonates in the waters of the sea is very small.

Wattenberg and Timmerman (1936) have established that at a water temperature of 10-30° (the fluctuation limits of the temperatures of waters of the Mediterranean Sea), the waters become saturated with calcium carbonate when the pH is 7.62-7.20 and the $p\text{CO}_2$ is 12.6-16.0 x 10⁻⁴ atmospheres. Thus, in spite of the negligible arrival and reserves of carbonates, the waters of the Mediterranean Sea contain a potential possibility not only for the active extraction of carbonates by organisms but for their chemical precipitation everywhere (presumably to depths of 3000 m).

This assumption is confirmed by the data of our observations. A map (scale 1:3,000,000, Figure 1) compiled according to the data of Soviet observations, shows the total content of CaCO_3 .

Basin	Horizon	Temperature °C		Salinity, ‰	Specific Alkalinity	pH	pCO ₂ 10 ⁻⁴ atm.
		In Summer	In Winter				
Black Sea	Surface	23,0-27,0	7,0-9,0	17,0-19,0	0,312	8,36	3,5-5,5
	Layer at bottom*			22,54	0,351	7,62	3,5-55,0
Mediterranean Sea	Surface	24,9-29,0***	8,0-9,0	38,0-39,5**	0,120-0,132	8,4-8,5	3,0-4,5
	Layer at bottom	21,0-26,3***	13,5-18,2**	36,4-38,0***			
Atlantic Ocean (equatorial part)	Surface		13,0-14,0	38,5-38,9	0,119-0,125	8,25	2,7-3,0
	Layer at bottom			36,0-37,0	0,120-0,121	8,1-8,35	4,0-6,0

Table 1. Carbonate regime of the Black Sea and the Mediterranean Sea and the Atlantic Ocean. According to the data of Wattenberg, 1933; Strakhov, 1951 a, b) Middellandse Zee, 1957; Bruyevich, 1962; Yemel'yanov, Chumakov, 1962; Yegorova, Institute of Oceanography, Academy of Sciences, USSR).

* Data at the very bottom were obtained only for the Black Sea. In the rest of the cases -- this is the lowest hydrological horizon (10-200 m from the surface of the bottom).

** For the eastern part of the sea.

*** For the western part of the sea.

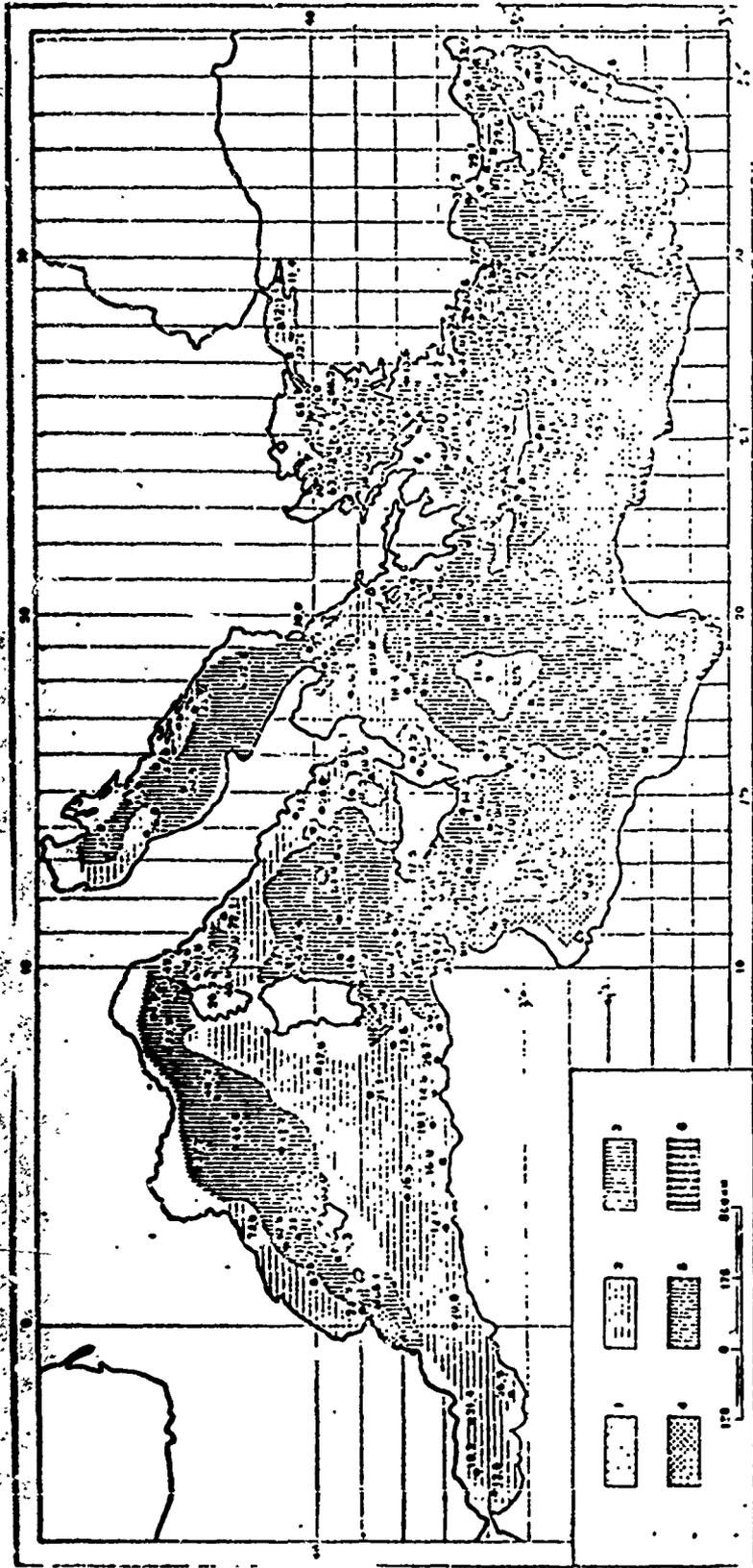


Figure 1. Map of the distribution of CaCO₃ (in %) in the upper layer of sediments.

1 - less than 10, 2 - 10-30, 3 - 30-50, 4 - 50-70, 5 - 70-90, 6 - more than 90.

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The data of foreign scientists are taken into consideration for those regions with regard to which observations are lacking principally for the coastal sectors of the sea). The boundaries of sediment classification of present-day reservoirs have been adopted as the basis of the boundaries of carbonate content (Bezrukov, Lisitsyn, 1960).

Non-calcareous sediments are distinguished in regions of the active arrival of terrigenous and pyroclastic materials, or in regions with strong sea currents, which hinder the precipitation of light carbonaceous shell material.

Weakly calcareous sediments (10-30% CaCO_3) are noted in similar regions, as well as deep-water troughs and basins (up to 4,000 m in depth) and in the Algiers-Provence basin.

Calcareous sediments (30-50% CaCO_3) predominate in the Mediterranean Sea. They lie at the bottom of the bed, on the slopes, and on the shelf.

Strong calcareous sediments (50-70% CaCO_3) occur in small spots in the northern part of the Aegean Sea, in the depression of the Cretan Sea, at the bottom of the African-Sicilian sill, and cover an extensive area of the bottom between Crete and Cyrenaica, descending sometimes to a depth of over 3,000 m. Sediments containing 70-90% CaCO_3 occur in small spots, mainly within the limits of the shelf and on underwater banks. Sediments with a CaCO_3 content greater than 90% (up to 92.32%) have been noted only in several places, particularly within the limits of the African shelf. Possibly the upper boundary of the CaCO_3 content is even in excess of 93%, if it is recomputed in terms of an absolutely dry substance. In recomputing CaCO_3 for an air-dry sample, an inaccuracy is always introduced due to moisture, which sometimes reaches 3-5%.

From what has been said, it can be seen that the distribution of carbonates in the Mediterranean Sea is rather varied. In the western part of the sea there is considerably less of them than in the eastern part. This is explained by the more intensive arrival, into the western basin, of detrital terrigenous material which dilutes the carbonate material, as well as by less favorable physicochemical conditions for the habitat of lime - extracting organisms and for the chemogenic deposition of carbonates, than in the eastern part of the sea.

Less calcareous sediments occur principally in regions adjacent to sectors of the shore with a well-developed river network or with active abrasion processes, which deliver a large quantity of non-calcareous detrital material.

The high content of calcium carbonate in the deepwater parts of the eastern Mediterranean region is due to the intensive deposition here of foraminiferal and pteropodal shell material as a result of which deepwater aleuritic-argillaceous oozes may be called foraminiferal. The carbonate content of the oozes occurring between Crete and Africa is also increased due to /76 pelitomorphous (biogenic and chemogenic) calcite and as a consequence of the formation here of argillaceous calcareous concretions.

The strong calcareousness of the sediments of the northern part of the Aegean Sea and the African-Sicilian sill is due to the deposition of organogenic residua, but already of benthic fauna. Organogenic shell sands occur in these regions. The strong calcareousness of the shelf sediments of the African coast, from Alexandria to Tunis, is due to the occurrence here of chemogenic oolites and shell detritus.

Figure 2 shows the relationship of the carbonate content to the depth. The greatest scattering of the points corresponds to

depths of 0-500 m and an offshore distance of up to 50 km. In this case there is observed a maximum and a minimum content of carbonates. This zone corresponds to the occurrence of sands, large aleurites, and small-aleuritic oozes (see the article by Ye. M. Yemel'yanov "the granulometric composition of present-day sediments..." in the present collection). The large scattering of points at small depths and close to shore is obtained due to the occurrence here both of terrigenous and strongly calcareous sediments. Deeper down they gradually intermix, and the scattering of points on the graph becomes less pronounced. The decrease in the content of carbonates at depths of 500-1100 m may be explained by less favorable conditions for the deposition of easily transportable fine shell material (foraminifera, pteropods, coccolites) on a steep continental slope, and the absence of fragments of large shell material of benthic fauna. Below 1100 m and further than 50 km offshore, the quantity of CaCO_3 varies within the limits of 15-65% (on the average 40-50%).

The relationship of the content of CaCO_3 to the pelitic fraction is shown in Figure 3a: as the quantity of this fraction increases, the carbonate content decreases (coarse differences of sediments are most enriched by CaCO_3), but unevenly. The sharp drop of the average curve (excluding coastal terrigenous sands which have been insufficiently studied by us) correspond approximately to 20 and 70% of the content of the pelitic fraction. On the sector between 20 and 60% the curve flattens out.

Thus, sharp bends of the curve are observed at boundaries of the separation between sands (maximum and minimum content of CaCO_3) and aleurites, and between aleuritic-argillaceous and argillaceous (minimum content of CaCO_3) oozes. This pattern is average for all types of sediments in the Mediterranean Sea.

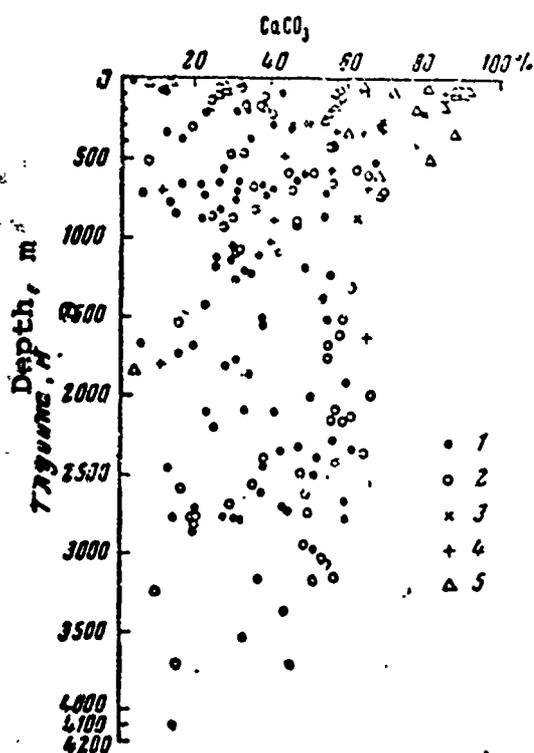


Figure 2. Relationship of CaCO₃ content to depth.

1 - Argillaceous ooze, 2 - aleuritic-argillaceous ooze, 3 - fine-aleuritic ooze; 4 - large aleurite, 5 - sand.

If, on the other hand, individual sectors of the sea are taken, the pattern changes substantially. Average curves of the content of CaCO₃ in relation to pelite for individual sectors of the Mediterranean Sea are shown in Figure 3b. The curves of '77 the Adriatic Sea and of the African-Sicilian sill are not subject to the general rule. In the first instance this is explained by the predominance of terrigenous non-calcareous particles in the entire sediment spectrum, in the second case this is explained by the large amount of pelitomorphous calcite in the sediments.

Such a dependence of CaCO₃ on the enumerated factors is explained by the special features of the supply of terrigenous and organogenic material to the water reservoir and, to a lesser degree, by the chemogenic precipitation of carbonates. It is known (see the article by Kiseleva and Chukhchin in the present collection) that the Mediterranean Sea is very poorly supplied with benthic life forms. The biological mass of benthos

is 50-100 times less than in the Black Sea, and fluctuates in various biotopes of the sea from 0.3 to 18.9 g/m². Benthic organisms, constructing their skeleton from a calcareous substance, on the average inhabit depths up to 500 m. At greater depths, we have encountered only individual shell fragments, i.e., the part played by them in carbonate formation in deep water of the pelitic fraction, the first place in carbonate formation becomes occupied not any longer by benthic organisms but to plankton organisms-- foraminifera, pteropods, coccolites, pelitomorphic calcite.

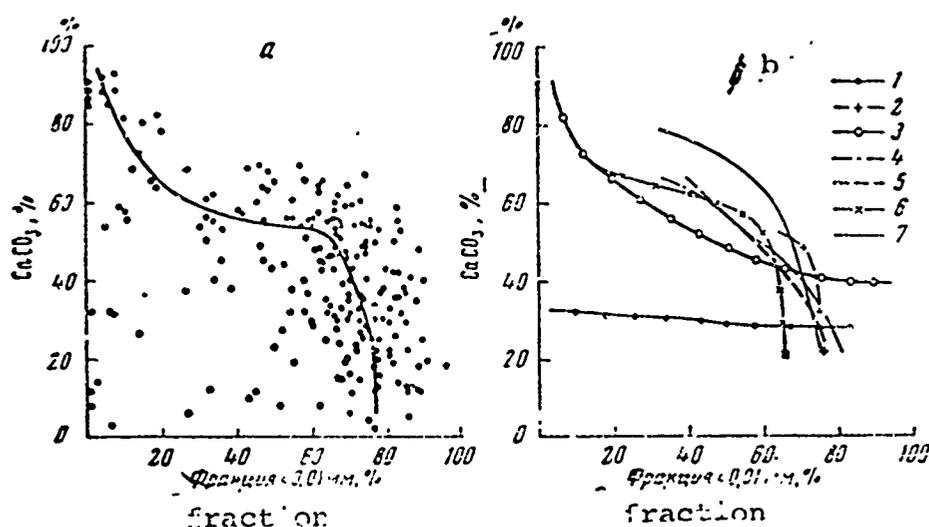


Figure 3. Relationship of the content of CaCO₃ to the content of the fraction more than 0.01 mm (a) and average curves of the relationship of the content of CaCO₃ of the fraction less than 0.01 mm (b) for sectors of the Mediterranean Sea.

1 - Adriatic Sea, 2 - Ionic Sea, 3 - African-Sicilian sill, 4 - Tyrrhenian Sea, Ligurian Sea, 5 - Algiers-Provence basin, 6 - Aegean Sea and Sea of Marmara, 7 - eastern part of the Mediterranean Sea.

Terrigenous calcite occurs mainly in regions adjacent to mountainous regions (Turkey, Crete, Peloponnesus, Italy, the Ligurian Sea, the Strait of Gibraltar). Here it comprises on /78 the average 6-10%, going as high as 46.6% (station 718, south of Karpathos Island) and 60% (Ligurian Sea).

In the southern part of the Mediterranean Sea, the Aegean Sea, and particularly in the Tyrrhenian Sea, there is considerably less calcite (Table 2).

Terrigenous dolomite occurs in the same fractions as does calcite. In the light large-aleuritic subfraction its content is on the average 1-2%, only in rare cases does it reach 18% (station 539). In a heavy subfraction (specific gravity greater than 2.9, the dolomite content fluctuates within broader limits - from 0 to 38.9% (on the average 1.0-2.0). An increase of the dolomite content is observed at most of the stations south of Crete-Rhodes, at stations 599, 405, 410, 529, 412 (for the location of the stations see the article by Yemel'yanov, "The granulometric composition of present-day sediments..." in the present collection) to 5-25%. On the whole, dolomite comprises 3-4% of the large aleuritic fraction, and south of Crete -- up to 30%. In distinction from calcite, dolomite most frequently of all consists of regular, clean, rhombohedral with $n_g = 1.682$. Soils and irregular grains, as well as grains with a zonal structure, are encountered more rarely.

Anchorite, magnesite and ferrous anchorite are found among ferruginous carbonates. Their total content does not exceed 1%, but sometimes increases greatly. Thus, at station 539 (south of Crete) magnesite ($n_g = 1.702$) comprises 1%, anchorite ($n_g = 1.692$) comprises 5%, Fe-anchorite ($n_g = 1.718-1.734$) comprises 30%. Ferruginous carbonates are mostly clean, oval, without cleavages. Rhombohedral shapes were not observed.

A mineral of the type of the siderite is frequently found in sediments of the Mediterranean Sea. Its refraction is usually higher than 1.75-1.78, the birefringence is very high. Siderite grains are oval and more infrequently - irregular.

The distribution of carbonates of the heavy fraction in sea areas varies. Dolomite occurs principally in the same regions as does calcite. There is particularly much of it at stations 374 (30.5%) and 299 (38.9%).

Ferruginous carbonates are most frequently of all encountered in the sea of Marmara and in the Aegean Sea, where they occupy

first place among the heavy carbonates with regard to frequency of occurrence, while in the Ionian and Tyrrhenian Sea and in the region of the African-Sicilian sill, they are either absent or are very rare.

Siderite, on the other hand, is very scarce in the Sea of Marmara and in the Aegean Sea, and is frequently found in the Ionian Sea and in the region of the African-Sicilian sill. With respect to contents in the sediments of the Mediterranean Sea, siderite is second to dolomite and ferruginous carbonates.

Thus, the arrival of terrigenous minerals in the Mediterranean Sea is unequal: there are regions which receive an abundant supply of them, and regions where terrigenous carbonates are almost totally absent (the southeast part of the Tyrrhenian Sea).

The maximum-content values for individual types of terrigenous carbonates most frequently of all do not coincide; this indicates that their sources are different.

Organogenic-detrital shell carbonate is a component of the entire spectrum of the granulometric composition of the sediment. A negligible admixture of it is encountered only in coastal terrigenous sands. In shallow-water sediments, as has been indicated, the larger part of the carbonates is formed by mollusk-shell fragments. Under the microscope, these are rounded and irregular fragments, semi-transparent or almost opaque, yellowish-white in reflected light. The content of CaCO_3 in such fragments (in the Tunisian Strait) is equal to 93.5%. In deepwater sediments the sand fraction and the aleuritic fraction consist of foraminifera and pteropods and their fragments. The shell chambers of foraminifera are usually empty (under a microscope yield a black ring) or are filled with calcite, which with crossed nicols, always yields a black cross. Sometimes fragments of fragile plankton organisms indicate $2V = 5-20^\circ$, on the basis of which they may be included with aragonite.

Table 2
Distribution of carbonates in the large-aleuritic fraction and in the sand fraction.

Sectors of the Mediterranean Sea	Light subfraction (0.1-0.15)			Heavy subfraction (0.01-0.05 mm)			Fraction more than 0.1 mm		
	Organo-genic	Calcite	Dolomite	Total, light	Dolomite	Ferrous Carbonate		Siderite	Total heavy
Sea of Marmara	I	2	2	2	3	3	3	3	
	II	2	2	2	1	2	1	3	
	III	3,0-23,8	4,0-0,4	EA. sh. -4,3	7,0-34,6	0,0- EA. sh.	0,4-8,1	0,0- EA. sh.	EA. sh. -8,1
	IV	13,4	5,2	2,2	20,8	EA. sh.	7,3	EA. sh.	4,0
	V	13,4	5,2	2,2	20,8	EA. sh.	4,8	EA. sh.	4,0
Aegean Sea	I	14	14	14	21	21	21	21	
	II	11	12	10	14	8	11	2	
	III	1,3-83,0	0,0-7,2	0,0-5,2	1,5-80,9	0,0-30,5	0,0-5,8	EA. sh.	0,0-30,0
	IV	63,8	2,9	1,0	66,8	4,8	2,1	EA. sh.	4,6
	V	63,8	1,2	0,7	66,8	1,8	1,1	EA. sh.	3,2
Eastern part of Mediterranean (Sea of Levant)	I	38	37	37	38	30	39	39	
	II	38	37	33	38	22	8	0	
	III	EA. sh. -85,8	EA. sh. -74,7	0,0-10,2	11,5-91,2	0,0-10,5	0,0-3,7	0,0-10,0	0,0-15,5
	IV	46,7	12,6	2,1	60,8	2,0	1,0	4,0	0,0
	V	46,7	12,6	1,8	60,8	1,5	0,3	0,6	0,3
Ionian Sea	I	20	20	20	20	17	17	17	
	II	20	18	17	20	14	3	0	
	III	3,4-100,0	0,0-17,0	0,0-17,0	4,0-100,0	0,0-38,0	0,0-35,0	0,0-13,8	0,0-45,0
	IV	37,1	7,8	3,1	46,8	5,4	12,5	2,0	14,0
	V	37,1	7,1	2,6	46,8	4,4	2,2	1,5	13,3

EA. sh. values close to 1

[continued on next page]

Sectors of the Mediterranean Sea	Light subfraction (0.1-0.15)				Heavy subfraction (0.01-0.05 mm)				Fraction more than 0.1 mm
	Organogenic	Calcite	Dolomite	Total, light	Dolomite	Ferrrous Carbonate	Siderite	Total, heavy	
African-Sicilian Sill	I	11	11	11	12	12	12	13	8
	II	11	5	11	6	1	6	5	8
	III	EA. III. 90,0	0,0-0,0	4,5-90,0	0,0-7,0	0,0-1,7	0,0-4,4	0,0-11,4	93,7-100,0
	IV	(40,7)	3,3	63,85	1,8	EA. III.	1,2	4,1	59,3
	V	(40,7)	2,7	63,85	0,9	EA. III.	0,6	2,8	55,3
Tyrrhenian Sea	I	9	9	9	10	10	10	10	2
	II	8	7	3	2	—	—	4	2
	III	0,0-86,9	0,0-2,8	0,0-1,9	0,0-0,7	0,0	0,0-EA. III.	0,0-c. 3.	3,0-95,8
	IV	47,5	1,1	0,9	0,54	0,0	EA. III.	EA. III.	49,4
	V	42,2	0,8	0,3	EA. III.	0,0	EA. III.	EA. III.	49,4
Algiers-Provence Basin	I	4	4	4	18	18	18	17	—
	II	4	4	4	9	2	4	11	—
	III	23,0-84,0	0,0-60,0	EA. III.	0,0-16,5	0,0-13,7	0,0-1,0	0,0-25,0	—
	IV	54,8	23,5	79,0	2,2	7,4	0,8	3,5	—
	V	54,8	23,5	79,0	1,1	0,8	0,2	2,2	—
Mediterranean Sea	I	98	97	98	120	120	120	129	99
	II	97	89	98	62	27	30	93	99
	III	0,0-90,0	0,0-74,7	0,0-17,0	0,0-58,9	0,0-35,0	0,0-13,8	0,0-45,9	EA. III. 100,0
	IV	48,3	7,1	1,9	3,3	3,4	2,1	4,8	78,0
	V	47,8	6,5	1,5	1,7	0,8	0,5	3,5	73,6

*I. Number of investigated samples; II. Number of samples in which the given mineral was detected; III. Fluctuation limits (in %); IV. Average content (in %) of the mineral samples (samples with zero content not taken into account); V. Average content (in %) in all investigated samples.

The foraminifera and pteropods of the eastern part of the /81 sea contains 82.7 and 85.7% CaCO_3 respectively, and in shells that have been thoroughly washed free of argillaceous particles (which is almost never possible), the content of CaCO_3 is up to 90% and more. The part played by foraminifera and pteropods in carbonate formation increases with depth up to 3,000 m. Deeper, their quantity decreases somewhat. The possibility is not excluded that decomposition takes place at greater depths, and that the shell material dissolves in part, this decreasing the carbonate content of the oozes that occur at such depths. To clarify this question, additional material must be collected in the deep-water depressions of the Mediterranean Sea.

Whole-shell foraminiferal material usually predominates in the sand fraction and in the large-aleuritic fraction. The sand fraction, according to planning data, consists almost entirely of shells. The large-aleuritic fraction contains from 0 to 84% foraminifera, on the average they amount to 40-45% of the entire fraction. There are few foraminifera only in the zone of the active arrival of pyroclastic material. A relationship is not always noted between the content of foraminifera and pteropods in sand-aleuritic fractions and the carbonate content of the sediments; this indicates the subordination of the organogenic factor of carbonate formation in such regions. A more or less clear relationship between the content of CaCO_3 and the content of organogenic shell material in fractions more than 0.05 has been established only for aleuritic oozes and sands.

A large part of the carbonate formation in the Mediterranean Sea is played by the calcareous algae, the coccolithophorides, whose significance in this process, as has been shown by Bernard and Lecal-Schlauder (1953), has been greatly underestimated by geologists. Coccolithophorids multiply very rapidly. One liter of them contains up to several million, or up to $1-5 \text{ mm}^3$. Bernard considers it probable that coccolites alone can form up to

57 cm of sediment in 1,000 years. Our research on oozes in smears has shown that coccolites in actual fact comprise a considerable part of the pelitic fraction. Coccolites of elliptical and disklike shape usually predominate. There are also rhabdoliths and discoastera. Of the species most frequently encountered in sediments, mention may be made of Tremalithes rotulatus sp. In spite of the miniscule dimensions of the coccolites, there is no doubt that they, as well as the larger shells, decay into tiny crystals, therefore the part played by them in carbonate formation is probably greater than what we have observed.

Oolites and quasioolitic carbonates have been encountered by us on the shelf of the African coastline. According to the data of Lucas (1955), oolites are formed particularly actively in the Gulf of Syrtis Minor (Jerba Island). Serving as the center of crystallization are shell fragments, lithothamnium, quartz grains, plagioclases, hornblende, etc. Oolite grains usually have an oval shape and a concentric structure. In crossed nicols they yield a cross. Along the Egyptian coast occur the so-called pseudoolites, brought there by the wind from the Eocene-Cretaceous formation of the Western Desert of Africa (Hilmy, 1950) and then well rounded in the coastal zone of the sea. Pseudoolites sometimes consists of well-rounded shell fragments, almost opaque under the microscope. Up to now it has been impossible to determine the depth of occurrence of pseudoolites and oolites. In the region of the Arabian Gulf (station 390), pseudoolites and oolites have been encountered at a depth of 61 m. They comprise 72.5% of the light large-aleuritic subfraction.

Carbonate crusts and calcareous-argillaceous concretions are formed mainly in the southern part of the Aegean Sea, in the region south of Peloponnesus-Crete in the Gulf of Syrtis Major,

on the Tunisian shelf and in the Strait of Tunis. Calcareous crusts are formed around worm tracks (tubes; Gulf of Syrtis Major), they cover mollusk shells, lithothamnium, bryozoans bedrock, etc. Calcareous crusts in the form of irregular conchoidal formations frequently exceed 10 cm in diameter. They have been detected at depths of 101 m (Aegean Sea, station 726) and 50 m (station 764-A).

Lithothamnium have been encountered in large numbers in the sands of the Darnanelles sector of the Aegean Sea at a depth of 71 m. These are usually rounded calcareous concretions /82 with a rough surface, reaching 2-3 cm in diameter. A layer structure can be found in the cross section of calcareous crusts and carbonate tubes, as well as in lithothamnium. Calcareous-argillaceous concretions have been encountered by us to a depth of 2167 m. At station 536 (between Crete and Cyrenaica, depth 2130-2167 m) they cover about 20-40% of the entire sea-bottom area. The shape of the concretions is irregular, vesicular-conchoidal, similar in external shape to a wedge which has grown by its "roots" into a viscous aleuritic-argillaceous ooze of soft consistency. The surface of the concretions, which is at the same level with the surface of the ooze which contains them, is rough and differs almost not at all in color from the color of the ooze (light brown, sometimes light yellow). The principal mass of such concretions occurs at the 0-5 cm horizon, i.e., at the very surface of the bottom. This indicates that diagenetic carbonate formation takes place at the very water-silt boundary, or in any case in the very uppermost centimeters of the sediment. Lower, within the sediment series, the concretions dissolve. Serving as a confirmation of this can be the sharp increase of the alkaline-chlorine coefficient - from 0.120-0.122 in the "bottom level" layer of the water to 0.136-0.169 in ooze water at horizons of 0-10 and 21-40 cm (stations 538 and 561; Yemel'-yanov, Chumakov, 1962)

The carbonate composition of the concretions was studied by the coloring method and optically -- under the microscope. It was established that it consists of calcite. In lithothamnium (Aegean Sea), aragonite was also detected (Mor, salt yields a green color). The calcite grains in the concretions are clean, needlelike, or wedged-shaped. They frequently converge at a single point at a center, forming "stars." Argillaceous aggregates are sometimes observed in the center. Irregular crystal growths exist, as well as individual crystals.

Pelitomorphic cryptogenic carbonate is contained in oozes everywhere. Its grains are of various sizes, but small crystals from fractions of a micron of 10 μ predominate (the principal mass is 1-4 μ). In rare cases the size of the crystal exceeds these sizes. Study of the fine fraction in microscopic sections and in oriented film preparations has shown that pelitomorphic carbonate consists predominantly of calcite. Dolomite (rhombohedrons) and siderite are rarely encountered.

The origin of pelitomorphic calcite is to date unclear (cryptogenic). Presumably it is formed by chemogenic and biogenic means (decay of shells into the finest crystals). Evidence of the chemical precipitation of crystals from sea water is borne by the clearly defined facets of the tiny crystals and the occasionally encountered crystal growths. Coccolite shells frequently enter into the composition of pelitomorphic calcite.

The chemogenic precipitation of CaCO_3 is also confirmed by large wedge-shaped calcite crystals in the pores of floating and already sunken pumice, as well as by the filling of foraminifera shell chambers with calcite. Calcite and dolomite of pelitomorphic and aleuritic dimensionality, presumably of chemogenic origin, have been observed by us in a suspended state in the upper layer of the waters of the eastern part of the Mediterranean Sea when the suspension was studied by means of

membrane filters. A particularly large amount of calcite and dolomite was detected in the upper layer of water east of the islands of Malta and Sicily. Possibly the clean, regular crystals of dolomite are also of chemogenic and diagenetic origin.

In the western part of the Mediterranean Sea, there is much less pelitomorphous calcite than in the eastern part.

Since the pelitic fraction in deepwater sediments comprises 60-92%, and calcite of biogenic and chemogenic origin predominates in it, it follows that these factors of carbonate formation predominate in the deepwater sediments of the Mediterranean Sea.

Thus, Mediterranean Sea water containing negligible reserves of carbonates are a medium in which the evolution and redistribution of carbonates takes place very rapidly. In this respect, the Mediterranean Sea differs from the Black Sea, the waters of the lower depths of which are strongly enriched with carbonate (Strakhov, 1951 a, b). Consequently, the cycle of carbonate formation in the Mediterranean Sea is completed much more rapidly than in the Black Sea or in the northern reservoirs. /83

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A HISTORICAL SURVEY OF HYDROLOGIC RESEARCH
IN THE MEDITERRANEAN SEA

84

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The European Mediterranean Sea is one of the most interesting basins in the World Ocean regarding its history of hydrologic research; it serves as an example for tracing the development of oceanography, from the first, primitive and inaccurate readings of water temperature to integrated oceanographic research work. As we study the history of the research it also becomes possible for us to trace the constant improvement of oceanographic instruments and marine research methods.

The extent to which the Mediterranean Sea has been studied is determined to a considerable degree by its geographic position and the overall historical development of European civilization, trade, and navigation. Naturally, that the first attempts to study its conditions were undertaken by representatives of countries located on the coast of the Mediterranean Sea, principally by representatives of France and Italy, which were highly developed countries according to the standards of that time.

The early period of research and the subsequent stage of more thorough and detailed study of the principal features of the hydrologic regime of the Mediterranean Sea have been excellently set forth in the basic work of Nilsen, "The Hydrology of the Mediterranean Sea and of the Waters Adjacent to It" (1912), including details on all achievements in the field of Mediterranean Sea research since the beginning of the 18th century. In this work, which even today is considered a classic, thorough consideration is given to the instruments and observation methods used, and a critical evaluation of these is offered.

To complete the historical survey, we considered it necessary to our work to deal briefly with this period of research (sections I. and II), taking Nilsen's detailed survey as a basis, and supplementing it with some data not touched upon in his work.

The first data on the temperature regime of the surface and deep-waters of the western basin of the Mediterranean Sea were obtained by Marsigli in the winter of 1706-1707, by Saussure in 1780, Dumont d'Hurville in 1826-1829 and 1837-1840, and by Captain Verer in 1831-1832.

On the basis of material obtained by d'Hurville and Verer, in 1838 Arago replaced the very important conclusion that the cold deep-water mass extending in all bottom layers of the Atlantic Ocean cannot penetrate into the Mediterranean Sea, therefore the temperature of the deep waters of the basin ($12.7-12.8^{\circ}$) is comparable to the mean winter temperature of the given region of the sea. This assumption was an important stage in the study of the hydrologic regime of the Mediterranean Sea.

In 1841-1845, more complete and important research on the temperature regime of the waters of the Mediterranean Sea was carried out by the outstanding French oceanographer Eme (?). On the basis of a prolonged series of observations, Eme found that the diurnal temperature fluctuations of the waters penetrate to 18 m, and that the maximum depth of penetration of annual fluctuations reaches 350 m. At this depth, a constant temperature of 12.6° was observed. In addition, Eme determined that the mean temperature of the water at the surface in the winter is equal to 12.7° ; this corresponds to the temperature of the deep waters of the Mediterranean Sea. On the basis of this Eme concluded that "the minimum temperature of the deep layers of the Mediterranean

Sea is equal to the mean temperature at its surface in winter," i.e., that the deep waters formed by the process of the descent of cooled surface layers in the course of the winter. Thus, in his works Eme substantiated the assumption, already expressed by Arago, about the isolation of the deep waters of the Mediterranean Sea, and proved the participation of cooled surface layers in the process of their formation.

Great credit is also due to Eme for the fact that, for his research, he was the first to use a reversing thermometer of his own design. The quality of his findings is considerably lesser than the earlier results, and they are scientifically valuable.

The first hydrologic research in the eastern and central regions of the Mediterranean Sea was carried out in 1845-1861 by Captain Spratt and in 1857 by Wuellerstorf-Urber on the Austrian frigate "Novara" (Ionian Sea). The materials obtained by these researchers have on a historical value due to the inaccuracy of their instruments.

Up to 1870 there was no standard system, nor any reliable method, for determining the salinity of the waters of the Mediterranean Sea. This was the cause of very inaccurate and erroneous opinions concerning the salinity of the Mediterranean Sea.

The first detailed investigation of the waters of the Mediterranean Sea was carried out by the Danish chemist Forchhammer in 1865. According to his determination, the salinity of the surface waters of the various basins have the following values:

- 1) minimum salinity (strait of Gibraltar) 36.301‰
- 2) maximum salinity (region of Crete, coast of Syria) 39.257‰
- 3) mean salinity of the Mediterranean Sea 37.936‰

The salinity percentage data obtained by Forchammer are comparable to contemporary data.

Early investigations of the Mediterranean Sea from a present-day viewpoint concerning its hydrology have little scientific value, since the use of impractical and cumbersome maximum-minimum and other thermometers yielded very questionable temperature values between the surface horizon and the assigned horizons.

However, already by the end of the early research period (Eme, Forchammer), in spite of the small number, incompleteness, and inaccuracy of the determinations, some important rules for the temperature regime of the sea were established, and a correct idea on the distribution of salinity on its surface was formed.

II

The second stage of the study of the Mediterranean Sea, approximately since 1870, is characterized by a more diversified oceanographic research by individual expeditions, and by the improvement of marine research methods and instruments.

In 1870-1871, an expedition on the ships "Porcupine" and "Shirvete", commanded by Carpenter, carried research into the western and the eastern basins of the Mediterranean Sea.

Carpenter studied the horizontal and vertical salinity distribution in the Mediterranean Sea, and was the first to indicate the existence of a surface current from the Atlantic Ocean, into the Mediterranean Sea along the coast of Africa. /86
At the same time, instrument observations established the existence of a current from the Mediterranean Sea into the Atlantic Ocean in the bottom layers of the Strait of Gibraltar.

According to materials on observations on the ships "Delhi," "Nautilus" (1874-1876), and "Gerta" (1880), in the Adriatic Sea and the Ionian Sea by Wolf and Lusch, in addition

to the rules governing the horizontal and vertical distribution of temperature, obtained previously, general conclusions concerning the circulation of waters in the Adriatic Sea, and concerning water exchange in the surface layer of the Strait of Otaranto were reached.

Deserving special attention are projects carried out on the Italian ship "Washington" under the leadership of Magnata in 1881. This expedition introduced reversing thermometers of the Negretti and Zambra design into the practice of oceanographic projects. It became therefore possible to establish the presence of a temperature minimum (200-300 m) and maximum (~ 500 m) with respect to depth. However, the Italian oceanographers themselves did not pay any attention to this and did not attempt to provide any kind of explanation for this curious and important phenomenon. In addition, this expedition made the first attempts at measuring currents at great depths.

A large contribution to the study of the hydrologic regime of the sea of Marmar and the Mediterranean Sea was made by Russian oceanographers, in the first place by the outstanding Russian research S. O. Makarov. In 1869, on the corvette "Vityaz", 12 hydrologic stations were completed to a depth of 800 m in various regions of the Mediterranean Sea. The obtained materials permitted S. O. Makarov (1894) to reach a number of extremely valuable scientific conclusions, many of which became the basis for the present-day interpretation of various questions dealing with the hydrologic regime of the Mediterranean Sea.

S. O. Makarov proposed to study the participation of the surface waters of some regions of the Mediterranean Sea in the formation of a deepwater mass in the winter period. He also investigated in detail the distribution of Atlantic waters in the Mediterranean Sea and the exit of Mediterranean

Sea waters in the Atlantic Ocean. Observations in the Strait of Gibraltar once again confirmed the presence here of two currents flowing in different directions.

Large-scale research work in the Ionian Sea, the eastern basin, the Aegean Sea, and the Sea of Marmara was carried out from the Austrian ships "Pola" and "Tauros" in 1890-1894 under the leadership of Wolf, Luksch, and Naterer. The research of the Austrian expedition showed that the temperature of the deep layers of the water in the eastern basin changes insignificantly: its values are 0.5-1° higher than the temperature of the deep waters of the western basin of the Mediterranean Sea. Study of the horizontal and vertical distribution of salinity made it possible to make a number of very important conclusions, from which it follows that in the eastern basin of the Mediterranean Sea there exists a general water movement of cyclonic character, and that the maximum water salinity east of Crete is explained by intensive evaporation. However, the Austrian scientists were unable to explain correctly the vertical salinity distribution, in particular the origin of the intermediate salinity maximum. Chemical analysis carried out by Naterer showed that even at great depths the oxygen content does not fall below 70% of saturation, which testifies to active vertical circulation.

When studying the Aegean Sea, a considerable difference was established in the temperature of the deep waters of this sea, which is determined by the presence of several reservoirs, separated by sills. Noted in the salinity distribution were the high salinity values on the surface in the eastern and the southeastern parts of the sea and the comparatively low (up to 33‰) values in the north and along the shores of Greece. The salinity differences tend to be smoothed out with increasing depth.

Materials obtained by the expedition on the ships "Pola" and "Taurus" are remarkable for the comparatively high quality, for that period, of the observations made, which makes them make partially usable for the hydrologic regime of the Mediterranean Sea at present.

The Russian Geographic Society, with the consent and cooperation of the Turkish government, organized in 1894 on expedition on the steamship "Selanik" under the leadership of I. B. Shpindler. In September-October 1894, 61 stations were completed in the Sea of Marmara, in the Bay of Bosphorus and in the Bay of the Dardanelles, which permitted Shpindler to give a detailed description of the distribution of temperature and salinity of the Sea of Marmara, and to explain the structure of the waters of this basin (see Shlyamin, 1949). On the basis of an analysis of the horizontal and vertical distribution of temperature and salinity, and drawing upon a number of instrumental observations on currents carried out by himself and by other investigators, Shpindler gave a comparatively detailed characterization of the overall circulation of waters in the sea of Marmara, and confirmed the presence of a two-layer movement of the waters in different directions in the straits. /87

Buanan, working in 1892 on the yacht "Princess Alice I," detected maxima of temperature and salinity in the western basin at a depth of about 500 m. In 1902, in the vicinity of Monaco, from the ship Princess Alice II, a series of temperature observations were made, to a depth of 1500 m. On the basis of these results Tule came to the conclusion that the thick bottom layer, previously considered to be motionless, cannot be in a state of total immobility.

In addition to special oceanographic expeditions, many of which we do not consider here because they do not offer any more or less important conclusions on the matter, large

scale meteorologic and hydrologic observations were carried out in the 1886-1902 period aboard German passenger ships.

Utilizing the findings of previous expeditions, Krummel in 1907 established the boundary of vertical circulation for the western basin of the Mediterranean Sea at a depth of about 300 m (somewhat lower than the boundary of Carpenter), and for the eastern basin -- at a depth of about 500 m. At the same time Krummel considers that in the winter period, vertical intermixing can reach the bottom; this explains the constancy of temperature along the vertical; and coincides with the conclusions of S. O. Makarov.

In 1909, Professor Natanson, using materials of observations near Monaco in 1907-1908, wrote an interesting article in which he again devoted much attention to vertical circulation in the upper layers of the water, which in his opinion in winter reached 150 m, sometimes 200 m and even more. At the same time Natanson indicated the possibility of convective intermixing all the way to the bottom.

The stage of hydrologic investigations of the Mediterranean Sea examined by us, as stated earlier, is characterized by efforts to find new, more developed and precise methods for studying the physical and chemical characteristics of sea water and by the introduction of new instruments for oceanographic research. The findings of this period, which helped to obtain many important features of the hydrologic regime of the Mediterranean Sea, vary as to precision and reliability, since they were obtained with various instruments and methods. However, by the beginning of the 20th century a gradual transition to a single method of marine research is noted, with the use of instruments of the same type. This was done largely by reversing thermometers, which thoroughly proved their worth, and with the method of salinity determination according to Moru-Buke de la Gre.

The beginning of the third stage of hydrologic research of the Mediterranean Sea, characterized by the use of standard observation and determination methods comparable to those used at present, may be considered to be the Danish expedition on the ship "Tor" under the leadership and with the participation of the well-known oceanographer Nilsen. In the winter of 1908-1909 the expedition worked in the western basin and in the Ionian Sea, in the summer of 1910 operations were carried out along the entire basin of the Mediterranean Sea, including the Sea of Marmara. The results of this expedition, was the work of Nilsen: "The Hydrology of the Mediterranean Sea and of the Waters Adjacent to It" (1912). This is the first, and up to date, the only survey of the hydrology of the Mediterranean Sea, in which all achievements of the preceding research periods in this field are generalized.

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In his monograph, Nilsen examines in detail the hydrologic structure of each basin, and comes to the conclusion that a homogeneous (with respect to temperature and salinity) thick, deep water layer does not exist. In fact, the layer of water for which such a structure was assumed consists of two parts, differing substantially from each other and separated by a temperature minimum. Below this temperature minimum is the deep-water layer with constant salinity and a temperature which increases slightly toward the bottom.

For the western and the central basins of the Mediterranean Sea, similar in structure, Nilsen distinguishes three masses:

- 1) a surface layer with less salinity, below which is observed a temperature minimum determined by cooling during the preceding winter; the waters of this layer are subject to the strong influence of waters arriving from the Atlantic ocean;

2) an intermediate layer of salty and comparatively warm waters of east Mediterranean origin, limited underneath by the deepwater temperature minimum;

3) the deepwater (bottom) layer.

A similar structure of the waters is noted also in the southern part of the eastern basin. Here, however, in the uppermost surface part of the layer, rather high salinity is observed, due to intensive evaporation in this region.

In the northern part of the eastern basin, above the deep water mass is a layer with a salinity which constantly increases toward the surface, up to 39%. This part of the Mediterranean Sea is at the same time a region where "intermediate" waters with high salinity form in winter. The "intermediate" waters formed here extend to the west, causing the characteristic layers of the water structure of the central and the western basins, and form cyclonic current systems in individual basins. In addition, the "intermediate" current carries the salt surplus into the Atlantic Ocean, which facilitates the maintenance of the constant salt contents of the waters of the Mediterranean Sea.

Concerning the question of horizontal circulation of surface waters, Nilsen considered that the prime cause of this special feature is an intensive evaporation, the value of which exceeds the "fresh-water component" of the water balance. This excess is compensated by the basic influx of waters from the Atlantic Ocean, which spread out in the Mediterranean Sea predominantly along the coast of Africa. At the same time, branches from the principal current of Atlantic waters into the Algiers-Provence basin and into the Tyrrhenian Sea are observed.

Investigating questions of vertical circulation and the formation of deep waters, Nilsen comes to the conclusion that in the winter period, at the north of the Algiers-Provence

basin, in the Ligurian Sea, in the south of the Adriatic Sea, and in the southeast part of the Egyptian Sea, cooling of the surface layer of the water may generate vertical currents extending to the greatest depths, as a result of which the waters of the bottom layer are well-aired. Nilsen considers that the bottom (depth) waters of the central and the eastern basins are renewed mainly by the deep waters of the Adriatic Sea, which are reconstituted during the winter season. The great homogeneity of the waters of the bottom layer in a horizontal direction makes it possible at the same time to assume that considerable horizontal shifts take place in it.

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Much credit is also due to Nilsen for the fact that he was the first to give an estimate of the principal components of the water balance of the Mediterranean Sea (in km³ per year):

Evaporation	5,200
"Fresh-water component" (precipitation, river runoff). . . .	2,200
Compensating part of the influx through the Strait of Gibraltar. . .	3,000
Influx.	59,200
Exflux.	56,200

In order to evaluate this work scientifically, it is sufficient to say that Nilsen's monograph is quoted in almost all works devoted to the hydrology of the Mediterranean Sea for the last 15 years.

Expeditions on the "Cyclone" (Italy) and the "Naiad" (Austro-Hungary) in 1911-1914 collected an enormous amount of material on the hydrology of the Adriatic Sea, since during these years rather detailed surveys were carried out in various seasons for the entire body of the sea. According to the materials of this expedition, the Yugoslav oceanographer N. Bulian gave a detailed analysis of seasonal salinity

regime variations and temperature regime variations (Bulian, 1953, 1957). In addition, having examined in detail the hydrologic regime of the Adriatic Sea for a number of years, Bulian established a considerable variability from year to year.

The materials obtained by the ship "Tor" in 1908-1910 were once more subjected to thorough analysis by Schott (1915), who refined somewhat the characterization of the water masses of the Mediterranean Sea, and recomputed the water exchange through the Strait of Gibraltar. The excess of the incoming surface (Atlantic) current over the deepwater (Mediterranean) current amounts to 3310 km^3 per year, i.e., somewhat more than obtained by Nilsen and the subsequent researchers who studied the regime of the strait of Gibraltar.

Oceanographic research, interrupted by the first world war, started again in the 1920's. However, the materials obtained by numerous expeditions of various states are characterized by an insufficient depth for observations (up to 300 mm and more, rarely to 500 m), which hinders their utilization for an analysis of the hydrologic structure and circulation of the waters of the Mediterranean Sea.

Most of the expeditions of the third research period (see Appendix 2) did not plan to carry out a detailed oceanographic survey, but proceeded along the path of the regional study of the individual basins and providing for the needs of the fishing trade. However, this research, which was not extensive, was interrupted for a long period by the Second World War.

The hydrometeorological observations in this period have been collected in the work by B. N. Shlyamin (1949), which characterizes the principal features of the climate and the hydrological regime of the Mediterranean Sea, and gives monthly surveys of the hydrologic conditions.

IV

Oceanographic research of the Mediterranean Sea on a larger scale began after the second World War, particularly in the period of the International Geophysical Year (1957-1959) and later. However, at this stage of research the expeditions of various governments and departments were also studying mainly individual basins of regions of the sea, situated in the immediate vicinity of these states, with no account being given to the extent to which the entire Mediterranean Sea basin has been studied. This led, as we shall see, certain basins have been more or less thoroughly studied, this being explained by inadequate coordination of oceanographic operations in the Mediterranean Sea carried out by the various departments and states. /90

After the war, oceanographic research in the Aegean Sea was at first carried out by the newly organized Greek Hydrological Institute. Its ships "Glavki" (1946 and 1948) and "Alkioni" (1949), in addition to operations in the coastal section, carried out a considerable scope of hydrologic observations in the open sea.

A considerable contribution to the study of the Adriatic Sea has been made by Yugoslav ships of the Institute of Oceanography and Fishing. The "Predvodnik," working almost without interruption from September 1947 through February 1951, completed more than 250 stations in the region adjacent to Yugoslavia. On the ship "Khvor" about 300 stations were completed from March 1948 through March 1949. The data of these expeditions, as supplementary material to preceding research of the Adriatic, were used by Bulian (1953) for analyzing the seasonal and perennial fluctuations of salinity in the sea. Bulian was successful in establishing the relationship between exceptionally cold winters and an increasing salinity content, this being explained by the

intensive inflow of waters with high salinity from the Ionian Sea. The salinity fluctuations in the Adriatic Sea are apparently part of the same phenomenon, characteristic of the Mediterranean Sea as a whole, and presumably connected with the influence of the Atlantic Ocean, or with strong atmospheric depressions over the Mediterranean Sea. The noted salinity fluctuations have an approximately 9-year cycle.

The first large contribution of the USA to the study of the hydrologic regime of the Mediterranean Sea were data collected during the cruise of the "Atlantis" in 1948. Using the observations of the "Atlantis" and a number of preceding expeditions, M. Pollak (1951), studying the origin of the deep waters of the eastern part of the Mediterranean Sea, came to the conclusion that they originate in the Adriatic Sea: proceeding from there, these waters envelop the central and the eastern basin in a counterclockwise direction.

Since 1949, various French oceanographic establishments have started active research in the Mediterranean Sea. Particularly in the first few years (1949-1952), research in the southern part of the western basin was especially thorough, from the Strait of Gibraltar to the Tunisian Strait, carried out by the ships "Marine Francaise," "President Theodore Tissier," "Mameluke," "Lancier," "Sabre," "Crisia," "Simetter," and the "Lacaze Dutier." However, about 500 hydrologic stations completed by the ships have an insufficient depth for observations; it rarely exceed 500 m, and in some of the expeditions the accuracy of the observations is questionable.

Four interesting and comparatively complete hydrologic surveys in various seasons of 1950-1952 were carried out from aboard the Italian ship "Robusto" in the Ligurian Sea. The materials of the 78 stations have the same drawbacks as the materials of the French expeditions mentioned above.

In 1951-1954, the ship "Ksauen" of the Spanish Oceanography Institute carried out rather detailed hydrological surveys in the sea of Alboran and in the Strait of Gibraltar. Of the 282 stations completed during 9 surveys, 144 are for the winter season and 138 are for the summer season.

In February 1953 and in May 1954, the French ship "Professor Lacaze Dutier" surveyed by the bay of Lyons, completing 20 and 29 stations respectively.

Thus, in the first half of the 20th century an extensive amount of material was collected on the hydrology of the Mediterranean Sea, particularly from its western basin. However, for solving specific hydrologic problems and for a deeper oceanographic characterization of each basin, it was necessary to have access to data of "standard" sections, carried out in various seasons of the year. In this connection, worthy of great attention are the very valuable observations obtained aboard the French scientific research ship "Eli Monier," which several times carried out a section along 6-7° E (September 1952, October 1953, March 1954, 1955). Operations on this section were continued on the "Eli Monier" in February-March 1960 on the sector from 40° N to the French coast (9 stations), and in the period of the joint American French expedition in February-March 1961 on the "Atlantis" (19 stations). Thus, the section along 6-7° E became standard for French oceanographers, since it clearly shows the basic features of the hydrologic regime of the Algiers-Provence basin. In addition to work on the "standard" section, the research on the "Eli Monier" (March 1955, September 1966, April 1957, August 1957, February-March 1960) encompassed to a considerable extent almost the entire western basin with the exception of the Tyrrhenian Sea. A special feature of the collected materials is their quality and great observation depths (2,000-3,000 m).

A large contribution to the study of the eastern basin of the Mediterranean Sea, including the Aegean Sea, were the operations on the "Calypso" in June-August 1955 (106 stations) and in September-October 1956 (72 stations). During these expeditions, a series of very valuable sections was carried out in the western and in the central basins.

In September 1957 and in July-August 1958, operations on the "Calypso" were conducted in the Atlantic Ocean, in the regions adjacent to the strait of Gibraltar.

Utilizing the observation results of the "Eli Monier" and the "Calypso" and drawing upon the most valuable data of earlier expeditions, it became possible for the French oceanographers to refine, and in a number of cases to provide an explanation for, some special features of the hydrologic regime of the Mediterranean Sea.

In his articles, Tchernia (1954, 1960) discusses details of the hydrologic structure of the waters of the western basin; he distinguishes three principal water masses, and cites their features. In addition, Tchernia, having at his disposal high-quality winter observation material, devoted much attention to questions of the formation of deep waters in the period of winter cooling in the Liburian Sea and along the French coastline, and comes to the conclusion that the deep water mass of the western basin is a mixture of the intermediate water mass (25%) and the cooled surface water (75).

Tchernia and Saint-Guily (1959) elaborated the previously reached conclusions concerning the geographical extent of the processes of vertical circulation and concerning the circulation of intermediate and surface waters. The authors note the penetration of "intermediate" waters into the region of the Strait of Gibraltar along the coast of Africa, whereas another branch of these waters along the exit from the Sardinian Strait branches off to the north, passes into the Ligurian Sea, envelops it counterclockwise, and is supplemented

there by "intermediate" waters from the Tyrrhenian Sea. The cyclonic circulation of the "intermediate" waters in the Ligurian Sea is noted also in the circulation of the surface waters. In addition, the authors explain the origin of the "subsurface" temperature minimum by the subsidence and spreading of waters formed on the surface along the shores of France in the winter period.

The articles of Lacombe and Tchernia (1958) are also of considerable interest: they give a detailed characterization of the "intermediate" Levantine Waters in the western basin, and consider questions concerning the formation and interaction of the deep waters of various basins of the Mediterranean Sea.

On the basis of previous research, and using the materials of 10 of the most important expeditions, Lacombe and Tchernia (1960) made preliminary conclusions concerning the hydrologic regime of the Mediterranean Sea as a whole. On the basis of the salinity minimum and maximum, the authors traced the propagation of the surface (Atlantic) and "intermediate" (Levantine) waters in the Mediterranean Sea. In addition, the article dealt with the transformation of Atlantic waters under the influence of climatic factors into Mediterranean "intermediate" and deep waters. Utilizing the data on currents in the Strait of Gibraltar on the "Vinarretta Sinjer" in 1958, Lacombe and Tchernia computed the incoming and outgoing current (in $10^6 m^3/sec.$):

	Incoming flow	Outgoing flow	Excess flow
7-11 August	1.1	0.6	0.5
16-20 August	1.8	0.8	1.0
According to Sverdrup (1946)	1.75	1.68	0.07

They reached the conclusion that the considerable variability of these currents in comparatively short intervals, is due to

fluctuations of the atmospheric pressure over the Mediterranean Sea.

Lacombe, Tchernia, and Benoist (1958), on the basis of the data from the "Calypso" (1955), gave a preliminary analysis of the hydrologic features of the Aegean Sea, and attempted to clarify water exchange with the western and the central basins.

A very useful manual for the analysis of the hydrologic regime of the Mediterranean Sea is the Dutch Atlas (Middel-landse Zee, 1957), which includes generalized observations made principally on Dutch, English and German ships which collected about 3 million data of water and air temperature, atmospheric pressure, surface current, humidity, etc.

A valuable contribution to research on the sea of Alboran are the projects on the ship "Passer du Printemps" in July 1957 (33 stations). In August 1958, on the same ship, with average coordinates of 35° 39' N, and 6° 42' W, 25 bathometric series to a depth of 200-250 m and a prolonged series of observations on currents in the surface layer with rare measurements at horizons of 150, 200, and 250 m were completed within 12 days.

At the same time (August 1958) on the ship "Vinaretta Sinjer" jointly with the Spanish ship "Segura," operations were being carried out in the Strait of Gibraltar itself. On the ship "Vinaretta Sinjer," on two sections on each side of the Strait, nine daily stations were completed, at each of which four bathometric series to 500-1000 m were taken and instrument readings of currents were carried out. This made it possible for Lacombe (1961) to calculate the above-cited values of the discharges of Atlantic and Mediterranean water in the Strait of Gibraltar and to investigate the relations of the values of the currents to the level fluctuations and changes of the atmospheric pressure over the Mediterranean Sea.

In another article, Lacombe and Richevz (1961) thoroughly investigated, on the basis of these observations, the features of the hydrologic regime of the Strait of Gibraltar, in the first place the position of the dividing surface between the currents flowing in different directions.

In addition to the joint expedition mentioned by us (on the ships "Passer du Printemps," the "Vinçetta Sinjer" and the "Segura"), the Strait of Gibraltar and the regions adjacent to it were studied in 1958 by the ships "Calypso," "Videl," "Discovery II", "Yamakrou," and the "Helland Hansen." The large-scale research in the Strait of Gibraltar was prompted by the need to gain knowledge on the hydrometeorological regime of this region; these operations were subsequently continued.

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In the period of the IGY, six Italian ships completed eight detailed hydrological surveys of individual regions in the Tyrrhenian Sea. These surveys, each of which consisted of five latitudinal sections, were completed in the northern part of the sea in June, September 1957, and in February 1958. In the central part of the sea, on sections comprising a triangle, operations started in July, September 1967 and in August 1958; in the southern part two surveys were made (July, September, 1957). Thus, in July and September 1957 two detailed surveys were completed for the entire body of the Tyrrhenian Sea, which fully discloses the special features of its hydrological regime in the summer period.

Very important operations within the scope of the IGY program were carried out by the Yugoslav ships "Miner" and "Spasilats" in the Adriatic Sea, including the strait of Otranto. Operations during each of the six trips (July), September, and December 1957, March, July and December 1958) were carried out along a single course. As a rule, the hydrologic series in these expeditions were taken almost all the

way to the bottom. In addition to observations of temperature and salinity, tide observations were carried out at some stations.

In addition to ships of the Mediterranean countries, ships from a number of other states participated in the study of the Mediterranean Sea basin during the IGY period.

On the American ship "Atlantis," which operated principally in the Red Sea and in the Gulf of Aden, on the return trip across the Mediterranean Sea in July-August 1958, twelve deep-water series of observations were carried out. From April through August 1959, observations with a thermistor circuit were carried out from the American ship "Cheyne" along the entire body of the sea.

In 1960, a second French expedition was working on the ships "Calypso" and "Espandon" in the strait of Gibraltar, with the aim of supplementing and confirming data obtained in 1958. In addition to 25 hydrologic stations, at which bathometric series were taken and observations were made of current at the horizons of 10, 50, 100, 200, and 500 m, at 13 tracks currents were measured.

In 1961, a joint group of the Oceanographic Institute in Woods Hole (USA) and the Laboratory of Physical Oceanography (France) made a trip in the western part of the Mediterranean Sea on the ship "Atlantis" to study the winter regime of the basin and the formation of deep waters (138 stations).

According to the program drafted by Lacombe, in May-June 1961 operations were continued in the region of the Strait of Gibraltar. Seven expeditionary ships for France, Italy, Spain, Belgium and Norway ("Calypso," "Origny," "Stafetta," "Aragonese" "Ksauen," "Epan," and "Helland Hansen") participated in the synchronized survey.

In February-March 1962, questions concerning the formation of deep waters and of water exchange through straits were again

investigated on by the American ship "Atlantis." The research work, in principle, included the Adriatic Sea, the Ionian Sea, and the Aegean Sea, as well as some straits of the island from Asia Minor to Peloponnesus.

Recently, some of the most important questions of the hydrology of the Mediterranean Sea were discussed in the works of Wuest. In one of his articles he considers the circulation of the methods for investigating this circulation (Wuest, 1959 a). In another article, which deals with the components of the water balance of the atmosphere, the ocean, and the Mediterranean Sea, Wuest (1959b) gives a critical evaluation of all earlier methods for calculating the water balance of the sea, and makes some recommendations concerning these calculations. One of the latest works of Wuest (1959) concerning the vertical circulation in the Mediterranean Sea is also of considerable interest. /94

Starting in 1958, a large contribution to research on all features of the Mediterranean Sea was made by Soviet oceanographic establishments and ships, which by now have undertaken more than 10 integrated trips into various parts of the sea at various seasons of the years (see Appendix 2).

The expeditionary ship of the Sevastopol Biological Station of the Academy of Sciences, Ukrainian SSR, the "Academician A. Kovalevskiy," from 1958 to 1962 made five trips to investigate the majority of the basins of the Mediterranean Sea at various seasons of the year (Figure 1). The Bosphorus region of the Black Sea, and the region adjoining the mouth of the Nile, were covered with a more detailed network of stations. During the five trips 114 hydrologic stations were completed, of which 20 stations have a diurnal observations cycle.

The hydrologic operations on the expeditionary ship "Academician A. Kovalevskiy" in the Mediterranean Sea were of an auxiliary nature, since the principal aim of these trips

was hydrobiological research. However, in spite of the secondary role of the hydrologic observations, a number of sections and some diurnal stations yielded some valuable data, on the basis of which important conclusions can be reached concerning some features of the hydrologic regime of the Mediterranean Sea.

Large-scale operations for the study of hydrology in the central and the eastern basins of the Mediterranean Sea was carried out in 1959-1962 by the expeditionary ships of the hydrometeorological observatory of the Black Sea Fleet.

In the summer of 1959 the expeditionary ship of the Black Sea Experimental Scientific Research Station of the Institute of Oceanography, Academy of Sciences, USSR, the "Academician S. Vavilov," investigated all features of the Mediterranean Sea. By 1962, four integrated trips and one specialized trip were carried out, during which 389 hydrologic stations were completed, with a comparatively uniform distribution along the entire body of the Mediterranean Sea in the summer and winter seasons, (Figure 2).

The third and fourth trips of the expeditionary ship "Academician S. Vavilov" were carried out in the fall-winter period of 1960-1961 and in the winter-spring period of 1962 respectively. They yielded observation materials which will be helpful for disclosing the basic features of the regime of the waters of the Mediterranean Sea in the winter period and some special features of the regime of its waters in the transition seasons.

Since the investigation of the hydrologic regime of the Mediterranean Sea was one of the basic tasks of the Mediterranean expeditions, a comparatively large amount of data was collected on the hydrology of these or those regions of the sea during each of these four expeditions. In addition to

temperature measurements and salinity determination to a depth of 1000-2000 m, the complex of hydrologic observations included:

1) temperature soundings by an electrobathythermosonde or by a bathythermograph to a depth of 150-270 m,

2) measurement of currents at anchor buoy stations at 3-4 horizons to a depth of 1000 m within the space of 24 hours,

3) meteorological observations four times every 24 hours.

The materials obtained during the four trips of the expeditionary ship "Academician S. Vavilov" made it possible to reach a number of interesting conclusions concerning some features of the hydrologic regime of the Mediterranean Sea. The results of the investigations, which are as yet of a preliminary nature, are published in the present collection.

Starting in 1908, a wealth of material has been collected on the hydrology of the Mediterranean Sea, including more than 5,000 hydrologic stations, in addition to which there is a large amount of shipboard findings on the temperature and salinity of the surface layer of the water. In the present work, we have not been able to take account of the still unpublished data obtained by numerous foreign expeditions. However, we can at this time, having at our disposal the available data (from 5,000 stations), give an overall characterization of the hydrology of the Mediterranean Sea by seasons and by bodies of water (see Appendixes 1 and 2, Figures 3 and 4), as it is known today.

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In this painstaking work selecting literature and material concerning observations in the Mediterranean Sea, which we started in 1960-1961, by the manuscript of B. N. Filyushkin, which has now been published, was not helpful.

A large number of investigations (at about 2,000 stations) were completed in the summer season which is favorable for

the operations, during three months -- July, August and September. The greatest number of stations is in the western basin of the Mediterranean Sea, and a much smaller number is in the central and the eastern basins, particularly in the Gulfs of Syrtis Major and Syrtis Minor (Figure 3, Appendix 1).

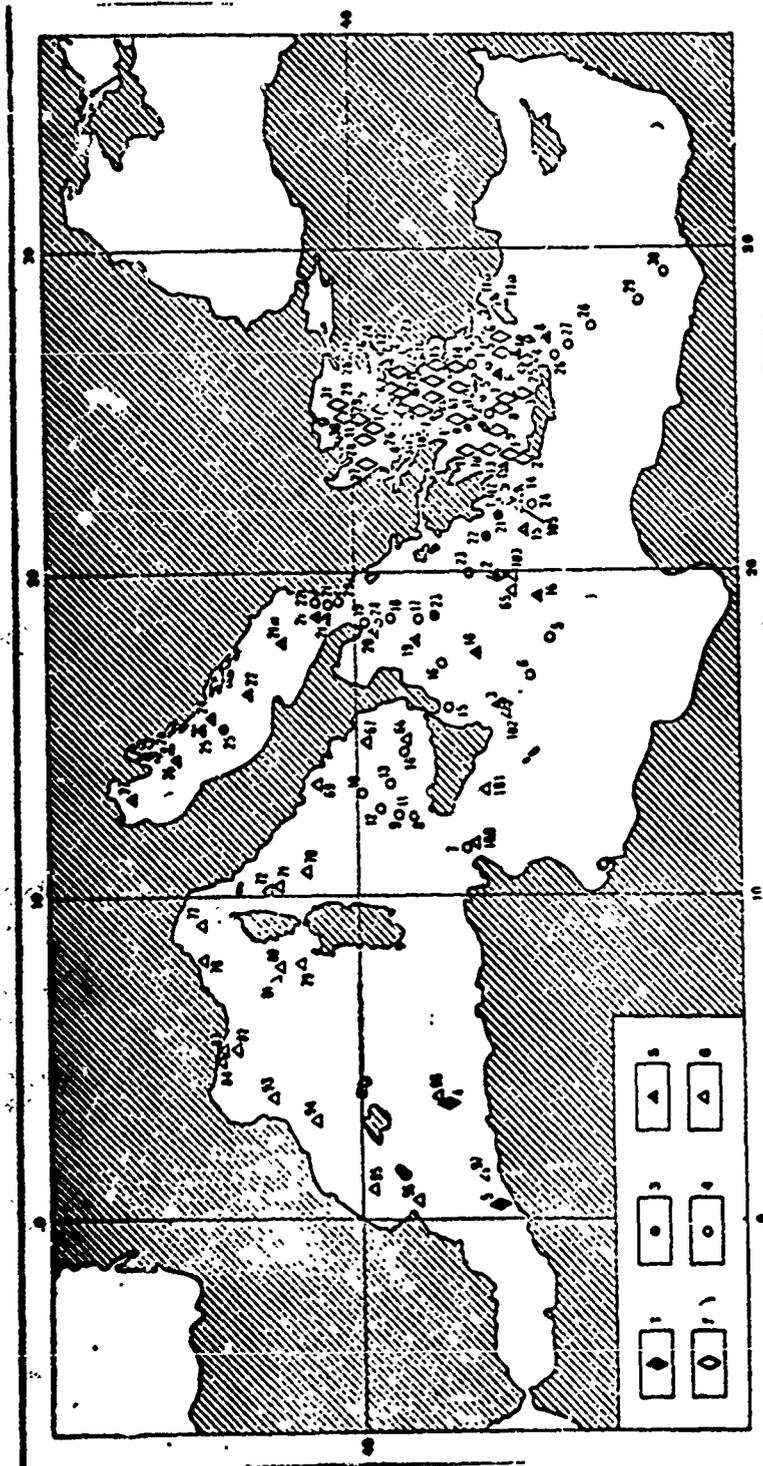


Figure 1. Map of hydrologic stations completed by Soviet expeditionary ships.
1 - "Sedov," 2 - "Gonets," 3-6 - "Academician A. Kovalevskiy" in 1958-1961
(3 - first trip, 4 - second trip, 5 - third trip, 6 - fourth trip).

In winter (in January-March) only about 1,000 stations were completed, the distribution of which along the body of the Mediterranean Sea follows almost exactly the same rules as in summer (Figure 4, Appendix 1).

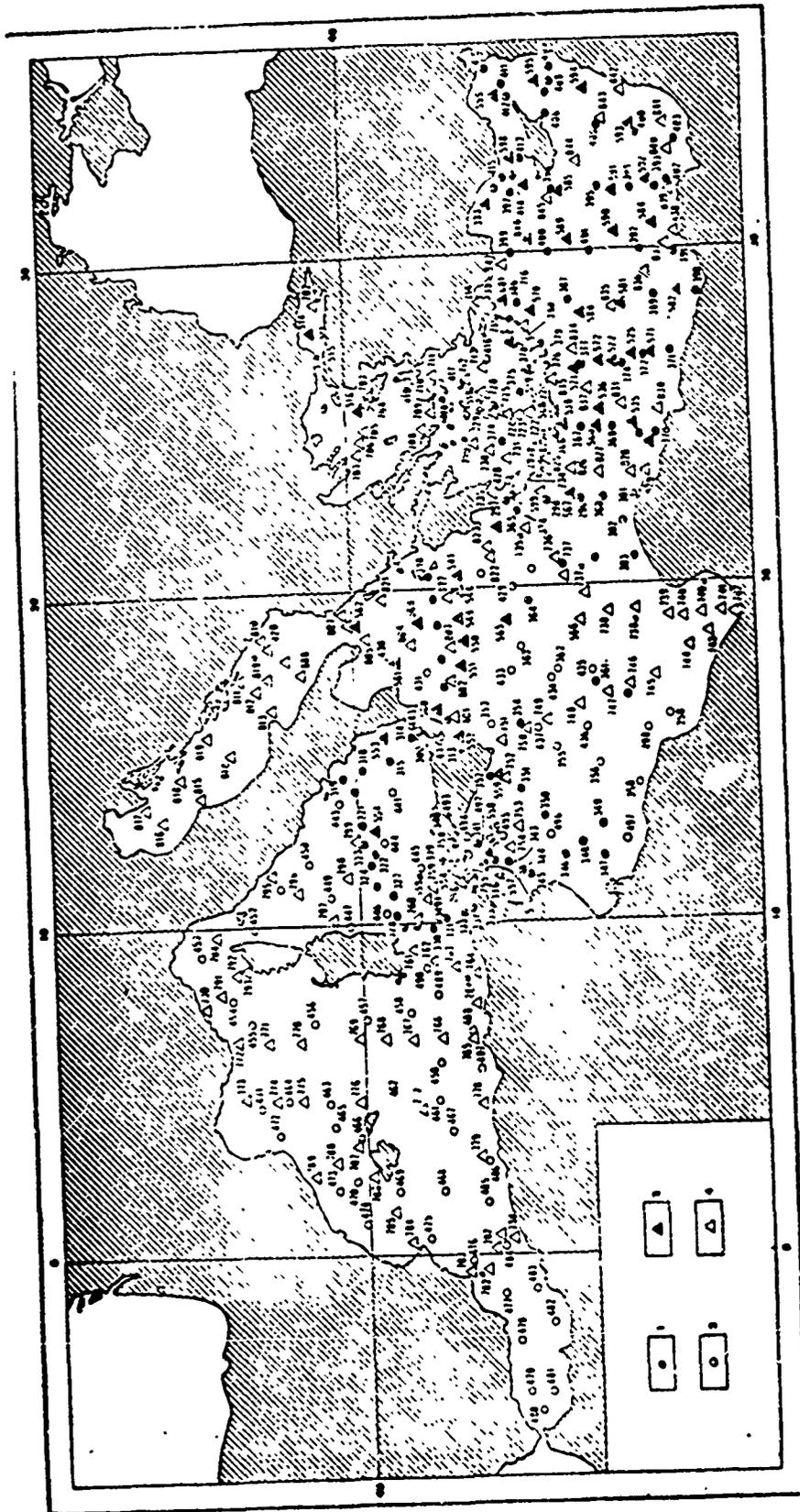


Figure 2. Map of hydrologic stations completed by the expeditionary ship "Academician S. Vavilov" in 1959-1962.

1 - first trip, stations 293-418; 2 - second trip, stations 428-498; 3 - third trip, stations 514-602; 4 - fourth trip, stations 702-847.

For the spring and fall seasons, we have a still smaller number of data; this excludes the possibility of comparing even the general hydrologic characteristics of these transition periods.

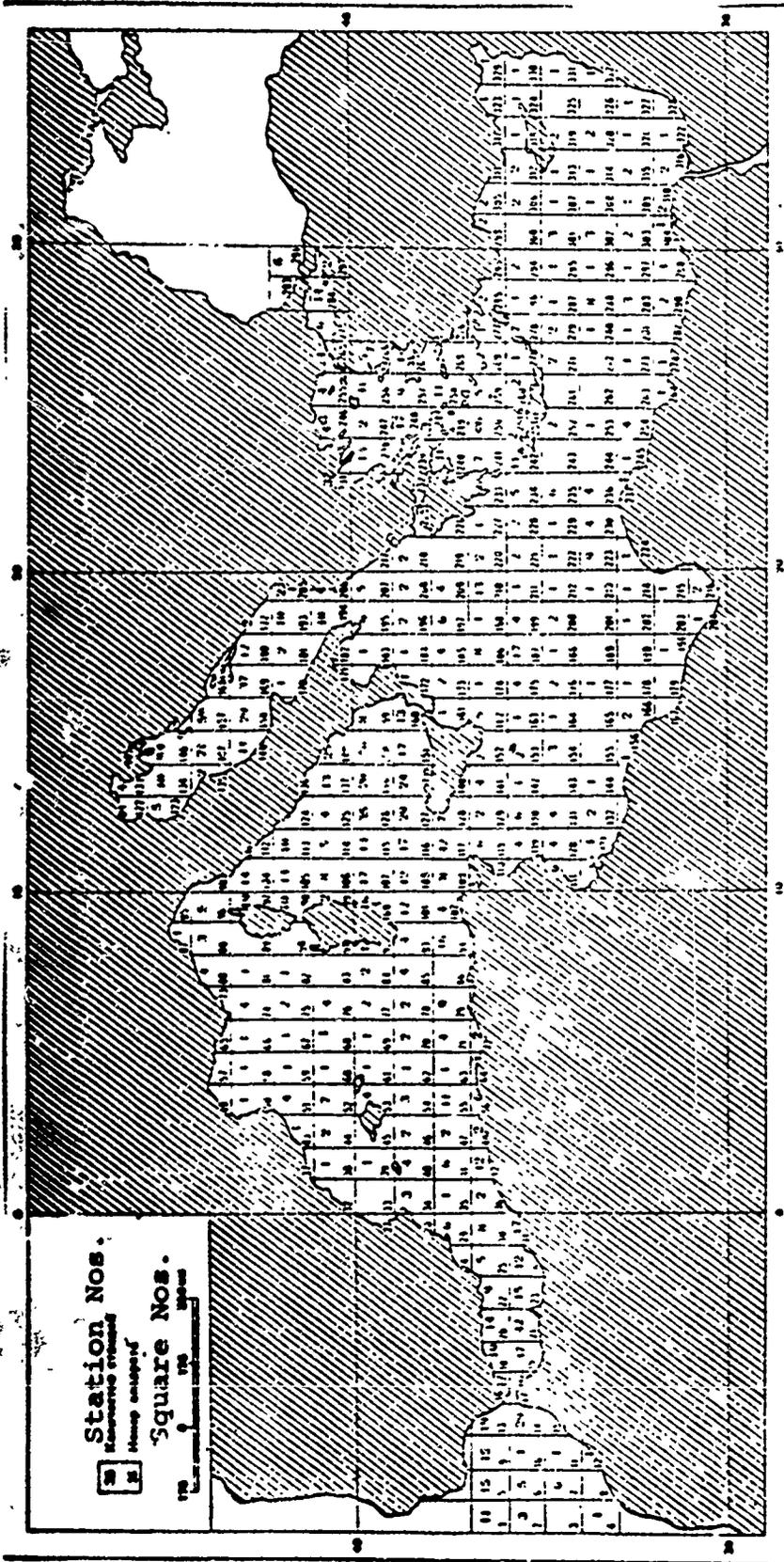


Figure 3. Distribution of hydrologic stations according to one-degree "squares" in the summer season (1908-1962).

Fine figures are the numbers of the "squares," large figures at the station numbers.

Thus, having at our disposal a considerable amount of hydrologic findings, we can at present undertake only a general characterization of the hydrologic regime of the Mediterranean Sea in the summer, since the small extent to which

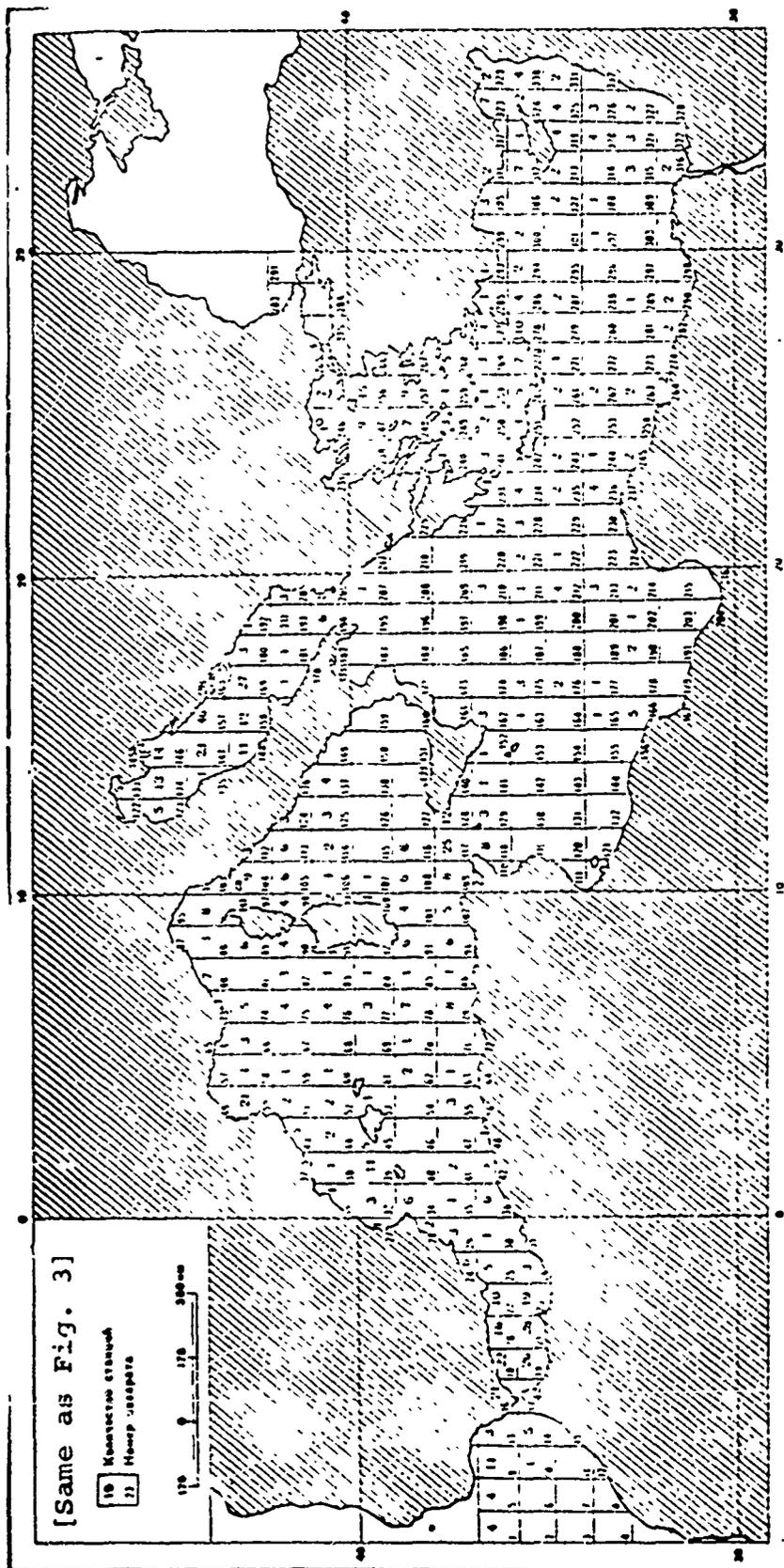


Figure 4. Distribution of hydrologic stations on the basis of one-degree "squares" in the winter season (1908-1962).

Fine figures are the numbers of the "squares," large figures are the station numbers.

some of the regions of the Mediterranean Sea has been studied, particularly during the winter period, does not permit the regime to be described in detail. Due to the limited extent to which individual regions have been studied, there is an urgent need for supplementary, detailed research. In the summer season, as can be seen from Figure 3 and Appendix 1, it is necessary to conduct a supplementary survey of the eastern and the central basins. The Gulfs of Syrtis Major and Syrtis Minor, which as compared to other regions of the Mediterranean Sea, have been insufficiently studied, require more thorough research. In the winter period it is urgently necessary to study, in addition to the regions noted, the southern part of the Tyrrhenian Sea and the central part of the Algiers-Provence basin (Figure 4) as well. Only when supplementary data will be available can a detailed characterization of the hydrologic regime of the Mediterranean Sea as a whole be undertaken.

However, the presence of a comparatively large number of hydrologic observations on the Mediterranean Sea makes it possible already now to start the preparation of a generalizing work on its hydrology. Each scientific work with a detailed description of the hydrologic regime of a sea must become the theoretical basis for settling various problems which are economically important.

Researchers of the Mediterranean Sea, in addition to supplementary regional observations are faced with specific tasks, such as the detailed study of certain questions concerning the hydrologic regime by seasons. Special attention must be paid to the following problems, which are of interest for many fields of applied oceanography.

1. The water exchange of the Mediterranean Sea with the adjoining basins. Precise knowledge of this is a starting point for the analysis of any question pertaining to the hydrological regime of that basin. At present such operations have

been carried out, and instrument readings have been undertaken on the discharge of incoming Atlantic waters and outgoing Mediterranean waters, in the Strait of Gibraltar only. In the future it is necessary to have available data concerning the water exchange through the Straits of Bosphorus and Otranto, and to similar research in the Bay of Tunis should be carried out.

2. Horizontal circulation on the surface, intermediate, and deep layers of the sea. It is necessary to continue operations on "standard" sections, selected in each basin, in a region which is characteristic for its physical-geographic and hydrophysical features. In addition, this problem could be clarified by a synchronized survey of the sea, with the participation of several states.

3. The penetration depth of the winter vertical circulation in various parts of the sea. Up to now no precise answer could be obtained to this question; however, in many fields of applied oceanography, it is of extreme interest. We know the regions of the formation of the deep waters of the Mediterranean Sea with specific climatic conditions. For solving this problem it is necessary to obtain, in specially selected regions, accurate data, employing the available improved computation methods.

4. Constant circulatory water movements of different sign. In an analysis of the data of the latest expeditions in the Mediterranean Sea, several such circulatory movements were registered (Rhodes, Crete-Africa, Sardinia). It is known that each region of convergence and divergence in the surface

Appendix 1

Distribution of hydrologic stations according to individual basins and regions of the Mediterranean Sea in the winter and the summer seasons.

Basins and individual regions of the Mediterranean Sea.	Number of Stations	
	In Winter	In Summer
Gulf of Cadiz	28	107
Region of the Strait of Gibraltar . .	63	123
	91	230
Western basin of the Mediterranean Sea		
Sea of Alboran	141	193
Algiers-Provence basin, including the Balearic Sea and the Ligurian Sea and the region between the strait of Sardinia and the Strait of Tunis	249	261
Tyrrhenian Sea	57	339
	447	793
Central basin of the Mediterranean Sea		
Ionian Sea and the Gulfs of Syrtis Major and Syrtis Minor	73	219
Adriatic Sea	210	335
	283	554
Eastern basin of the Mediterranean Sea		
Sea of Levant	110	99
Aegean Sea	94	192
Sea of Marmara	1	26
	205	317
TOTAL STATIONS	1026	1894

Appendix 2. Chronological enumeration of expeditions
in the Mediterranean Sea (since 1970)

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No.	Ship	Country	Year of work	Regions of work
1	Porcupine	England	1870	Western basin
2	Shirvoto (?)	Austro-Hungary	1871	Western basin
3	Nautilus	" "	1874	Adriatic Sea
4	"	" "	1874	" "
5	Deli	" "	1875	" "
6	Deli	" "	1876	" "
7	Deli	" "	1880	Tyrrhenian Sea, Icnian Sea
8	Travailleur	France	1881	Western basin
9	Washington	Italy	1881	Tyrrhenian Sea
10	Vityaz'	Russia	1889	Aegean Sea, east- and western basins
11	Pleade (Hi- rodelle I)	Monaco	1890	Western basin
12	Pola	Austro-Hungary	1890	Ionian Sea
13	"	" "	1891	Aegean Sea, Eastern basin
14	"	" "	1892	Ionian Sea, Eastern basin
15	Challenger	England	1892	Western Basin
16	Princess Alice I	Monaco	1892	Western basin
17	Pola	Austro-Hungary	1893	Aegean Sea
18	Princess Alice I	Monaco	1893	Western basin, Tyrrhenian Sea
19	Taurus	Austro-Hungary	1894	Sea of Marmara
20	Selyanik	Russia	1894	" " "
21	Princess Alice I	Monaco	1894	Western basin
22	Princess Alice I	"	1895	" "
23	Princess Alice I	"	1896	" "
24	Princess Alice II	"	1902	" "
25	Princess Alice II	"	1904	" "
26	Goldfinch	England	1905	Strait of Gibralt- ar
27	Planet	Germany	1906	Western and Eastern basins
28	Eider	Monaco	1907	Western basin
29	Eider	"	1908	" "
30	Princes Alice II	"	1908	" "
31	Tor	Denmark	1908	" "
32	Eider	Monaco	1909	" "
33	Princess Alice II	"	1909	" "
34	Tor	Denmark	1909	Ionian Sea
35	Tor	"	1910	Ionian Sea The entire body of the Mediter- ranean Sea. The Sea of Marmara and the Black Sea.
36	Princess Alice II	Monaco	1910	Western basin

37	Michael Sars	Norway	1910	Strait of Gibraltar
38	Mov [Moeve?]	Germany	1911	Eastern basin
39	Naiad	Austria	1911	Adriatic Sea
40	Cyclope	Italy	1911	" "
41	Hirondelle II	Monaco	1912	Western basin
42	Naiad	Austria	1912	Adriatic Sea
43	Cyclope	Italy	1912	" "
44	Naiad	Austria	1913	" "
45	Cyclope	Italy	1913	" "
46	Vila Velebita	Croatia	1913	" "
47	Naiad	Austria	1914	" "
48	Cyclope	Italy	1914	" "
49	Vila Velebita	Croatia	1914	" "
50	Armauer Gansen	Norway	1914	The Gulf of Cadiz
51	Military Trawler	Spain	1914	Western basin
52	"	"	1915	" "
53	Perche	France	1920	" "
54	Giralde	"	1920	" "
55	"	"	1921	" "
56	Orve	France	1921	" "
57	Gana	Denmark	1921	Strait of Gibraltar
58	Armauer Gansen	Norway	1922	Western basin
59	Shtevart	Germany	1922	" "
60	Orve	France	1922	" "
61	Pourquoi Pas	"	1923	" "
62	Sinko-do-Cuto-pro	Portugal	1923	Gulf of Cadiz
63	Admiral Lobo	"	1923	Sea of Alboran
64	Berlin	Germany	1924	Eastern basin
65	Meteor	"	1925	Western & eastern basins
66	Albacore	Portugal	1925	Western basin
67	Meteor	Germany	1926	Western & eastern basins
68	Albacore	Portugal	1926	Western basin
69	Fritone	Italy	1926	Tyrrhenian Sea
70	Meteor	Germany	1927	Western basin
71	Dana	Denmark	1928	Sea of Alboran
72	Berlin	Germany	1928	Eastern basin
73	Emden	Germany	1928	" "
74	Ksauen	Spain	1929	Sea of Alboran
75	Berlin	Germany	1929	Eastern basin
76	Emden	"	1929	" "
77	Litke	USSR	1923	" "
78	Ksauen	Spain	1930	Sea of Alboran
79	Dana	Denmark	1930	Western & central basins
80	Ksauen	Spain	1932	Sea of Alboran
81	Karlsruhe	Germany	1932	Eastern basin
82	Ksauen	Spain	1932	Sea of Alboran
83	President Theo Tissier	France	1933	Western basin
84	Karlsruhe	Germany	1933	Eastern basin
85	Dana	Denmark	1934	Sardinian Strait
86	Ksauen	Spain	1934	Sea of Alboran
87	President Theo Tissier	France	1936	Western basin
88	Emden	Germany	1937	Eastern basin
89	Glavki	Greece	1946	Aegean Sea
90	Predvodnik	Yugoslavia	1947	Adriatic Sea
91	Ksauen	Spain	1947	Sea of Alboran
92	Predvodnik	Yugoslavia	1948	Adriatic Sea
93	Ksauen	Spain	1948	Sea of Alboran

94	Khvar	Yugoslavia	1948	Adriatic Sea
95	Albatross	Sweden	1948	Eastern basin
96	Atlantis	USA	1948	Western, eastern & central basins /103
97	Glavki	Greece	1948	Aegean Sea
98	Alkioni	Greece	1948	" "
99	Predvodnik	Yugoslavia	1949	Adriatic Sea
100	Khvar	"	1949	" "
101	Marine Fran- caise	France	1949	Western basin
102	Pres Theo Tissier	France	1949	" "
103	Mameluke	"	1949	" "
104	"	"	1950	" "
105	Lancier	"	1950	" "
106	Challenger	England	1950	Eastern basin
107	Predvodnik	Yugoslavia	1950	Adriatic Sea
108	Pres Theo Tissier	France	1950	Western basin
109	Marine Francaise	"	1950	" "
110	Robusto	Italy	1950	Ligurian Sea
111	Sabre	France	1950	St. of Gibraltar
112	Simetter	"	1950	Western basin
113	Robusto	Italy	1951	Ligurian Sea
114	Predvodnik	Yugoslavia	1951	Adriatic Sea
115	Simetter	France	1951	St. of Gibraltar
116	Krizia	France	1951	St. of Gibraltar
117	Ksauen	Spain	1952	" " "
118	Robusto	Italy	1952	Ligurian Sea
119	Ksauen	Spain	1952	Sea of Alboran
120	Prof. Lacaze Dutier(?)	France	1952	Bay of Lyons
121	Eli Monier	"	1952	Sec. along 6° E
122	Simetter	"	1952	Western basin
123	Ksauen	Spain	1953	Sea of Alboran
124	Eli Monier	France	1953	Sec. along 6° E
125	Prof. Lacaze Dutier(?)	France	1953	Bay of Lyons
126	Ksauen	Spain	1954	Sea of Alboran
127	Professor Lacaze Dutier	France	1954	Bay of Lyons
128	Eli Monier	"	1954	Sec. along 6° E
129	Adm. Mouchet	"	1955	Western basin
130	Eli Monier	"	1955	Sec. along 7-8° E
131	Calypso	"	1955	Med. Sea, Black Sea & of Marmara
132	Vema	USA	1956	Eastern basin
133	Eli Monier	France	1956	Sec. along 3° 13' E
134	Calypso	France	1956	Entire body of the Mediterranean Sea
135	Lancier	France	1956	Coast of Tunis
136	Mameluke	"	1957	" " "
137	Eli Monier	"	1957	Western basin
138	Calypso	"	1957	St. of Gibraltar
139	Ruze	France	1957	Bay of _____
140	Passer du Printemps	France	1957	St. of Gibraltar
141	Confiance	France	1957	Entire body of the Mediterranean Sea
142	Jeanne d'Arc	France	1957	Entire body of the Mediterranean Sea
143	Cormorano	Italy	1957	Tyrrhenian Sea
144	Flora	"	1957	" "
145	Pomona	"	1957	" "
146	Cimitarra	"	1957	" "

147	Miner	Yugoslavia	1957	Adriatic Sea
148	Spasilats	"	1957	" "
149	Videl	England	1957	Western basin
150	Videl	England	1958	" "
151	Jeanne d'Arc	France	1958	Entire body of the Mediterranean Sea
152	Atlantis	USA	1958	Western basin
153	Discovery II	England	1958	Bay of
154	Calypso	France	1958	St. of Gibraltar
155	Vinaretta			
	Sinjer	Monaco	1958	" " "
156	Passer du Printemps	France	1958	" " "
157	Segura	Spain	1958	" " "
158	Spasilats	Yugoslavia	1958	Adriatic Sea
159	Baionetta	Italy	1958	Tyrrhenian Sea
160	Danaida	"	1958	" "
161	Gelland Gansen	Norway	1958	Bay of Cadiz
162	Yamakrou	USA	1958	St. of Gibraltar
163	Acad. A Kovalevskiy	USSR	1958	Aegean Sea and Ionian Sea
164	Sedov	USSR	1958	Entire body of the Mediterranean Sea
165	Acad. S. Vavilov	USSR	1959	Entire body of the Med. Sea, exclud. the Adriatic Sea
166	Jeanne d'Arc	France	1959	Entire body of the Mediterranean Sea
167	Pres. Theo. Tissier	USSR	1958	Western basin
168	Acad. A. Kovalevskiy	USSR	1959	Entire body of the Mediterranean Sea
169	Lots - 60	USSR	1959	Aegean Sea, eastern basin
170	Gonets	USSR	1959	Aegean Sea
171	Cheyne	USA	1959	Entire body of the Mediterranean Sea
172	Diana	Italy	1958	Tyrrhenian Sea
173	Lots-60	USSR	1960	Aegean Sea, eastern basin
174	Aytodor	USSR	1960	Central & eastern basins
175	Academician	USSR	1960	Entire body of the Med. Sea, excluding the Adriatic Sea
176	Acad. A. Kovalevskiy	USSR	1960	Eastern & central basins
177	Eli Konier	France	1960	Western basin
178	Calypso	"	1960	St. of Gibraltar
179	Espadon	"	1960	" " "
180	Passer du Printemps	"	1960	" " "
181	Acad. S. Vavilov	USSR	1960	Aegean Sea & eastern basin
182	Lots-60	USSR	1961	Eastern & central basins
183	Acad. A. Kovalevskiy	USSR	1961	Ionian Sea and Adriatic Sea
184	Atlantis	USA	1961	Western basin
185	Talassa	France	1961	" "
186	Gelland Gansen	Norway	1961	St. of Gibraltar
187	Epan	Belgium	1961	" " "

188	Stafetta	Italy	1961	St. of Gibraltar
189	Origny	France	1961	" " "
190	Calypso	"	1961	" " "
191	Aragonese	Italy	1961	" " "
192	Ksauen	Spain	1961	" " "
193	Atlantis	USA	1962	Entire body of Mediterr. Sea
194	Aragonese	Italy	1962	Southeast part of Aegean Sea
195	Acad. S. Vavilov	USSR	1962	Entire body of Mediterr. Sea
196	Acad. A. Kovalevskiy	USSR	1962	Eastern basin
197	Lots-60	USSR	1962	Eastern & central basins
198	Bataysk	USSR	1962	Entire body of Medit. Sea
199	Academician	USSR	1963	Eastern & central basins

layers brings about a subsidence of the surface waters or the flow of deep waters to the surface. The latter is of particular interest to researchers working, for example, in the interest of the fishing trade. In the subsequent expeditions, attention must be paid to the regions indicated above. Generally speaking, the dissection of the Mediterranean Sea basin facilitates the engendering of stationary and quasistationary dynamic formations of different sign, and a detailed dynamic chart, constructed on the basis of mean data for many years, would be of great help in solving this problem.

The individual questions, as has already been indicated in our present historical survey, are receiving much attention from Soviet, French, Italian, Spanish, and Yugoslav oceanographers.

In recent years, a considerable contribution of the study of some of the most important questions of the hydrology of the Mediterranean Sea has been made by American scientists. To investigate such questions, Soviet oceanographic establishments also intend in the near future to make several specialized trips in the Mediterranean Sea.

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THE HORIZONTAL CIRCULATION OF THE WATER OF THE
MEDITERRANEAN SEA DURING THE SUMMER AND WINTER SEASONS

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by

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Due to insufficient number of instrument readings on the currents of the Mediterranean Sea, we can discuss the general character of water circulation during the winter and summer only by using dynamic charts, compiled for the surface and for a 500 m horizon in relation to 1000 db, according to the findings of the first and second voyages of the oceanographic ship Academician S. Pavlov (summer season) and the third and fourth voyages (winter season).

When evaluating the circulation of the Mediterranean Sea water according to the dynamic charts, one should clearly understand that these charts show only geostrophic wind and convection currents, and that drift currents in the surface layer of the sea are not taken into consideration in this system. The random selection of the investigated surfaces at a depth of 1000 db, where, generally speaking, one still observes sufficiently well-defined currents of a temporary character, did apparently not introduce, significant errors in this scheme of geostrophic and convection currents. Under such conditions, the speed ratio which is a function of uneven density distribution, is decisive for almost the entire density distribution in the 0-1000 m layer, since horizontal density gradients are considerably reduced below 1000 m.

The Circulation of the Surface Waters
of the Mediterranean Sea

An analysis of the dynamic charts of the surface horizons has shown that the circulation of the Atlantic waters (in the layer of decreased salinity) is identical to the system of the surface circulation, therefore, in the present case, we are discussing mainly the movement of the waters of Atlantic origin.

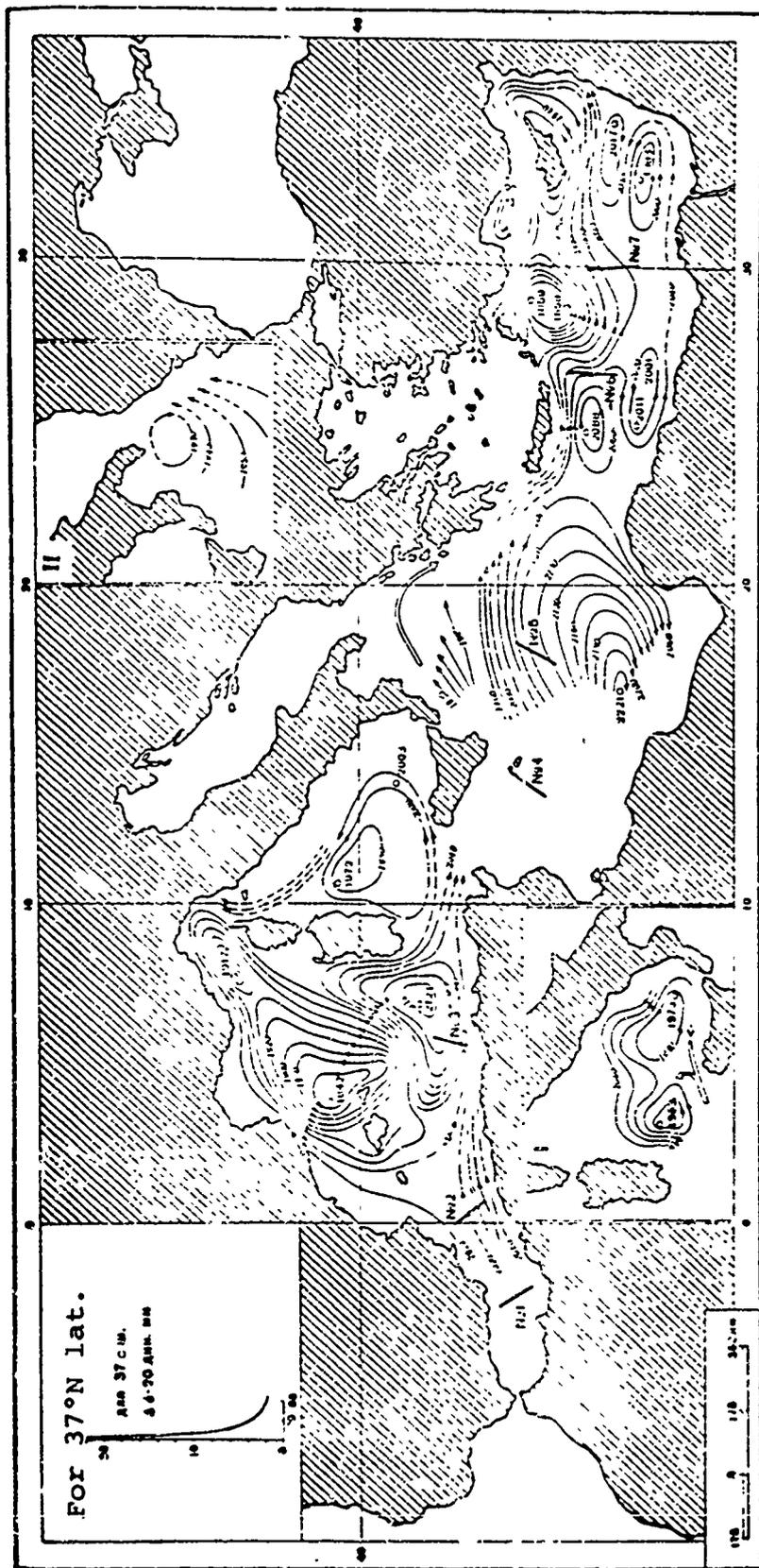


Figure 1. Dynamic chart of 0/1000 db for the summer season.

I - circulation of the surface waters of the Tyrrhenian Sea according to the data of the first voyage of the oceanographic ship Academician S. Pavlov;

II - circulation of the surface waters of the Ionian Sea according to the materials of the second voyage of the oceanographic ship Academician S. Pavlov. The graph at the top (Figure 1, 3-5): along the vertical axis - cm/sec, along the horizontal axis-miles.

THE SUMMER SEASON
(July-September)

From the Strait of Gibraltar, the waters of Atlantic origin are moving in a single stream, hugging the African shore (Figure 1). In the region at 5-6° Lat. East, a branch separates the main stream and moves in a northwestern direction, closing the cyclonic circulation, circle in the western basin. The cause of such a separation of the waters of Atlantic origin should be sought, it seems, in the wind regimen of this region, (Berehger 1955; Middellandse Zee, 1957). The high pressure ridge of the Azores maximum, which can be distinctly observed from Spain to the Tunisian Strait (Middellandse Zee, 1957), causes the summer formation of very strong stable eastern and northeastern winds which predominate over the Algerian shores. Such a meteorological situation can be constantly observed during summer and explains the branching and countercurrents in the Atlantic water stream, noted previously by certain authors (Lacomb, Tchernia, 1960).

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At the western shores of the Island of Sardinia part of the Atlantic waters of the northwestern branch, probably under the influence of the northwestern winds determined by the same high pressure ridge, turn south, creating an anticyclonic circulation west of the Sardinian Strait (Tchernia, 1954), and partially fill the main stream which flows along the African shore. A considerable part of the Atlantic waters separates at the Tunisian Strait and flows around the Tyrrhenian Sea along a cyclonic trajectory (Fig. 1).

After leaving the Tunisian Strait the Atlantic waters enter the general anticyclonic circulation of the waters of the central basin, typical, it seems, for the summer season (Zore Mira, 1956).

The noted movement of the waters in the central basin of the Mediterranean Sea can occasionally be strongly disturbed. Such an abnormal deviation has been observed during the summer of 1960, when water movement of cyclonic character was clearly observed (Fig. 1, II) in the northern part of the central basin (in the Ionian Sea).

The intensity and limits of penetration of the waters of Atlantic origin in the eastern basin, probably depend, to a considerable extent on the wind regimen in this region. As known, during summer the eastern basin is under the influence of stable air currents (etesian currents). The etesians are monsoon-type winds, caused by the presence during summer and a quasi-stationary cyclonic formation above the Asia Minor Peninsula. The active period of the etesian winds is confirmed almost entirely to the summer season (approximately from May to October); but it has two maximums, which occur during the last 10 days of May and during July, as well as during August (Middellandse Zee, 1957). The etesian winds, which follow approximately the same direction as the distribution of the main current of the Atlantic waters, probably facilitate the advection of these waters toward the east. The distribution of these waters can be well observed on the dynamic chart (Fig. 1).

Part of the waters of Atlantic origin, which penetrated the eastern basin of the Mediterranean Sea, mainly through the northern part of the Creta-Africa Strait, becomes part of the anti-cyclonic circulation, south of which is situated a small cyclonic turbulence. Farther down these waters circle the Levant Sea along the cyclonic trajectory, entering into the extreme northeastern region of the Sea. South of the Rhode's Islands a strong cyclonic circulation is noted.

On the map also indicates that the surface waters enter the Aegean Sea through the Rodhos (Rhodes) and Karpathos

straits, and the Aegean waters enter through the Kasos Strait into the Sea of Levant.

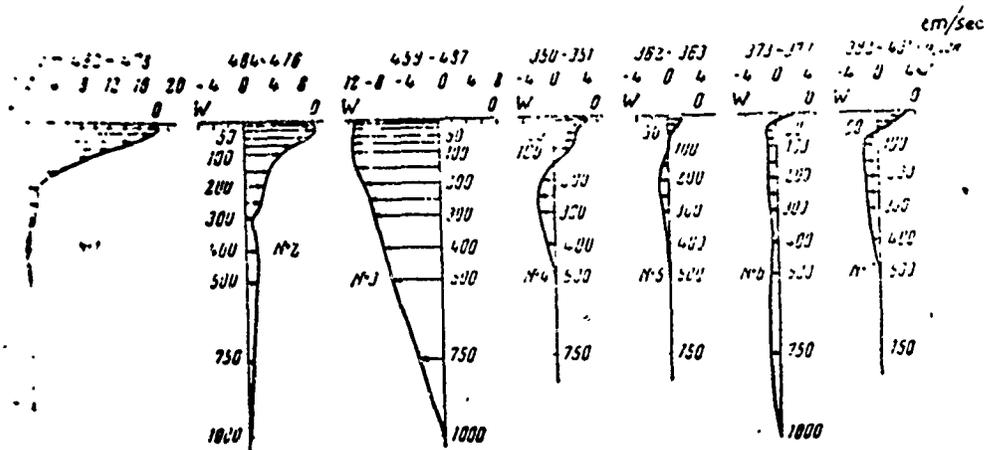


Figure 2. Diagrams of the summer season currents calculated by the dynamic method.

In order to observe the development of the flow of the Atlantic waters at different depths and to increase the speed of its movement in general circulation, we calculated (with the dynamic method) the component speeds of the current on the sections with positions conditionally assumed to be normal to the direction of the flow (see sections 1-7 in Fig. 1).

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On the projection diagrams Nos. 1 and 2 (Figure 2) the surface flow is well-defined, and its speed at the horizon of 10 m reaches 10-20 cm/sec. Beginning approximately from 5° of Lat. East, the permanence of the easterly flow is disturbed, and the projection diagram No. 3 shows at the surface a counter-current to the west, which represents the southern periphery of a clearly defined anticyclonic water circulation (Fig. 1). In the eastern basin the weak components of the easterly flow (2-4 cm/sec) are shown in all projection diagrams, but the minor values of the speeds point to the instability of the currents within the surface waters of this region of the Mediterranean Sea.

The Winter Season
(January-March)

During the winter season (Figure 3) certain common features of the circulation of the surface waters in the Mediterranean Sea remain. For example, in the Algeria-Provence Basin two circulation systems of different types are observed: cyclonic and anti-cyclonic. One can assume the presence of the cyclonic movement in the waters in the Tyrrhenian Sea. In the central basin circulation of the waters remains clockwise in the Sea of Sirte, whereas in the Ionian Sea the movement of the waters is evidently cyclonic, and which most probably is peculiar to the winter period (Zore Mira, 1956). A completely different picture of water flow during the winter is observed in the Crete-Africa Strait: Atlantic waters penetrate the eastern basin through its southern part, and in the north of the Strait a drift from east to west is observed. The anti-cyclonic circulation, observed during the summer in the Crete-Africa Strait, developed greatly during the winter and moved to the southeast. The currents in the southeastern straits of the Aegean Sea did not change their direction.

For the winter season, we also calculated (with the dynamic method) the component speeds of the flow on certain sections (Fig. 3) which appear to be generally close to the sections shown in Fig. 1. All the diagrams (See Figure 1), excluding diagram No. 2, showing the direction of the surface current is easterly. Diagram No. 2 indicate the persistence, during the winter period, of a westerly countercurrent of westerly (southern periphery of the anticyclonic circulation) in the western basin of the Mediterranean Sea. Diagram Nos. 6 and 7 show the multidirectional character of the water flow in the Central-African Strait up to great depths, and this concurs with the conclusions of Pollak (Pollak, 1951).

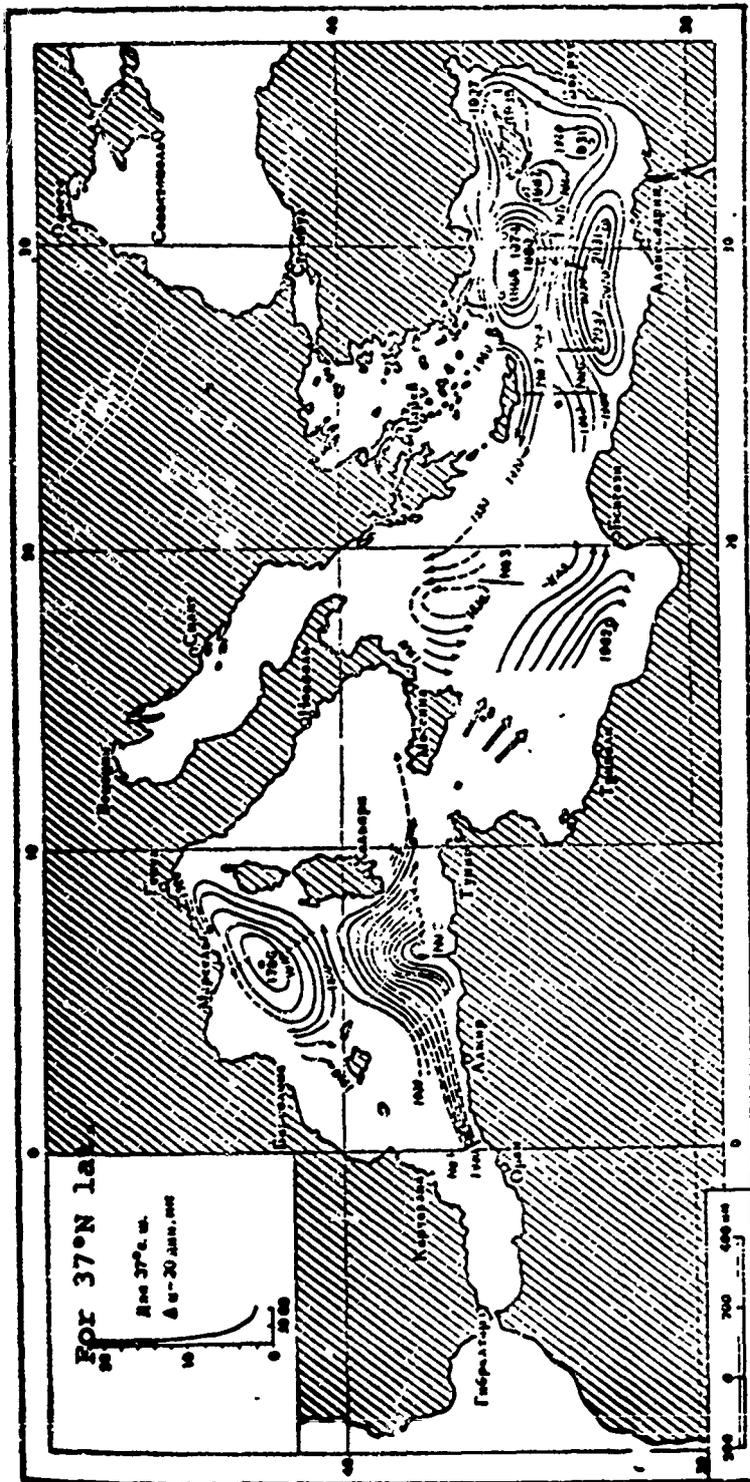


Figure 3. Dynamic chart of 0/1000 db for the winter season.

The circulation of the surface waters in the eastern basin has a very complex character in summer and winter. The presence of several intensive circulation systems with different directions of flow in the center of which considerable rises and subsidences of waters are found as well as the divergence & convergence zones between them, exert a very strong influence on the hydrological regimen of the Mediterranean Sea as a whole, primarily on the transformation of the waters. Therefore, the circulation of waters of the eastern basin must become, in our opinion, an object of more intensive observation and study

The Circulation of Intermediate (Levantine Waters in the Mediterranean Sea

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Guided by the indirect peculiarities (distribution of the intermediate salinity maximum, etc.), the previous investigators created a picture of the movement of the intermediate waters (Nielsen, 1912; Schott, 1915; Atlas, 1957; Lacombe, Tchernia, 1960). The term "intermediate water mass" has firmly established itself in the practice of hydrological analysis of the Mediterranean waters and has been used in the literature starting with Nielsen's work (Nielsen, 1912). Nevertheless, this term should be considered unsuitable, because it does not reflect the cause of the abnormal characteristics of this water mass. This water is formed mainly in the northern part of the Sea of the Levant, and the values of its hydrological characteristics are quite well explained by the hydrometeorological regimen of this region, in conjunction with which it would be more appropriate to use the term "levantine water mass." This fact was already observed by Wuest (Wuest, 1959).

In order to investigate the distribution of the levantine waters we composed dynamic charts for the 500 m horizon relative to 1000 db (Figures 4 and 5). Besides this, a chart

was designed according to the data of the first voyage, for the 250 m horizon relative to 1000 db, which shows to a larger extent the movement of the Levantine waters, the nucleus of which in the eastern basin is situated at the depth of 200-300 m.

The Summer Season

The dynamic chart for the summer season shows that the circulation of the intermediate waters in the Sea of Levant, in spite of its complexity, has an overall cyclonic character. It also shows the preservation of Rodhos (Rhodes) cyclonic circulation and the development of other turbulences of a different type. The Crete-Africa anticyclonic circulation, merging with a circulation of the same type in the central basin, determines the drift of the intermediate waters from the Levant Sea through the southern part of the Crete-Africa Strait, and further through the southern periphery of the Sea of Sirte toward the Tunisian Strait. The same character of circulation of the intermediate levantine waters in the eastern Mediterranean is observed at the horizon of 250 m (Figure 6).

Having penetrated into the western basin, a considerable part of the levantine waters moves along the northern African shores in the direction of the Strait of Gibraltar. At the same time one can observe their branching into the Tyrrhenian Sea and into the Algeria-Province basin. In the Tyrrhenian Sea the Levantine waters move along a cyclonic trajectory and penetrate into the Algeria-Province basin, either by passing through the Corsican Strait or by going around the southern side of the Island of Sardinia. In the Algeria-Province Basin they become a part of the general cyclonic circulation, to the south of which remains a small anticyclonic circulation. Part of the Levantine waters from the cyclonic circulation along the Spanish shores enters the

Alboran Sea and is connected with the branch which moves along the African shores. Therefore, on the dynamic chart for the summer season one can observe well the general western drift of the Levantine intermediate waters.

This process is also quite evident in Figure 2, where western components of the currents are noted in the intermediate layer on all projection diagrams, except Diagram 2. See illustrations in Figures 4, 5, and 6.

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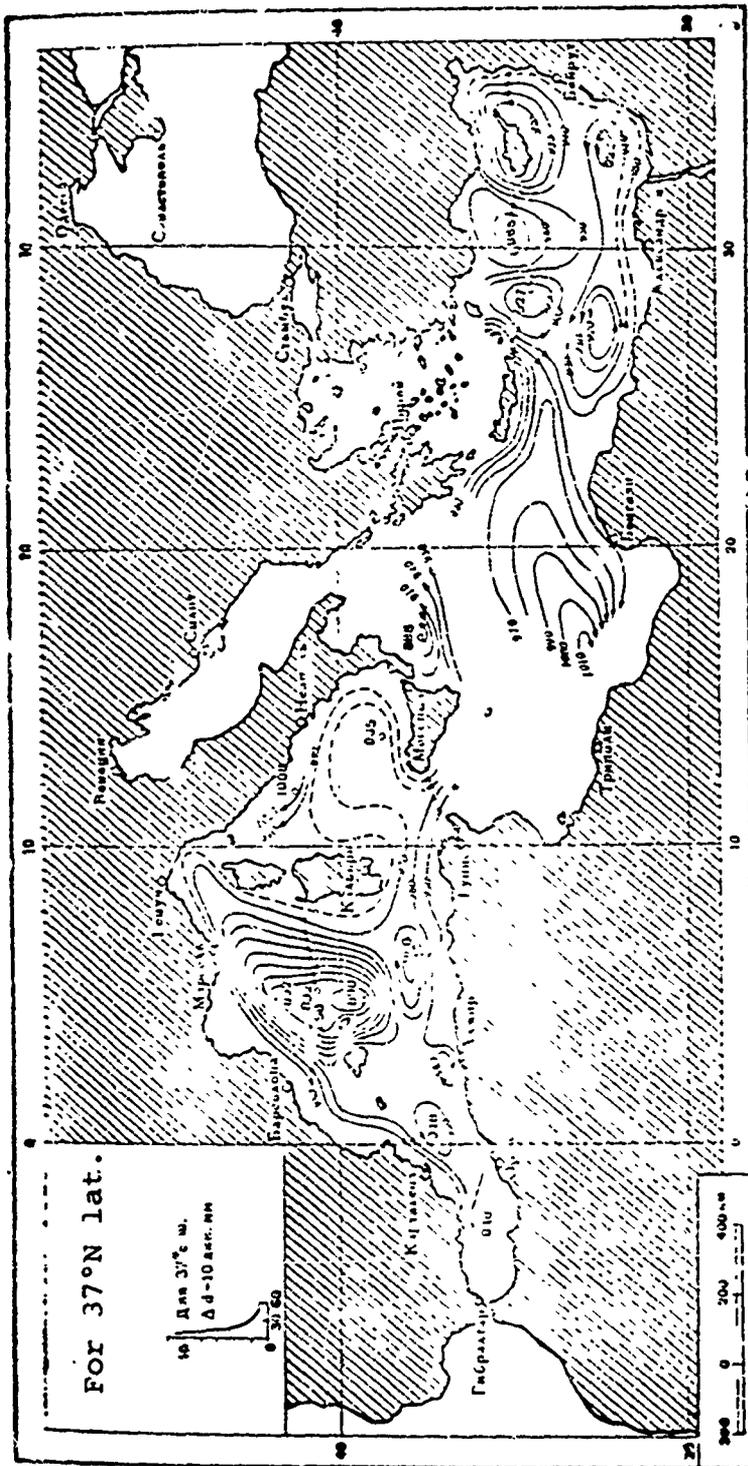


Figure 4. Dynamic chart of 500/1000 db for the summer season.

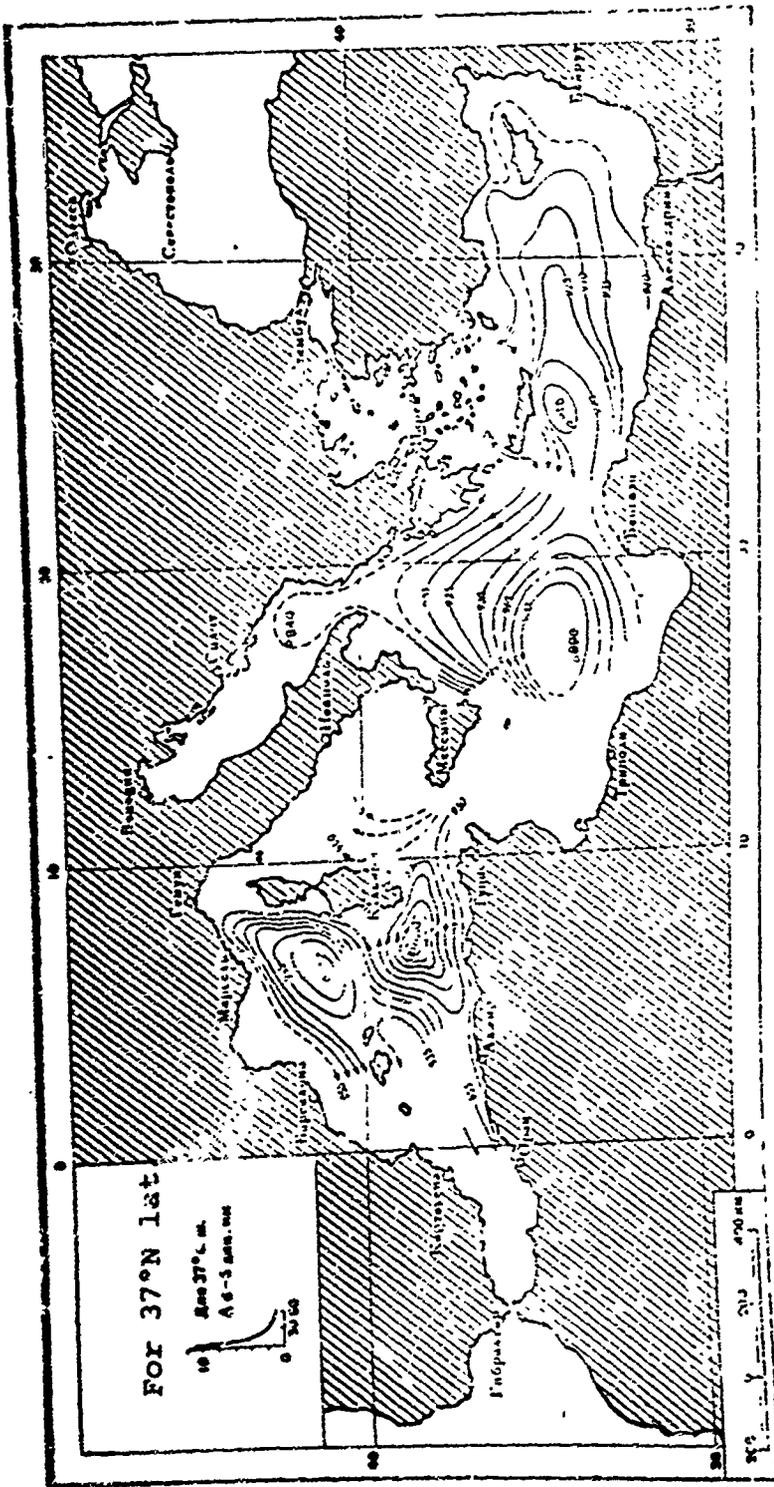


Figure 1. A dynamic chart of 500/1000 db for the winter period.

Winter Season

A more distinct aspect of the movement of the levantine intermediate waters can be observed during the winter (Fig. 5). In the central and eastern basins of the Mediterranean Sea a well-pronounced general circulation of the intermediate waters, leading to their two-directional movement of the Crete-Africa Strait can be observed. At variance from the summer season, the entire water area (aquatory) of the central basin is

subjected to a strong cyclonic circulation, which seems to engulf the deep water part of the Adriatic as well. In the western basin circulation characteristics are the same as during summer. The intensification of the anticyclonic circulation at the southwest of Sardinia and a certain decrease of cyclonic circulation in the north of the Algerian-Provence basin should be noted.

On all speed projection diagrams (Figure 7), except on diagrams No. 4, the western components of the currents on the intermediate horizons are noted. A considerable difference (mainly for the eastern basin) in the circulation system of the Levantine waters for the summer and winter seasons are due, in our opinion, to the following basic causes:

The first cause is undoubtedly the seasonal changeability of the wind regimen (Middellandse Zee, 1957). For example, during the summer season, when the etesian winds blow above the eastern basin, the Rodhos (Rhodes) turbulence grows stronger and the Crete-Africa anticyclonic circulation is less developed (Figure 1 and 3). During the winter season this circulation is considerably reduced.

The second cause, in our opinion, consists of the following facts: During the summer, in conjunction with increased evaporation, the water balance deficit increases in the Mediterranean Sea, and must be compensated by a more intensive inflow of Atlantic waters, which comprise a thicker layer during this period. The increased inflow of waters of Atlantic origin must undoubtedly exert a considerable influence on the circulation of the intermediate Levantine Waters. As Figures 1, 4, and 6 indicate, the general circulation system of the Levantine waters, especially in the eastern part of the Mediterranean Sea, in the horizons of 250 and 500 m repeats the main features of surface water circulation.

The third cause consists in the fact that the intermediate and deep water masses of the eastern Mediterranean are formed, which leads to increased intensity and a more clearly pronounced displacement of the levantine waters in the entire water area (aquatory) of the Mediterranean Sea.

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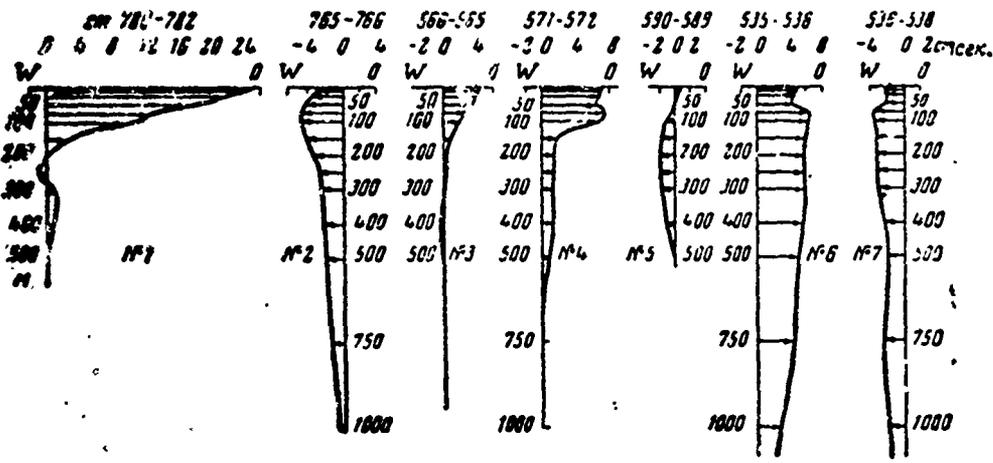


Figure 7. Projection diagrams of currents, calculated by the dynamic method for the winter season.

The schemes of the Levantine water circulation during the winter season are also supported by certain instrument readings which indicate the intensity of the displacement of the Levantine intermediate waters. As shown by observations, the speed of their movement is an average of 11-15 cm/sec., reaching, in individual cases, 40 cm/sec.

A comparatively good correlation is also noted when comparing the dynamic charts for the intermediate horizons (250 and 500 m) with the charts of the maximum salinity distribution, which comparison reflects the qualitative picture of the Levantine intermediate water distribution in the Mediterranean Sea.

The Circulation of the Deep Waters Of the Mediterranean Sea

The insignificant number of instrument readings in depth of currents, including those of the hydrological stations, which reached bottom depths, makes it impossible to present

adequately well founded data on the circulation of the deep waters of the Mediterranean Sea. Nevertheless, using certain indirect peculiarities, one can reach individual conclusions about the horizontal circulation of the deep waters.

As shown with the dynamic calculations, a movement of the deep waters from the north of the Ionian Sea is noted in the central basin, it can be assumed that these waters have an Adriatic origin. This proposition is confirmed by the observations made at two anchor buoy stations, established in the Otranto Strait, which have shown an intensive discharge of the waters from the Adriatic at the 600 and 700 m level with a speed which reaches 28 cm/sec.

In the Crete-Africa Strait the dynamic cross-section, calculated in the relation of 2000 db, indicates the two-directional movement of the abysmal waters (Figure 7, projection diagrams 6 and 7). Diagrams 6 and 7 show that in the northern part of the strait the current is westerly, and in the southern part its flows is easterly with a speed of up to 6 cm/sec. This was confirmed by the instrument readings as well.

The two-directional movement of the deep waters in the Crete-Africa Strait, their cyclonic movement in the central basin, and other data make it possible to assume that in the eastern and central basins of the Mediterranean Sea deep waters join in cyclonic circulation and have a common region of origin.

The cyclonic motion characteristics of the deep waters in the western basin which are formed separately in its northern regions, are probably similar to those of the higher layers.

The analysis conducted by us shows that our dynamic maps concur comparatively well with the previously known systems of circulation of the surface waters in the Mediterranean Sea

(Nielsen, 1912; Schott, 1915; Atlas, 1957: Middellandse Zee, 1957; Pollak, 1951; Wuest, 1959; Lacombe, Tchernia, 1960). Nevertheless, one should note those characteristic peculiarities, which, to our knowledge, have not received due attention.

1. During the winter and summer seasons an intensive anticyclonic circulation is noted west of the Sardinian Strait. The southern periphery of this circulation was repeatedly observed by French explorers (Tchernia, 1954 et al) as a countercurrent which divides the stream of the Atlantic waters into two branches. We have already pointed out the causes of the formation of this countercurrent and anticyclonic circulation during the summer period. At the same time we noted the absence of an intensive discharge of surface waters from the Tyrrhenian Sea along the southern extremity of the Island of Sardinia in the Algeria-Provence basin.

2. During the summer one can sometimes observe completely different types of circulation of the surface water in the Ionian Sea:

1) the displacement of the waters along the shores of Southern Italy and the Balkan Peninsula, which is connected with the general anticyclonic movement in the central basin, and

2) the cyclonic circulation (Figure 1, II), created partially by the waters of Atlantic origin and the surface waters of the Adriatic, which come out of the Otranto Strait.

3. During the summer, between the Island of Crete and Africa a flow from the central basin of the Mediterranean Sea into the Sea of Levant is observed in the surface layer. This current has great intensity along the shores of Crete

but not along the African shores. Therefore, we can definitely state that during the summer season, in the northern part of the Crete-Africa Strait, a westerly current, which carries the surface waters from the eastern basin of the Mediterranean Sea into the central one, does not exist.

4. During the winter in the northern part of the Crete-African Strait a discharge of the waters from the eastern into the central basin, and in the southern part an inflow of waters of Atlantic origin was observed.

5. During the summer and winter seasons the circulation of the surface waters of the Sea of Levant is very complex. From the several types of circulation systems, the most intensive and stable are the Rodhos (Rhodes) cyclonic and Crete-Africa anticyclonic circulations (Ovchinnikov, Plakhin, 1963).

6. During the summer the circulation of the intermediate waters in the Sea of Levant has the same complex character as the surface layer, and during the winter the clearly defined general cyclonic movement of the waters in the eastern basin has been observed.

7. In the central basin during the winter, the circulation of the intermediate waters has a reverse (cyclonic) direction as compared with circulation in summer.

8. In the western basin the intermediate levantine waters become part of the cyclonic circulation of the Tyrrhenian Sea and Algeria-Province basin; at the same time they spread in the direction of the Strait of Gibraltar along the African shores.

The systems established for the circulation of the surface and intermediate waters have, so far, a preliminary character. The peculiarities of the circulation of the Mediterranean Sea waters brought disclosed in these systems will be used for data comparisons when drafting dynamic charts according to multiyear data.

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THE WATER MASSES OF THE MEDITERRANEAN SEA

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by L. V. Moskalenko and
I. M. Ouchinmikov

The water balance of the Mediterranean Sea consists of atmospheric precipitation, river runoff, inflow from the neighboring basins, evaporation, and outflow into the neighboring basins.

In the incoming water, atmospheric precipitation and river inflow are insignificant. Therefore the runoff into the neighboring water reservoirs and evaporation in the Mediterranean Sea balance most of the inflow of waters from other basins. Because evaporation acts as an outside factor, one can mention the deficit of the water balance of the Mediterranean Sea and the compensating currents, which replace this deficit. The index for this mechanism can be a characteristic such as the level, which, in the Mediterranean Sea, is considerably lower than the levels of the neighboring water reservoirs. Therefore the inflow of the water from the neighboring basins and evaporation are the main components of the water balance and are the decisive factors for the hydrological structure of the Mediterranean Sea.

The data obtained during the first two voyages of the oceanographic ship Academician S. Pavlov, which make it possible to analyze the peculiarities of the hydrological regimen of the Mediterranean Sea during the summer season throughout its entire water territory (aquatory) are most interesting. The data of the third and fourth voyages, which characterize the peculiarities of the hydrological regimen of the sea during the winter season, were used only for comparison between individual regions.

The vertical hydrological structure of the Mediterranean Sea during the summer season is well-defined in the cross-section of the Mediterranean Sea from the Strait of Gibraltar

to the Levantine shores (Figures 1 and 2). As can be seen from the longitudinal section of the salinity distribution (Fig. 2), which is more representative than the temperature distribution (Fig. 1), in the Mediterranean Sea, three main water masses: those with decreased and increased salinity, and a deep water mass, are clearly evident.

During the summer, under the influence of thermal and mechanical factors (intensive heating and evaporation, wind mixing) a surface water mass which is characterized by a high temperature (25° and higher) and higher salinity is also formed. Its lower boundary coincides with the upper boundary of the thermocline.

Below this, a water mass with decreased salinity is located. Its formation is mainly due to the water which comes from the Atlantic Ocean and has low salinity. The low salinity water mass can be well observed along the entire length of the cross-section (its distribution from west to east in Fig. 2 is shown by a dotted line). The tongue of the decreased salinity lies within the thermocline stratum, and the minimum itself is situated slightly above the maximal temperature gradients. The thermocline layer is characterized by considerable water stability despite the fact that the values of stability as a function of salinity have a negative or a small positive value here. The maximal stability of the waters is noted at the depth of 15-40 m in the western part of the Mediterranean Sea and at 40-70 m in the eastern part. Consequently, intermixing of the "Atlantic" waters with the waters beneath them during the summer season is minor, and as a result, the Atlantic waters are traced on the basis of minimum salinity on almost the entire aquatory (water territory) of the Sea. /121

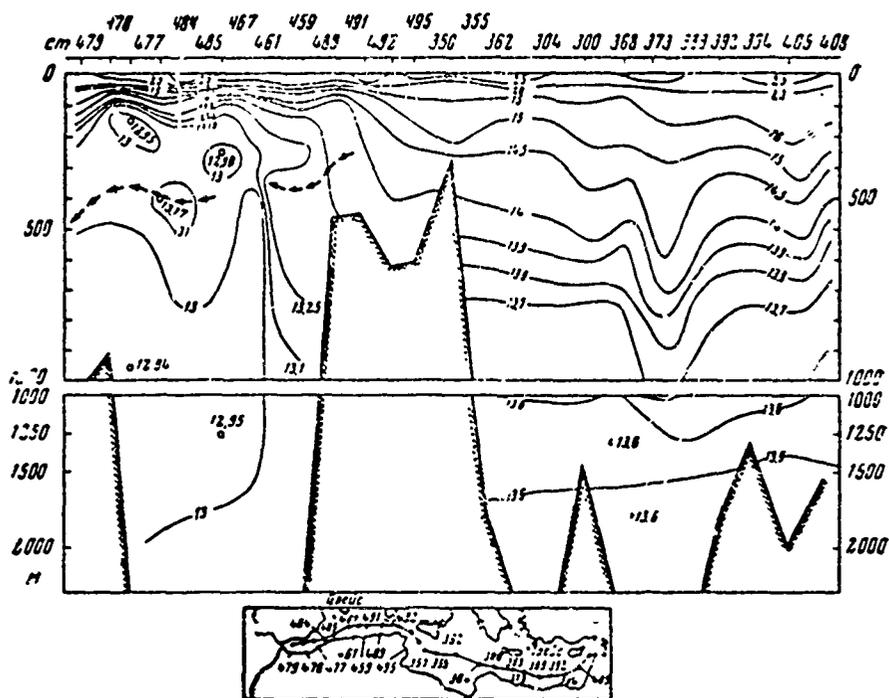


Figure 1. The distribution of water temperatures (C°) along the longitudinal section from the Strait of Gibraltar to the Levantine shores.

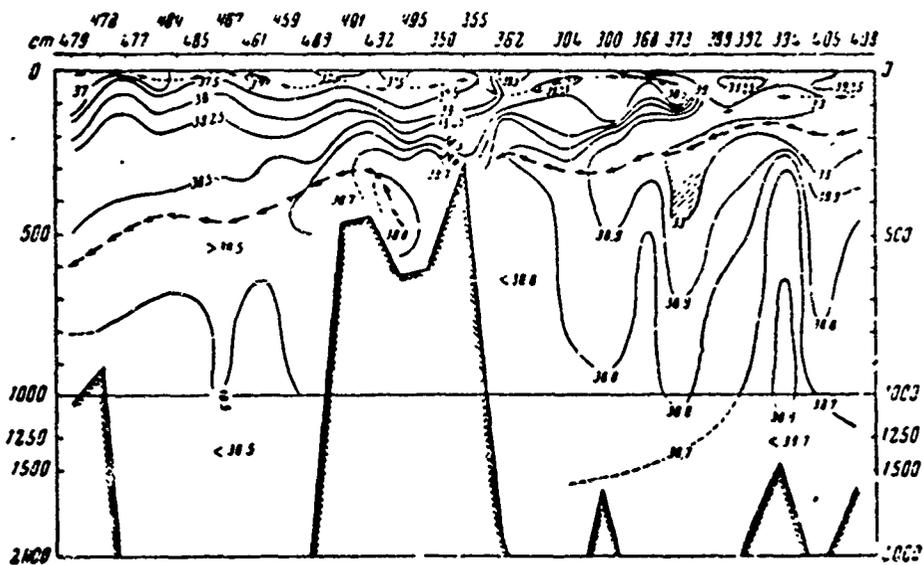


Figure 2. The distribution of salinity along the longitudinal section from the Strait of Gibraltar to the Levantine shores.

The lower boundary of the water mass with decreased salinity, in the lower part of the Mediterranean Sea, lies somewhat above the minimum temperature at 200-250 m. In the central and eastern basins it lies at a depth of 100-150 m.

In the Sea of Levant, especially in the regions of the Crete-Africa Strait and the southwestern straits of the Aegean Sea, is noted in the upper interlayering of more or less saline waters of different origins (Atlantic, Aegean, and probably, Adriatic).

The intermediate water mass of higher salinity is formed in the northern regions of the Sea of Levant and partially in the southeast of the Crete basin of the Aegean Sea. The high salinity (39.4‰ and more) which is intensely heated in the summer, is subjected to considerable cooling in autumn and winter. The consequence of such cooling is convective intermixing, which is especially strong in the convergence regions of the dry and cold masses of polar and arctic continental air, and determines the homohalinity of the waters to a great depth. The layer of the intermediate maximum of salinity during the summer is probably a remnant of the homohaline layer of the winter.

The movement of the intermediate waters of increased salinity can be well observed on the basis of maximum salinity, and shown in Figure 2 by black arrows. The depth of the position at the lower boundary of the water mass of increased salinity fluctuates considerably (from 400-500 to 800-900 m), increasing from East to West. This boundary is less well-defined than the boundaries of the upper masses, and it can be evaluated with a certain tolerance as a depth at which the vertical temperature and salinity gradients disappear.

In the western part of the Mediterranean Sea the movement of the intermediate waters of increased salinity can be detected also from maximum temperature, (Figure 1).

At the boundary of the water masses of the increased and decreased salinity two layers can be distinguished: one of minimal, and one of maximal temperature. It seems that these

layers have a convective origin and are mainly the result of the decreased temperature layer within the stratum of apparent vertical salinity gradients. On the other hand, the minimal temperature layers can also partially result from wedging in of warmer, but more saline intermediate waters of the western basin.

The deep water mass, as can be seen from Figures 1 and 2, has almost uniform depth temperature and salinity values. It is necessary, nevertheless to note that its characteristics in the eastern and central part ($13.5^{\circ} < T < 13.7^{\circ}$; $36.6\% < S < 38.8\%$) are considerably higher than in the western part ($12.95^{\circ} < T < 13.0^{\circ} - 13.1^{\circ}$; $38.45\% < S < 38.5\%$).

The deep waters in the western part of the Mediterranean Sea are originated from strong winter cooling of surface waters in the northern regions of the Algeria-Provence basin and the intermixing of these waters with more saline intermediate waters.

The analysis of data from the fourth (winter) voyage has shown that the abysmal waters of the central and eastern part of the Mediterranean Sea are of Adriatic origin; at the same time the charts of the temperature and salinity distribution at the 1000 m horizon according to the data of the second voyage lead to the supposition that the formation of the deep waters depends to some extent on the warmer and saltier waters, which penetrate here from the Crete basin of the Aegean Sea. This concurs with conclusions reached previously by Nielsen (Nielsen, 1912) and the opinion of Wuest (Wuest, 1952), and contradicts the conclusions of Pollak (Pollak, 1959), who considered the Adriatic the only source of the deep water mass in the central and eastern basins of the Mediterranean Sea. We are unable to furnish a more detailed analysis of the deep mass due to insufficient

number of deep water data. The cross-section along the entire Mediterranean Sea which we discussed (Fig. 2), showing clearly and graphically intermediate waters of increased and decreased salinity, and the route of their distribution and transformation, corresponds well to similar sections compiled by Shott (Shott, 1915), Lacombe and Chernia (Lacombe, of "Thorr" and a number of other expeditions during the 1908-1958 period.

The distribution of temperature and salinity at the section in 7° e. generally coincides with the sections of Thorr, (1910); Nielsen, (1912) and "Eli Monier" (1952; Chernia, 1954). It is necessary to note, however, that our section shows: 1) that higher values of salinity are characteristic for the intermediate layer (38.5-38.6‰), whereas in the above-mentioned sections the salinity is only slightly higher than 38.4‰, and 2) that higher temperature values are characteristic for the deep waters (12.95°-13.00°).

The mentioned facts of the temperature increase and salinity at depths of 500-1000 m and more, deserve serious attention and must be thoroughly studied. It is quite possible that they are determined not so much by the actual warming-up and salinization of the deep waters, as by the different methods of measurements.

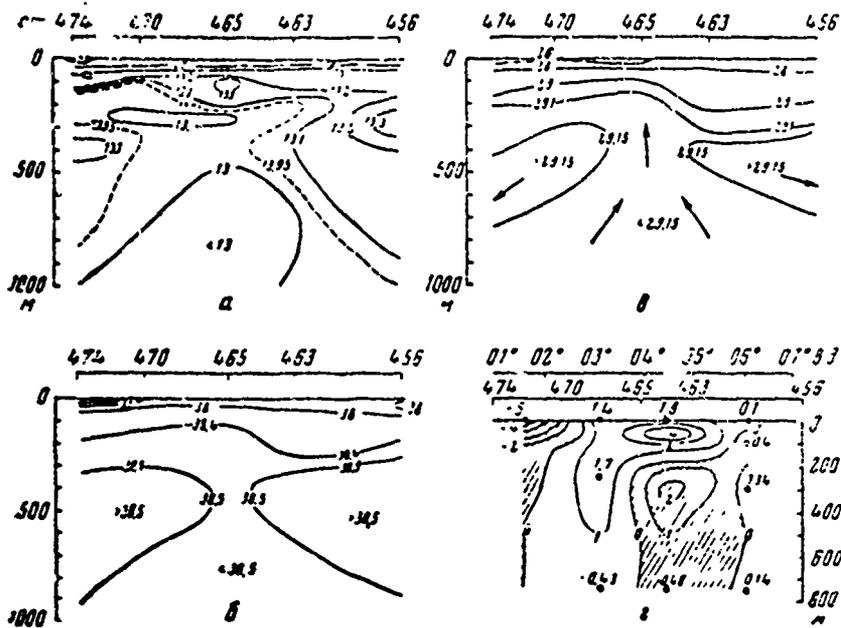
The section along the 49° 30' N. Lat. (Fig. 3) gives us a clear picture of the structure of the waters in the cyclonic circulation in the north of the Algeria-Provence Basin. In the center of the cyclonic circulation traces of intensive rising of deep waters were observed and as a result, the typical vertical structure was disturbed to a certain degree. Such a displacement of the vertical structure of the waters is characteristic for other regions of the Mediterranean Sea, in particular for the eastern basin, where we noted a complex system of currents. In order to investigate

the zones of the descent and ascent of the waters in more detail, a vertical cross-section was made of the temperature and salinity, oriented along the axis, passing through the centers of the Rhodes cyclonic and Crete-Africa-Atlantic anticyclonic circulations. Along this section zones of ascent and descent of the waters are very clearly indicated.

Quite representative for the characteristic of the nucleus of the intermediate waters of increased and decreased salinity are the charts showing the distribution of minimal and maximal salinity (Figures 5 and 6). When identifying the nucleus of the low salinity water mass (minimal salinity) with the waters of Atlantic origin, it can be stated that the Atlantic waters, as they move farther down to the east, are changing considerably and gradually descend from 0-25 m in the western basin of the Mediterranean Sea to 50-75 m in the eastern basin. As can be seen from Figure 5, the Atlantic waters, on the basis of their minimum salinity, are found everywhere, up to the northeastern part of the Sea of Levant. At the same time in certain regions of the Sea of Levant, mainly to the north of the Island of Cyprus, the "Atlantic waters" are no longer encountered; this can be judged according to the disappearance of the surface minimum, which is born out by the TS curves. The distribution route of the Atlantic waters, noted by us on the chart of minimal salinity by arrows, coincides comparatively well with the dynamic chart compiled for the surface relative to 1000 dt. The chart of minimal salinity compiled by us, with the exception of certain details, generally matches a similar chart compiled by Locombe and Chernia (Locombe, Chernia, 1960).

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One can form an idea on the distribution and transformation of the intermediate waters of increased salinity from the chart of maximal salinity distribution (Figure 6). The regions of high salinity water formations are well-defined



on it (bounded conditionally by the 39.1‰ and hatched); the movement of these waters is shown by arrows. The depth of the surface of maximum salinity increases from east to west from 150-250 m in the western part. The maximum salinity can be clearly observed along the entire Mediterranean Sea, to the Strait of Gibraltar, where the waters retain a salinity of 38.5‰ and somewhat higher. The chart for the distribution of maximum salinity compiled by us generally matches the maximum salinity charts compiled by Wuest (Wuest, 1959) and Lacombe and Chernia (Lacombe, Chernia, 1960). The correspondence of the maximum salinity charts for the summer season, compiled according to the data of completely different observations, testifies to a certain stability of the characteristics of the "intermediate" waters of increased salinity in the Mediterranean Sea. The changes in the characteristics of these waters are so small, that on general charts for the entire sea they are hardly perceptible.

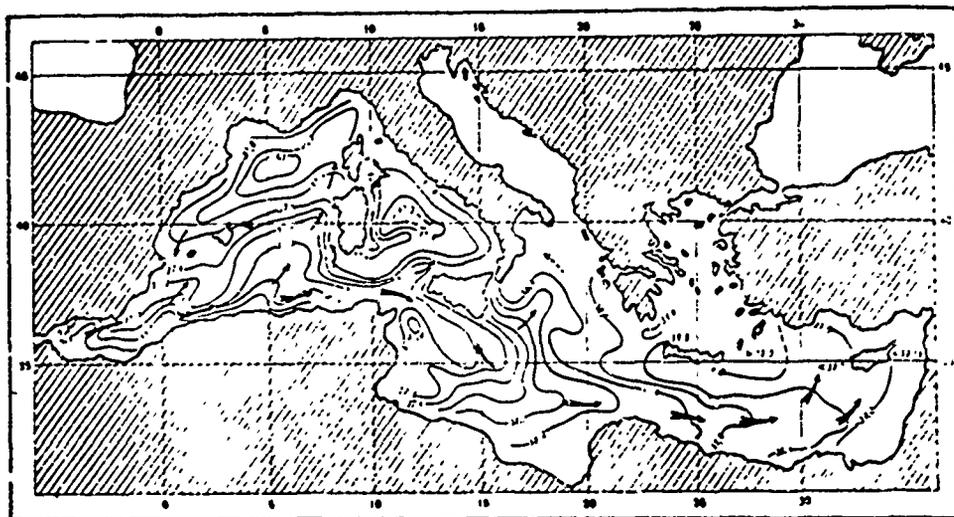


Figure 5. Dynamic chart 500/1000 db for the winter season.

All the main peculiarities of the hydrological structure of the waters, observed in sections and charts of the minimal and maximal salinity distribution, are confirmed by the TS curves compiled for different regions of the Mediterranean Sea.

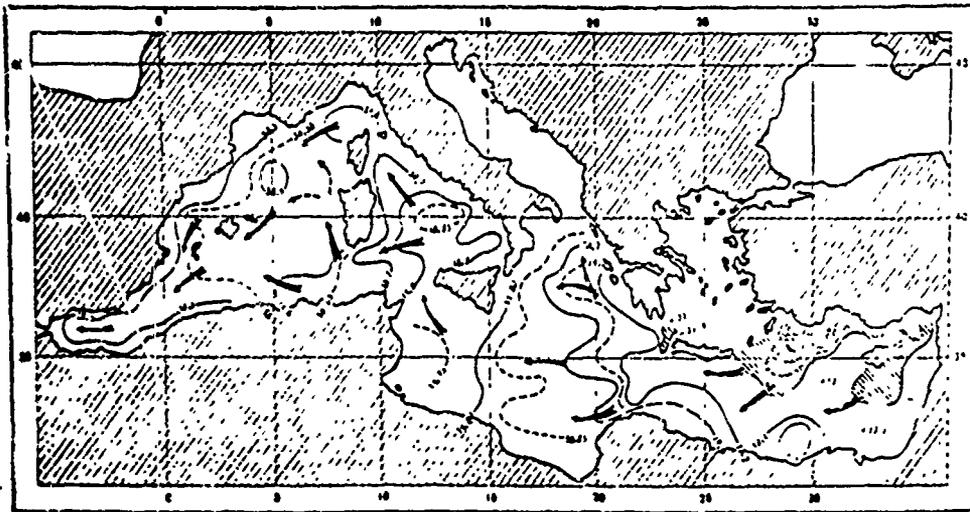


Figure 6. A chart of the maximum salinity distribution.

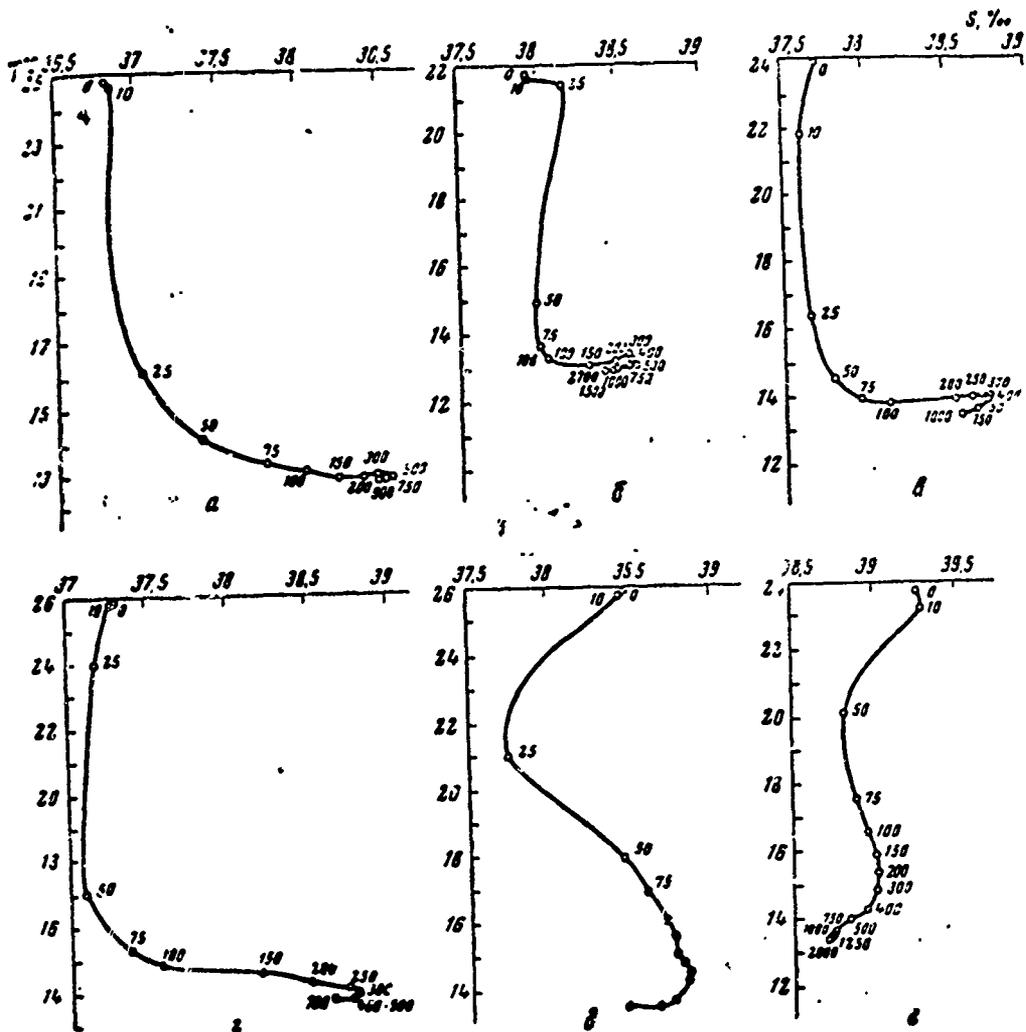


Figure 7. Characteristic TS curves for individual regions of the Mediterranean Sea during the summer season.

- a) western part of the Alboran Sea (p. 478, July 29, 1960);
- b) Algeria-Province Basin (p. 456, July 11, 1960);
- B) Tyrrherian Sea (p. 441, July 19, 1960)
- 1) Tunisian Strait (p. 337, August 12-13, 1959);
- 2) Central Basin (p. 363, August 30, 1959);
- e) the Sea of Levant (p. 388, September 19, 1959).

On the basis of the analysis of the summer season TS curves, one can distinguish the following water masses (Figure 7):

- 1) the Surface water mass ($T = 22-27^{\circ}$; $S = 36.4-39.5\%$);

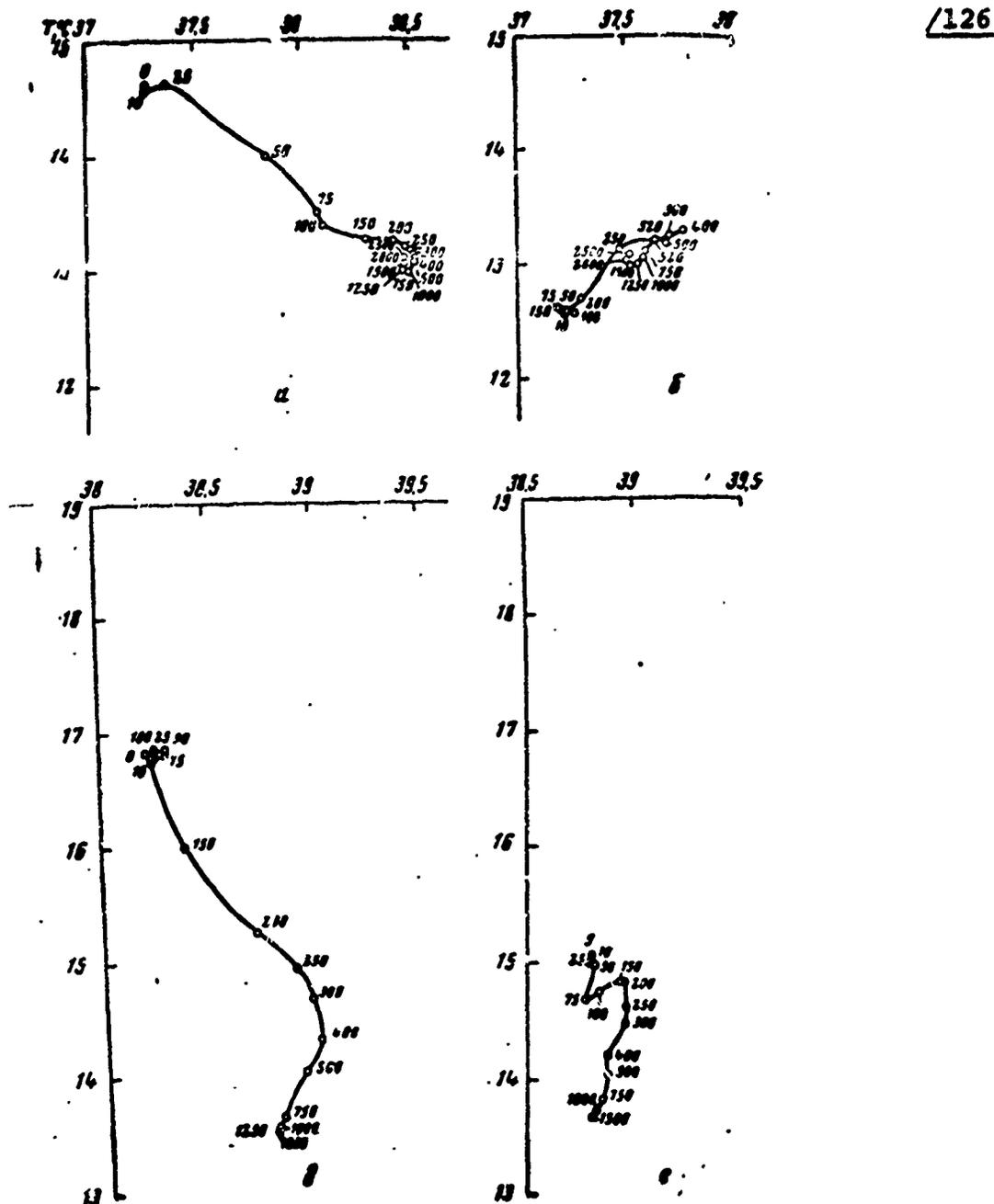


Figure 8a. Characteristic TS curves for individual regions of the Mediterranean Sea for the winter and spring periods.

- a) eastern part of the Alboran Sea (p. 781, March 27, 1962);
- b) Algeria-Provence Basin (p. 770, March 7, 1962);

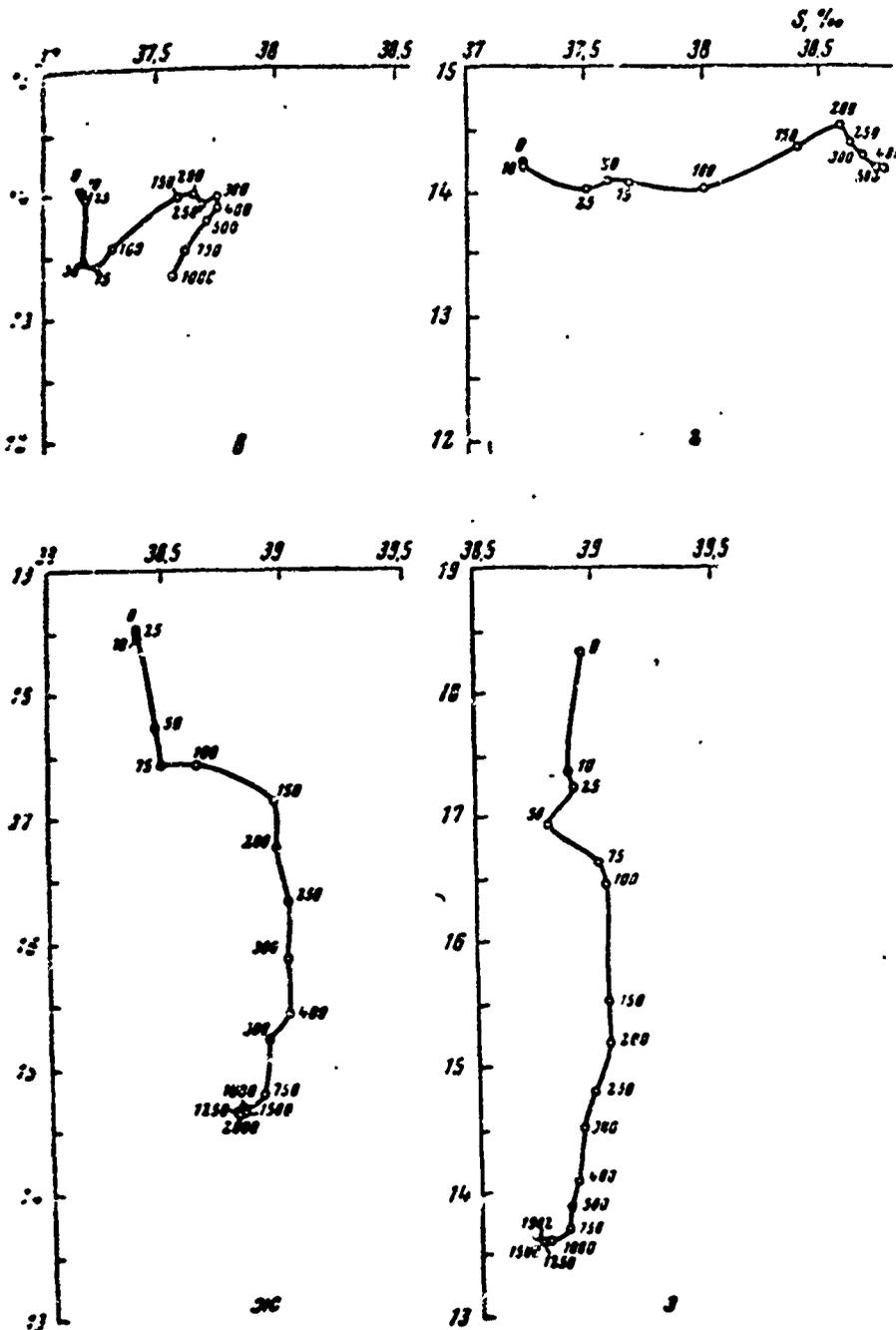
- 2) the Atlantic water mass or decreased salinity ($T = 13.1-20.0^{\circ}$; $S = 37.2-38.7\%$);

3) the Levantine water mass or intermediate increased salinity ($T = 13.4-15.5^{\circ}$; $S = 38.56-39.15\%$);

4) the deep water mass ($T = 12.9-13.6^{\circ}$; $S = 38.45-38.7\%$); (the first values are shown in the temperature and salinity of the water masses of the Alboran Sea; second are the values for the Sea of Levant).

Figure 8b

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- B) Tyrrhenian Sea (p. 798, April 15, 1962);
- Г) the region of the Tunisian Strait (p. 758, Feb. 28, 1962);
- Д) Gulf of the Greater Sirte (p. 745, February 10, 1962);
- Е) Ionian Sea (p. 603, April 12, 1962); and
- З) the Sea of Levant p. 832, May 7, 1962 and p. 834, May 10, 1962).

It is our opinion that it would be rational to distinguish and separate the surface water mass only in the eastern and central basins of the Mediterranean Sea; in the western basin this layer appears as transformed Atlantic water.

Data of our expedition are insufficient for a detailed description of the water masses of the Mediterranean Sea during the winter season. Nevertheless; for the sake of comparisons, let us take a look at several TS curves, characteristic for different regions of the sea, according to the data of the fourth Mediterranean voyage of the expedition ship Academician S. Pavlov (Figure 8).

The common characteristic of TS curves representing the hydrological structure of the Mediterranean Sea during the winter, is the decrease of the vertical temperature gradients as a result of the cooling of the surface water and the convective displacement. The region of the most intensive cooling and convective cooling during the winter time is the Algeria-Province Basin. From the typical TS curve, for the given reason (Figure 8, a), it follows that the temperature and salinity characteristics level off downwards to the depth of 75 m, and the water temperature increases in depth (from the surface to 300-400 m, i.e., almost down to the depth of the position of the nucleus of the intermediate waters of maximal salinity. The characteristics of the deep water change very little. In the shallow-water Tunisian Strait (Figure 8, b), the water temperature levels off in such a way that the TS curves lie almost horizontally, characterizing two layers of water of different salinity and similar temperatures, moving towards each other. A small increase of the temperature in depth is noted within the 100-250 m layer.

During the winter season in the Sea of Levant the decrease of the salinity gradient along the vertical plain,

especially in the region of Crete-African anticyclonic circulation, is evident.

The TS curves presented in Fig. 8B, e-z, are typical for the Tyrrhenian and Ionian seas as well as the Sea of Levant and were compiled on the basis of the data of the fourth expedition; they indicate the hydrological structure of the waters of these regions during the spring. These curves clearly show the cold intermediate layer, the formation of which is determined by the heating of the surface layer during the spring period.

For the description of the water masses we also used calculations of the vertical stability, done according to the formula of Hesselberg-Sverdrup (using the data collected during three voyages of the expedition of ship Academician S. Pavlov).

Within the surface layer during the summer, at a large number of stations, a negative stability, determined by the increase in density as a result of the increase in salinity due to evaporation can be found maximum stability is noted at the lower boundary of the wind displacement layer.

If the progress of stability is a function of temperature in the surface layer during the summer is approximately the same in all regions (differences exist only in the absolute value of the stability maximum and depths at which it is situated), then the progress of stability as the function of salinity is different:

1) in the western part of the Mediterranean Sea the stability, which depends on salinity, increases with depth, and this leads to the increase of the maximum stability layer thickness, or its second maximum; this phenomenon is connected with the increase of salinity from the layer of decreased salinity to the layer of increased salinity;

2) in the central and eastern parts of the layer of maximal stability as a function of temperature, the

stability as a function of salinity is negative, with a well-defined minimum; this is connected with the decrease of salinity from the surface to the layer of decreased salinity.

In the surface layers of the Levantine Sea additional maximums and minimums are found determined by excessive local salinity of waters of other origins. Below the stability, the maximum at first decreases rapidly and then more slowly. At a depth from 300-400 m to 750-1000 m, the predominating factor determining the stability of the water is the salinity gradient; the decrease in salinity in depth leads to well defined minimum stability. Somewhat deeper, one observes a small maximum of stability with the decrease of negative salinity gradients and with the lowering of the temperature. At depth of more than 1500 m and down to the bottom, the absolute values of the vertical stability are very small; this actually leads to a neutral equilibrium.

During the autumn-winter period, in the surface layer convection is intensively developed, on the lower boundary of which maximal stability is noted. The greatest depths of the convection distribution (150-175 m) in December-January were observed at the northern shores of the Levantine Sea.

During the analysis of the stability distribution along the vertical plane, an attempt was also made to determine the depth of the boundary position between the intermediate water masses of the increased and decreased salinity for the entire area of the basin along the second maximum of stability, determined by the increase in salinity with depth (toward the nucleus of the "Levantine" waters). This maximum is especially well developed in the regions where Levantine waters moving in the opposite direction lie underneath the slightly transformed Atlantic waters.

In the central and eastern regions of the Mediterranean Sea the discussed maximum is leveled off and can even disappear. As a result of considerably inaccuracies in the method (Ivanov. Frantskevich, 1956) and comparative small values for the maximum stability, as well as the availability of instrument readings for standard horizons, it was impossible to obtain a picture of the boundary position between the above-mentioned water masses along the entire territory of the sea.

Therefore, the specific appearance of the hydrological structure of the Mediterranean Sea is determined by the interaction of the Atlantic waters of maximal salinity and Mediterranean (Levantine) waters of increased salinity. The peculiarities of their distribution in individual regions of the sea are determined by the current system. One of the unstable traits of the water circulation in certain regions of the sea is the movement of these waters in opposite directions at different depths. The observed distribution of the hydrological characteristics is created as a result of the influence of the climatic factors and the mixing of the waters which accompanies this movement.

We have discussed the most general characteristics of the water masses, deducting them from the TS curves, vertical sections of temperature and salinity distribution, charts of the minimal and maximal salinity distribution, and by analyzing the vertical distribution of stability. For a more complete definition of the water masses of the Mediterranean Sea it would be necessary to utilize multiyear data based on the findings of individual expeditions, to investigate a more detailed complex of peculiarities of the water masses and the methods for their determination, and to study in detail the questions of formation, displacement, and transformation of the water masses.

These questions are of great interest, but have not yet been adequately investigated.

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SEASONAL FLUCTUATIONS IN THE INFLOW AND DISTRIBUTION OF
THE MEDITERRANEAN WATERS OF THE BLACK SEA

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by

A. K. Bogdanov

The question of water exchange through the Bosphorus, its fluctuation according to seasons, years, and periods, is most important for the oceanography of the Black Sea. Nevertheless, it has not yet been thoroughly clarified and is often the subject of discussions. Our ideas about the water exchange between the Black and Mediterranean Seas are based on the fundamental investigations of S. O. Makarov (1885), who was first to discover the true nature of water exchange and its quantitative characteristic. Thirty-five years later Makarov's conclusions were confirmed and somewhat expanded by Merz's investigations (Merz, 1938). Nevertheless, the investigations conducted in the Bosphorus in 1941-1943 by Ullyott and Ilgaz (Ullyot, Ilgaz, 1946) and those conducted in 1952-1953 by Pektas (Pektas, 1953, 1954), lead to conclusions which differ drastically from the principal conclusions reached by Makarov and Merz.

Ullyot and Ilgaz believe that under normal weather conditions in the Bosphorus region, when lower and upper currents can be observed in the strait, no inflow of Marmara Sea water into the Black Sea takes place at all, because the boundary of the upper current in the northern end of the strait passes exactly at the level of the sill. The lower current, under such conditions, collides during the entrance into the Black Sea with the elevation in the bottom and, rising along it, is carried by the surface current back into the Sea of Marmara.

Pektas reached the conclusion that the Mediterranean waters nevertheless enter the Black Sea, not during the entire year, but only during the months of the lowest water level in the Black Sea (from the end of August up to the beginning of February)

During the remaining part of the year the separation boundary of the currents descends to the level of the sill, and as a consequence the Bosphorus waters do not penetrate into the Black Sea.

The arguments of Ullyott, Ilgaz and Pektas, at first glance, appear to be well-founded, but they are actually erroneous, and as a result many Russian oceanographers have criticized them (Vodyanitskiy, 1948, 1958; Bruyevich, 1953; Lebev, 1953; Bogdanova, 1959, and others).

In spite of Ullyott's and Ilgaz's contentions, Mediterranean water has been repeatedly detected in the Black Sea: on 27-28 July, 1882, by S. O. Makarov (1885); on 3-6 July, 1891 by I. B. Shpindler and F. F. Vrangel (1899); 10-11 August, 1910 by Nielsen (1912); during the oceanographic expedition of the hydrographic ship of *Gidrograf*, 24-26 March 1935; in June, August, September, October, and November 1952-1953, by Pektas (1954); in May 1957, by Petran and Elian (1961); and in May 1958, by A. V. Rozhdestvenskiy (1958). It should be noted that the observations made during March, May, and July were carried out during the considerable increase of the average monthly water level of the Black Sea above that of the Mediterranean, when, according to Pektas, the Mediterranean waters do not enter the Black Sea.

First investigations in the Bosphorus region of the Black Sea were carried out in July of 1890 and 1891 by Shpindler and /132 Vrangel. In spite of the fact that the position of the stations did not coincide with the predominant direction of the movement of the Mediterranean water, it was detected at a distance of 4.7 miles NNW of Bosphorus; the temperature of the water in the bottom layer was 11.4° and salinity was 33.8‰.

The second investigation of this region took place with the participation of the Sevastopol Biological Station, at the end

of March 1935, by the hydrographic ship *Gidrograf*. Fifteen stations were established, situated to the north and northwest of the entrance into the Bosphorus. Mediterranean water was detected all over the investigated region; this water was situated in a thin layer at the bottom, to the north and northwest of Bosphorus.

Maximal temperatures (12.10°) and salinity (33.83‰) were found at a distance of six miles from the Bosphorus. Mediterranean water with a temperature of 9.9° and a salinity of 29.56‰, was found 40 miles northeast of Bosphorus.

The Sevastopol biological station undertook to compile factual data on the inflow of the Mediterranean water into the Black Sea, and the fluctuation of its volume depending on the seasons of the year and the wind regimen. In order to accomplish this, in July 1958 the station began a thorough and systematic investigation of the Bosphorus region of the Black Sea. Up to the present time the expedition ship "*Academician A. Kovalevskiy*" has conducted eight hydrological surveys, and three 24-hr. stations have been established. The surveys were carried out during different seasons and during different wind conditions. The observations were conducted outside the confines of the Bosphorus sill vicinity, and Mediterranean water was detected in all cases. A dense network of stations made it possible to determine the boundaries in detail, observe the direction of the movement, speed of transformation, and the mixing of the Mediterranean with that of the Black Sea.

The data collected by the expedition ship "*Academician A. Kovalevskiy*" completely negates the conclusions not only of Ulyott and Ilgaz, but also of Pektas. As the data below indicates, the Mediterranean waters flow into the Black Sea during all the seasons, including the period of maximal increase of the monthly average level of the Black Sea above that of the

Mediterranean Sea, as for example in May-June, when the difference in levels reaches 55-57 cm.

Shown below are the numbers of cases when Mediterranean water was discovered in the Black Sea according to months (according to the data of all investigations):

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Number of Cases	1	1	1	-	4	1	3	4	3	6	2	1

A greater number of cases of Mediterranean water detection in the Black Sea occurs during the warm season of the year. This is natural, because the majority of the expeditions were conducted during this period.

Month	II	VI	VI VII-VIII	IX	X	XII
Temperature °C	12.98	13.10	12.10	12.98	16.24	15.34
Salinity ‰	30.34	31.74	30.86	32.40	34.42	34.19
Temperature	-	-	-	-	15.61	-
Salinity	-	-	-	-	32.56	-
Temperature	-	-	-	-	17.03	-
Salinity	-	-	-	-	34.26	-

Above is presented the characteristics of the Mediterranean /133 water found by the Sevastopol Biological Station in the bottom layer of the Bosphorus region of the Black Sea during different seasons of the year (the temperature and salinity of the Mediterranean water in the bottom layer of the Bosphorus region of the Black Sea, according to the observations of the Sevastopol Biological Station (SBS) conducted during different months).

In addition, individual investigations were conducted by the ship Vityaz during August and by the ship Lomonosov in October 1960, during which time Mediterranean water was also

observed in the Bosphorus region of the Black Sea, but it was considerably diluted by the Black Sea water (salinity 22.56 and 25.81‰, respectively). The main stream of the Mediterranean water was probably not observed, because at approximately the same time the ship Academician A. Kovalevskiy found water with a salinity of 32.56‰ northwest of the Bosphorus, in the bottom layer.

On the basis of detailed measurement, data charts for the temperature and salinity distribution in the natural layer of the Bosphorus region of the Black Sea have been compiled, which make it possible to observe the seasonal changes of the inflow of Mediterranean water into the Black Sea.

The seasonal changes in the inflow of the Mediterranean water are determined by the difference in levels of the Black and Mediterranean seas, and the wind regimen above the Bosphorus and the adjoining regions of both seas.

The comparison of the annual fluctuation progress of the water level in the Black (Yalta) and Mediterranean (Izmir, Antalya, Catania) seas shows that the greatest increase of the Black Sea level above that of the Mediterranean is observed from March to July. During these months the upper current of the Bosphorus becomes stronger and the lower current becomes weaker. From August to February the difference in the levels of the Black and the Mediterranean Seas decreases; consequently, during this period the upper current of the Bosphorus becomes weaker and the lower one becomes stronger. Taking, as a zero point the 43 cm mark of the Yalta station (average difference between the levels of the Black and the Mediterranean Seas for every month). See below the average monthly levels of the Black and the Mediterranean Seas, and the amount the Black Sea level is above the Mediterranean Sea level (according to the multiyear data; in cm):

Table 1

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Fluctuation Amplitude
Black Sea level (laite)	41	40	40	41	50	57	52	47	39	36	37	42	21
Mediterranean Sea level (average for Izmir, Antalya, & Katania stations)	2	2	5	3	3	0	-4	-5	-2	-1	-2	-3	10
Amt. Black Sea water level is above Med. Sea water level.	43	42	45	49	53	57	48	42	37	35	35	38	22

The annual average difference between the levels of the Black and the Mediterranean Seas is 42 cm. The maximal difference between the levels (57 cm) is observed during June, and the minimal difference (35 cm) during October-November. According to Markov's deductions, the cessation of the lower current is possible only when the level of the Black Sea is 83 cm higher than that of the Sea of Marmara.

The seasonal changes in the inflow of the Mediterranean water into the Black Sea, about which the researchers previously could judge only on the basis of annual progress of the continental runoff and the level of the Black Sea, at the present time can be well observed on the basis of the changes in quantity of the Mediterranean water, observed during different seasons of the year in the Bosphorus vicinity of the Black Sea. The high temperature and salinity of the Mediterranean water /134 (in comparison with the Black Sea) makes it possible to utilize the temperature and salinity data for the detection of the Mediterranean water in the Black Sea, as well as for the study of the direction of the movement, transformation, and depth of its descent. In order to achieve this, on the basis of all

the measurement data, charts of temperature and salinity distribution in the natural layer of the Black Sea were compiled, as well as TS curves, vertical sections and block diagrams in the direction of the movement of the Mediterranean waters. The obtained data present first a concrete picture of the character of the movement of the Mediterranean waters and their transformation depending on the season, wind regimen, and receding and surging water circulation in the Bosphorus vicinity of the Black Sea. In order to detect the periodicity in the inflow of the Mediterranean water into the Black Sea, we viewed the materials of our observations in relation to the seasonal change in the difference between the levels and not in relation to the time when the measurement was made.

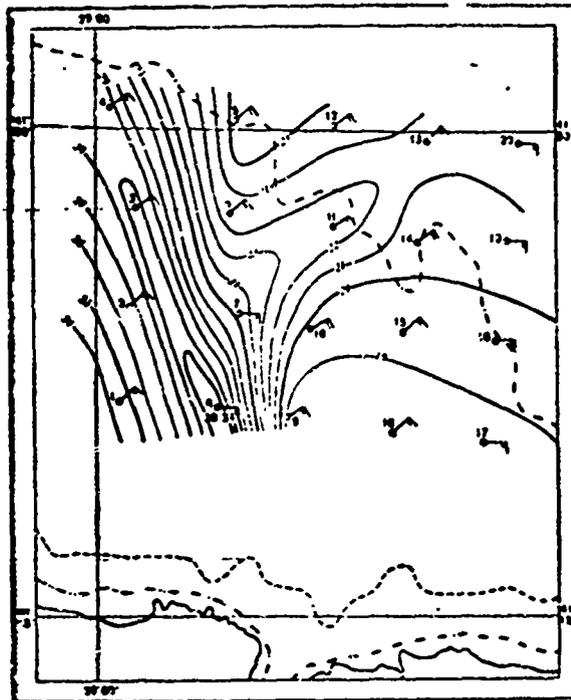


Figure 1. The distribution of the salinity in the natural layer of the Bosphorus vicinity of the Black Sea on February 21-22, 1961.

Figure 1 shows the distribution of the salinity of water in the natural layer of the Bosphorus vicinity of the Black Sea in February 1961. These measurements were conducted during the period when the difference between the levels of the Black Sea

and the Mediterranean Sea was close to the yearly average difference (42 cm), during northeast wind (3-7 m/sec.) unfavorable to the Mediterranean waters. According to Pektas' conclusion in February during the above-mentioned winds the boundary of the upper current descends down to the sill level, therefore the waters of the low current of the Bosphorus do not reach the Black Sea. Nevertheless, on the charts the stream of warm and salty waters, which characterizes the presence of the Mediterranean waters, is well pronounced. It can be clearly seen at a distance of 18 miles in the NNW direction from the entrance into the Bosphorus, i.e., on the entire investigated sector of the sea. It is possible that during the observations the local anticyclonic ring of the currents, in the southwestern corner of the Black Sea was larger, because with the usual network of stations the turn of the main stream of the Mediterranean water toward the north and northwest was not noted. A small branch of the Mediterranean water deviating toward east-northeast can be observed at a distance of 10-11 miles; nevertheless, the main stream is directed toward NNW.

The maximal temperature (12.93°) and salinity (30.34‰) have been noted in the natural layer at a distance of 8 miles from the Bosphorus, at the station closest to the shore (the observations are always conducted outside the bounds of the six mile shore water zone), 62% of the water consisted here of a layer with Mediterranean salinity 38‰ and temperature 15.5-16.00. Fifteen miles from the Bosphorus, in the same direction, the temperature of the water in the natural layer was 12.33°, salinity 29.2‰, i.e., it consisted of 56% Mediterranean water. If one assumes as the boundary of the Mediterranean water the 135 25‰ isohaline, then the width of the stream of the Mediterranean water was 3.8 miles, and the depth 2-3 m.

The distribution of salinity of the Mediterranean water in May of 1962 is shown in Figure 2. May is even less favorable

for the inflow of the Mediterranean water. A considerable increase in the river runoff leads to the increase of the level of the Black Sea and increases the difference between its level and that of the Mediterranean Sea (the multiyear monthly difference in levels is 50 cm). During the observations western and southwestern winds of 3-7 m/sec. were noted. However,

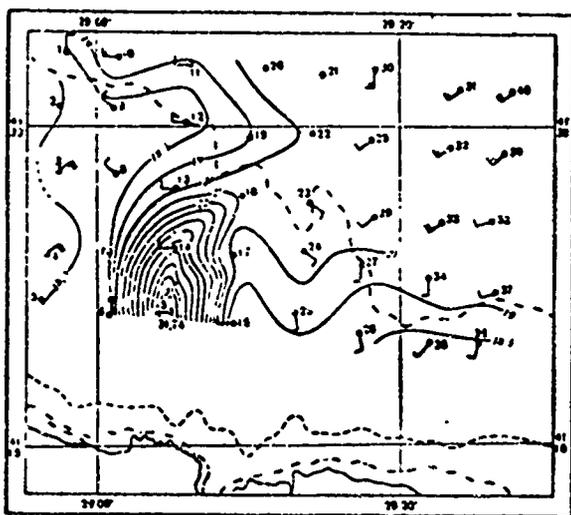


Figure 2. The distribution of salinity in the bottom layer of the Bosphorus vicinity region of the Black Sea, May 7-13, 1962.

these winds somewhat weaken the upper current of the Bosphorus and strengthen the bottom current. Nevertheless, the increase of the discharge of the lower current of the Bosphorus will be to a considerable degree due to the pull back into the Black Sea of the lower layer of the Black Sea waters.

The greatest quantity of the Mediterranean water admixture (temperature 13.10° , salinity 31.74‰), as in February, was noted in the bottom layer in the north-northwestern direction from the entrance to the Bosphorus, at the station closest to the shore. Nevertheless, at variance with the February measurements, at a distance of 8-9 miles from the Bosphorus the stream of the Mediterranean water assumed a northern and then a northeastern direction. The total quantity of the Mediterranean water in May was smaller than in February. The width of the stream of the Mediterranean water, defined by the isohaline of 25‰ at

a distance of 7.6 miles from the Bosphorus was 3.3 miles, and its depth 3-4 m. Nevertheless, if in February the water with 25‰ salinity went beyond the confines of the investigated region (20 miles from Bosphorus) than in May, it penetrated only up to 11 miles. The traces of the Mediterranean water identified by temperature and salinity can be detected up to the depth of 500 m at station 28, situated at a distance of 19.4 miles northeast of the Bosphorus.

During the May measurements a 24 hour station was established, which made it possible to observe the direction and speed of the movement of the Mediterranean water. The excessive salinity has been noted with considerable weakening of the current, down to 4-6 cm/sec., at a depth of 25-50 m. In the natural layer during a 24 hour period a stable current, as far as direction and speed are concerned (315-340°; 44-50 cm/sec.), was observed, which at a depth of 50 m was weak and unstable in direction; in the upper 10-meter layer the current followed a northeastern direction with a speed of 12-23 cm/sec. Detailed observations of the current show that during the switch from Black Sea water to Mediterranean a sharp increase in density is paralleled with an equally sharp increase in the speed of the current. For example: at a depth of 66-67 m, where the maximal density gradient has been noted ($\frac{\partial \rho}{\partial z} = 8.75$ conditional units of density per meter), the gradient of the speed of the current. $\left(\frac{\partial v}{\partial z}\right)$ reached 21.4 cm/sec. per meter.

The observations of June 9-11, 1960, were conducted during calm weather with light winds, during the period of maximal /136 increase of the average monthly level of the Black Sea, as compared to the level of the Mediterranean ($\Delta h = 57$ cm). Nevertheless, in spite of Pektas' contentions, in the Black Sea, outside the confines of the Bosphorus vicinity ledge, even during this month, the boundaries of the Mediterranean waters were detected and determined. Their largest quantity has been noted

northwest of the Bosphorus at a distance of 12-15 miles, at the stations 2, 4, 6, where a thin bottom layer consisted of up to 64-61% of Mediterranean water. The temperature of the natural water was 12.04°, 11.54° and 11.74°, salinity was 30.86‰, 30.09‰, and 30.05‰. The total volume of the Mediterranean water in June was small. The main stream of Mediterranean water probably moved in a narrow shore strip, beyond the limits of the region of our investigation. On the charts the tongue of the Mediterranean water stretches from west to east. The turn of the stream toward the north and northeast is also situated outside the bounds of the investigated region. The traces of the Mediterranean water were observed at the Stations 19, and 23, about 13.5 miles northeast of the Bosphorus.

The measurements of July 31-August 1, 1958 were carried out during a southeastern wind of 3-7 m/sec., and during the increase in the difference in levels between the Black and the Mediterranean Seas (42 cm) which was close to the yearly ratio. The main stream of the Mediterranean water was directed from the Bosphorus toward the north-northwest up to 41° 27' Latitude; further on it was split: one branch turned toward the east-northeast, the other toward the northwest. Besides this, a small stream was observed also flowing toward the northeast from the entrance of the Bosphorus; it passed somewhat to the west of the section established by Pektas on November 16, 1953. Pektas was convinced that the Mediterranean waters, when exiting from the Bosphorus, move toward the northeast; therefore, conducting investigations in this direction, did not encounter their main stream. The total quantity of the Mediterranean water in August was greater than in June and May. The width of the main stream, defined by the 25‰ isohaline, was 3.4 miles, the depth was 3-6 m, and the length in the northwestern direction was 12 miles. Maximal temperature (12.98°) and salinity (32.40‰) have been noted in the natural layer in the north-

northwestern direction 8 miles from the Bosphorus. The water here consisted of up to 70% of Mediterranean water.

As an example of the most favorable conditions for the inflow of the Mediterranean water into the Black Sea, we will discuss the measurements conducted during October 13-15, 1960. October is characterized by the lowest mark of the average monthly level of the Black Sea and the least difference between its level and the level of the Mediterranean Sea. Besides this, the given measurements were preceded by western winds (6-10 m/sec.) above the Mediterranean Sea, as well as by southwestern winds over the Black Sea. During the period of observation the winds in the western half of the Bosphorus vicinity were mainly eastern and southeastern, and in the eastern half they were from northwestern to southwestern.

The maximal salinity of 32.56‰ with a temperature of 15.61° was encountered at a depth of 81 m, the same as during previous measurements conducted in the northwestern direction from the entrance of the Bosphorus. In this direction the stream of warmer salty water was situated next to the bottom in a layer 3-8 m thick and 5.4 miles wide. It consisted of 72% Mediterranean water. The isohaline of 25‰ was assumed as the boundary of the Mediterranean water. At the latitude of 41° 32', i.e., 20 miles from the Bosphorus, the tongue of the Mediterranean water deviated toward the northeast. In the area of great depths, a distance of 26 miles from the Bosphorus in the northeastern direction, the Mediterranean water according to the temperature and salinity measurements, in the stratum of water at a depth from 75-100 to 500-550 m was observed in an area of 24 square miles. The water was unevenly distributed in the form of individual layers. The greatest interlayering was noted on the basis of temperature measurements, a smaller layering was noted as a result of salinity measurements, and an even smaller layering was noticed due to the density

measurements. The second, thinner stream, with a salinity of 25.70‰, and a temperature of 13.96°, was at first probably displaced toward the northeast. At a distance of 7.8 miles from the Bosporus this stream turned also toward the northwest; its width was 0.8 miles, thickness 3 m.

The chart of the distribution of the salinity in the natural layer (Figure 3) provides a graphical picture of the inflow of the Mediterranean water and the direction of their movement in the shallow water region of the Bosporus vicinity. The character of the isohaline in the natural layer points out the presence of a local anticyclonic ring of currents of small diameter (12-15 miles).

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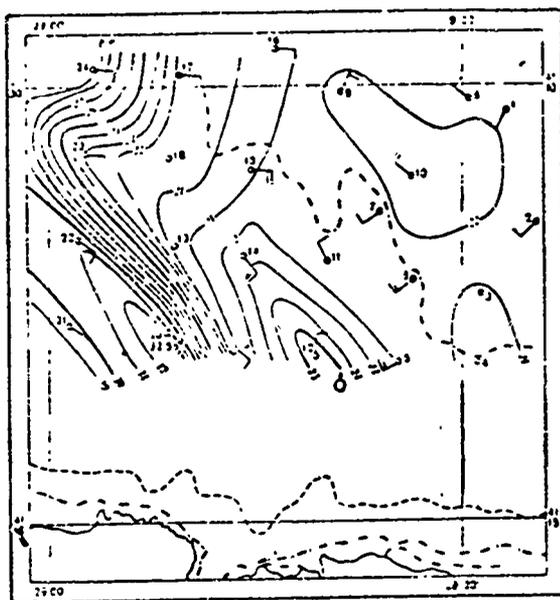


Figure 3. The distribution of the salinity in the natural layer of the Bosporus region of the Black Sea on October 13-15, 1960.

Along the bottom of the Mediterranean sea the water moves only up to the sharp depth drop; in the area of the continental slope they are pulled along by the main stream of the Black Sea waters. Until the density of the water with a considerable admixture of the Mediterranean water greatly exceeds the density of the surrounding Black Sea water, an intensive descent of the incoming water takes place. The cooling and continuous intermixing with the Black Sea water decreases its temperature and

salinity, and at a certain depth the density of the considerably diluted Mediterranean water becomes equal to that of the Black Sea water. Nevertheless, according to temperature and salinity it still remains above the surrounding Black Sea water, and therefore a gradual cooling leads to its further descent. This process of cooling and further descent continues up to the point when full equalization of temperature and salinity occurs.

TABLE 2

a) The Characteristic of the Transformation of the Mediterranean Water as its Movement and Descent Progress. (According to observations made in October 1960).

b) Станция	c) Путь, пройденный водой от Босфора, миль	d) Время с момента выхода воды из Босфора, часы	e) Глубина наблюдения сгущенной земноморской воды в Черном море, м	f) Изменение характеристик средиземноморской воды в процессе движения и заглабления			g) Плотность окружающей черноморской воды
				Т, °C	S, ‰	σ _t	
20	8	14	81	15,61	32,56	29,98	14,67
22	12,6	22	83	14,74	30,96	22,94	14,80
24	22,6	39	100	13,28	29,44	22,06	15,42
9	35,6	64	125	9,72	22,30	17,11	15,83
8	40,6	73	532	9,92	22,20	17,03	16,96
1	42	75	300	10,14	22,12	16,95	16,95

b) Station; c) distance covered by water counting from the Bosphorus in miles; d) time elapsed from the moment of entrance from the Bosphorus, in hours; e) the depth at which Mediterranean water has been observed in the Black Sea, in m; f) the change of the characteristic of the Mediterranean water during the process of movement and descent; g) density of the surrounding Black Sea water.

Table 2 presents data on the temperature, salinity, and density of the Mediterranean water as its movement and descent progress. The time from the movement of its entrance from the Bosphorus was calculated on the assumption that the water was moving with an average speed of 30 cm/sec., and the direction of the movement coincided with the distribution of the tongues of the saline warm water.

Therefore, with the accepted tolerances the Mediterranean water descends to a depth of 500-530 m three days after its entrance from the Bosphorus. During this time it changes its initial characteristics considerably, but still differs in

temperature and salinity from the surrounding Black Sea water.

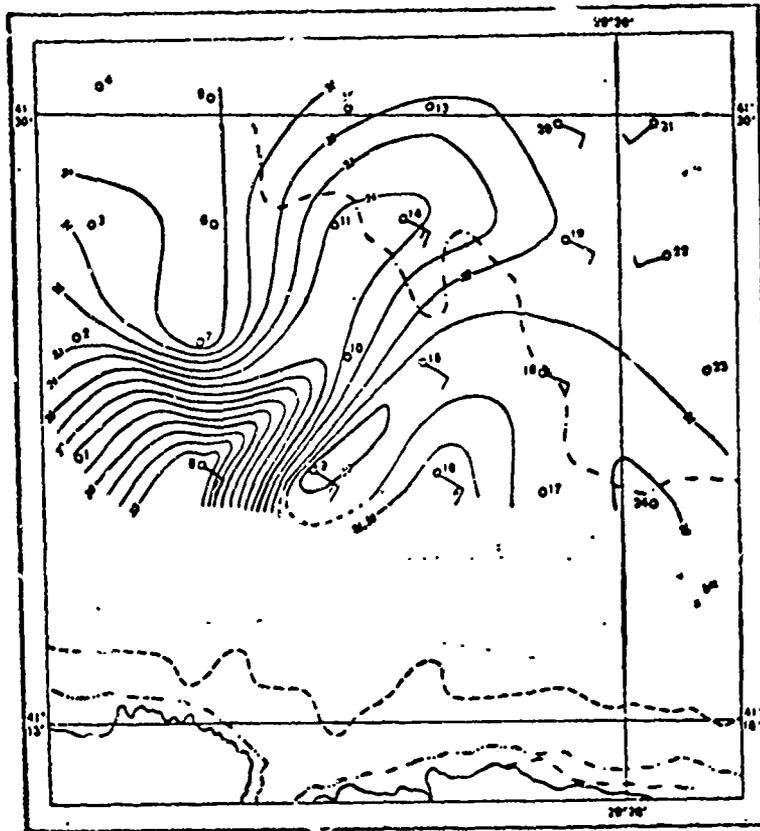


Figure 4. Distribution of salinity in the natural layer of the Bosphorus region of the Black Sea for December 5-6, 1961.

During the beginning of December 1961 the observations were conducted during a weak southwestern wind of 2-7 m/sec., and calm during the second half of the work. December is characterized by our insignificant increase of the Black Sea level above the Mediterranean level (38 cm), which is very favorable for the inflow of Mediterranean water into the Black Sea. The total amount of Mediterranean water, encountered in the Bosphorus vicinity of the Black Sea was greater in December than in May and June, but was considerably smaller than in September and October, i.e., during the period of the least difference between the levels of the Black and Mediterranean Seas.

The distribution of salinity in the natural layer is shown in Figure 4. When entering from the Bosphorus, the Mediterranean water also moved in a northwesterly direction.

Nevertheless, at a distance of 8-10 miles from the shore (pp. 1 and 8 of the original Russian text) it had already deviated to the east. In this direction the water can be observed up to the depths of 250-400 m (pp. 19 and 20 of the original Russian text); its temperature was $10.22-9.12^{\circ}$, salinity 21.73-21.83‰. In the shallow water sector of the Bosphorus region, the Mediterranean water was observed in a thin natural layer (2-5 m). At a distance of 6-9 miles toward the northwest of the Bosphorus, the water in the natural layer consisted of 75-54% of Mediterranean water; its temperature was $15.43-13.96^{\circ}$, salinity 34.19-28.74‰. North of the Bosphorus the smallest quantity of Mediterranean water was encountered; its temperature in the natural layer was 8.81° , salinity 19.33‰. East of this station the temperature and salinity increased somewhat -- up to 10.76° and 21.99‰, respectively.

The measurement presented in this work (data) for the Bosphorus region of the Black Sea, show that Mediterranean water enters the Black Sea throughout the entire year, excluding rare cases of an unfavorable combination of very strong, long lasting northern winds coinciding with the period of maximal difference in levels between the Black and Mediterranean Seas.

The charts with exact boundaries in the regions of distribution of the Mediterranean water in the Bosphorus region of the Black Sea (outside the boundaries of the Bosphorus vicinity ledge), which give thickness of the layer, show a sufficiently clear picture of the change in the actual quantity of the Mediterranean water which enters the Black Sea during different seasons of the year.

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CERTAIN DATA ON THE ORGANIC CARBON CONTENT
IN THE SURFACE LAYER OF THE AEGEAN SEA

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by

D. M. Vityuk

In presenting the data of organic carbon content in the Aegean Sea, a short description of the methodological part of such work should first be given. Having thoroughly examined the methods of measuring the organic matter content in the sea water that are recommended by different authors, we switched our attention to the possible source of error in the measurement, determined by underestimating the ability of part of the organic matter to evaporate from the water during certain analytical operations. To the operations which can lead to the evaporation of the organic matter, should first of all be designated the evaporation of the sample and drying of the solid residue.

According to the methodology recommended by V. G. Datsko (1959), L. P. Krylova (1957), B. A. Skopintsev, and S. N. Timofeyeva (1961), certain volumes of water evaporate during the process of determining the quantity of carbon in the dissolved organic matter, and the solid residue is dried under an increased temperature (50-70°).

As is well known, the dissolved organic matter of the sea water is a complicated organic complex, most probably, of change in composition. There are no reasons to assume that in this complex there are no substances with different degrees of volatility considerably higher than that of water. On the basis of complexity of content the dissolved organic matter of the sea water can to some degree probably be compared to the live matter. Even N. P. Zelinskiy (1960) has shown that the living matter contains strongly volatile proportions of organic matter; therefore, in order to forestall losses, the dehydration of the live matter during its analysis should not be carried out under any kind of increased temperature.

In order to determine the applicability of N. D. Zelinskiy's conclusion about the organic matter in sea water, we conducted parallel evaluations of the content of organic carbon under two different regimens of dehydration and drying: in a desiccator under 60°, and in an exsiccator over sulfuric acid at room temperature.

Four samples of sea water were taken for this test: two in the region of Sevastopol in August 1962, one from the water system of the aquarium of the Sevastopol Biological Station, and one from the glass aquarium, where it was kept for 48 hours with a large quantity of freshly gathered seaweed (cystozire). The results of the analysis are presented in Table 1. As can be seen, the organic carbon content changes considerably, depending on the temperature, conditions of dehydration and drying used during the analysis. When dried by heating to 60° the obtained quantity of carbon (in mg/l) in the samples of natural sea water was 2.80 and 2.64, in the water from the aquarium system 4.44 and in the water that stood 48 hours with the seaweed, 9.84.

Table 1

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Carbon content of the dissolved organic matter in sea water when using different methods of drying

Sample	Carbon content after dehydration (in mg/l)		Carbon of the strongly volatile substances (in mg/l)	Share of volatile matter in total organic complex (in %)
	At 60°	Over H ₂ SO ₄ at room temperature		
Black Sea water taken on August 1, 1962 from the surface of the water 3 miles from the entrance into Sevastopol Bay.	2.88	3.48	0.6	17.2
	2.76	3.36	0.6	17.8
	2.76			
Average	2.80	3.42	0.6	17.5

Table 1 continued

Sample	Carbon content after dehydration (in mg/l)		Carbon of the strongly volatile substances (in mg/l)	Share of volatile matter in total organic complex (in %)
	At 60°	Over H ₂ SO ₄ at room temperature		
Sea water from the aquarium system of Sevastopol Biological Str. taken August 18, 1962.	2.64	3.24	0.6	18.5
	2.64	3.36	0.72	21.4
Average	2.64	3.3	0.66	20.0
Water from Sevastopol Bay (region of biostations' buoy) taken Aug. 18, 1962	4.32	5.16	0.84	16.3
	4.56	5.16	0.6	11.5
Average	4.44	5.16	0.72	13.9
Sea water which stood 48 hours in a glass aquarium with cystozire.	9.84	12.96	3.12	24.0

The same samples, dehydrated and dried at room temperature in an exsiccator above sulfuric acid, had organic carbon contents of 3.42, 3.30, 5.16 and 12.96 mg/l respectively. Therefore, in all cases without exception, analyses with dehydration and drying at room temperatures have shown a higher content of organic carbon than the analyses with dehydration and drying at raised temperatures. The difference between the results of the analyses, conducted under different temperature conditions, fluctuates within the limits from 12 to 24% depending on the sample.

The presented data shows that during the determination of the content of the organic carbon in the sea water the temperature regimen has a great significance. The dehydration and drying at raised temperatures led to considerable losses of carbon. These losses, it seems, can be entirely attributed to the strongly volatile substances existing in the dissolved organic complex of the sea water. Taking this into consideration, we rejected the dehydration and drying under high temperature

when determining the quantity of the organic carbon in the sea water, in order to avoid the loss of part of the carbon due to evaporation of its volatile compounds. Keeping this in mind, we designed a modified version of the elementary carbon determination method recommended by B. A. Skopintsev and S. N. Timofeyeva (1961). In our variation of the method additions have been made, the most significant of which is dehydration and drying at room temperature in an exsiccator over a strong sulfuric acid, instead of dehydration of the water and drying out of the solid residue at a temperature of 50° to 60°. Even though dehydration over sulfuric acid at room temperature takes considerably more /142 time than processing in the desiccator, it significantly reduces the losses of the strongly volatile part of the dissolved organic matter.

The organic matter was incinerated in a quartz tube, into which oxygen was pumped (Skopintsev and Timofeyev conduct incineration by using laboratory air previously purified in a special apparatus). All the measurements of carbon in the dissolved organic substance of the sea water presented in our work were made according to the described method.

The material was collected from 12 deep-water and 11 surface stations in the Mediterranean and Red Seas and the Gulf of Aden during the voyage of the expedition ship Academician A. Kovalevskiy in December 1961-February 1962. At the deep-water stations the samples were taken from the standard horizons to the bottom. A total of 216 samples was collected.

Since the processing of the collected material is still not complete, the distribution of organic carbon in the surface layer of the Aegean Sea is discussed in the present compilation.

Our observations in the Aegean Sea have been conducted at 11 stations (127 and 131-140) along the lengthwise cross-section from north to south.

Table 2

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The carbon content of the dissolved organic matter (in mg/l in the surface layer of the Aegean Sea

Date	Station	N. Lat.	E. Lat.	Depth where sample was taken	Content mg/l
26.11 1962	127	37°25'9"	25°57'2"	393	5,52
	131	38°00'5"	25°46'0"	300	6,00
	132	38°21'5"	25°43'8"	512	5,16
	133	38°31'1"	25°41'5"	229	6,00
	134	38°45'3"	25°42'1"	320	4,92
	135	38°56'3"	25°42'2"	201	5,04
	136	39°07'4"	25°41'4"	130	5,88
27.11 1962	137	39°25'5"	25°41'5"	380	4,92
	138	39°34'1"	25°45'1"	128	5,04
	139	39°44'2"	25°47'1"	95	5,28
	140	39°53'3"	25°53'9"	48	5,40

The samples were taken from the surface water layer as the vessel was moving, were immediately filtrated through a membrane filter No. 5, were placed into glass vials and covered with tin foil which was firmly held against the outside of the vial by a rubber band. The vials with samples were stored in a dark box and were delivered in this condition to the laboratory of the Sevastopol Biological Station. Under this type of storage no water evaporation from the vials was detected. The carbon content determinations were conducted on land after return from the voyage. The results of the determinations are presented in Table 2, which shows that the carbon content of dissolved organic matter in the surface water layer of the Aegean Sea in February 1962, fluctuated between 5-6 mg/l. In the water of the Black Sea the organic carbon content, according to our determinations, as well as the numerous determinations of V. G. Datsko, was of the order of 3-4 mg/l, i.e., considerably smaller than the ratio we determined for the Aegean Sea. At the same time, the oxidation of the Aegean Sea water, according to M. A. Dobrzanskiy's data (1962), is approximately twice as small as the oxidation of the Black Sea water. This large

divergence in the data for the Black and Aegean Seas cannot be due to a methodical error because the determinations of organic carbon and oxidation in the Black and Aegean Seas were conducted in each case with identical methods and, significantly, by the same person. The latter excludes the possibility of subjective error. /143

If the relatively high organic carbon content of the dissolved matter obtained from the Aegean Sea was a consequence of a determination error, then this error would also naturally affect the analyses of the Black Sea water, which were carried out simultaneously with the analyses of the Aegean Sea water. In this case our data would not match V. G. Datsko's data (1959), but would be considerably higher. Nevertheless, we did not obtain excessively high readings for the organic carbon content in the Black Sea. On the contrary, our data, obtained during the analyses with drying and at room temperature (3.42 and 3.30 mg/l) coincide well with the data of V. G. Datsko (3-4 mg/l). The results obtained by heating the samples up to 60° (2.8 and 2.64 mg/l, Table 1) turned out to be even somewhat lower than V. G. Datsko's data.

In conjunction with the comparatively high results of the dissolved organic carbon content determination, obtained for the surface layer of the Aegean Sea, it should be noted that the method applied in this case to determine the organic carbon content of the dissolved organic substance has provided a more complete determination of the dissolved organic complex, because it precluded the loss of its volatile fraction. The latter, as mentioned above, is not retained when the method applied involves the use of water evaporation and drying of the solid residue at higher temperatures. In these cases, the proportion of organic carbon connected with volatile fractions in the Black Sea water amounted to 17-20%.

If one starts with the assumption that the proportion of highly volatile fractions of dissolved organic matter in the

Aegean Sea water is the same as in the Black Sea, then determination of the organic carbon in the Aegean Sea by the method recommended by B. A. Skopintsev would yield a carbon content approximately 20% lower, i.e., it would be approximately 4-5 mg/l. At the same time the probability is not excluded that the correlation between the volatile and non-volatile fraction of dissolved organic matter in the water of the Aegean Sea is not the same as in the waters of the Black Sea. Correspondingly, the carbon content determined by methods which take into consideration only the nonvolatile fraction of organic matter will be different.

Furthermore, as M. A. Dobrzhanskaya's data indicates, the oxidizability of the Aegean Sea water is approximately that of the Black Sea water, and it does not necessarily follow that the carbon content of dissolved organic matter is lower in the Aegean Sea than in the Black Sea. As is well known, the method of permanganate oxidation in a neutral medium involves the most easily oxidized part of the organic matter. In the Aegean Sea, especially in its surface layer, organic substances which are hard to oxidize by permanganate may be present. This alone is sufficient to cause divergences between the carbon content of dissolved organic matter and permanganate oxidation.

It is also necessary to note that, when oxidizability is determined by the permanganate method, the main mass of highly volatile organic compounds does not have time to oxidize, but is lost during the 10-minute boiling of the sample. Our experiments have shown that such highly volatile compounds as acetone, methyl and ethyl alcohol, when dissolved in sea water, evaporate in boiling before they can react to the permanganate (Table 3).

Table 3

Permanganate oxidizability of sea water with organic additives (equivalent quantities of carbon) and without the additives.

b. Sample	Температура кипения вещества, излитых и качество добавок, °C	d. После кипения пробы в течение 10 мин.			h. Проба не кипятилась, но выдерживалась с перманганатом калия в течение 24 ч.		
		e. окисляемость (O ₂ , мг/л)	f. абсолютное увеличение окисляемости по сравнению с окисляемостью натуральной воды (O ₂ , мг/л)	г. Увеличение окисляемости, отнесенное к окисляемости натуральной воды, %	e. окисляемость, O ₂ , мг/л	f. абсолютное увеличение окисляемости по сравнению с окисляемостью натуральной воды (O ₂ , мг/л)	г. Увеличение окисляемости, отнесенное к окисляемости натуральной воды, %
Natural sea water	—	0,65	—	—	0,22	—	—
Sea water + acetone	56°	0,67	0,02	3,1	0,28	0,06	27,2
Sea water + methyl alcohol	64°7'	0,71	0,06	8,2	0,32	0,10	45,5
Sea water + ethyl alcohol	78°3'	0,72	0,07	10,8	0,35	0,17	72,2
Sea water + glycerine	290°	1,05	0,40	61,7	0,62	0,10	182,2

b) Sample; c) Boiling point of the additive substances in C°; d) After boiling of the sample for 10 minutes; e) Oxidizability (O₂, mg/l); f) Absolute increase in oxidizability as compared to oxidizability of natural water (O₂, mg/l); g) Ratio of the oxidation increase to that of natural water (in %); h) The samples were not boiled but were kept with the potassium permanganate for 24 hours.

It follows from Table 3 that, when a considerable quantity of highly volatile organic compounds is present in the water, their content has little influence on the magnitude of permanganate oxidizability. At the same time these substances can be determined by combustion in a quartz tube, if the dehydration and drying is done at room temperature. Since the stations at which the samples were taken lie in a part of the Aegean Sea which abounds in islands, the influence of the shore on the carbon content of dissolved organic matter will, most probably, be more significant here than in the ocean, and possibly even more significant than in the sectors of the Mediterranean Sea that are at some distance from the coast. The correctness of

this assumption is confirmed by data from stations 134, 135, 137 and 138, which are farthest from the coast, and at which the carbon content is lower (4.92-5.04 mg/l) than at the stations which are closer to the coast.

Moreover, our observations were carried out during stormy weather and this facilitated the aeolian washdown and roiling of the bottom sediments. Under such conditions the surface layer was presumably the first one to be enriched by organic substances.

In summing up, mention should be made of three basic factors which, acting together, could have brought about the high (5-6 mg/l) carbon content of dissolved organic matter in the surface layer of the Aegean Sea obtained by us in February of 1962:

1. The expansion of possibilities offered by the determination method, as a consequence of which the volatile part of the dissolved organic matter can be determined.
2. The geographical peculiarities of the region where the samples were taken (a dense network of islands, relatively shallow waters), which cause the shore washoff to exert considerable influence on the degree of concentration of dissolved organic matter.
3. Stormy weather, which facilitates intensified aeolic washdown and roils the bottom sediments.

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SOME DATA ON THE COBALT CONTENT
IN THE MEDITERRANEAN SEA

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by

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Cobalt is one of the vital elements. It is part of the vitamin B₁₂ compound and plays an important role in the life of plant and animal organisms. The first findings on the cobalt content in sea water, according to A. P. Vinogradov's announcement (1944), were made by Forchammer in 1865.

The cobalt content in sea water is extremely insignificant and, according to the data of different authors, fluctuates in different seas from 0.038 to 4.8 micrograms per liter (Table 1).

Table 1

Cobalt content in sea water (according to the data
of different investigators)

Location where sample was taken	Content (micro g/l)	Author
Black Sea (in different regions)	2.5-4.8	D. P. Malynga, 1946
In the same area	1.6-4.0	Our data, 1963
Azov Sea (in different regions)	2.4-4.5	Our data, 1963
Barents Sea at entrance to Yarnyshnaya Bay	1.5	D. P. Malynga, 1946
Aral Sea, from 5 km area	0.54	D. P. Malynga, 1946
Pacific Ocean (at shores of Shirahama Wakayama)	0.38-0.67	Ishibashi, 1953
English Channel	<0.30	Black, Mitchell, 1952
San-Juan Archipelago & Puget Sound (NE part of Pacific Ocean)	0.28	Thompson, Laevastu, 1960
Skagerrak (Gullmar-Fjord)	0.10	J. Noddack, W. Noddack, 1939
Pacific Ocean (40 miles W of San Francisco, from the surface)	0.038	Weiss, Reed, 1960.

The highest cobalt content, as one can deduce from the meager bibliographical data, is found in the waters of the Black and Azov seas; the lowest - in the waters of the Pacific

Ocean.

Different methods were used to determine the cobalt content of sea water, and this to a certain extent explains the great disparities in the content data cited by different authors. Nevertheless there is also no doubt that these disparities are connected with actual differences in the cobalt content of different regions of the World's Ocean and at different seasons of the year.

In order to determine the cobalt content in the Mediterranean Sea, water samples were taken from the expedition ship "Academician A. Kovalevskiy" of the Sevastopol Biological Station in December 1961, and in February 1962 at three deep-water stations in the eastern half of the sea: in its central and northeastern part. The samples were taken from the horizons of 0.50, 100, 200, 500, 1000, 1500, and 2000 m and were immediately preserved by 6N hydrochloric acid of the ratio of 20 ml of 6N HCl per 1 liter of sea water.

In order to determine cobalt content in sea water, we designed a modification of V. F. Oreshko's and A. A. Memodruk's method (1959) for the determination of cobalt in runoff waters and of V. V. Kovalskiy's and V. V. Stasyuchenko's¹ method for the determination of cobalt content in soils, plants, and live animal organisms (Kozhdanskaya, 1964). This modification makes it possible to make relatively fast mass determinations of the cobalt content in sea water.

1. V. V. Kovalskiy supplied me with the data from his work, now ready for printing, for which I am grateful.

Table 2

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Cobalt content in the eastern part of the Mediterranean Sea at different depths (in micro grams per liter)

Depth in m	Central part	Northeastern region	Northeastern region (Island of Rhodes)
	$\phi = 33^{\circ}47'$ $\lambda = 90^{\circ}02'0''$ Stn.25, 2700 m	$\phi = 36^{\circ}34'5''$ $\lambda = 34^{\circ}58'5''$ Stn.114, 1000 m	$\phi = 36^{\circ}05'9''$ $\lambda = 25^{\circ}18'4''$ Stn.122, 3000 m
	11.XII 1961	9.II 1962	21.II 1962
0	0,0	1,0	0,8
50	0,0	1,0	0,4
100	1,2	1,9	0,6
200	1,8	2,3	1,8
500	2,1	2,6	2,0
1000	1,9	3,0*	2,3
1500	2,4		2,5
2000	3,0		3,0

* Sample was taken at a depth of 900 m.

Unlike the other authors who determined the cobalt content in the dry residue (Malyuga, 1946; I. Noddack, W. Noddack 1939), we determined the cobalt content by the method of its direct extraction from the water. Beta-Nitrozo-alpha-naphtol was used as a complex-formator, and toluene was used as a solvent.

In order to transfer cobalt from the colloidal state into the ionic one, the water sample was boiled 15 minutes with 6N hydrochloric acid. The action of the iron, aluminum and calcium was eliminated by the addition of 20% citrate of ammonium. The sample was alkalized by concentrated ammonium up to pH 7.4 and was transferred to a separatory funnel. The cobalt was extracted from the sea water by means of energetic shaking with a solution of beta-nitrozo-alpha-naphtol in toluene. In order to form a stable neutral complex $\text{Co}(\text{C}_{10}\text{H}_6\text{NO}_2)_3$ the sample was kept until the next morning. After this, the lower water layer was poured out, and a painted toluene layer was

treated with 30% hydrochloric acid and 10% solution of caustic soda. Such treatment guaranteed the removal of complexes of all other metals except the cobalt complex from the toluene layer, as well as the removal of the excessive reagent not tied to the complex. After treatment with the acid and alkali, the toluene layer was washed with doubly distilled water and was filtered into a cuvette for colorimetrization on PhEC-M. Simultaneously with every series of experiments, a blank experiment was conducted. The cobalt content was determined according to the calibrated curve.

The results of the analysis (average out of two to three parallel determinations) are presented in Table 2. As can be deduced from this data, the cobalt content in the eastern part of the Mediterranean Sea varies from a hardly distinguishable measure (0-50 m horizon) up to 3.0 mic. g/l.

In the vertical distribution, cobalt was found to have a trend of regular increase with depth. The largest gradient is observed in the 50-200 m layer, amounting to 0.009 mic. g/l per 1 m of depth (average for three stations). In the layer from 200 to 1500 m, the cobalt concentrations increase very slowly and the gradient amounts to only 0.005 mic. g/l per 1 m of depth. Further down, one notes again a sharper increase in the cobalt concentration, but with a considerably smaller gradient than in the 50-200 m layer; for example, in the layer from 1500 to 2000 m the gradient is equal to 0.001 mic. g/l per 1 m of depth.

Therefore, the vertical distribution of cobalt in the eastern part of the Mediterranean Sea seems to form three layers:

- 1) the 50-200 m layer with the largest gradient of cobalt,
- 2) 200-1500 m layer, where the cobalt content, even though it continues to grow, has a small gradient, and
- 3) 1500 m and deeper where a considerable increase of cobalt concentration with depth is again found.

At station 114 (depth 1000 m), situated between the Island of Cyprus and the coast, a higher concentration of cobalt has

been observed than at stations 25 and 122, and this seems to be connected with the relatively strong influence of the Continent. The general character of cobalt distribution at this station is the same as the other two, i.e., the cobalt content even though it is insignificant, increases with depth.

One can assume that the increase in cobalt content is connected on the one hand with a sharp decrease in the amount of phytoplankton, and on the other, with the process, at great depths, of mineralization of the organic matter with the depositing of cobalt into the water. A similar picture can also be observed in the Black Sea (Rozhanskaya, 1963).

Comparative data on the vertical distribution of cobalt in the Mediterranean and the Black Seas are shown in Table 3.

A comparison of the data for the Mediterranean and the Black Seas shows that the cobalt content in the Mediterranean Sea at corresponding depths is somewhat lower than in the Black Sea.

Table 3

Vertical distribution of cobalt in the waters of the Mediterranean and Black Seas (in mic. g/l)

Depth m	Average for the 3 sta- tions of Med. Sea	Central part of W. half of Black Sea	Depth, m	Average for the 3 sta- tions of Med. Sea	Central part of W. half of Black Sea
0	0,6	1,6	300	—	3,4
25	—	1,8	500	2,2	3,4
50	0,5	2,1	1000	2,4	3,4
75	—	2,0	1500	2,5	3,7
100	1,2	1,8	2000	3,0	4,0
200	2,0	3,2			

One of the reasons for the lower cobalt content in the Mediterranean Sea, might be the relatively smaller inflow of continental waters into this sea as compared to the Black Sea,

as well as the continuous intensive inflow into the Mediterranean Sea of Atlantic Ocean waters, the cobalt content of which, just as in the Pacific Ocean, is insignificant. The character of the vertical cobalt distribution in the Mediterranean Sea is analogous to the character of its distribution in the Black Sea (the same regular increase of the cobalt content with depth).

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DISTRIBUTION OF PHYTOPLANKTON IN THE TYRRHENIAN SEA

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by

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At the present time there are only fragmentary data on the qualitative distribution of the phytoplankton in the open waters of the Mediterranean Sea.

Many of Margalef's articles are devoted mainly to the determination of the chlorophyll in the phytoplankton of the Spanish coast.

Koringa and Postma (1957) also conducted investigations in the Neapolitan Strait for determination of the chlorophyll content.

Bernard's works are closest in character to our own. His investigations are directed toward the study of the quantitative development and distribution of phytoplankton, but in most cases they are limited to the coastal regions of the western part of the Mediterranean Sea, mainly off the Algerian coast and Monaco. Only in one of his last works, based on material from the "Calypso" expedition of summer 1955, did Bernard (1961) present data covering a significant area of water (aquatory) of the western and eastern basins of the Mediterranean Sea. To our regret, almost all of Bernard's data is limited to quantitative data of the phytoplankton. As for as biomass is concerned, it is seldom given, even for coastal regions, and we find no data for the open sea in the literature.

The study of the quantitative distribution of phytoplankton in the Mediterranean Sea is of interest for the solution of the most important questions of biological productivity of the water reservoirs of this basin, and, primarily, for the Black Sea.

The phytoplankton from different regions of the Mediterranean Sea, from the quantitative point of view, has been studied

unevenly: in greater detail in the western part, very poorly in the eastern part. Compared to other regions of the basin, the phytoplankton of the Tyrrhenian Sea was also studied superficially.

This report made use of bathometric measurements conducted in 1959-1960 from the ships "Academician S. Vavilov" and "Academician A. Kovalevskiy" of the Sevastopol Biological Station and Oceanologic Institute of the Academy of Science, USSR. During the summer of 1959, the material was collected at eight stations in the eastern part of the Tyrrhenian Sea; during the winter of 1960, the material was collected at three stations in the northern part of the Tyrrhenian Sea. The collection of samples by the ship "Academician S. Vavilov" was carried out within the limits of the euphotic zone, to a depth of 200 m. Stations established by the ship "Academician A. Kovalevskiy" were deep-water ones; material was collected down to 1000-2000 m. We processed a total of 118 bathometric samples from the Tyrrhenian Sea. Of these, 20 samples (at four stations) were from 300-2000 m depths. At depths of 1000, 1500, and 2000 m only seven samples were collected.

The range of species of phytoplankton in the Tyrrhenian Sea was distinguished by great diversity. In the investigated region we discovered 326 species of algae. The most numerous were the dinoflagellates (182 species, 56%). This group was /151 the predominant one for plankton during both periods of observation. During the summer they comprised approximately 55%, and during the winter, 40%, of the total number of plankton algae species.

The deep-water phytoplankton from a depth of 1000-2000 m was distinguished by uniform-system content. Eight species were distinguished; determination of some of these has to be verified. These are mainly representatives of colorless

flagellates of the *Glenodinium* species and small flagellates of other groups. The diatoms recorded here were the *Nitzschia delicatissima* *Thalassionema nitzschioides*, *Thalassiothrix frauenfeldii*, and the coccolithophorides recorded here were the *Pontosphaera*. The quantity of phytoplankton at these depths was characteristically low, up to 1000 kl/1, which is approximately 10-20 times lower than in the upper 200 m layer.

Considerable variety was found in the coccolithophorides in the Tyrrhenian Sea. We recorded 67 species of this group¹, amounting to approximately 21% of the total number of species (Table 1).

Table 1.
Phytoplankton composition in the
Tyrrhenian Sea

Systematic group	Number of species	
	Absolute	%
Dinoflagellatae	182	55.8
Coccolithophoridae	67	20.6
Diatomeae	61	18.7
Silicoflagellatae	5	1.5
Others	11	3.4
TOTAL	326	100.0

During the period of investigation, 24 species of coccolithophorides were found in the Black Sea, and this is more than 7% of the total number of the plankton algae. Other systematic groups occupy a subordinate position.

Among the Tyrrhenian Sea plankton, nano and ultrananoplankton forms are found to be predominant; comparatively large plant organisms are encountered more rarely than in the Black Sea. Many species of algae, common to the Black Sea, have been recorded here, but as a rule they are smaller in size.

1 The determination of the coccolithophorides was conducted according to morphological peculiarities of the cell and coccolites under a MBI-3 microscope, with magnification of 600 and 1350 times; the collection and processing of the samples was conducted according to generally accepted procedure by the sedimentation method, with fixation by 40% Formalin.

In the Tyrrhenian Sea there are no phytoplankton species predominating either in summer or in the winter, and this is the distinguishing feature of this sea. In the Black Sea, as is well known, each biological season is characterized by masses of some particular species, whose quantitative development during individual periods determines the total quantity of the phytoplankton. In the Tyrrhenian Sea the phytoplankton population consists of many species of plankton algae, but with no high-numbering species.

It is well known that the distribution of phytoplankton is closely connected with the conditions of the surrounding medium and is influenced to a considerable degree by hydrological and hydrochemical factors: currents, salinity, temperature, etc.

The Tyrrhenian Sea, which occupies a more isolated position than other seas of the Mediterranean Basin, is of special interest from this standpoint. This sea, on the one hand, is subjected to the constant influence of the less saline Atlantic waters, relatively rich in nutrient substances; and on the other hand, a considerable quantity of saltier waters which are poor in nutrient salts flow into it from the eastern basin of the Mediterranean Sea.

Furthermore, Buljan (1954) attributes great importance to the influence of the geochemical factor, which in the Tyrrhenian manifests itself in the form of underwater volcanic phenomena. As a consequence of this, the bottom water is enriched by a large quantity of different byproducts of volcanic origin, some of which can be used by the plant plankton as a food source.

The higher phosphate content in the depths of the Tyrrhenian Sea was first discovered by Thomsen (1931), but he does not explain this phenomenon. On the basis of Thomsen's data, as well as on the basis of his own observations, Buljan

comes to the conclusion that the relatively high phosphate and nitrate content in the depths of the Tyrrhenian Sea is connected with volcanic activity. All these factors cannot fail to have an effect on the phytoplankton of the Tyrrhenian Sea. According to our data during the summer period the phytoplankton comprised, on the average, approximately 8 million kl/m³ or 15 mg/m³*. During the winter period the quantitative indexes were lower: quantity was approximately 6 million kl/m³. The data on quantitative distribution of the phytoplankton are given in Table 2.

Table 2

Quantity and biomass of phytoplankton in the Tyrrhenian Sea in the 0-200 m layer in July-August 1959.

Systematic group	Stn. 314		Stn. 319		Stn. 324		Stn. 325	
	1	2	1	2	1	2	1	2
Dinoflagellatae . . .	1363	7,7	1708	2,0	1545	3,4	1490	11,7
Sml. flagellates	2422	0,5	3878	0,8	1998	0,5	2924	0,5
Diatomeae	5450	7,8	771	3,7	1438	1,3	1571	4,3
Coccolithophoridae . .	681	0,4	1773	0,9	1017	0,9	1518	1,0
Silicoflagellatae . .	—	—	—	—	—	—	36	<0,1
Others	22	0,1	47	<0,1	70	<0,1	361	0,1
Total	9938	16,5	8177	7,4	6068	6,1	7899	17,6

Table 2 (continued)

Systematic group	Stn. 323		Stn. 331		Stn. 333		Stn. 326/29	
	1	2	1	2	1	2	1	2
Dinoflagellatae . . .	1371	35,4	2211	3,3	1735	5,5	1491	10,1
Sml. flagellates	2794	0,6	3170	0,6	2461	0,5	1984	0,4
Diatomeae	1630	1,7	1284	1,8	682	2,3	993	1,7
Coccolithophoridae . .	1777	1,6	2204	2,2	2479	1,3	894	1,0
Silicoflagellatae . . .	70	<0,1	40	<0,1	35	<0,1	20	<0,1
Others	—	—	307	0,1	80	<0,1	24	<0,1
Total	7701	39,3	9216	8,0	7471	9,6	5395	13,2

Note: For Tables 2, 3, and 4, 1 is quantity in thousands of kl/m³; and 2 is biomass in mg/m³.

* The biomass of the phytoplankton is determined by the size of the cells. Every species was identified with the closest matching geometrical figure and the volume was calculated on the basis of their dimensions. The specific weight of phytoplankton organisms was used as a unit.

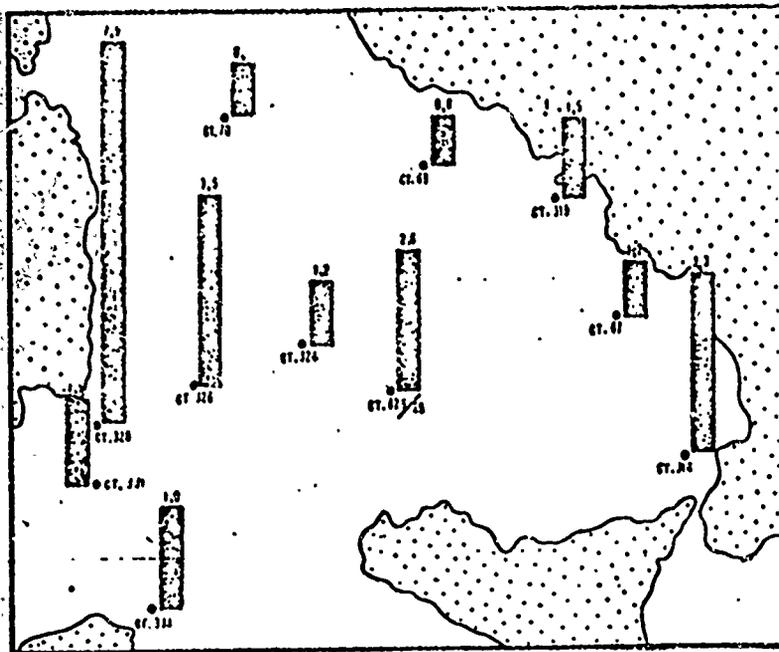


Figure 1. Phytoplankton biomass in the Tyrrhenian Sea in grams per 1 m² of sea surface in the 0-200 meter layer.

This Table shows that, in the summer of 1959, the richest phytoplankton was noted by us at three stations: 314, 326, and 328. At station 314, situated in direct proximity to the Strait of Messina, phytoplankton amounted to 10 million kl/m³, and biomass was 16.5 mg/m³ in the 0-200 m layer. It seems that the higher phytoplankton content was determined here by the intensive current which in the Strait of Messina reached a speed of 5 knots. This current causes intensive intermixing of the water masses in the vertical plane and enriches the photosynthesis zone with nutrient substances. Another index of deep intensive water displacement may be found in the fact that the personnel of the Messina Institute of Thalassography have repeatedly recorded encounters with deep-water fauna in the upper layers of water stratum and also on the shores.

Two other stations were situated in the region of the Island of Sardinia: station 326, situated 50 miles from shore, and station 328, situated 15 miles from the shore. The quantity

of phytoplankton at these stations was approximately of the same order, up to 8 million kl/m³. The biomass at the station farthest from shore was approximately 18 mg/m³, while at the coastal one it was 39 mg/m³. Most probably, the increase in the quantity of phytoplankton in this region can be explained by the influence of the coast on the one hand, and of the Atlantic current on the other. The inflow of the Atlantic waters into the Tyrrhenian Sea can be clearly observed in the upper 75-100 m layer of the water stratum, as witnessed by the decreased salinity of the water (37.5-37.8‰)*. Its minimal quantity was observed at a depth of 25 m.

The Atlantic current was observed during the summer of 1959 in the Tyrrhenian Sea along the entire length of the investigated region. Lacombe and Chernia (1960) point out that the current is observed during the summer period over almost the entire length of the Mediterranean Sea and extends up to the Sea of Crete.

We found the phytoplankton to be poorest (6 million kl/m³, 6 mg/m³) at station 324, situated in the center of the Tyrrhenian Sea (Fig. 1). This sector of the sea, according to the data of I. M. Ovchinnikov (see his collected works), is subject to /154 the effects of cyclonic circulation. Under the influence of this surface current, the surface waters, relatively rich in phytoplankton, were at the periphery of the circulation, while the bottom waters, poorer in plankton, rose to the surface in its center. The salinity of the water in the upper layers was higher here - 38.0-38.7‰.

During the winter of 1960, the quantitative indexes of development of the plankton in the Tyrrhenian Sea, as already pointed out, were lower than during the summer, amounting to

* All data on salinity are taken from reports of the Black Sea Research Institute (CHENIS).

5-7 million kl/m³, 4-5 mg/m³ on the average in the upper 200 m layer (Table 3).

In the Tyrrhenian Sea the phytoplankton is distributed mainly in the euphotic zone. The thickness of this layer changed depending on the season. This, most probably, is connected with the varying intensity of illumination and the degree of depth penetration of the light.

Table 3

Quantity and Biomass of Phytoplankton in the Tyrrhenian Sea in the 0-200 m layer in December

Systematic GROUP	Stn. 70		Stn. 80		Stn. 87	
	1	2	1	2	1	2
Dinoflagellatae	296	0,9	259	1,8	845	2,3
Sml. flagellates	2429	0,4	1842	0,3	2637	0,5
Diatomeae	622	1,1	764	1,3	540	0,5
Coccolithophoridae	3621	1,5	1720	0,7	1864	1,6
Silicoflagellatae	268	<0,1	6	<0,1	59	0,2
Others	8	<0,1	61	<0,1	27	<0,1
Total	6944	3,9	4652	4,1	5932	5,1

During the summer of 1959, the richest phytoplankton was observed within the confines of the 150 m layer. In the Black Sea the thickness of this layer is usually less than 50-75 m. In the Tyrrhenian Sea, during the summer, two layers were marked out as being richest in phytoplankton: an upper one, 0-25 m, and a lower one, 75-100 m. The upper, relatively rich layer is characterized in the main by a larger quantity of dinoflagellates, while in the 75-100 m layer, an increase was noted in the number of diatonic algae. Almost all of the groups we encountered (of the species *Chaetoceros*, *Rhizosolenia*, *Nitzschia*, *Bacteriastrum* *Thalassionema*) were confined to this layer and only a very small number of diatoms were found in the upper horizons (Figs. 2-3).

In the Black Sea, during the summer period, an accumulation of diatoms is also observed in the 50-75 m layer, which phenomenon was repeatedly observed by N. B. Morozova-Vodyanitskaya (1954) as well as by the author of the present article (Belogroskaya, 1954). The coccolithophorides and small flagellates in the Tyrrhenian Sea are more or less evenly distributed within the confines of the 200 m stratum.

The nature of phytoplankton distribution was found to be somewhat different in the winter. During this period it was chiefly concentrated in the relatively thin upper 100 m layer of the water stratum, with maximum concentration in the 0-25 m layer. During the winter the diatomea were not confined to the bottom layers. The coccolithophorides and small flagellates, just as in the summer, were more or less evenly distributed along the vertical plane up to a depth of 100 m (Figs. 4 and 5).

At a depth of 1000-2000 m the quantity of phytoplankton was insignificant. We did not encounter it in such large quantities as cited by Bernard in his works.

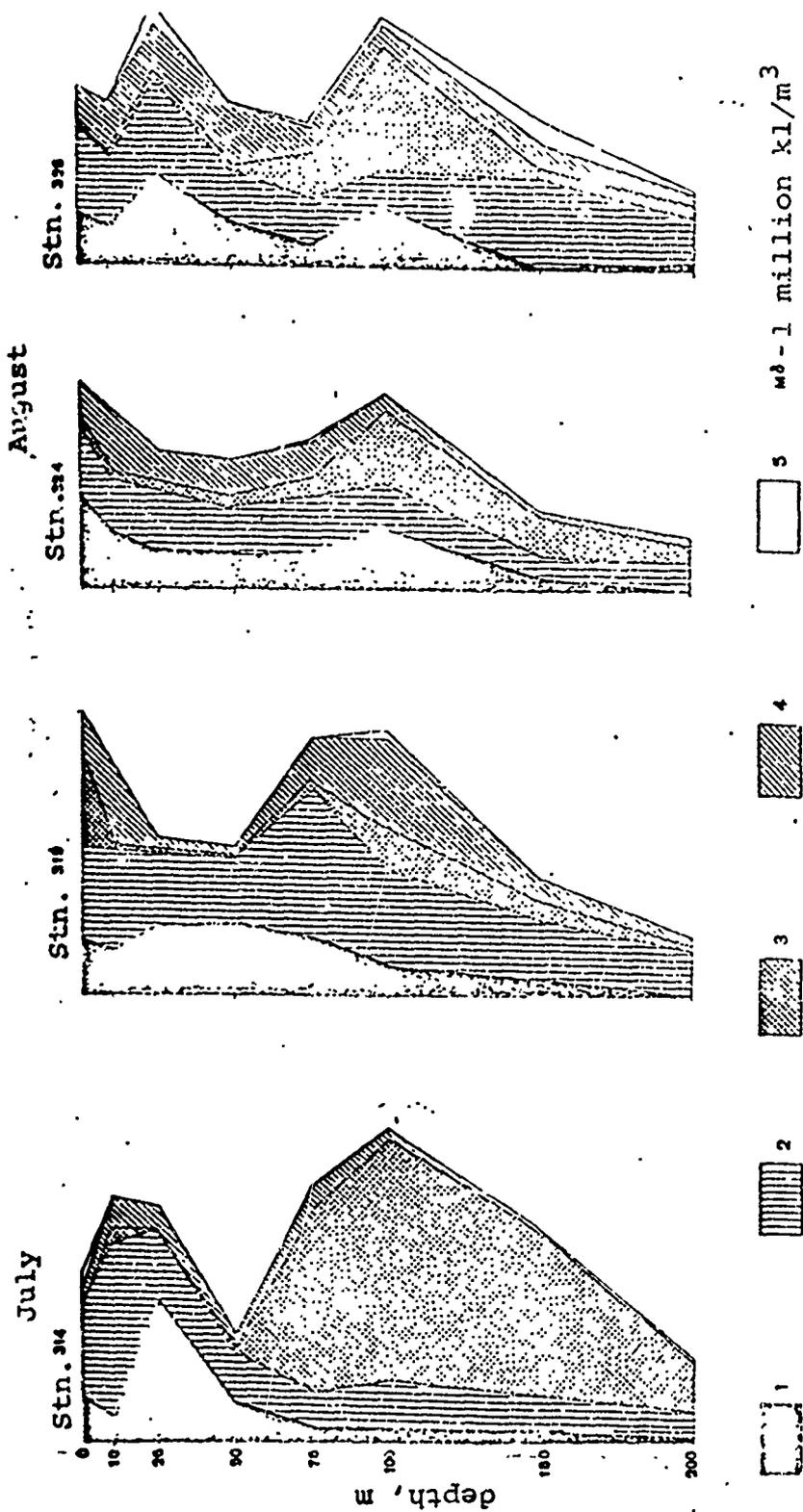


Figure 2. Vertical quantitative distribution of phytoplankton in the Tyrrhenian Sea during the summer period of 1959. b) July; c) August; d) depth; $z = M6 - 1$ million kl/m^3 ; $y = Ct.$ - station. 2 = small flagellates; 5 = others.

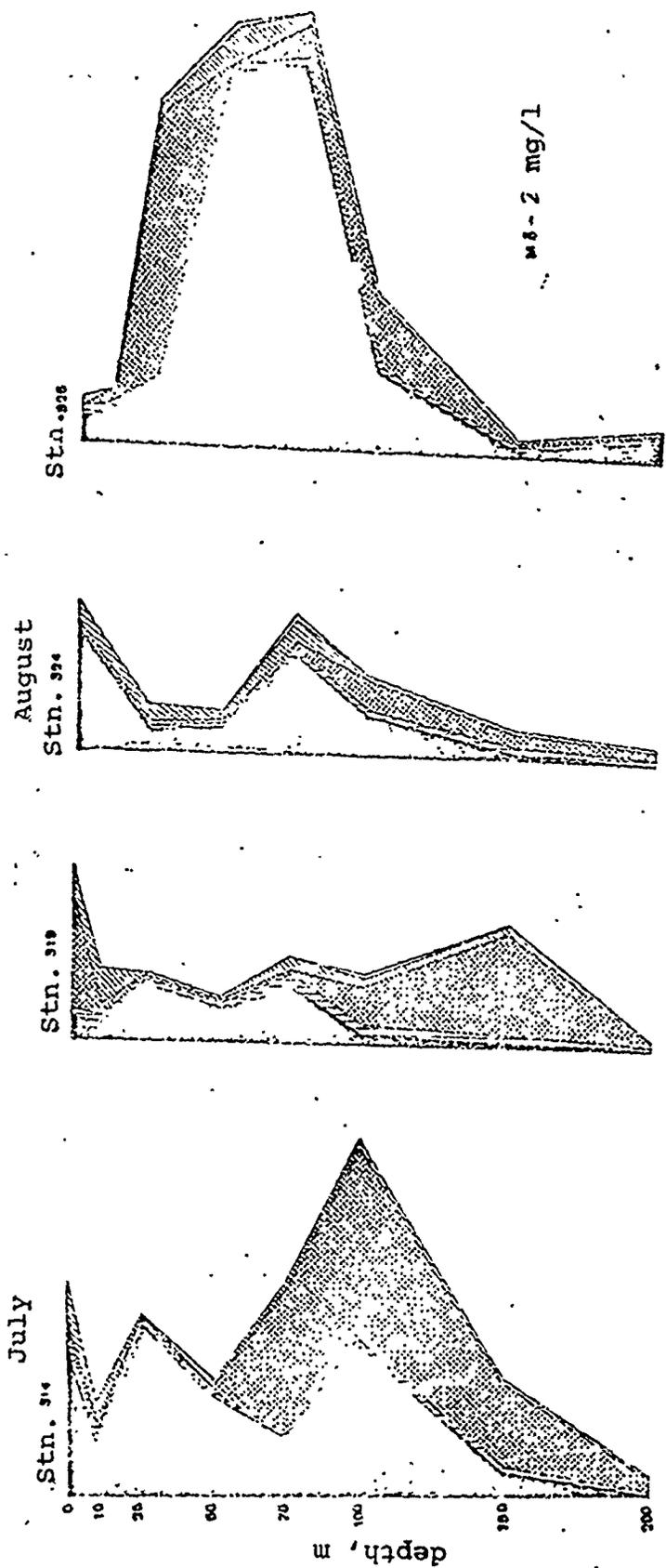


Figure 3. Vertical distribution of the phytoplankton biomass in the Tyrrhenian Sea during the summer period of 1959, (for conditional markings see Fig. 1).
b) July; c) August; d) depth;
 $y = Ct.$ - station; $z = M\delta - 2 \text{ mg/l}$.

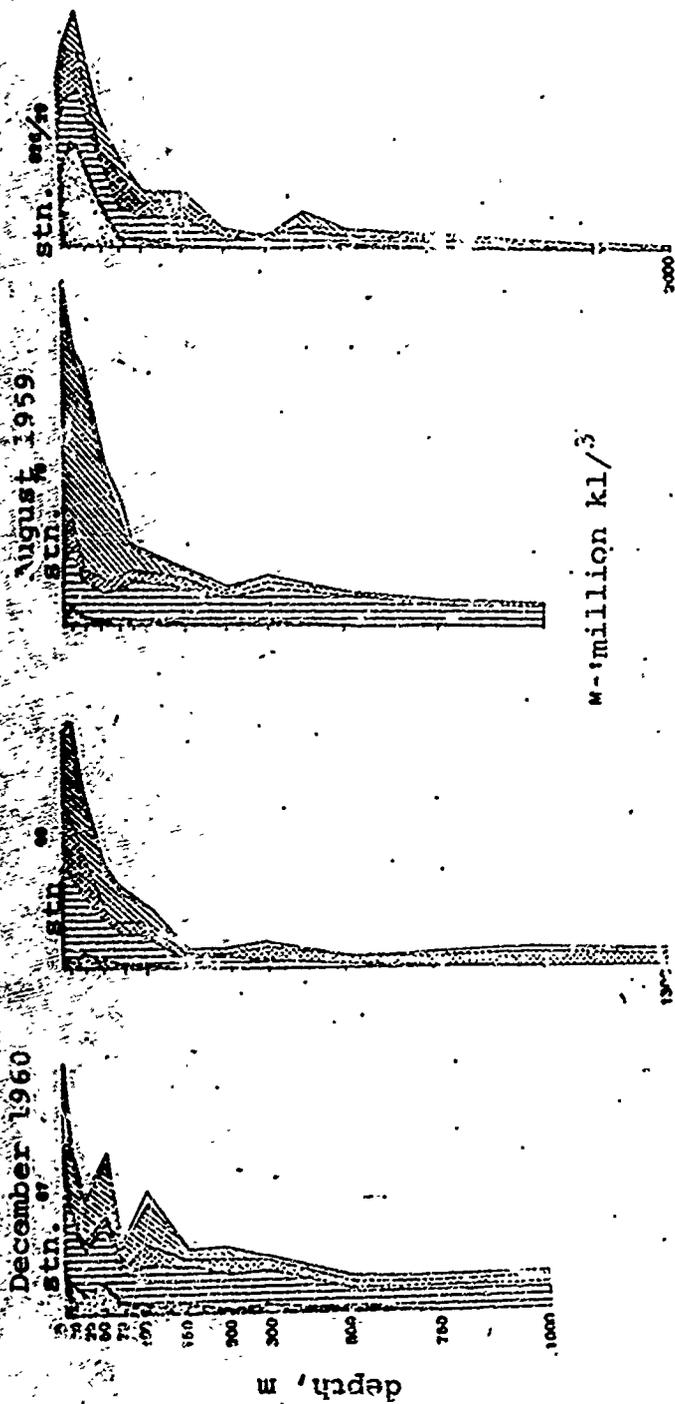


Figure 4. Vertical quantitative distribution of phytoplankton in the Tyrrhenian Sea at the deep-water stations. (For conditional markings see Fig. 2).

b) December 1960; c) August 1959; d) depth in m; 6) Ct. = station; 2) M - 1 million kl/3.

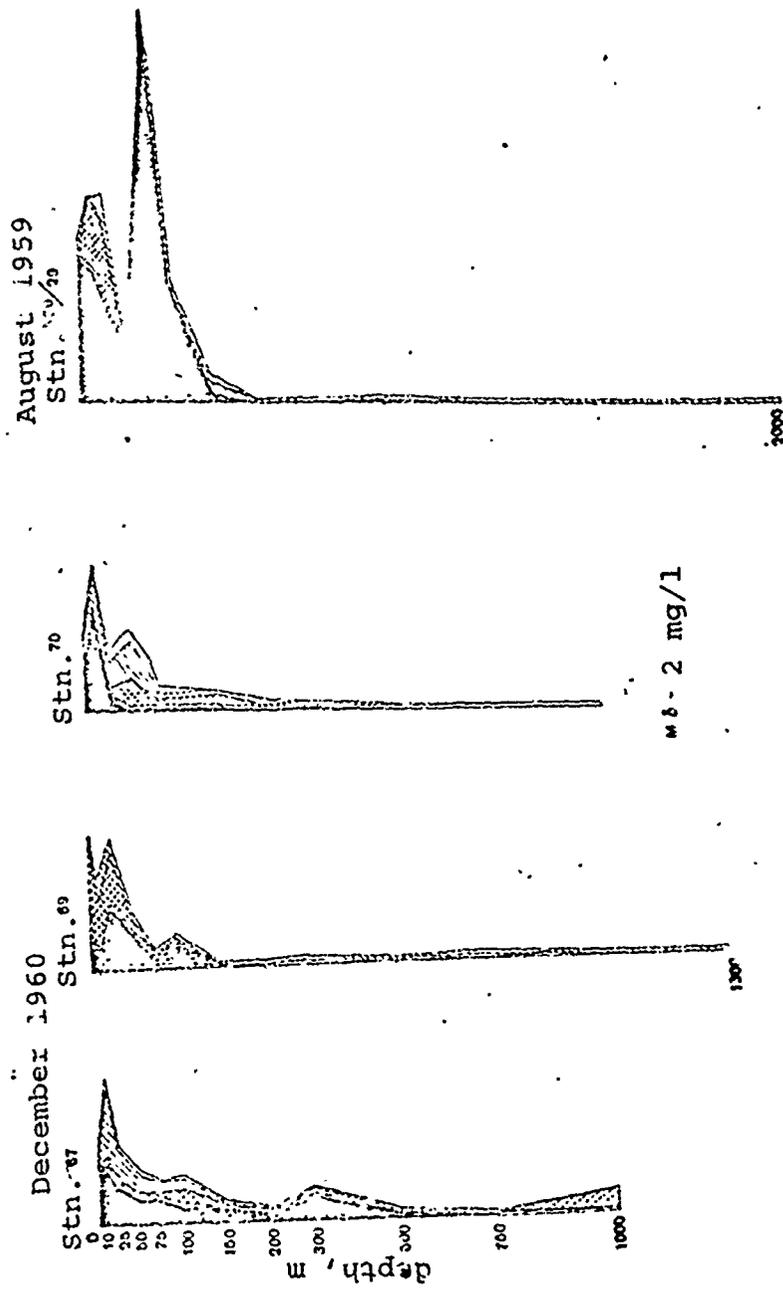


Figure 5. Vertical distribution of the phytoplankton biomass in the Tyrrhenian Sea at the deep-water stations, (for conditional markings see Fig. 2).

A comparison of our figures with data for other regions /159 shows that the average figures for quantity and biomass of phytoplankton in the Tyrrhenian Sea (9 million kl/m³ or 22 mg/m³ in the 0-100 m layer) during the summer period are very close to the corresponding figures for the Aegean Sea (according to A. A. Mikaylov's and V. V. Denisenko's data, 14 million kl/m³ or 14.6 mg/m³) and high when compared to the Ionian Sea (2.6 million kl/m³, according to Kondratyeva).

The biomass of the nanoplankton in the region of Algiers and Monaco, according to Bernard's data (1948), equals 10-15 mg/m³, i.e., figures of the same order or those for the Tyrrhenian Sea. Nevertheless, the figures for phytoplankton quantity given by Bernard for the open sea are 50-100 times higher than those we obtained.

In the Tyrrhenian Sea, quantitative indexes of the phytoplankton, as compared to those for the Black Sea for corresponding periods are 2 1/2-3 times lower in quantity and six-eight times lower in biomass (Table 4).

Table 4

Quantity and biomass of the phytoplankton for the 0-100 m layer

Sea	Year	Month	1	2	1	2
Tyrrhenian	1960	XII	6,100	7.1	-	-
The same	1959	VII-VIII	-	-	9,000	22.3
Black (open part)	1954	XI-XII	15,000	41.0	-	-
The same	1951	VIII	-	-	27,700	177.0

Thus the Tyrrhenian Sea is close in productivity to the relatively rich regions of the Mediterranean Sea, but is considerably poorer than the Black Sea.

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THE PRODUCTION OF PHYTOPLANKTON IN THE MEDITERRANEAN SEA

/160

by

T. M. Kondratyeva

A quantitative evaluation of primary production is of the greatest significance for understanding the basis of the biological and commercial productivity of water reservoirs, as well as trophic classification of the latter, which in its turn provides a base for developing a classification of the water reservoirs on the basis of the fish economy. Therefore the interest of many hydrobiologists in this questions is understandable. During recent years there have been extensive investigations of primary production in many regions of the World's ocean. Nevertheless the Mediterranean Sea has been poorly studied in this respect. It is only in the more recent years that we find some data in the literature about the size of primary production in specific regions of the sea (Margalef, Saiz, etc., 1952; Braurdel a. Rinck, 1956, Sorokin, Klyashtorin, 1961; Sushchenya, 1961), obtained by radiocarbon and chlorophyll methods.

During the voyages of the expedition ship "Academician A. Kovalevskiy" of the Sevastopol Biological Station during the summer-autumn period 1959-1960, determinations of magnitude of daily production of phytoplankton were made at twelve 24-hour stations in different seas of the Mediterranean Basin. The method we used for this was one designed by us to determine production according to the accretion of the plankton algae during a certain period of observation, the experiments being conducted directly in the open sea. To this end, glass cylinders of 500-600 cm³ valance, covered at both ends with dense gauze No. 67-76, sewn double on a diagonal, were suspended in the sea in a horizontal position at different depths and were kept at their positions 24 hours. The initial quantity of phytoplankton in the sea water and the accretion of algal cells in the vessels after a 24-hour period were calculated under microscope.

These experiments were conducted in the Tunisian Strait, the Sea of Levant, and the Tyrrhenian, Ionian, Aegean, Adriatic, and Black Seas. At the 24-hour stations, in 1959, the experimental cylinders were suspended only to depths of 9 and 5 m. Later on the investigations included deeper layers, extending to 75 m in the Black Sea and to 200 m in the Mediterranean. In order to obtain a comparative evaluation, only data for the 0-5 m layer were utilized.

In spite of the fact that the proposed method, based on a straight count, is quite labor-consuming, it makes it possible to obtain not only the size of the so-called effective production, but also its qualitative characteristics as well as to calculate the speed of reproduction of the mass species of plankton algae, provide the main parameters for mathematical analysis and determination of the size of the biomass, which enters into the next link of the trophic chain.

In order to exclude, if not entirely, at least as far as possible, the factor of corrosion, the sea water is filtered through fine gauze (No. 21) before the cylinders were filled. Therefore the phytoplankton accretion during the 24-hour period is viewed as the potential effective production, which almost /161 never exists in the sea, because there the cells are constantly reduced not only through natural desiccation (the extent of which can be determined for the majority of species by the remaining shells), but also as a result of corrosion. In the experiment, corrosion is almost excluded.

Judging by the figures of potential effective production for different seas given in Table 1, they are subject to considerable fluctuation. In the different regions of the Mediterranean Sea the potential production during the periods of observation varied from 7 to 157 mg/m³ per 24 hours. Its lowest values (7-21 mg/m³) were noted in the Ionian Sea and the Sea of Levant, and the highest values (up to 160 mg/m³)

were noted in the Adriatic Sea. In comparison to the Black Sea, where the production of phytoplankton reaches 106-1330 mg/m³, the Mediterranean Sea was distinguished by lower indexes.

It was interesting to compare our data with the data of other authors, obtained for the same regions of the Mediterranean Sea by the radiocarbon and chlorophyll methods (Table 1). For the sake of comparison, the values expressed in mg C/m³ were recalculated by us to represent biomass. And the ratio of the phytoplankton biomass to the carbon was assumed to equal 42, in accordance with the equivalents agreed on in 1957 at the symposium "On the measurement of primary production in the sea" (Cushing, Hemphrey, etc., 1958).

From a comparison of the cited figures, it follows that the quantitative characteristics of primary production, obtained by the algologic and radiocarbon methods, are quite similar for all regions of the Mediterranean Sea, whereas the figures obtained by the chlorophyll method turned out to be considerably higher. And we purposely underestimated the latter during recalculation of the 0 and 5 m horizons, because Table 1 gives average figures for the 0-50 m layer. According to the observations of Margalef and others (Margalef, Saiz, etc., 1952), the production determined on the basis of chlorophyll for the Spanish coast during the cold season was expressed by the value of 50 g C/m². If one makes a very rough calculation of the average value of the daily production for the 0-50 m layer, expressed as biomass, one obtains values of the same order as L. M. Sushcheni's data (1961).

The above comparison of quantitative production indexes does not claim to be very exact; it only makes it possible to estimate the order of the figures, because observations for different years and different seasons were compared. Up to

the present time it remains unclear just what is measured by the radiocarbon method - overall, or effective production. In the literature, as known, different points of view are expressed on this question, but most authors are inclined to think that, as a rule, this method determines the overall production. The great similarity of the results obtained by the radiocarbon method and by the algologic method, which we used, makes it possible to accept the proposition that both of these methods determine effective production.

The determinations of the daily phytoplankton production, conducted simultaneously in the central part of the Black Sea with radiocarbon and algologic methods, have shown considerable divergence in their results. According to our data, in September 1960, the primary production at all three stations was two to four times higher than according to the data obtained with the radiocarbon method (Vinberg, Muravleva, and Finenko, 1964). The figure cited by Sorokin (1962) for overall phytoplankton production, determined by the C^{14} method for the central regions of the Black Sea, turned out to be approximately two to three times higher than the figure cited in G. G. Vinberg's work, and is almost identical with our data.

As already noted, the production obtained in the experiment may be viewed as the maximum achieved by plankton when no devouring occurs. Under natural conditions, with the constant subtraction of a certain proportion of the cells as a result of devouring, a considerably smaller number of cells enter each succeeding generation than the number resulting from cell division. Therefore actual production will be considerably below the potential one. /162

The initial experimental parameters obtained in particular, the initial quantity of phytoplankton in the sea, its quantity

Table 1

Primary production in the seas of the Mediterranean Basin

Station No.	Sea and region investigated	Time of observation	Primary production (recalculated into biomass) in mg/m ³		
			Algologic method (our data), 0 to 5 m layer	C14, 0 to 5 m layer	By chlorophyll, 0 to 5 m layer
20	Tunisian Strait	July 1959	90	-	-
III	NE of Tunisian Strait	Feb. 1958	-	103*	-
29	Tyrrhenian Sea	Aug. 1959	5	-	-
	Same, Monaco region	July 1955	-	41°	-
	Same	Oct. 1960	-	58°	-
60	Ionian Sea (SE)	Sept. 1959	29	-	-
58	Same	July 1960	7	-	-
	Same	July 1960	-	-	231
67	Sea of Levant	Sept. 1959	21	-	-
I	Same	Feb. 1958	-	55*	-
Ia	Same	Feb. 1958	-	31*	-
II	Same	Same	-	25*	-
IV	Mediterranean, western half	Same	-	-	-
	Same (Algerian coast and Gibraltar)	Feb. 1958	-	1243*	-
36	Aegean Sea (middle part)	June 1960	59	-	378
69	Adriatic Sea (central part)	July 1960	157	-	271
		July 1957	516	-	-
	Black Sea	Nov. 1957	1330	-	-
	Same, central part	Sept. 1960	372	81+	-
	Same	Same	106	58+	-
	"	"	372	67+	-
	"	August 1961	-	100+	-
	"	Sept. 1961	-	100+	-
	"	July 1961	-	-	642

in the experimental cylinder and in the water after 24 hours as well as the character of daily variations in the phytoplankton population in the investigated sector of the sea - make it possible to calculate the extracted part and the net production of phytoplankton. Formulas designed by a member of the Sevastopol Biological Station, V. S. Ten (1962), were used for the calculations according to given parameters. At the same time, separate calculations were made for each species of plankton algae and the overall production of phytoplankton was determined by totalling the values obtained (See Table 2).

Table 2

Net production of phytoplankton in the seas of the Mediterranean Basin

Stn. No.	Sea and region investigated	Time of observation	Net production in mg/m ³	As % of potential production	P/B coefficient
20	Tunisian Strait	July 1959	14	13	2.0
	Same	Same	16	20	2.3
29	Tyrrhenian Sea	Aug. 1959	13	14	2.3
60	Ionian Sea	Sept. 1959	7	37	1.8
	Same	Same	3	47	0.6
58	Same	July 1960	9	13	1.5
67	Mediterranean Sea (E part)	Sept. 1959	6	27	0.7
	Same	Same	10	46	0.8
36	Aegean Sea	June 1960	18	29	1.0
69	Adriatic	July 1960	21	20	0.6
	Black Sea (Central part)	Sept. 1960	66	17	1.5
	Same	Same	31	28	0.7
	Same	Same	51	14	0.8
	Same	July 1957	138	27	1.6
	Same	Same	142	27	1.6
	Same	Nov. 1957	201	15	2.0

As Table 2 shows, the net production of phytoplankton, as obtained by calculations, is two to eight times lower than the potential one, usually not exceeding 100% are rarely reaching 200% of the initial biomass, i.e., the coefficient P/B, in different seas of the Mediterranean Basin, fluctuates between 0.6-2.3. The minimal values of net production were obtained in the Ionian Sea and the Sea of Levant, maximal ones in the Black Sea. /163

Table 3

Rate of cell division of plankton algae in the seas of the Mediterranean basin. (Number of hours between two cell divisions).

Algae group	Sea and region						
	Tunisian Strait	Tyrrhenian Sea	Ionian Sea	Mediterranean Sea	Adriatic Sea	Aegean Sea	Black Sea
Dinoflagellatae	11	9	12	10	10	8	10
Sm. flagellates	6	9	11	12	10	9	15
Diatomeae	17	10	10	15	7	14	8
Coccolitophoridae	24	13	12	14	11	13	14

It has been established that the net production depends to a greater extent on the initial quantities of a given species of algae, than on the rate of cell division. For example, in comparing data obtained in experiments on the average rate of cell division for the main groups of algae in different seas, it was ascertained that they differ little from one another.

Table 3 gives data on the average rate of cell division of the main algae groups. As one can see, the cells of dinoflagellatae divided, on the average, every 8-12 hours. Their division was more intensive (every 8-9 hours) in the Tyrrhenian and Aegean Seas. A high division rate (every 6 to 9 hours) was noted for

the small flagellates in the Tyrrhenian and Aegean seas, as well as in the Tunisian Strait. For the diatomane, encountered in large quantity in the Adriatic and Black Seas, the cell division rate was two times higher (every 7 to 8 hours) than in the other seas of the Mediterranean Basin (10 to 17 hours).

The above data show that the speed of reproduction in the Black Sea was higher only for diatomeae, while for the remaining groups it was on the same level as, and sometimes lower than, in the Mediterranean Sea. Nevertheless the overall production in the Black Sea exceeded by several times that of the Mediterranean Sea. This confirms the proposition was advanced previously, that the magnitude of the net production is determined in the final analysis by the phytoplankton cells. The quantity of phytoplankton, i.e., initial quantity, on the basis of which production is determined, does not exceed 8-10 mg/m³ in the Mediterranean Sea. In the Black Sea it is usually much higher. /164

As is well known, quantitative indexes for plankton in the sea depend on a series of physico-chemical factors (turbulence, biogenic elements, temperature, salinity, etc.), and biological characteristics (interrelationship between the phytoplankton and zooplankton, seasonality of their development, etc.). Undoubtedly every one of these factors can be a determining one in the production processes during certain periods of observation.

Nevertheless, in our opinion, the most significant influence on these processes is exerted by zooplankton. For example, low levels of phytoplankton production in the Mediterranean Sea during a high cell division rate, are probably related to the fact that the constant and probably relatively intensive consumption of algae by the zooplankton with very low initial values limits the accretion of the phytoplankton cells.

Calculations were made of the biomass quantities from examples found in the Black Sea which have lost a certain of their number under natural conditions as a result of their being

devoured and natural mortality. During the established concentration of plankton in the sea, when no considerable increase or lowering of it occurs during a 24-hour period, all daily net production will be consumed and die naturally. The mortality rate can be calculated according to the quantity found in empty traps before the experiment and after. In the Black Sea it usually comprised from 2 to 20% of the net production. This makes it possible to assume that the main part of the production is being utilized by the zooplankton. In those cases when the quantity of the phytoplankton during the 24-hour period undergoes considerable changes, correction of the 24-hour progress of the phytoplankton quantity is introduced in the calculation data (the calculations were made according to formulas proposed by Ten, 1962). They have shown that in September 1960 the phytoplankton consumed, comprised 2 to 17% of the total biomass of zooplankton, i.e., a real quantity, which agrees with the data of many authors on daily food rations of different species of copepods. Calculations could not be given for the Mediterranean Sea only because we do not have as yet sufficient experimental data for the entire euphotic spectrum. Later on, when such data will be collected it will be possible to make complete calculation.

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ON THE BIOLOGY OF THE PONTOSPHAERA HUXLEYI LOHM

/165

by

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The presence of a large quantity of the coccolithophorides among the plankton is characteristic of the seas and oceans of the warm zone belt. The mass development of coccolithophorides up to great depths has been registered in the Mediterranean Sea, along the Algerian and Toulon shores as well as in other regions, and also in the Adriatic Sea (Bernard et Fage, 1936; Bernard, 1948, 1956, 1961, etc.).

The coccolithophorides were first discovered in the Black Sea by P. I. Usachev (1947). Later on, N. U. Morozova-Vodyanitskaya (1948, 1954) gave a systematic listing of this group, which already contained 18 species. At the present time 23 species of coccolithophorides in the Black Sea have been registered (Pitsyk, Mikhaylova, 1963, 1964).

On the basis of expeditionary investigations in different regions of the Black Sea, and stationary observations in the Sevastopol Bay, Morozova-Vodyanitskaya and Belogorskaya (1957), obtained new data on the quantitative development and distribution of the coccolithophorides. It has been discovered that one of the numerous forms of this group is the *Pontosphaera huxleyi*, first described by Lohmann (1902); it is found among the plankton of the Black Sea throughout the entire year with maximum development occurring in early spring, when its quantity sometimes reaches 1 to 1.5 million kl/l. The highest quantitative indices of this form were noted in the neritic area.

In the open sea, *pontosphaera* was encountered in a considerably small quantity. Its maximal quantity is usually noted in the upper 50 meter water layer (Belogorskaya, 1959).

Bernard (1942) notes that the *Pontosphaera huxleyi*, an extremely small form of coccolithophorides, is often found in

different regions of the Mediterranean Sea. Its great adaptability to the changing conditions of the environment has been noted. It is mostly found at the horizons from 0 to 200-400 m. Bernard also points out the possibility of the existence of several breeds of this species. Unfortunately, in his later works Bernard (1956, 1961) takes only large forms of coccolithophorides, larger than 10 microns), mainly *Coccolithus fragilis* Lohm, into account.

0 According to the data of the Sevastopol Biological Station, obtained during the expedition of ship Academician A. Kovalevskiy in 1959-1960, *Pontosphaera huxleyi* was encountered in the Mediterranean Sea during different seasons of the year at almost all the horizons from 0 to 3000 m. *Pontosphaera* is encountered in the greatest numbers in the 0 to 200 m layer, with a maximum in the 10 to 25 m layer. At great depths its quantity is considerably lower (Belogorskaya, see the article in the present collected works; Mikhailov and Denisenko, 1963; Kondratyeva - Unpublished data).

In conjunction with the fact that the classification of the coccolithophorides, as noted by Bernard (1961), varies to a considerable extent, it is quite possible that certain authors attribute the same form to different species. At the present time, /166 in conjunction with the use of electronic microphones, the categorization of the coccolithophorides is completely restudied.

0 Cultivated algae could be most useful for an investigation of this type. To our regret, little information was published up to the present time on the growing of coccolithophorides under conditions of cultivation (Braarud A. Fagerland, 1946; Mjaaland, 1956).

Our experiments on the content of *Pontosphaera huxleyi* under laboratory conditions were begun early in 1958, when it was periodically separated from the mixed cultures and the cell

division rate was observed. Maximal division rate of two to three times per 24 hours was noted in the spring, during the period of intensive development of the pontosphaerae in the sea. In 1961-1962 monocultures of *Pontosphaera huxleyi* were extracted from the Black, Mediterranean, and Red Sea. The purpose of our investigation was a comparative study of the biology of the *Pontosphaera huxleyi* taken from different water reservoirs of the Mediterranean Basin.

The sea water samples obtained by a bathometer from different horizons and in different regions of the sea served as the initial material. They were placed in glass vessels containing Allen-Nelson's nutrient solution (Allen a. Nelson, 1910), where algae cultures were cultivated. After certain times in such "intermixed cultures" the algae quantity increased. *Pontosphaera huxleyi* appeared; it was separated by the solution method.

The cultures were kept in filtered sea water under scattered daylight illumination and at room temperature. The "Erdschreiber" (earth extraction) medium and Allen-Nelson's (1910) nutrient solutions was used as food.

Also, to determine the speed of division of the *Pontosphaera huxleyi* under the different temperatures and types of illumination, experiments were conducted by a cooled chamber. Luminescent lamps served as a light source. The change in illumination was achieved by re-positioning the lamp: placing it closer or further from the retort.

The study of cell lifetime was conducted with cultures under dark covers.

The experiments took place during a period of six months, from April to July, and from October to November, 1962. The duration of the experiment did not exceed five to seven days, in several cases 10 to 15 days. A series of experiments was

conducted every month, and the average speed of cell division was determined. *Pontosphaera huxleyi* were grown in flasks and Petri dishes, on the bottom of which a considerably dense sediment formed during intensive cell division. The normal culture usually has a golden hue. A lighter, almost white sediment indicates the bad conditions of the culture.

During unfavorable conditions (bright illumination, lengthy darkness, frequent shaking), the *pontosphaera* frequently partially or entirely discard their coccolites. The cells of *Pontosphaera huxleyi* vary greatly in size. As a rule, larger cells (15 to 16 microns) were found in cultures extracted from the Red and Mediterranean Seas; the small cells (4 to 6 microns) have been noted on the Black Sea *pontosphaera*. Nevertheless, different sized groups of *Pontosphaera huxleyi* were also noted among the cultures extracted from the same water reservoir. Among the cultures of the *pontosphaerae* extracted from the Mediterranean Sea, for example, are encountered cells from 8 to 16 microns.

The experiments conducted during different seasons of the year have disclosed the fact that the *Pontosphaera huxleyi* from April to May-June has a considerably high speed of cell division. The maximal division speed of 4.8 times per 24 hours has been noted in May for the *pontosphaerae* extracted from the Black Sea, and 2.8 times per 24 hours in April for the *pontosphaerae* extracted from the Red Sea. During the following months the speed of the cell division decreases perceptibly, (Figure 1). In the rates of cell division of the *pontosphaerae* extracted from differences were observed during our experiments. The Mediterranean *pontosphaerae* is an exception: its cell division rate is somewhat lower.

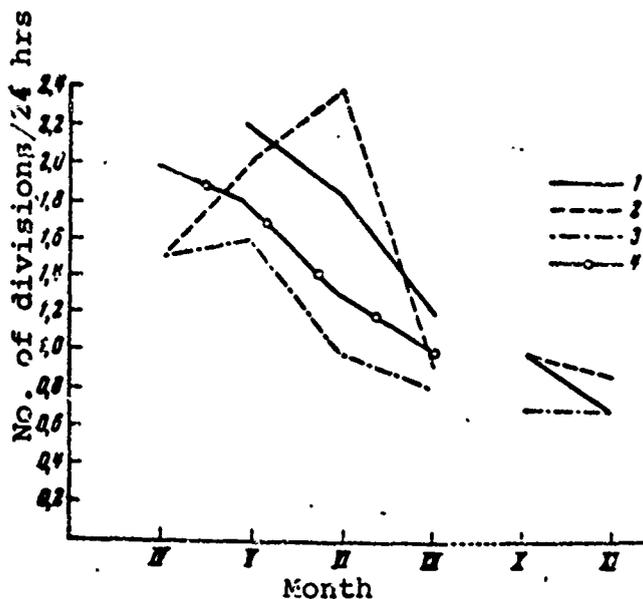


Figure 1. The speed of the cell division of the *Pontosphaera huxleyi* extracted from different seas.

- 1) From the Black Sea (Central part);
- 2) From the Black Sea (Bosporus vicinity region);
- 3) From the Mediterranean Sea;
- 4) From the Red Sea.

Braarud and Fagerland (1946), who cultivated *Pontosphaera huxleyi* and *Syracosphaera carterae*, also noted the high speed of their growth under favorable conditions. During their experiments, the cells of *Syracosphaera* divided more than every 24 hours under temperatures of 18 to 20° C.

In our experiments the high speed of cell division of the *Pontosphaera huxleyi* was noted at a temperature of 20 ° to 22° and daylight illumination of up to 2500 to 3000 luxes. When the temperature was lowered to 15 to 16° and 10 to 12°, the speed of cell division of the *pontosphaerae*, under the same illumination decreased somewhat.

It should be noted that during lengthy cultivation the speed of the cell division of the *pontosphaera* decreased somewhat from spring to autumn (see Fig. 1). It is possible that the slow-down is due to seasonal changes, but the possibility is not excluded that it is connected with the aging of the culture. The latter phenomenon can probably explain the slow

speed of cell division of the *Pontosphaera huxleyi* extracted from the Mediterranean Sea, which was cultivated much earlier (1961).

The results of the observations of the speed of cell division of the *Pontosphaera huxleyi* in a cultivated state, under various conditions of illumination and temperature, are presented in Table 1. The values given in the Table are the average for three experiments.

As can be deduced from this Table, the maximal speed of cell division of the *pontosphaerae* was noted under illumination of 4000 luxes and a temperature of 22 to 24°. A higher temperature up to 32° and illumination up to 6000 luxes exerted an inhibiting influence on it.

The experiments of cultivation of the *Pontosphaerae huxleyi* in darkness showed that when cultivated under different temperature conditions, and when an organized medium of "Erdschreiber" was added, the cells did not divide and died after 10 to 15 days.

This makes it possible to assume that *Pontosphaera huxleyi* and possibly many other species of coccolithophorides, are autotrophs which are able to develop intensively only in the illuminated zones of the sea. The vertical distribution of coccolithophorides within the sea also testifies to this. In the Black Sea the maximal quantity of *Pontosphaera huxleyi* is usually encountered in the 0 to 50 m illuminated zone. In the Mediterranean Sea the main mass of coccolithophorides is distributed in the 0 to 200 m layer.

The encounter of the great quantity of coccolithophorides of a depth of 1000-4000 m, according to Bernard's proposition (1938, 1948, 1961) is connected with its heterotrophy.

On the basis of the results of our experiments and data on the vertical distribution of coccolithophoridae, one can assume that the fact that they are often encountered at great depths in

Table 1

The speed of the cell division of the *Pontosphaera huxleyi* under different conditions of temperature and illumination (number of divisions per 24 hours)

Water reservoir from which initial material was extracted	Luminosity in luxes					
	6000	4000	2000-2500	500	200-150	50
	Temperature in °C					
	30-32	22-24	15-16	15-16	8-9	8-9
Black Sea (central region)	do not divide	1.5	0.9	0.5	do not divide	Dies
Black Sea (Bosporus vicinity region)	Same	1.2	1.0	0.4	Same	Same
Mediterranean Sea	"	1.1	0.8	0.3	"	"
Red Sea	"	1.0	0.7	0.3	"	"

considerable quantities is not connected either with the heterotrophy or with settling due to some causes. This is confirmed also by the fact that *Pontosphaera huxleyi* taken from the illuminated zone of the sea develops very intensively when cultivated. It probably is in a good physiological state. On the contrary, the *Pontosphaera huxleyi* extracted from great depths does not develop when cultivated, even under the most favorable conditions for the heterotrophes (shading, organic mediums, lowered temperature).

We have conducted experiments on the speed of cell division of the *Pontosphaera huxleyi* taken from different seas and cultivated in Red, Mediterranean, Black Sea and Azov Sea water with corresponding salinity (Table 2).

Table 2 indicates that *Pontosphaera huxleyi* extracted from different seas has a maximal speed of cell division in the water of the reservoir from which it has been taken. The *pontosphaera*

extracted from the Mediterranean and Red Seas does not withstand sharp changes in salinity well, and stops reproduction altogether in the Black Sea and Azov Sea water. At the same time, the *Pontosphaera huxleyi* extracted from the Bosphorus vicinity withstood wider fluctuations in salinity (from 18 to 41.5%), and was dividing quite intensively in the Black Sea water with a salinity of 18.5%, as well as in the Mediterranean Sea water with a salinity of 38.53%. Within narrower limits of salinity, (18-25%), development of *Pontosphaera* was noted in the central part of the Black Sea.

Braarud and Fagerland (1946) have observed maximal development of *Syracosphaera carterae* in cultivation under salinity of 26-34‰, but its development did not complete cease even when the salinity was increased to 40‰ or lowered to 10‰. At the same time, they noted that in the small water reservoirs vigorous development of *Syracosphaera* was possible (in quantities of several million kl/l) even when the water is considerably desalinated down to 17.4‰.

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Table 2

The speed of cell division of the *Pontosphaera huxleyi* in sea water of varying salinity

Water in which cultures were grown	Salinity in ‰	<i>Pontosphaera huxleyi</i> , from sea:			
		Black Sea (central region)	Black Sea (Bosphorus vicinity region)	Mediterranean Sea	Red Sea
Red Sea	41.55	0.55	0.8	1.6	2.2
Mediterranean Sea	38.53	0.61	1.6	1.5	1.9
Black Sea (Bosphorus vicinity)	24.15	1.8	2.2	0.5	0.3
Black Sea (Central region)	18.03	2.0	1.8	0	0
Azov Sea	12.2	0	0	0	0

The increased development of the *Syracosphaera* Braarud and Fagerland relates to the large quantity of organic matter, which facilitates its development in the water reservoirs.

Bernard (1956, 1961) notes that in certain regions of the Mediterranean Sea the productivity of plankton is limited as a consequence of frequent salinity changes. For example, the permanent quantity of coccolithophoridae *Coccolithus fragilis* in the plankton, when the water is desalinized, decreases by 40% or this form disappears completely.

It is possible that this explains the weak procreation in our experiments, as well as complete termination of development (see Table 2) of the *Pontosphaera* taken from the Mediterranean and Red Seas with higher salinity (38.5 to 41.5%), in the Azov and Black Sea waters (with a salinity of 12 to 18%). As far as *Pontosphaera huxleyi* separated from Mediterranean waterstream of Prebosporus region of the Black Sea is concerned, the development of this form occurs within wider limits of salinity, and this seems to be connected with the great adaptability of the mentioned form to salinity fluctuations.

The experimental data obtained by us makes it possible to arrive at a preliminary conclusion that, because it has a high division rate, one can obtain considerable value for the primary productivity of the Black, Mediterranean, and Red Seas. The same as many other coccolithophoridae, it probably is a typical autograph and descends to great depths in some quantity, probably as a result of settling.

Pontosphaera huxleyi develops most intensively under cultivation conditions in waters of the reservoir from which they have been taken and under the temperature of 15 to 24° and illumination of 2000-4000 luxes.

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THE PENETRATION OF THE MEDITERRANEAN
ZOOPLANKTON ORGANISMS INTO THE BLACK SEA

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by

E. V. Pavlov

The Bosphorus region of the Black Sea, which is subjected to the influence of the high salinity Mediterranean waters, has repeatedly attracted the attention of the investigators and hydrologists from the standpoint of water exchange between the Black and the Mediterranean Seas (Makarov, 1885; Merz, 1918; Ullystt, Ilgaz, 1946; Pektas, 1956; Bogdanova, 1959, 1960, 1961). Biologists are attracted because of the area of contact between Black Sea and Mediterranean Sea organisms.

In 1892-1893 A. Ostroumov conducted hydrobiological work in the Bosphorus Strait (1893, 1894). The content of the surface and deep water plankton in the strait was varied; the surface content was composed of Black Sea organisms, whereas at a depth, as expected, forms peculiar to the Sea of Marmara (Tomopteris, Doliolum, etc.), were found. Nevertheless, during the zooplankton investigation along the Turkish Black Sea shores (Hermann Eunarsson, Necla Guertuck, 1959), no Mediterranean representatives were found.

In the spring of 1957 and 1959 the investigation in the Bosphorus region were conducted by Rumanian scientists. In the zooplankton samples, against expectation, not a single Mediterranean organism was found. This made it possible for the authors to reach the conclusion that during the period of investigations the inflow of Mediterranean waters was absent, and that the pelagic fauna of the Bosphorus vicinity region of the Black Sea is similar to the Black Sea fauna (Petran a. Elian, 1961).

The plankton algae, which are peculiar to the Black Sea, were detected in the Bosphorus region by Skolka (1961).

In September 1960 in the central part of the western half of the Black Sea, at a depth of 25 to 50 m, seven species of Mediterranean organisms were detected, which could have penetrated only through the Bosphorus (Favlova, 1964).

In relation to increased interest in the problems of the influence of the Mediterranean waters in the hydrologic regimen of the Black Sea, the Sevastopol Biological Station of the Academy of Science of the USSR began in 1958 to conduct planned observations in the Bosphorus region according to seasons. In 1962 two test investigations were conducted during which the zooplankton samples were collected parallelly with the hydrological work (Figure 1).

The collection, was mostly conducted with the help of Djedi's net made of No. 49 gauze for the following horizons:

- 1) bottom to upper boundary of Mediterranean water layer;
- 2) upper boundary of the mediterranean water - lower boundary of the jump layer; 3) jump layer-surface. The depth of the position of each above-mentioned horizon was determined at the station according to the thermobathygraph data. The lower horizon, a layer of inflowing Mediterranean water, as a rule, was situated at the bottom; its depth does not exceed 3 to 5 m above the bottom surface. In order to carry out the sample collection in this layer more thoroughly, it was necessary to drag a plankton net along the bottom. Two other horizons were studied in order to determine the possibility of penetration by the Mediterranean organisms into the upper water layers. /172

During two investigations, 75 zooplankton samples were collected. During the processing it was necessary to reject the usual method of calculating the number of organisms per volume of the stamp-pipette, because Mediterranean species were found in minimal quantities. The processing was reduced to a thorough observation of the sediment of each sample under a binocular microscope and to the determination of the detected Mediterranean organisms species.

When processing the samples collected in May at two stations, along with the usual Black Sea species, Mediterranean species were detected such as *Microsetella rosea* and *Corycaeus*

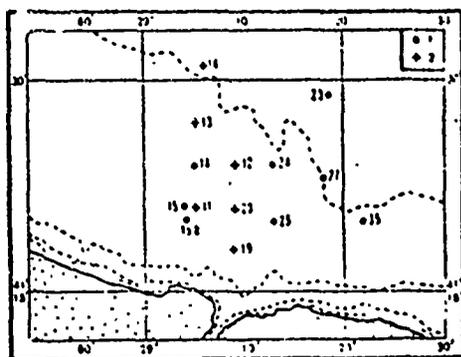


Figure 1. The Zooplankton stations in the Bosphorus region of the Black Sea in 1962.

1) in May; 2) in October.

furcifer. In October, at a smaller number of stations, Mediterranean organisms were found in four of them and in much lesser quantities and species. Table 1 present data on the detection of Mediterranean organisms in the Bosphorus region.

Table 1

The Mediterranean organisms detected in 1962 in the plankton of the Bosphorus region of the Black Sea (number of examples in a sample).

Species	May		October				Length of body in mm.	
	st. 13	cr. 15a	cr. 11	cr. 12	cr. 13	cr. 20		
	Depth in m.							
	82-27	73-30	73-20	82-20	20-30	30-73	60-35	
<i>Calocalanus pavoianus</i> Faran ♀	—	—	—	—	—	5	—	0.62
<i>Calocalanus (tenuis?)</i>	—	—	—	1	—	—	—	0.90
<i>Microsetella rosea</i> Dana ♀	—	—	—	1	—	—	—	0.75
cop.	2	—	2	1	—	13	—	0.4-0.6
<i>Euterpina acutifrons</i> Dana ♀	—	—	7	7(1)*	3	1	2(2)	0.70
♂	—	—	—	—	—	2	—	0.62
cop.	—	—	—	—	1	8	—	0.50
<i>Cucaea minuta</i> Giesbr. ♀	—	—	—	—	—	14(2)	—	0.60
♂	—	—	—	—	—	2	—	0.47
<i>Cucaea dentipes</i> Giesbr. ♀	—	—	—	1	—	12(3)	—	0.55
♂	—	—	—	—	—	4	—	0.45
<i>Cucaea</i> sp. ♀	—	—	2	—	—	—	2	0.55
♂	—	—	—	—	—	—	2	0.45
cop.	—	—	—	4	—	32	—	0.3-0.5
<i>Corycaeus furcifer</i> Claus ♀	1	1	—	—	—	—	—	1.60
♂	—	—	—	—	—	2	—	1.35
<i>Corycella</i> sp. ♀	—	—	1	—	—	1	—	1.12
♂	—	—	—	—	—	1	—	1.07
cop.	—	—	—	—	—	1	—	0.75

* Number of females with egg sacks is shown in parenthesis.

All above-mentioned Mediterranean organisms were in good condition when detected, and this makes it possible to presume that they were in fact alive when detected. The females of three species (*Enterpina acutifrons*, *Oncaea mimeta*, *O. dentipes*) in some cases were carrying egg sacks.

As a rule, these organisms were found in the lowest horizon, within the layer of Mediterranean water. At Station 12, however, female copepodae at the *Enterpina acutifrons* stage were detected in a layer lying 69-70 m above the Mediterranean water layer. This makes it possible to assume that the Mediterranean organisms are able to survive for the same time in the Black Sea. It is interesting that the stations on which Mediterranean species have been found in the May (15, 15a) and October samples (11, 12, 13, 20) are distributed somewhat to the west of the exit to the Bosphorus Strait. /173

The Mediterranean plankton organisms enumerated in the Table are the typical representatives of the Mediterranean plankton (Rose, 1933) Adriatic plankton (Shmeleva, in print), Ionian plankton (Grese, in print), and Aegean plankton (according to our data) and can serve as indications that of the Mediterranean is present.

The spring period, according to the hydrological data, is not very favorable for the penetration of the Mediterranean water through the Bosphorus. For example, according to Peetas' data (1956) during the spring the level of the Black Sea is so much higher than the Mediterranean, that the inflow of the Mediterranean water into the Black Sea almost completely ceased, which is due also to the frequency of winds blowing in a northern direction during this season. But the results of the processing of the hydrological materials collected in May 1962 (Bogdanova, see present collected works), as well as preliminary investigation data of the preceding years (Bogdanova, 1961),

make it possible to make a conclusion in reverse: even during the spring period, Mediterranean water enters the Black Sea, although in small quantities, as a thin bottom layer. The zooplankton organisms not originally from the Black Sea detected in the natural layer confirm the presence of the Mediterranean water at the bottom in the Bosphorus region.

In October, according to bibliographic data, during favorable winds a maximum inflow of Mediterranean water into the Black Sea is observed. In October 1962, during the period of hydrological investigations, northern winds were blowing, which facilitated the piling up of the Black Sea water in the Bosphorus region. Winds from this direction are extremely unfavorable for the penetration of the Mediterranean Sea water from the Sea of Marmara into the Black Sea. But, as it turned out, even under such conditions saltier Mediterranean water can be observed in the bottom layer. This was also confirmed by the content of the plankton organisms. At the four stations, in October 1962, nine species of small crayfish, characteristic for the Mediterranean Sea, were detected, and in May *Corycaeus furcifer* and *Microsetella rosea* were found singly, while in October such plankton organisms as *Oncaea*, *Microsetella*, and *Enterpinis* have been detected in dozens and more for each catch. Consequently, the inflow of the Mediterranean water into the Black Sea took place in the spring as well as in the autumn of 1962.

But it is possible that the Mediterranean water entered through the Bosphorus only during 1962, and that during the spring of 1957 and 1959, during the investigation conducted by the Rumanian scientists Petran and Elian (1961), no inflow of the more saline Mediterranean waters did occur.

If hydrological data presented in the above-mentioned work are studied, then the lower horizon shows a certain increase in salinity, for example, at station 491 - 20.99‰ at

a depth of 70 m as compared to 18.62‰ at a depth of 50 m; at station 493 - 19.09‰ at a depth of 70 m as against 18.77‰ at 50 m (1957 investigation). The same fact was detected in April 1959: at station 687, at a depth of 75 m the salinity was equal to 18.73‰ and at a depth of 50 m - 18.48‰; at station 691, /174 closest to the Bosphorus, the salinity at a depth of 50 m increased up to 18.48‰ as compared to 17.48‰ at a depth of 25 m. It is very likely that such an increase of salinity at the bottom is caused by an intermixture with water of high salinity, which comes from the Sea of Marmara. The Mediterranean plankton organisms were not detected at these stations, probably because the lowest layer (3 to 5 m from the bottom) was not dredged with the plankton nets. It should also be remembered that the processing of the plankton samples with the help of a pipette, as done during the investigations of Petran and Elian, could produce wrong results, because Mediterranean organisms could have been in the plankton in very small quantities. Taking into account their small size, they could therefore have been detected only during a thorough observation of the entire sediment of the sample.

At the Turkish shores the absence of the Mediterranean water and accompany organisms is quite logical, because after leaving the Bosphorus, as has been shown by hydrologists (Bogdanova, 1961), and biologists (Yakubova, 1946), and as confirmed by the zooplankton materials, Mediterranean water deviates to the northwest.

In conclusion, it can be stated that nine species of the Mediterranean zooplankton organisms have been found in the plankton of the Bosphorus region of the Black Sea, in the thin bottom layer, in small quantities. The presence in the plankton of organisms characteristic for the Mediterranean Sea, along

with typical Black Sea organisms, confirms the data of the hydrologists on the inflow of the Mediterranean water through the Bosphorus into the Black Sea during the Spring, as well as the autumn of 1962. The places where the Mediterranean species have been found coincide with the main movement of the Mediterranean Sea in the Black Sea according to hydrological data.

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THE DISTRIBUTION OF ZOOPLANKTON IN THE WESTERN HALF OF
THE MEDITERRANEAN SEA DURING THE WINTER OF 1960-1961

/175

by

L. I. Sazhina

The zooplankton of the Mediterranean Sea has been considerably studied from the systematic point of view by the Neapolitan station, by the Monaco Oceanographic Institute and other institutions. Nevertheless, information of a quantitative nature mainly pertains only to the shallow water coastal zone and is often confined to the study of the distribution of individual representatives only of the zooplankton complex (Anichine, 1957; Bernard, 1958; Furnestine, 1957, 1960; Hoenigman, 1958). Jespersen's data (1923, 1935) on the quantitative distribution of the zooplankton, based on the materials of the expedition of Thor and Dana, as a consequence of the specific method for collecting and processing make it possible to evaluate only its relative abundance in one or another part of the sea. Repeated descents to a great depth in a bathyscaph in the regions of Algeria, Toulon, and Villa-Franca (Bernard, 1955; Peres, Picar et Ruivo, 1957; Tregouboff, 1957) make it possible to make visual observations of the zooplankton according to layers.

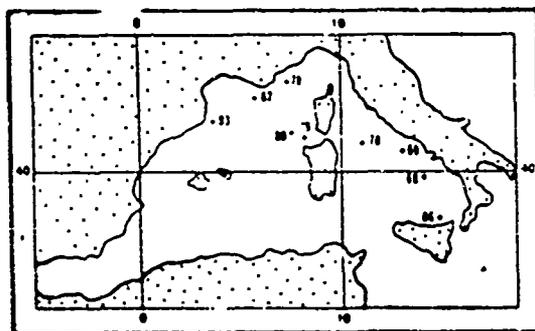


Figure 1. Scheme of station distribution.

One of the problems of the planktonological investigations conducted by the Sevastopol Biological Station, was the determination of the quantitative characteristic of the zooplankton of the open region of the sea during the winter. As the material for present work data collected by the expedition ship Academician A. Kovalevskiy at eight deep-water stations in the Tyrrhenian

and Balearic Islands, and at a station nearest the shore in the western part of the Ligurian Sea (Figure 1) were used. The plankton was collected in December-January 1960-1961 by Djedi's nets, which had an entrance diameter, at the openings of 36 and 80 dm, and is made of millers' sieve No. 49 and 22. The catches were made at standard horizons: with a small net up to the depth of 300 m, and with a large net up to the depth of 1500-2000 m. As a result of the frequent storms and large slant angles of the cable, the collection of the material in certain cases was conducted by the method of gradual catches, from a certain horizon to the surface. The count of the organisms was conducted in a Bogorov chamber with the help of stamp-pipettes of 1 cm³ in volume. In order to determine the biomass, weights obtained by A. A. Shmelevoy (1961) were used. /176

The Distribution of the Plankton in Different Regions of the Sea

During the period of investigation in the Tyrrhenian Sea the temperature on the surface exceeded 17°. The well-mixed layer was bounded by the 50 m depth. The temperature jump layer still remained and was quite well pronounced. In the Ligurian and Balearic Island Seas the temperature of the surface waters in the coastal strip was equal to 15°, and in the central regions it was 13°. The salinity decreased as one moved toward the west.

Among the plankton of the western half of the Mediterranean Sea, during the autumn-winter period, organizations of 20 systematic groups represented by 179 species were encountered. Most varied was the Copepoda group (121 species), which comprises on the average 76% of the overall quantity of the zooplankton.

Table 1

The species content and quantity of organisms according to the seas of the Mediterranean Basin in the 0 to 300 m layer

Group of organisms	No. of definite types	Number of species in seas, %		
		Tyrrhe- nian	Ligurian	Balearic
Foraminifera	4	1,2	0,8	2,2
Radiolaria	9	4,5	3,0	4,3
Tintinnidae	3	0	0,4	0,3
Medusae	—	0,5	1,5	0
Siphonophora	11	1,0	0,8	0,5
Polychaeta	3	1,0	1,2	0,6
Copepoda	12!	74,7	68,2	78,7
Ostracoda	—	4,7	1,4	1,8
Decapoda larvae	—	2,7	0,4	1,0
Amphipoda	11	0,1	weak *	weak
Euphausiacea	—	0,5	weak	0,1
Mysidacea	—	0,2	0	0
Mollusca	9	1,2	1,9	0,4
Gnathopoda	—	1,7	0,8	1,0
Appendicularia	5	3,6	9,1	2,6
Salpa	2	0,8	1,9	0,1
Doliolidae	—	weak	0	0
Pirozoma	1	same	0	0
Echinodermata larvae	—	0	3,0	0,1
Cyclothone	—	0,1	0	0,1
Varia	—	1,5	5,6	6,2
Total % spec/m³	—	100,0 134	100,0 150	100,0 267

* Less than 0.01.

The most numerous are the Calanus Graciles Dana, Calocalanus styliremis Giesbr., Clausocalanus arcuicornis Dana, C. paululus Farran, Ctenocalanus vanus Giesbr., Euchaeta marina Prestan, Pleuromamma abdominalis Lubbock, P. gracilis Claus, Centropages typicus Kroyer, Lucicutia flavicornis Claus, Heterorhabdus papilliger Claus, Haloetilus longicornis Claus, Acartia negligens Dana, Mormonilla minor Giesbr., Oithona setigera Dana, O. similis Giesbr., Marcocetella rosea Dana and numerous species of the Oncaeae genus. All these organisms were found on the investigated aquatory in equal quantities.

The correlation of the different systematic groups of the organisms in the plankton of the seas of the western half of the

Mediterranean Basin is presented in Table 1, where percentage content of their quantity in the upper 300 m layer is presented.

Over all the open waters of the Mediterranean Sea are characterized by a small quantity of zooplankton, but, as can be seen from Table 2, in individual regions the quantity can fluctuate significantly. In Table 2 are presented the values of the quantity and the biomass on the aquatory (water territory) of the investigated region, obtained mainly by Djetei's net for large plankton.

Table 2

Average quantity and biomass of the zooplankton of the Mediterranean Basin seas

Horizon in m	Sea					
	Tyrrhenian		Balearic		Ligurian	
	1	2	1	2	1	2
0-300	134	26.5	150	12.3	267	15
0-2000	63	12.0	31	5.8	-	-

1 - Average quantity in specimens/m³;

2 - Biomass in mg/m³.

The quantity as well as biomass of the deep water plankton is considerably larger in the Tyrrhenian Sea. The upper water layers of the open regions of the Tyrrhenian Sea are also considerably richer in biomass than the Ligurian and Balearic Island Seas. A somewhat increased quantity in the two latter seas is the result of the predomination in our materials of the coastal stations with an abundance of small epiplankton forms.

Having analyzed the data obtained by the expedition of "Dana," Thomsen (1931) came to the conclusion that the quantity

of the phosphates and nitrates of the Mediterranean Sea decreases from west to east. An exception was the unexpectedly high nutrient salt content in the Tyrrhenian Sea. Buljan (1954) found that the quantity of the nutrient salts in the Tyrrhenian Sea at the depths from 800 to 2500 m significantly exceeds that of the Tunisian-Sardinian region as well as that of the Balearic Sea. He explains this on the basis of the influence of the underwater volcanism on the depth layers of the Tyrrhenian Sea.

During the winter the western part of the Mediterranean basin is subjected to the action of the Euro-Asian anticyclone, (Tcherria, 1960), which creates drifting cyclonic circulations and a consequence considerably raises the deep waters. According to A. K. Bogdanova (1961), during the period of investigation a well-pronounced ascent of the deep waters was observed in the central part of the Tyrrhenian Sea. On page 70 the depth of the surface layer with a temperature of more than 14° does not exceed 100 m, whereas on page 69 the layer of warm water had the thickness of 500 m. In turn, the quantity of plankton at this station in the 0 to 300 m layer, was more than /178 two and a half times smaller than on page 70 (93 and 212 specimens/ m^3). The ascent of the deep waters, enriched by nutrient salts probably as a result of the underwater volcanisms, causes a considerable increase in organic production.

The Vertical Distribution of the Plankton

The vertical distribution of the zooplankton during the daylight hours has been studied most thoroughly at station 66; to a considerable degree, it depends on the character of the vertical distribution of the hydrological factors and the distribution of the water masses. According to Bogdanova (1961), the work at station 66 was carried out under conditions of temperature jump preservation with a maximal gradient of 0.6° to 1 meter, or under stable stratification of water masses according to density, when the well-mixed layer was limited only by a 50 m

depth. The station's work has been carried out up to a depth of 300 m, and includes the surface layer of Atlantic origin and, partially, the intermediate layer of the Levantine water mass. The presence of the Atlantic water has been detected on the basis of minimum salinity, which can be found at a considerable depth (from 20 to 75 m) (Lacombe et Tchernia, 1960). The quantity of organisms (Figure 2) gradually decreases from the surface downwards. The maximal concentration of the organisms in the 0 to 25 m layer was formed by the epiplankton organisms (eggs and naupliuses of the copepoda, *Paracalanus* sp. *Clausocalanus furcatus* Brady, *C. paulus*, *Oithona similis*, *O. nana* Giesbr., *Oncaea tenella* I. O. Sars, *Oicopleura* sp.).

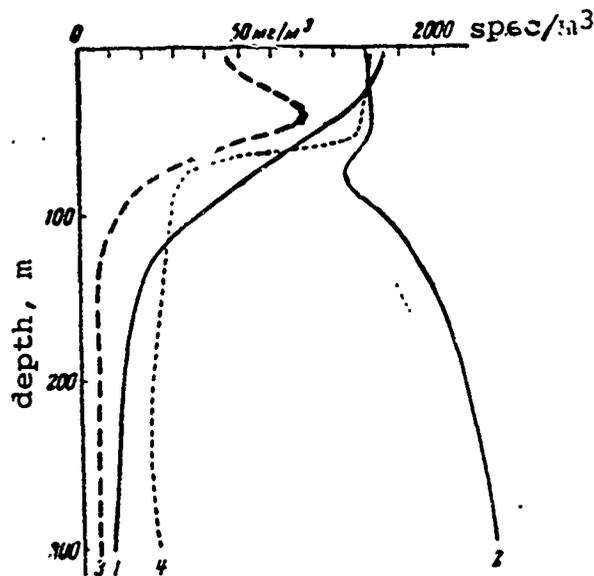


Figure 2. Vertical distribution of the quantity and biomass of the zooplankton on page 66 (small net).

1 - quantity; 2 - salinity in ‰; 3 - biomass; 4 - temperature in C °.

The biomass distribution curve produces a clearly defined peak in the layer above the thermocline. Here live part of the

epiplankton organisms and the juvenile stages of the mezo-planktonic large forms: *Calanus gracilis* (juv.), *calocalanus stylibremis*, *Clausocalanus arcuicornis*, *Euchaeta marina* (juv.), *Heterorhabdus papilliger*, *Ostracoda* gen. sp., *Sagitta* sp.

The upper limit for the distribution of the bioplankton forms, is most probably influenced by the illumination of the upper layers, and the intermediary layer of cold water at the depth limit of the distribution for organisms of the warm water epiplankton complex. Below the thermocline layer predominate large and more mobile forms, which are not caught easily with the Djetei's net with an opening of 36 cm in diameter (as shown on Table 3). Table 3 shows the distribution according to horizons of the quantity and biomass of the zooplankton, according to materials collected with small and large Djetei's nets. In the left half of the Table the values obtained with the help of a small Djetei's net for the collection of small plankton at Station 66 are shown, and in the right-hand part average values are shown, obtained with a large Djetei net for the collection of large plankton along the equatory (water territory) of the investigated region. /179

In the catches of the small net the number of species decreases with depth, whereas in the catches of the large net a large variety of species has been observed below 100 to 200 m. It seems that the quantity of the small epipelagic species decreases in depth, and the quantity of the bathyplanktonic species, which are not caught by the small net, increases but only to a certain limit - 7000 to 1000 m. Below these depths only the large bathyplankton organisms remain which produce low biomass values because they are extremely rare.

Key to Table 3.

b) Horizon in m. c) A net with the diameter of entrance opening of 36 cm made out of No. 49 gauze. d) A net with a diameter of entrance opening of 800 cm, made of No. 22 gauze. e) number of species. f) quantity in specimens/m³; g) biomass in mg/m³; h) number of species; i) quantity in specimens/m³; k) biomass in mg/m³; y) below 1000.

Table 3

The distribution of quantity and biomass of zooplankton according to horizons

Horizon, m	System with intake diameter 36 cm, Gas No. 42			System with intake diameter 80 cm, Gas No. 22		
	No. of types	Quantity spec/m ³	Biomass mg/m ³	No. of types	Quantity spec/m ³	Biomass mg/m ³
0-25	35	1870	57		1252	42
25-50	31	1608	102	39*		
50-100	28	872	25	63	886	26
100-200	24	445	10	41	88	22
200-300	25**	216	9	62	155	16
350-700	—	—	—	91	340	28
below 1000	—	—	—	9	0,1	0,002

* Data for the 0 to 50 m layer.

** Data for the 200 to 300 m layer.

The vertical distribution of the large forms of zooplankton is presented in Figure 3. The stations were established during the period of gradual washout of the temperature jump layer. Starting with the surface maximum the quantity gradually decreases with depth. The drop in the values continues down to 200 m at night, and to 600 to 700 m during daylight hours, after which there is another depth quantity maximum at 300 to 500 m or 750-800 m respectively. The second depth maximum of the organisms is represented by mezoplanktonic and bathyplanktonic forms: *Eucalanus elongatus*, *Lucicutia flavicornis*, *Pleuromamma abdominalis*, *Pleuromamma gracilis*, *Haloptilus longicornis*, *Euchaeta acuta* Giesbr, *Euchaeta marina*, *Spinocalanus abyssalis* Giesbr, *Scolecithricella dentata* Giesbr, *Heterorhabdus spinifrons* Claus, *H. abyssalis* Giesbr, *H. norvegicus* Boeck, *Euphausiacea* sp. *Cyclothone* sp. The organisms of the zooplankton depth maximum carry out daily displacements within the confines of the relatively warm intermediate levantine water mass. The upper boundary of their displacement is the cold interlayer, situated at a depth of 150 to 200 m.

It is interesting to note the predomination below 400 to 500 m of large fully grown Copepoda (*Heterorhabdus norvegicus*, *Euchaeta acuta*, *Pleuromamma abdominalis*) Euphausiacea, etc.

The characteristic mouth extremities of these animals testifies to the fact that all of them are active grabbers and predators. Therefore, an extremely small quantity of small plankton, detected in the depth layers, is made even smaller because it is eaten out of this zone.

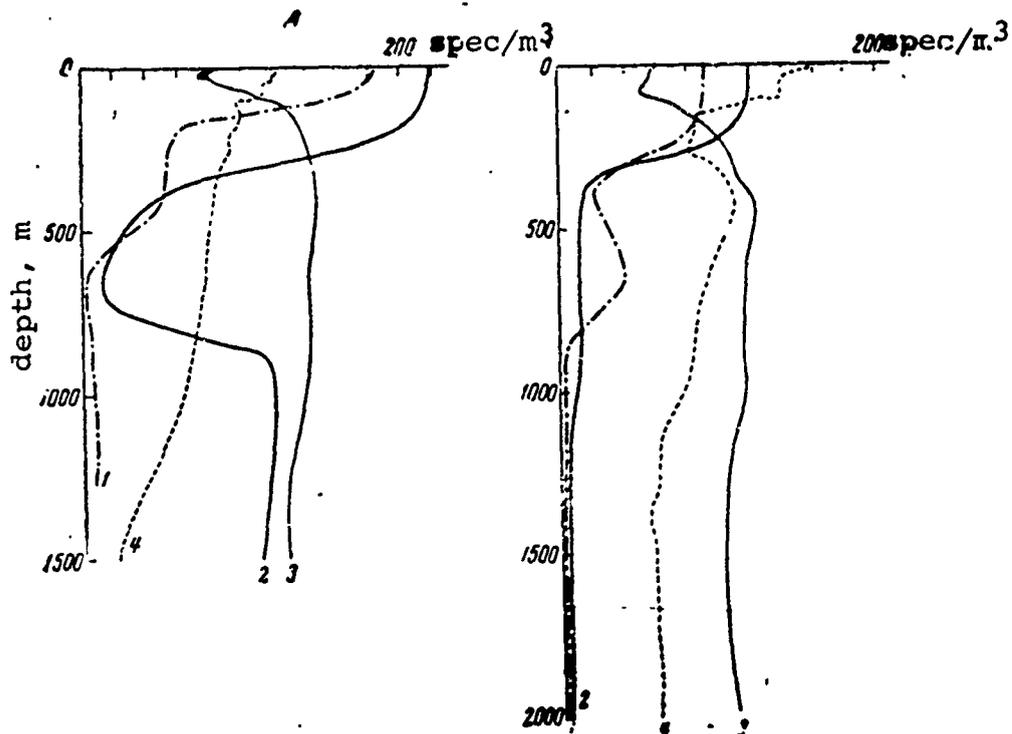


Figure 3. Vertical distribution of zooplankton quantity in the Tyrrhenian and Balearic Seas (large net).

- a - Tyrrhenian Sea: 1) Station 69 (night part of the 24-period); 2) Station 70 (daylight hours of the 24 hr period).
b - Balearic Island Sea: 1) Station 79 (night hours of the 24 hour period); 2) Station 80 (daylight hours of the 24 hour period); 3) salinity in ‰; 4) temperature in C °.

The comparison of organism quantities under 1 m² in the 500 m surface layer with the layers lying below shows (Table 4) that the percentage of the correlation of the zooplankton quantity in these two zones is not the same for the Tyrrhenian and Balearic Seas.

Table 4

Average quantity of organisms under 1 m² of surface

Layer in m	Tyrrhenian Sea		Balearic Island Sea	
	Spec/m ³	%	Spec/m ³	%
0-500	49,300	40	54,600	60
500-1500- 2000	71,800	60	34,600	40

In the upper 500 m layer of the Balearic Island Sea, where the animals directly connected with the surface productive zone live, is concentrated approximately 60%, and in the layers lying below 40%, of the overall quantity of zooplankton. Approximately the same correlation was also found to be characteristic for the majority of regions of the open ocean (Vinoogradov, 1960).

A completely different picture is found in the Tyrrhenian Sea, where the quantity of the surface plankton includes 40%, and that of the deep water plankton 60% of all organisms which inhabit the 0 to 2000 m stratum. This confirms the fact that /181 the increase of productivity of the deep waters of the Tyrrhenian Sea is influenced by a factor which is absent from the Balearic Island Sea, and which according to Buljan, is the result of underwater volcanic activity, which enriches the water with biogenic elements.

The biomass of small zooplankton in the Tyrrhenian Sea in the 0 to 200 m layer is equal to 26 mg/m³ with a maximum of 71 mg/m³ in the 25 to 50 m layer. It should be noted that in the overall biomass, no predomination of any type can be observed; it is composed of numerous species, each performing a very small role. A similar picture has been observed by A. K. Geyrikh (1957) for the tropical region of the Pacific Ocean. The over

all seston content for the 0 to 200 m layer, obtained with the help of a volume meter, is equal to 54.5 mg/m^3 . During the comparison of the seston biomass of the Tyrrhenian Sea with the data for other seas of the Mediterranean Basin, obtained by the same method (Vodyanitskiy, 1961), it can be seen that this value is not exceptional. In order to switch from the seston mass to the biomass of small zooplankton, a coefficient of 0.48 was determined.

The biomass of large zooplankton, gathered with a large net in the 0 to 300 m layer, is equal in the Tyrrhenian Sea to 26.5 in the Ligurian Sea to 15, and in the Balearic Island Sea to 12.3 mg/m^3 (see Table 2). The overall seston content, determined by the volume method, is equal respectively according to the seas, to 41, 25, and 17 mg/m^3 , and this makes it possible to arrive at the coefficient for the conversion of the biomass of the large zooplankton - 0.65.

The average biomass of large zooplankton in the Tyrrhenian Sea in the 0 to 1500 m layer is equal to 12 mg/m^3 , and in the 0 to 200 m layer of Balearic Island Sea is equal to 5.8 mg^3 .

When comparing the quantitative data on the zooplankton with that of the Black Sea, it is evident that even the overall content of the zooplankton in the 1500 m water stratum of the richer Tyrrhenian Sea is considerably smaller than the quantity of zooplankton in the productive 200 m layer of the Black Sea. According to the data of Petip, Sazhinoy, and Delalo (1963), obtained by an analogous method in February 1956 in the western region of the Black Sea, the average biomass of the zooplankton in the 0 to 200 m layer comprised 297 mg/m^3 , whereas in the Tyrrhenian Sea in the same layer it includes only 26 mg/m^3 .

Conclusions

1. The quantitative distribution of the zooplankton is closely connected with the circulation of the deep waters. In

particular, the relatively great abundance of plankton in the Tyrrhenian Sea is explained by the inflow into the surface layer of biogenic substances, probably created in the depths as a result of volcanic activity.

2. The vertical distribution of organisms is uneven. The quantity of plankton decreases from the surface down to the depth of 100 to 200 m. Then it increases again and at the depths of 300 to 500, 750 to 1000 m a second maximum is formed, which is displaced depending on the time of the 24-hour period.

3. The percentage correlation between the quantity of the surface (0 to 500 m) and the depth (500 to 2000 m) zooplankton is uneven in different seas of the Mediterranean Basin: 40% to 60% in the "Tyrrhenian Sea and 60% to 40% in the Balearic Sea."

4. The average biomass of the plankton in the surface to 1500 m layer in the Tyrrhenian Sea is equal to 12.0, and in the Balearic Sea to 5.8 mg/m³.

5. The average biomass of the zooplankton of the upper 200 m layer in all three of the investigated seas is considerably poorer than in the Black Sea.

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THE DISTRIBUTION OF COPEPODAE
AND SARDINES IN THE ADRIATIC SEA

/183

by

A. A. Shmelev

According to the investigation data (Gamulin, 1954, Hure, 1955, 1961; Battaglia, Mozzie, Varagnole, 1961; Vucetic, 1961, etc.), as well as to our own observations, the main mass of zooplankton of the southern Adriatic (up to 80 to 90%) is composed of paddle footed small crayfish - Copepoda. The predominate the food rations of the main plankton-eating fish - the sardine in the northern and middle Adriatic (Gamulin, 1954), as well as in the southern part of the sea (Lipskaya, in print; our data, manuscript of the Azov-Black Sea Science Research Organization (Az Cher NJPO).

It is known that the distribution of the plankton-eating fish depends partly on the distributions of seasonal changes of the quantity of the paddle-footed crayfish in the sea (Pchelkina, 1939; Pavshitiks, 1960; Lebour, 1927; Henderson, 1936, etc.). In conjunction with this, this article compares the results of the investigations on the distribution, biomass, and several dynamics of the quantity of the Copepoda in the southern part of the Adriatic Sea with the distribution of sardines.

The materials and method. The materials taken as the basis of the present work have been collected during four complex investigations conducted from the expedition ship Kristall of the Azov-Black Sea Science Research Organization. These investigations were conducted in the southern part of the Adriatic Sea in February, May, August, and November of 1958. The observations of the materials were collected from five permanent sections, situated from the estuary of the Mati River to the town of Kimary (Figure 1). The samples of the zooplankton were mainly taken with a Djete's net of 36 cm in diameter made of No. 38 gauze, from the horizons of 10-0, 25-10, 50-25, 100-50, and 200-100 m. Besides this, at individual stations, in the principal

areas of Sardine spawning, additional samples were taken with a denser gauze, No. 61, with the catches made at 10-0 and 25-10 m layers. The samples were fixed by 4% Formaline. The material was processed with the method of direct count. All stages of growth of the Copepoda were registered except Oithona, Enterpiana and certain other forms, for which only mature and young specimens were differentiated. The results of the counting were noted on cards and were recalculated into quantities per 1 m³ of water.

The Copepoda biomass was calculated by the multiplication of the number of crayfish by their individual weights determined by us (Shmeleva, in print). Overall, approximately 400 zooplankton samples were processed.

The distribution of the sardine was studied according to the materials of the expedition, for the use of which the author expresses his gratitude to the personnel of the Azov Sea-Black Sea Fisheries Science Research Organization (Az Cher NIPO).

The Horizontal Distribution

Figure 2 shows the distribution of Copepoda during the 1958 period in the entire investigated water layer of the southern Adriatic. As can be seen, the Copepoda developed in considerable quantity in a narrow coastal strip, from the estuary of the Mati River to the Vlora region. Their largest concentrations were noted in the estuary of the Mati River, i.e., in the region with the greatest inflow of river waters, and consequently with decreased salinity. The quantity of Copepoda here in the entire investigated layer was equal to 4000, and in the 10-0 m layer reached 6000 specimens/m³, with a biomass of more than 150 mg/m³. This comparatively high quantity and biomass were obtained as a result of the mass development of typical neritic forms, such as Paracalanus, Oithona, and Enterpina, the quantity of which reached 3500 specimens/m³ of 65% of the overall quantity of the Copepoda in the given region. The section with the poorest plankton content turned out to be the southernmost section from

Kimary, as well as the sea regions situated farthest from the shore, where the quantity of the Copepoda in the entire investigated layer comprised only 300 to 800 specimens/m³, with a biomass of the Copepoda in the entire investigated layer comprised 1050 samples and 30 mg/m³.

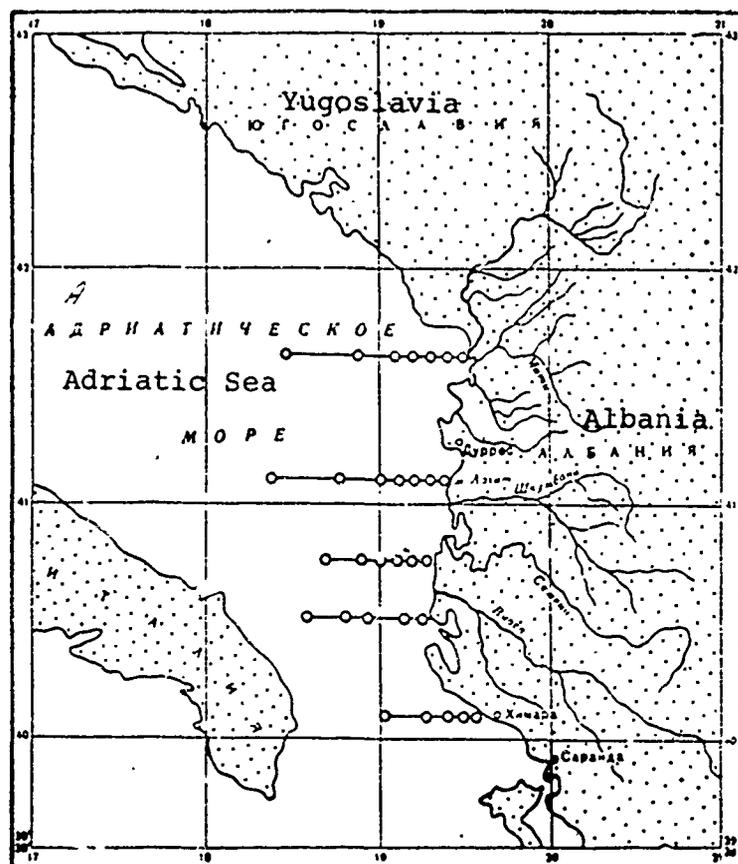


Figure 1. Station diagram.

During the spring, as well as during the winter period, the main mass of the fodder zooplankton was comprised of Copepoda. Especially numerous were the small crayfish. Along with the mature organisms, eggs were encountered in considerable quantity, as well as naupliuses and primary copepodic stages of many copepod types (from 34% in the 100 to 200 m layer to 88% in the upper 10 m layer), and this demonstrated their mass reproduction. The average quantity of the Copepoda in the entire investigated layer of the southern Adriatic was equal to 1700 specimens/m³, and of biomass, 50 mg/m³. From Figure 3 it follows that during the spring of 1958 they were distributed approximately the same manner as during the winter period. The

maximum development was observed in the coastal zone of the Mati River and Cape Lagit regions, where the quantity of crayfish in the entire investigated layer was equal to 4000 to 5000 specimens/m³ and the biomass to 150 mg/m³. On the stations situated 30 to 50 miles from the coast, the quantity of the Copepoda as a rule was always smaller. An exception was the southern most section, where the quantity of Copepoda in the open sea was almost three times less than on the coastal station (1035 as compared to 375 specimens/m³).

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The Copepoda are distributed somewhat differently in the 10-m layer. Large amounts of Copepoda were observed in it in the coastal sections as well as those situated 30 to 50 miles from the shore. And in certain sections in the open sea in the surface layer there were more copepodae than in the coastal zone. In the same regions was found mass development of the phytoplankton (Denisenko, 1964). The greatest quantity of Copepoda in the 10-1 m layer, at the five mile station of the section from Cape Lagit, reached 11,500 specimens/m³. Just as during the winter period, the high quantity of the crayfish is connected here with the mass development of the neritic forms - Paracalanus, Oithona - 2,300 specimens/m³. The overall quantity of the zooplankton reached here almost 12,000 specimens/m³ and the biomass approximately 2000 mg/m³.

- 1 - 10 thousand;
- 2 - 7-10;
- 3 - 6-7;
- 4 - 5-6;
- 5 - 4-5;
- 6 - 3-4;
- 7 - 2-3;
- 8 - 2-1;
- 9 - 0.5-1;
- 10 - 0.5.

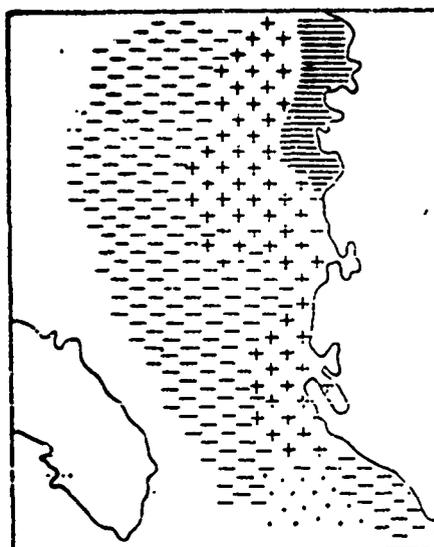
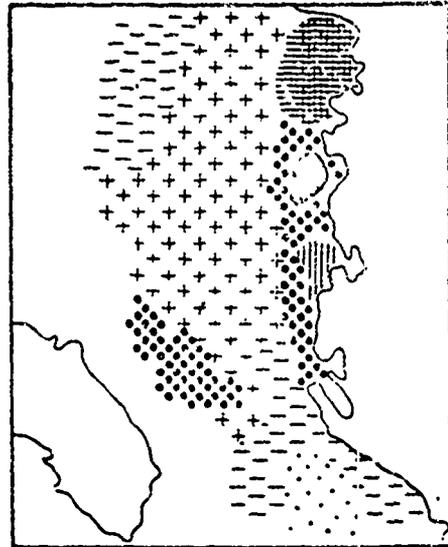


Figure 2. Distribution of the Copepoda in the Southern Adriatic during the winter of 1958 (in specimens/m³).



Figure 3. Distribution of Copepoda in the southern Adriatic during the spring of 1958 (in specimens/m³).

Condition markings are the same as in Figure 2.



During the summer, in comparison with the preceding seasons, no significant changes were observed in the qualitative content of the Copepodic plankton, or in its distribution along the aquatory (water territory) of the investigated sector of the sea. The younger age groups predominated as before, especially in the 10-m surface layer, where they comprised more than 90% of the overall quantity of the animals. The average quantity of the Copepoda in the investigated layer was equal to 1,475 specimen/m³, and the biomass to 40 mg/m³. Just as during the winter and spring time, the Copepoda was developed in largest quantities in the coastal zone, especially in the northern sectors of the investigated region (Figure 4), where their overall quantity reached 8,000 specimens/m³, and the biomass 150 mg/m³, and the foundation was, as previously, comprised of Paracalanus, Acartia, Clausocalanus and other small Copepoda.

The distribution of the autumn zooplankton in the region of the southern Adriatic is presented in Figure 5. From the chart one can see that the plankton of the coastal zone and more distant regions differs little from a quantitative standpoint. Analyzing its distribution along the coast, we see that again, the northern sectors of the investigated regions are the richest in Copepoda. In the upper 10-m layer the plankton was distributed more or less evenly in the direction of the open sea,

as well as in the direction from north to south; its quantity and biomass were 3000 specimens/m³.

The average quantity of Copepoda in the entire investigated layer comprised for the region 1700 specimens/m³ with a biomass of 37 mg/m³.

In Table 1 is given the distribution of the biomass of the Copepoda in the coastal part of the sea and in the open regions of the southern Adriatic according to the seasons of 1958.

Table 1

Change of the Copepoda biomass (in mg/m³) of the southern Adriatic in 1958

Horizon (in m)	Winter		Spring		Summer		Autumn	
	1	2	1	2	1	2	1	2
0-10	33	16	75	39	42	21	38	40
10-25	28	22	53	38	42	20	38	60
25-50	21	21	28	28	30	18	26	45
50-100	—	17	—	14	—	16	—	20
100-200	—	12	—	6	—	10	—	11
Average for investigated layer	23	16	60	16	35	14	31	28

1 - Coastal region; 2 - Open sea.

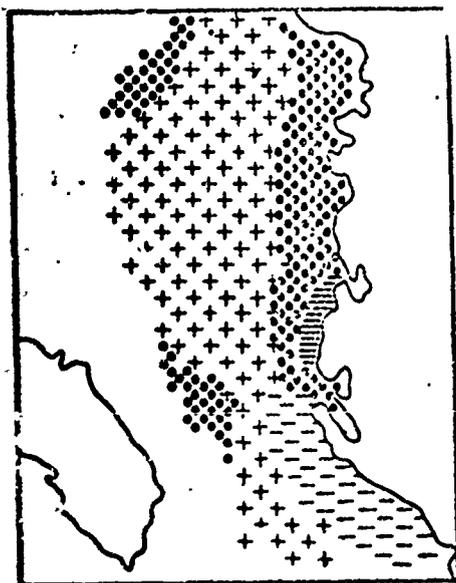


Fig 4. Distribution of the Copepoda in the southern Adriatic during the summer of 1958 (in samples/m³).

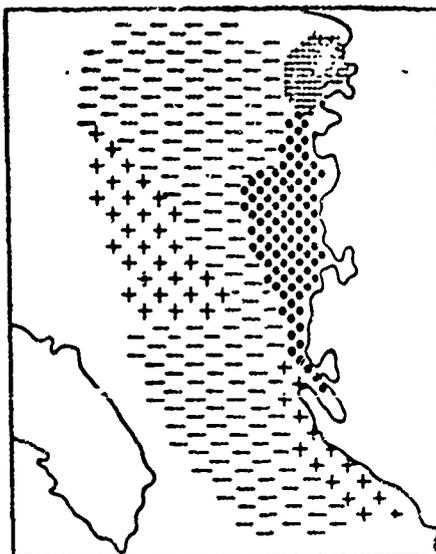


Fig 5. Distribution of the Copepoda in the southern Adriatic during the autumn of 1958.

The Vertical Distribution of Copepoda

In Table 2 is presented the vertical distribution of Copepoda of the southern part of the Adriatic Sea according to the seasons of 1958.

Table 2

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Vertical distribution of Copepoda (in specimens/m³) of the southern Adriatic according to the seasons of 1958.

Family group	in m					
	10-0	25-10	50-25	100-50	200-100	среднее в слое 0-200
Winter						
Calanoida	1371	981	675	517	184	746
Oithonidae	131	148	140	145	206	164
Oncaeiidae	43	101	113	82	81	84
Corycaeiidae	58	48	52	55	17	46
Total	1651	1278	980	799	487	1046
Spring						
Calanoida	3317	1829	735	474	193	1193
Oithonidae	580	660	746	545	136	432
Oncaeiidae	85	88	15	38	16	27
Corycaeiidae	89	65	46	32	20	34
Total	4027	2599	1499	1075	354	1668
Summer						
Calanoida	1593	1335	743	956	354	1198
Oithonidae	269	358	330	134	137	134
Oncaeiidae	76	132	105	122	173	109
Corycaeiidae	89	65	46	32	20	34
Total	2027	1890	1224	1244	684	1475
Autumn						
Calanoida	2418	1974	1259	759	322	1362
Oithonidae	326	326	427	168	147	204
Oncaeiidae	74	77	94	72	34	69
Corycaeiidae	80	100	80	27	17	49
Total	2898	2477	1860	1026	590	1684

The presented data indicate that the maximal quantity of Copepoda can be observed during all the seasons in the upper 25 m layer. During the winter this is caused here by relatively large concentrations of large calanuses (*Calanus gracilis*, C.

minor, Euchaeta hebes) and other organisms, which during the winter homothermium rise into the upper layers. During the rest of the seasons with the increase in water temperature, the quantity of small Copepoda, which constantly dwell in the upper layers and migrate very weakly also increases. They include the Clausocalanus, Paracalanus, Centropages, Acartis, Oithona, etc.

The quantity of Copepoda decreases as the depth increases. It reaches minimal values during all periods at the 200 to 100 m horizon.

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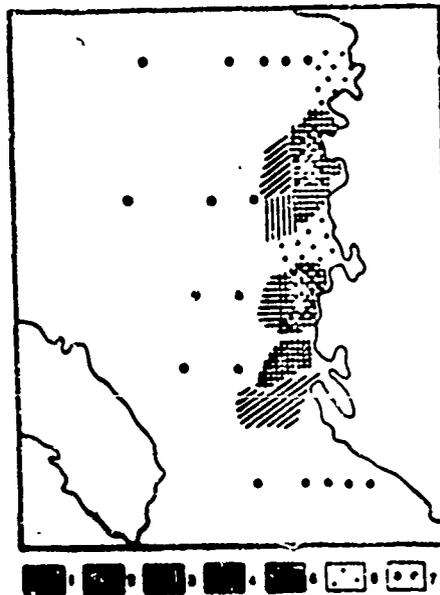
Distribution of Sardines and Copepoda

As a result of research, it has been found that during February, March and April of 1958 the sardines were mainly distributed in a comparatively narrow coastal strip of the sea, along the entire eastern coast of the southern Adriatic, from the estuary of the Mati River to Volara Bay where, above the depth of 20 to 120 m, the main spawning of the sardines also took place (Figure 6). In the catches of the fish roe net made above great depths, no sardine roe was included. The water temperature in the regions where the roe is found fluctuates from 13° to 14° and the salinity was 39‰. Along the Yugoslav coast the spawning of the sardines also took place above the depths up to 120 m, with a water temperature of 13.8 to 15.4°.

Figure 6. Distribution of sardine roe eggs in the southern Adriatic during February 1958. (Data of the Azov-Black Sea Fisheries Science Research Organ.)

Number of roe eggs caught during 10-minute surface layer dredging with a roe net:

- 1) 200-500;
- 2) 100-200;
- 3) 50-100;
- 4) 20-50;
- 5) 10-20;
- 6) 1-10;
- 7) no sardine roe was detected.



In Figure 6 is presented the quantitative distribution of sardine roe in the waters of the southern Adriatic in March of 1958, according to the data collected on the basis of 10-minute catches made with a roe net in the surface water layer. During this period a relative small quantity of sardine roe was caught - in the catches made by the roe net where were no more than 500 roe eggs, and the roe was distributed throughout a comparatively small aquatory (water territory). It is possible that a more intensive sardine spawning took place during an earlier period. In the central Adriatic (Gamulin, Karlovac, 1957), a considerably greater concentration of sardine roe was observed than in the southern part of the sea.

During the spring as well as in winter the sardines are distributed in the coastal part of the sea. Shoals of it have often been noticed in the Vlora region above the depths up to 50 m. A considerable accumulation of sardines was detected in the region of Cape Lagit. It turned out to be quite stable and remained there from the beginning of May to the end of November.

During the summer the sardines were also distributed in the coastal strip of the sea, up to the isobath of 50 to 70 m. South of Vlora no accumulation of sardines has been observed during the summer season.

In July, August, and September 1958, in the coastal waters of the southern Adriatic four main concentrations of sardines were constantly noted: in the region of Vlora, at the estuary of the Shkumbini River, at the Cape Lagit, and at the estuary of Mati River.

During the summer, following the considerable heating of the water of the 10-m surface layer, the sardine descends to the temperature jump layer and to the layers of the water stratum below, up to the isobath of 50, and sometimes even 70 m.

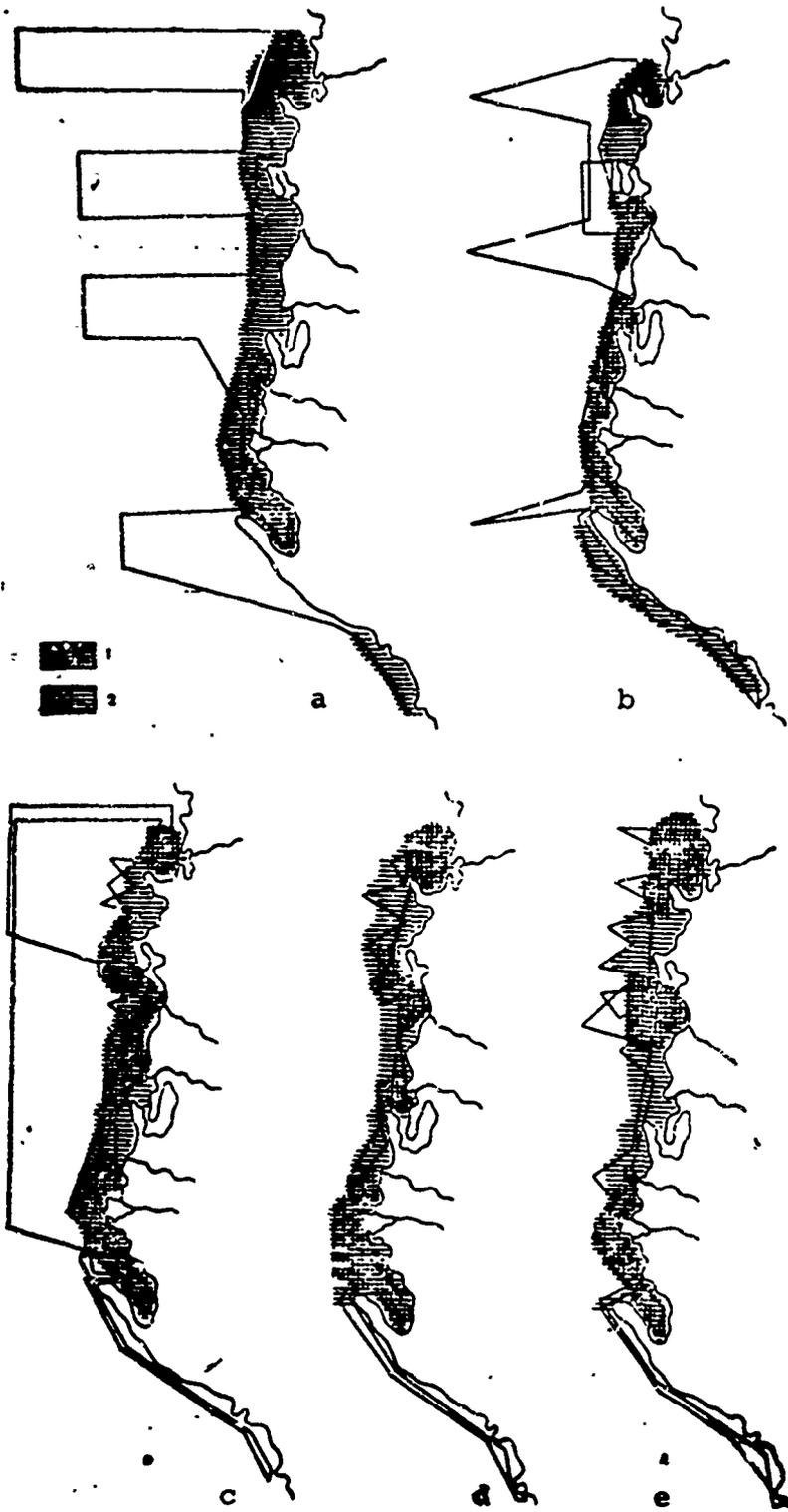


Figure 7. Distribution of the sardine in the southern Adriatic in 1958 (according to the materials of Az Cher NJRO).

a - in February; b - in May; c - in July; d - in August; e - in October

1) Frequency of sardine shoal encounter at a distance of less than 200 m.

2) Frequency of sardine shoal encounter at a distance from 200 to 500 m.

No significant changes in the distribution of sardines were observed during October-November.

The above information leads to the conclusion that the sardines were found everywhere in the southern Adriatic during the entire year, in the 10 to 15 mile coastal strip, in the sector from the estuary of the Mati River up to Saranda, at the depths mainly from 20 to 60 m (Figure 7). In the open regions of the

sea, beyond the confines of this zone, sardines have not been observed in quantities large enough to be of interest for commercial fishing (Babajan, Gololobov, Revin, 1959). Therefore, the sardine concentrations are situated in the regions of maximal development of the Copepoda, which, it seems, are one of the main factors determining its distribution in the southern part of the Adriatic Sea.

Even Lucas (1936) and Henderson (1936) noted the positive correlation between the quantity of herring and zooplankton. It is also true that they noted that herring probably avoid dense accumulations of medusa (Lucas, a. Henderson, 1936). According to our observations, sardines were not rare in the regions of mass development of medusas (jellyfish), salp, and siphonophores. It is possible that the sardine leaves the regions of intensive development of zooplankton unfit for food, but only in cases when this coincides with an insufficient quantity of food plankton. In the given case the sardine could probably find food by descending to deep layers, up to 50 m, where the plankton unfit as food (salpa, siphonophora, medusas, etc.), is rarely found. Such a case was observed for herring (Manteyfel, 1941) feeding at a certain depth, under the zone of plankton "bloom."

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Conclusion

1. The Copepoda of the southern Adriatic attain a considerable species diversity. During the winter season large species dominate, among them: *Calanus minor*, *C. gracilis*, *Euchaeta hebes*, *Pleuromamma*, as well as *Oithona similis* and *O. setigera* among the small crayfish. During the rest of the seasons small copepoda predominate - *Clausocalanus arcuicornis*, *C. furcatus*, *C. paululus*, *Ctenocalanus vanus*, *Paracalanus parvus*, *P. nanus*, *Oithona*, *Oncaea*, *Corycaeus*, etc.

2 The average quantity and biomass of the copepoda in the southern Adriatic differs little in the entire investigated

layer - from 1046 samples/m³ to 1700 samples/m³, and from 30 to 50 mg/m³. In the 0 to 10 m layer their quantity and the biomass increases considerably from winter to spring, and then decreases.

3. During all the seasons, among the plankton of the southern Adriatic predominated sexually immature stages of the copepoda, which often comprise 90% of their total number.

4. During the seasons of zooplankton Copepoda was richer in the coastal zone of the investigated region, especially in its northern part. This, most probably, depended on the local river runoff, which enriches the coastal waters with biogenic substances, which causes intensive development of the phytoplankton - the fodder base of the plankton Copepoda.

5. During the entire year the Copepoda are most abundantly represented in the upper 50-m layer. Their minimum is noted at a depth of 100 to 200 m.

6. The spawning, feeding, as well as active fishing for the sardines, the main plankton eating fish of the Adriatic, occurred in the regions which were the richest in zooplankton and in particular in Copepoda.

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CERTAIN DATA ON THE QUANTITATIVE DEVELOPMENT OF THE MARCO
AND MERIBENTHOS IN THE EASTERN PART OF THE MEDITERRANEAN SEA

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by

M. J. Kiseleva, and
V. P. Chukhchin

* The population of the bottom of the Mediterranean Sea has been studied only slightly from the quantitative standpoint. The expeditions of the end of the XIXth century (English - "Porcupine," 1870; French - "Travailleur," 1880-1882; the trips of the yacht "Princess Alice" of the Prince of Monaco, expedition of the "Pola," 1890-1891) have a faunistic character.

The biocenotic investigations of the benthos in the eastern part of the Mediterranean Sea were conducted on the expedition ship "Calipso" by F. Peres and F. Picard in 1954-1955. As a result of this work descriptions of the biocenoses of benthos were made of the coastal sectors of the Sicilian-Tunisian Region and of the Aegean Sea (Peres 1956; Peres and Picard, 1958).

The quantitative data, however, on the benthos of the Mediterranean Sea are very meager. In 1931, Spaerk (1931) published data about the biomass of the benthos on the western shore of Italy and in the Algerian Bay. In 1935, Vatova presented quantitative data about benthos around Alexandria (Vatova, 1935). Only the Adriatic Sea (its northern and central region) has been studied well as a result of the multiyear work of Vatova (1949).

But even the data which is available on the quantitative development of benthos pertains fully only to the macroforms. The meribenthos with a form not larger than 1 mm in length, were not taken into account by anyone. Meribenthos, as a rule, is counted in large numbers (tens of thousands, and in certain cases even hundreds of thousands of specimens per m^3), therefore the role of the Meribenthos organisms in the life of the

sea bottom must be quite significant. Many components of the meiobenthos (Nemertoda, Polychaeta) which swallow and process the ground through the intestines, change the ground in a certain way. As is well known from the bibliographical data, during the capitulation of ground their structure changes; enrichment of the soil with mucus, which facilitates a flourishing development of bacterial life (Rauser-Charnousova, 1935). Peres (1961) stresses the great significance of the microbenthos forms in the feeding of many organisms of macrobenthos.

From the above information the necessity for the quantitative determination of the microbenthos become apparent. The first information about the quantity of microbenthos in the Aegean Sea and in the eastern part of the Mediterranean Sea is contained in the works of M. I. Kiselova (1961, 1963) and V. D. Chukhchina (1963).

In the present article, data on the quantity of the microbenthos in the southern part of the Adriatic Sea is presented along with comparative material on the quantitative development of the microbenthos in the Aegean, Adriatic, and Mediterranean Seas.

In the eastern part of the Mediterranean Sea, in 1958-1961, on the expedition ship Academician A. Kouvalievskiy, and in 1959 on the expedition ship Academician S. Vavilov, 112 stations were made at depths from 12 to 2740 m. The samples were collected by "Okcan" Petersen's bottom scrapers, and Sigsbee's trawl. The collection and washing of the samples were conducted according to the generally accepted method. In order to catch the microbenthos forms, a bag made of miller's gauze No. 49 was attached to the lower sieve with cells 1 mm^2 .

The low density of the population of the benthos in the eastern part of the Mediterranean Sea (excluding the Adriatic) made it impossible to distinguish well pronounced biocenoses.

Therefore, description of the benthos is given according to the sand biotopes, crushed lithotamnium, silty sand, sandy silt, and silt. A short description of benthos in the enumerated biotopes is presented in Table 1.

Table 1

Number of species, quantity and biomass of benthos in certain seas of the Mediterranean Sea Basin.

Sea	Biotope	Total number of species in the biotope and average no. of species at the station [in ()]	Average quantity of the entire benthos and microbenthos, in samples/m ²	Average biomass mg/m ²
Black Sea (southern shore of Crimea)	Sand	53 (18)	43 900 (35 000)	326.5
	Silty sand	41 (24)	11 050 (9 520)	59.6
	Sandy silt	36 (31)	32 200 (27 370)	211.4
	Silt	71 (25)	24 140 (21 670)	135.4
Aegean Sea	Sand	61 (10)	2950 (2840)	3.4
	Silty sand	48 (11)	9900 (9300)	2.4
	Lithothamnium	36 (15)	5350 (1700)	5.2
	Sandy silt	33 (14)	700 (500)	1.5
	Silt	51 (5)	850 (820)	2.0
Adriatic Sea (southern part)	Silty sand	27 (27)	42 550 (11 180)	5.2
	Sandy silt	45 (21)	6590 (5100)	7.3
	Silt	97 (35)	35 070 (34 050)	7.7
Mediterranean Sea (eastern part)	Sand	14 (9)	870 (700)	3.2
	Silty sand	28 (15)	8150 (8100)	2.5
	Sandy silt	38 (26)	8940 (6400)	7.1
	Silt	27 (1)	72 (57)	1.3
Mediterranean Sea (Pre-suez region)	Sand	10 (4)	150 (100)	0.3
	Silty sand	19 (19)	22 920 (18 700)	—
	Silt	39 (12)	4000 (3650)	15.9

The population of the sand biotope. The greatest variety in species of the sand biotope was observed in the Aegean Sea. The sands in the Aegean Sea were noted in the Pre-dardanelles and central regions of the sea at depths from 40-200 m. The

ecological conditions of the mentioned depths are somewhat different, and this, it seems, made it possible to find favorable conditions for the habitating of a large number of species in this biotope. The quantity of species on individual stations fluctuates from 4 to 17, and the average is 10. Depending on the location of the region in which a station was established the groups whose biomass predominated in the sand biotope of the Aegean Sea are different. They are especially varied in the Pre-Dardanellis region. The leading groups in individual stations were Spongia, Mollusca (*Dentalium dentale*, *Meretrix* sp.), Echinodermata (*Ophiothrix fragilis*, *Amphiura filiformis*, *Ophiura lacertosa*), Tunicata (ascidiums of the type *Eudistoma* sp.).

In the sand biotope of the central region of the sea the Bryozoa and Echinodermata (*Leptometra falangium*) can be considered the dominant groups. In the Mediterranean Sea the sand biotope was found in the region of the Tunisian Strait and in the Pre-Suez region. The overall number of species in the sand biotope in the Mediterranean Sea is considerably smaller than in the Aegean biotope, but the average number of species according to stations is approximately the same as in the Aegean Sea. The sand biotope of the Pre-Suez region of the Mediterranean Sea is very poor in species content. The leading groups according to biomass in the biotope of the Tunisian Strait can be counted as Spongia and *Ascidia-Aarocium* sp. In the Pre-Suez region the leading group were the Mollusca. /194

The maximal quantity in the sand biotope was found in the Aegean Sea, and the maximal mineral quantity was noted in the Pre-Suez region of the Mediterranean Sea. As a rule, the quantity of the benthosic animals consists mainly of the benthos forms, which in individual cases surpass the quantity of forms

of the macrobenthos several hundred times. In the sand biotope of the Aegean Sea among the microbenthos forms were noted the Nematoda, Harpacticoida, small Polychaeta (Syllidae). Their quantity on individual stations fluctuates from 300 to 9000 samples/m², and the average was 2840. In the Pre-Suez region of the Mediterranean Sea in the biotope with the same name the quantity of microbentos was found from 25 to 300 samples/m², and the average 102. The Nematoda and small Polychaeta were found here.

The sand of the Aegean Sea on certain stations had varying degrees of maturity. The admixture of silt had a favorable influence on the development of the infauna, in particular of microbenthos. In the Pre-Suez region of the Mediterranean Sea the sand was clean without silt particles, and small forms of infauna are represented very weakly here.

The population of the silted sand biotope. The silted sand biotope was noted in all the seas, but in the southern part of the Adriatic Sea and in the Pre-Suez region of the Mediterranean Sea in this biotope only one station for each was taken, therefore, the given data for these seas must be viewed as preliminary and orientational. The greatest quantity of species in the silted sand biotope as been noted in the Aegean Sea. At the same time the number of species on the stations fluctuated from 2 to 24, with an average of 11. The leading groups in the silted sand biotope of the Aegean Sea were the Polychaeta (*Nephtys* sp., *Paraonis neapolitana*, *Hyalinoecia bilineata*) and *Ascidia* (*Phallusia fumigata*).

In the southern part of the Adriatic Sea 27 species of benthos animals were noted; those leading to biomass were the Polychaeta (*Nephtys hombergii*, *Chloeia venusta*, *Notomastus profundus*). The same group was the leading one in the silty clay biotopes in the Sicilian-Tunisian Strait and in the Pre-Suez region of the Mediterranean Sea.

The maximal quantity of benthos in the silted sand biotope was noted in the Pre-Suez region - 22,920 specimens/m²; at the same time, 18,700 specimens/m² consisted of Nematoda. In the remaining seas the quantity of benthos in the silty sand biotope was approximately the same (8 to 12 thousand specimens/m²) and was also composed mainly of Nematoda.

The population of the crushed lithothamnium biotope. This biotope was noted only in the Aegean Sea and in the region of the Sicilian-Tunisian Strait. According to the number of species, quantity and biomass the biotopes of these two regions are similar, even though the biotopes of the lithothamnium in the Mediterranean Sea are somewhat richer (especially according to the average quantity of species at the station). The leading forms according to the biomass were in the Aegean Sea: Mollusca (*Cardium* sp., *Dentalium* sp.), and Ascidia (*Ciona intestinalis*), in the Sicilian-Tunisian Strait - Polychaeta (*Eunica vittata*, *Hysidice minetta*), Coelenterata (*Eunicella verrucosa*, *Caryophylla cyanthus*).

The meiobenthos in the biotope of the lithothamnium is represented quite abundantly: its average quantity in the Aegean Sea reached approximately 5000 specimens/m², in the Mediterranean Sea - more than 6000 specimens/m². Unlike the preceding biotope, the microbenthos here was represented not only by Nematoda, but to an equal extent by small crayfish types (*Harpaeticoida*, *Tanaidae*, *Ostracoda*) and small polychaetas.

Population of the sandy silt biotopes is described by us only in two seas: the Aegean and the southern part of the Adriatic Sea. The sandy silt biotope in the southern part of the Adriatic Sea according to the number of species, quantity, and biomass is richer than the biotope of the same name in the Aegean Sea. The leading groups in the sandy silt biotope of the Aegean Sea were the Echinodermata (*Amphiura filiformis*), Polychaeta (*Terebellides stroemi*, *Nephtys* sp., *Hyalinoecia*

bilineata), in the Adriatic Sea - Echinodermata (*Amphiura filiformis*, *Amphiura mediteoranea*, *Brissopsis lyrifera*).

The microbenthos in the mentioned biotope of the Aegean Sea was quite poor; on the average 500 specimens/m², and consisted only of Nematoda and small Polychaeta. In the southern part of the Adriatic Sea in the sandy silt biotope the quantity of microbenthos on the average comprised 5100 specimens/m². Here, besides the Nematoda and Polychaeta, small Ophiura and Hydracarina were noted.

The population of the silt biotope. The silt biotope was noted in all the seas. The greatest species in variety in the silt biotope was observed in the southern part of the Adriatic Sea. Here also they were found in the greatest quantities. The leading groups according to biomass, on individual stations, in the silt biotope of the Adriatic Sea were the Polychaeta (*Sternaspis scutata*, *Lumbriconereis latreilli*, *Notomastus profundus*) and Echinodermata (*Brissopsis lyrifera*).

The smallest quantity of species has been observed in the central part of the Mediterranean Sea. The average quantity of species at the stations is especially low here. This is explained by the fact that at certain stations, at great depths, no benthos animals were detected in the bottom scraper. During the calculation of the average values these stations were taken into account, therefore, average data on the number of species, quantity, and biomass in the silt biotope in the Mediterranean Sea turned out to be very low.

The silt biotope of the Aegean Sea is very poor. Even though the overall number of species is considerable (51) here, the number of species at individual stations is not large - from 3 to 14, and the average is 5. The average quantity and biomass in the silt biotope of the Aegean Sea are also low. In the silt biotope of the Aegean Sea microbenthos is comparatively weakly developed. The maximal quantity of microbenthos in this

biotope of the Aegean Sea is 3000 specimens/m², with an average of 820 specimens/m². The microbenthos of the Aegean Sea is mainly represented by the Nematoda and small Polychaeta. The Harpacticoida, Cumacea, Tanaidae, Hydracarina are encountered very seldom. The Ostracoda and Kinorhyncha have not been found in the samples even here.

A completely different impression is made by the microbenthos of the silt biotope of the Adriatic Sea and of the Pre-Suez region of the Mediterranean Sea. It should be noted that the silt in these regions does not lie at great depths, as can be observed in the other seas, but occupies the coastal region (15 to 60 m depths). The river silt deposits, rich in organic matter, are situated in direct proximity to the shore, creating here very favorable conditions for the development of small forms of benthos.

Here the maximal quantity of microbenthos, noted in the silt biotope or in the Adriatic Sea, was 151,000 specimens/m², with an average of 34,000 specimens/m². In the Pre-Suez region the maximal quantity of the microbenthos is considerably lower - 13,080 specimens/m³, with an average of 3,700 specimens/m². In the Adriatic Sea and in the Pre-Suez region of the Mediterranean Sea the content of the microbenthos is very diverse. Here were noted the Nematoda, small Polychaeta, Harpacticoida, Ostracoda, Tanaidae, small Amphipoda, Cumacea, Hydracarina, and Kinorhyncha.

The highest average biomass of the benthos in the silt biotope turned out to be in the Pre-Suez region - almost 19 g/m². The group that predominates here in biomass was the Echinodermata (*Brissopsis lyrifera*). Therefore the depth silts of the Aegean Sea and the central region of the eastern part of the Mediterranean Sea are inferior in biomass and quantity to the coastal silts of the Adriatic Sea and the Pre-Suez region of the Mediterranean Sea.

Characterizing the fauna of the benthos of the eastern part of the Mediterranean Sea, it is possible to say that the group that predominates in biomass in the Aegean Sea are the echinoderms, in the southern part of the Adriatic Sea and in the Mediterranean Sea worms (Table 2). The microbenthos, rich in species content, is encountered in the Adriatic Sea in the Pre-Suez region of the Mediterranean Sea. In the Aegean Sea and the central part of the Mediterranean Sea the species content of the microbenthos is considerably poorer. Certain groups encountered in the content of the microbenthos in other regions of the eastern part of the Mediterranean Basin are absent here. The quantity of microbenthos in the Aegean Sea and the central part of the Mediterranean Sea is considerably lower than in the southern part of the Adriatic Sea and in the Pre-Suez region of the Mediterranean Sea.

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Table 2

The biomass (in %) of the main groups of benthos in the biotopes of certain seas of the Mediterranean Basin

Sea	Biotope	Worms	Crustacea	Mollusks	Echinodermae	Other groups
Aegean	Sand	11	4	23	36	26
	Lithothamnium	23	7	35	-	25
	Silty sand	29	5	13	17	36
	Sandy silt	30	3	3	45	19
	Silt	12	10	9	41	28
Adriatic (southern part)	Silty sand	88	7	2	2	1
	Sandy silt	19	4	9	67	1
	Silt	37	20	20	23	-
Mediterranean (eastern part)	Sand	9	4	12	2	73
	Lithothamnium	40	24	23	1	12
	Silty sand	42	29	24	4	1
	Silt	94	4	2	-	-
Mediterranean (Presuez region)	Sand	23	13	64	-	-
	Silty sand	72	14	7	7	-
	Silt	4	1	2	88	5

As was already pointed out, the bibliographical data on the biomass of benthos of the eastern part of the Mediterranean Sea belonged only to the northern and central Adriatic and to the region of Alexandria (Vatova, 1935, 1949). For the northern part of the Adriatic Sea Vatova obtained a biomass of up to 400 g/m². At Alexandria, the biomass is presented as 550 g/m². It should be said that the latter figure does not belong to the open sea, but to the port of Alexandria where the bio-caenosis of Tapes aureus was found. At Alexandria, in the open sea, according to our data, just as in the regions of the the Mediterranean Sea, the benthos biomass is low and does not exceed several grams per m². On the presented schematic chart of the benthos biomass distribution in the eastern part of the Mediterranean Sea, one can see that the insignificant increase of the benthos (macro, as well as meiobenthos) is so insignificant that it could not be caught by the bottom scraper and the biomass was here equal to zero (Figure 1).

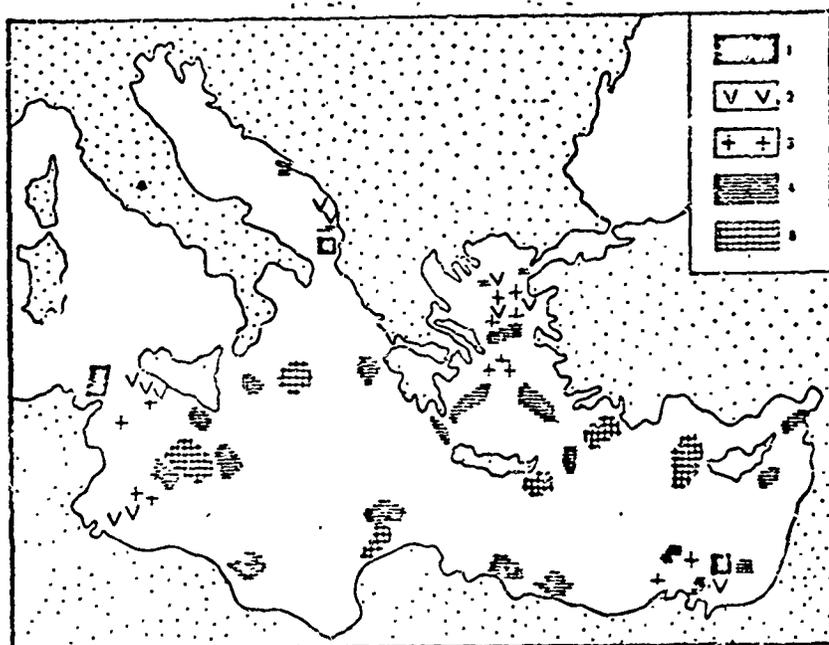


Figure 1. The distribution of the benthos biomass (in g/m³) in the eastern part of the Mediterranean Sea.

- 1) more than 10; 2) 5-10; 3) 1-5; 4) < 1;
b) benthos was absent.

The increase in benthos in the Aegean Sea at the entrance into the Sea of Marmara, which was assumed to exist by L. A. Zenkevich (1951), was not encountered. A very strong current shifting hard ground, turned out to be unfavorable for the benthos development here. Therefore, in this region of the sea the benthos biomass is lower than in the more southern sectors of the Aegean Sea.

In order to compare the obtained values of the benthos of the Mediterranean Sea with the data for the Black Sea, we present data in Table 1 on the number of species, average quantity and biomass of the benthos of the southern shore of the Crimea, in the biotopes which were analogous to the Mediterranean biotopes. From the Table one can see that according to the number of species the Black Sea is inferior to certain seas of the Mediterranean Basin, and probably, with larger material for the Mediterranean Sea, the quantity of species in all the biotopes of the Mediterranean Sea will be greater than in the Black Sea. But the quantity of benthos in the Black Sea in certain biotopes considerably exceeds the quantity of benthos in the Mediterranean Sea, and the biomasses of the benthos in all the biotopes of the Black Sea exceeds by several dozens of times the benthos biomass in the corresponding biotopes of the Mediterranean Sea.

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BIOCAENOSESSES OF CYSTOSEIRA AND POSIDONIA
 IN THE AEGEAN AND ADRIATIC SEAS

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by

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Of great significance in the productivity of the sea are the macrophytes, which form homogeneous overgrowths. Such overgrowths are represented mainly by the fucus sea weeds (cystoseiras, fucuses, laminarias) and phanerogamous plants from the Zosteraceae family, to which belong three genera: zosteria, posidonia and cimodocea. The overgrowth biocaenoses in the Mediterranean Sea are represented by seaweed biocaenoses, as well as by the phanerogamous plants.

The structural properties of thallus of the macrophytes create favorable conditions for the existence here of numerous animals and plants. In the overgrowths it is easy to hide from enemies, and easy to hold on during a storm. The overgrowths also have an abundance of food staples. But a large group of animals, firmly attached to the plants (Bryozoa, Hydrozoa, Polychetas, and Foraminifera), does not depend on the seaweeds for its food. These are mainly filtrators, which feed on plankton and which are using the plants only as a substratum. Therefore, among the seaweeds (algae) one often encounters the same types of filtrators, as on the rocks. Nevertheless, somewhat different ecological types live on the macrophytes - smaller animals and the large bushy forms with heavy skeletons are absent here. Large organisms of spherical and cylindrical forms are also absent. The majority of the mobile animals find their food objects in the macrophyte overgrowths. The representatives of this group are typical inhabitants of the overgrowth biocaenoses and are not usually encountered on cliffs.

The main overgrowth forming biocaenoses in the Black Sea are the biocaenoses of the phyllophora and Cystozeira. As was shown by the species content of these biocaenoses, the commonness of species coefficient between the zoocaenoses is

considerably high and comprises 59.5%. Nevertheless, the diversity of species, quantity, and biomass are more significant in the overgrowths of *Cystoseira* (Makkaveyeva, in print).

From 1958, the program of investigations of the Sevastopol Biological Station included the study of benthos of the Mediterranean Sea, including zoocaenoses of the macrophytes. During the period of investigations of 1958-1958 made by the expedition ship Academician A. Kovalevskiy in the Aegean Sea, in the regions of the islands of Lemnos and Milos, overgrowths of Posidonia oceanica were detected which were lying at a depth of 27-50 m (the collection of the material was done with a trawl and a trawlgraph).

The biocaenosis of the Posidonia in the Aegean Sea was not previously studied, but there are published works on the biocaenosis of *Posidonia* of other regions of the Mediterranean Sea. For example, Issel (1912) described the biocaenosis of *posidonia* in the region of Portofino; Bauer (Bauer, 1929) described it in the region of Napoli and Ravigno; Benacchio and Vatova (Benacchio, 1938, Vatova, 1939) in the region of the northern and middle part of the Adriatic Sea; Gautier and Kerneis (Gautier 1957, Kerneis, 1960) in the bay of Lyonsm and Ledoyer (1962) in the region of the port of Bandol and Brusik Lagoon.

The majority of the named authors did not pay any attention /199 to the forms of the bottom fauna, which lives in the overgrowths, and to the species content of such groups of Crustacea as Amphipoda and Tanaides. Therefore in our investigation special attention was devoted to meiobenthos (sizes up to 1 mm). In order to consider the entire meiobenthos, the *Posidonia* obtained by trawling was washed over a bag made out of miller's gauze. In order to make quantitative calculation of the meiobenthos, the fixed sediment was poured into a measured liter cylinder, the

level of liquid in which was made equal to 1 liter. After thorough mixing of the sediment in the crystallizer, one 1 ml was taken out of it with a plunger pipette and transferred into a glass. The individual portions were then placed onto the glass slide and were viewed in glycerine with water.

It was possible to distinguish a total of 65 species among the biocenosis of Posidonia in the Aegean Sea. Five species of Foraminifera have been discovered, among which two species were the most numerous: Quinqueloculina dilatata and Discorbina bertheloti. All the discovered species belong to comparatively small forms (mainly up to 1 mm). They attach themselves to the surface of the posidonia leaves with the help of their phlegm, which is exuded from numerous pores.

The surface of the posidonia leaves is covered with a large number of Bryozoa. We discovered 13 species in the Aegean Sea, among which the Fenestrulina malusii is encountered constantly and was constantly noted on the posidonia by all authors who studied the population of posidonia.

Among the worms in the biocenosis of posidonia of the Aegean Sea were six species of nematods, among which the most frequently encountered was the Eurystoma assimilis. Among the 10 types of polychets noted by us on the posidonia, six mainly large forms were also previously detected in the biocenosis of posidonia of other regions of the Mediterranean Sea. Numerous small forms of polychets, mainly those belonging to Sillidas, were not noted by other authors dealing with the posidonia (probably because they were not caught).

The Crustacea are the richest group of animals according to the species content in the biocenosis of posidonia. The greatest diversity of species exists within the Amphipoda and Thar-
pactidae. Over all in the biocenosis of posidonias of the Aegean Sea, 22 species of Crustacea were detected, including only four species with comparatively large forms (from 5 to 22 mm).

Six species of mollusks were encountered on the posidonia of the Aegean Sea, including two types of Loricata. Among the small mollusks the Plissoa splendida is encountered in mass, and among the large species the Turbo rugosa is encountered in mass.

Among the posidonia overgrowths two types of Echinaderma have been found - a small star, Asterina gibbosa, and a sea urchin, Sphaerechinus granularis. The former inhabits the leaves, and the latter the rhizoids of posidonia.

Among the mites only one species was discovered in the biocaenosis of posidonia - Copidognathus caudani.

The method studying the biocaenosis of posidonia in the Aegean Sea was identical to the method we used during the study of biocaenosis of the cystoseira in the Black Sea (Makkaveyeva, 1959). The methods were the same because the greatest similarity of the biocaenoses is distinguished during the study of small organisms, which we conducted, but which were almost completely absent in the works on the Mediterranean Sea of the foreign authors (excluding the Foraminifera, which in different biocaenoses of the Mediterranean Sea have been studied sufficiently well), the comparison between the biocaenoses of the cystozire from the Black Sea and of the posidonia from the Aegean Sea.

The Bryozoa is represented in the Aegean Sea, as was mentioned before, by 13 species. In the Black Sea two species are mainly encountered: Lepralia pallasiana and Boverbancia imbricata.

Among the nematodes encountered on the posidonia in the Aegean Sea and on the cystozire in the Black Sea two common species exist - Eurystoma assimilis and Draconema cephalatum. The remaining species which live on posidonia are very close

to those encountered in the Black Sea and are probably their /200 ecological variations. The species content of the polychets coincides up to 50% in both biocaenoses.

The degree of similarity is especially high between the species content of the small Crustacea situated in the overgrowth biocaenoses. Among the six species of the Amphipoda found on the posidonia of the Aegean Sea, four live in the Black Sea on the cystosire and phyllophora. Out of five species of the harpacticides, three live on cystosire in the Black Sea. The tanaid Leptochelia savignyi lives also in both biocaenoses. Among the capryllides the Caprella acantifera are common for the biocaenoses, and among the equipodae are the Stenosoma ca. to., and among the centipedes are the Hippolytae varians.

The Crustacea, which have a size greater than 5 mm, belong to the genres widely distributed on the overgrowth biocaenoses of the Mediterranean Sea, but which are generally not encountered in the Black Sea: Galathea, Alpheus, Athanas and Astacilla. If one takes into account only the small Crustacea harpacticides, Amphipoda, Caprellid, Tonaides, and Isopods, then the percentage of the commonness of the species will comprise 55%. Nevertheless, even among the small forms of Crustacea there are genres, representatives of which have not been noted even in a single biocaenose of the Black Sea. Among the Amphipoda to these should be assigned Aora, Proto, and Litopus, and among the Equipodae, the Paragnathia and Munna.

Among the mollusks two species - Rissoa splendida and Bittium reticulatum, live in the Black Sea on the cystosire, and in the Aegean on Posidonia. These are comparatively small forms. The large mollusks of the posidonia biocaenosis belong to the genres which are generally absent in the Black Sea (Turbo, Haliotis).

The Echinodermata in the biocaenosis of the Cystosira of the Black Sea were not encountered. The mites are almost without representation in the biocaenosis of posidonia of the Aegean Sea, and on the Cystosira in the less salty water of the Black Sea they are one of the most numerous groups of the meiobenthos.

If one compares the diversity of species of two biocaenoses of posidonia in the Aegean Sea and Cystosira in the Black Sea, then it develops that the species content of the harpacticides, mollusks, Ostracoda, Amphipoda and mites on the Cystosira in the Black Sea is richer than the species content of these animals on the posidonia of the Aegean Sea (Table 1). The richness of the fauna on the Cystosira can be connected with the fact that the Cystosira bush is more spread-out when compared to posidonia, and this is favorable for supporting the existence of small organisms. This phenomenon can be observed within the confines of one sea. For example, in the Black Sea the biocaenosis of the Phylophora is poorer than the biocaenosis of the Cystosira. This is explained by the fact that during equal dispersion of these of these two seaweeds the surface of the Cystosira is larger than the surface of the Phylophora. An important factor is also the fact that the biocaenosis of the Cystosira is situated closer to the shore and at lesser depths. As a consequence of this many macrophytes live on it, and consequently, also the herbivorous animals. It should also be taken into consideration that /201 the biocaenosis of the Cystosira has been studied more thoroughly than the biocaenosis of the posidonia; in particular, in the former the seasonal replacement of the species was taken into consideration.

For the biocaenosis of posidonia, Echinoderma (stars and sea urchines) are characteristic as well as a large quantity of Bryozoa, Foraminifera and a small quantity of mites (ticks). If one compares only two main groups of animals, which have

equally large significance in the life of the given biocaenoses, worms and Crustacea, than the coefficient of commonness of the species is considerably high and is equal to 60%. In order to analyze the role of macrophite-substrata and its specific properties in the formation of overgrowth biocaenoses, one should compare the biocaenoses of one type of cystosire Cystoseira barbata in the Black Sea, where the salinity is 17-18‰ and in the Adriatic Sea (Durres region), where the salinity is two times higher (38.7‰).

Table 1

The total quantity of species in the main groups of animals of the biocaenoses of the Black and Aegean Seas.

b) Группа животных		c) Черное море	d) Эгейское море
1) Nematodes	1 Нематоды	9	6
2) Polychetas	2 Полихеты	10	10
3) Mollusks	3 Моллюски	9	6
4) Echinoderma	4 Иглокожие	—	2
5) Ticks (mites)	5 Клещи	4	1
6) Crustacea	6 Ракообразные	27	22
x = Total	χ Всего	59	47

key:

b) Animal group; c) Black Sea; d) Aegean Sea.

Table 2

The quantity of macrofauna in biocaenosis of the cystoseira in the Adriatic and Black Seas.

b) Группа животных	c) Адриатическое море		d) Черное море		
	d) число организмов в 1 кг цистосиры	e) в % от общей численности	g) число организмов в 1 кг цистосиры	h) в % от общей численности	
1) Crustacea	1 Ракообразные	2764	26	28 274	77
2) Worms	2 Черви	6541	62	2 054	5
3) Mollusks	3 Моллюски	1194	12	6 553	18
x = Total quantity	χ Общая численность	10 502	100	36 881	100

b) Animal group; c) Adriatic Sea; d) Number of organisms, in 1 kg of cystoseira; e) in % of total quantity; f) Black Sea; g) Number of organisms in 1 kg of cystoseira; h) In % of total quantity.

The species content of the fauna in the overgrowths of cystoseira of the Black and Adriatic Seas turned out to be surprisingly similar, considerably more similar than the fauna of the posidonia in the Aegean Sea. The main differences consisted in the quantitative aspect of the different groups. For example, in the Black and Adriatic Seas the Crustacea predominating quantitatively on the cystoseira are the tanaides - *Leptochelia savignyi*. Among the Amphipoda and Isopods in the Black Sea of the greatest quantity are the *Amphithoe vaillanti* and *Idothea baltic*, and in the Durres bay first place is occupied by *corophium acutum* and *Dynamene bidentata*. The quantity of *D. bidentata* reaches 1000 specimens per 1 kg of cystoseira. In the Black Sea the quantity of this species is comparatively low and never exceeds more than ten specimens per 1 kg of seaweeds.

Among the mollusks in both biocoenoses the representatives of the *Rissoa* genus predominate. Nevertheless, only one type lives in the Black Sea - *Rissoa splendida*, and three live in the Adriatic: *R. lineolata*, *R. variabilis*, and *R. guerinii*. But the quantity and biomass are greater in the flower. *Lamelibrachia Brachyodontes lineatus* have the highest density in the Black Sea. In the Dwores Bay these species are absent, but there are many gymnobrachial mollusks (1150 specimens per 1 kg of cystoseira).

When comparing quantitative data for one season of the biocoenoses of the cystoseira of the Adriatic Sea and Black Sea, the quantity of the macrofauna in the Black Sea is considerably higher than in the Adriatic Sea (Table 2). Quantity-wise the Crustacea predominate in the Black Sea, and in the Adriatic Sea the worms predominate. According to the biomass the mollusks (as the largest forms) occupy first place in both sides; the second place is occupied by Crustacea and the third by the worms. The figures of percentage correlation of the biomasses of these

groups of animals are very similar for both seas. Similar correlation of the biomass is presented by Vatova (1949) for the benthos of the northern part of the Adriatic Sea (Table 3).

Table 3

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The macrofauna biomass in the biocaenosis of the cystoseira of the Adriatic and Black Seas

Animal group	Adriatic Sea		Black Sea		
	In mg per 1 kg of cystoseira	In % of total biomass		In mg per 1 kg of cystoseira	In % of total biomass
		Our data	Vatova's data		
Mollusks	1385	35	87	41,771	85
Crustacea	191	12	8	4,380	9
Worms	49	3	5	5,053	6
Total	1625	100	100	49,204	100

Table 4

The quantity of meiobenthos in the biocaenosis of cystoseira of the Black and Adriatic Seas

Animal group	Quantity of organisms per 1 kg of cystoseira	
	Black Sea	Adriatic Sea
Harpacticides	173,000	41,000
Nematodes	56,000	13,000
Turbellarii	27,000	8,000
Polychetas	37,000	6,000
Ticks (mites)	25,000	2,000
Ostracoda	1,000	1,000

During the conversion to 1 kg of cystoseira, the biomass of animals in the Adriatic Sea is considerably lower than in the Black Sea. The biomass of the worms when converted to 1 kg of cystoseira in the Adriatic Sea is lower than in the Black Sea by 62 times, the mollusks by 40 times, and the Crustacea by 23 times.

The meiobenthos were the harpacticides, nematodes, small polychetas, turbelliaria, mites and Ostracoda, in the biocaenosis of the cystoseira of the Black Sea is also considerably richer than in the Adriatic Sea. In both seas the harpacticides and nematodes were in the greatest quantity, but in the Black Sea the quantity of both is approximately four times larger than in the Adriatic Sea; the quantity of turbelliaria in the Black Sea is three times larger; the quantity of polychetas is six times larger and of the mites (ticks) twelve times larger than in the Adriatic Sea; and finally, the quantity of Ostracoda per 1 kg of cystoseira is the same in both biocaenoses (Table 4).

Preliminary conclusions which can be made comparing the mentioned overgrowth biocaenoses, will be confined to the following:

1. The overgrowth biocaenoses of the seas of the 203 Mediterranean basin have many common types, especially among the small forms.

2. The overgrowth biocaenoses in the Black Sea from a quantitative standpoint are richer than the biocaenoses of cystoseira in the Adriatic Sea and posidonia in the Aegean Sea.

3. In the formation of the overgrowth biocaenoses the form of the macrophite-substratum thallus plays the leading role. Therefore, in the seas with different salinity, on one type of macrophite-substratum exists a more similar fauna than on different species of macrophites in the seas with similar salinity.

4. The more branched out thallus of the macrophite facilitates the development of a richer fauna.

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CERTAIN PATTERN SEQUENCES IN THE DISTRIBUTION OF
THE FISH ROE EGGS AND LARVAE IN THE MEDITERRANEAN SEA

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by

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The beginning of the study of the ichthioplankton of the Mediterranean Sea belongs to the eighties of the XIX century.

After Raffaele (1887, 1888) described several dozens of species of the pelagic roe and larvae of the fish from the Neapoli Bay, the study of the Mediterranean ichthioplankton assumed a systematic character.

Almost simultaneously with the work of Raffaele appeared the works of Lo-Bianco (1888-1889), Grassi (1896), Sanzo (1905), Fage (1907), Taning (1918), Ege (1918), Jespersen (1915), D' Ancona (1928), Sparta (1924), etc.

Along with the description of the morphological peculiarities of the roe eggs and larva of different species of fish were studied their distribution, conditions of development, time of appearance in the plankton, and floating ability. In the numerous issues of the Italian Sea Study Committee are contained detailed data on the development of the roe and larvae in the reproduction of fish in the Messina Strait region as well as in other regions. In 1931 and 1956, a monograph on the roe and larvae of the fish in the Neapolitan Bay has been published, in which multiyear results of investigations of many scientists are summed up (D' Ancona, Sanzo, Bertolini, Sparta, etc., 1931-1956).

The extensive investigations on the morphology and distribution of the larvae of many fish were conducted by the Danish oceanographic expedition in 1908-1910 in the open regions of the Mediterranean Sea.

At the present time the study of the ichthioplankton of the Mediterranean Basin is conducted by the Split Oceanographic Institute, Albanian Fisheries Station in Durres, and by the Messina Sea Study Institute, where this work is headed by a great

specialist in the area of ichthioplankton study, Antonio Sparta. The laboratory of the Antonio Sparta continues the ecological-morphological direction of investigations of the Naples zoological station, conducting mostly experimental work and observations on the distribution of roe and larvae in the coastal regions.

The collection of the ichthioplankton during the Mediterranean expeditions of the Sevastopol Biological Station of 1958-1961 has been conducted at 117 stations (Figure 1). The method of roe and larvae collection was the commonly accepted one. A large plankton net made out of No. 20 gauze with an outside diameter of 80 cm and an inside diameter of 113 cm was used. At every station a series of horizontal catches at 0, 10, 25, 75, 100 and 125 m, and sometimes at 200 and 300 m, as well as one vertical catch from 125 to 0 m (or 150-0 m) were made. At the 24 hr anchor stations three vertical catches were conducted (300-100 m, 100-50 m, 50-0 m).

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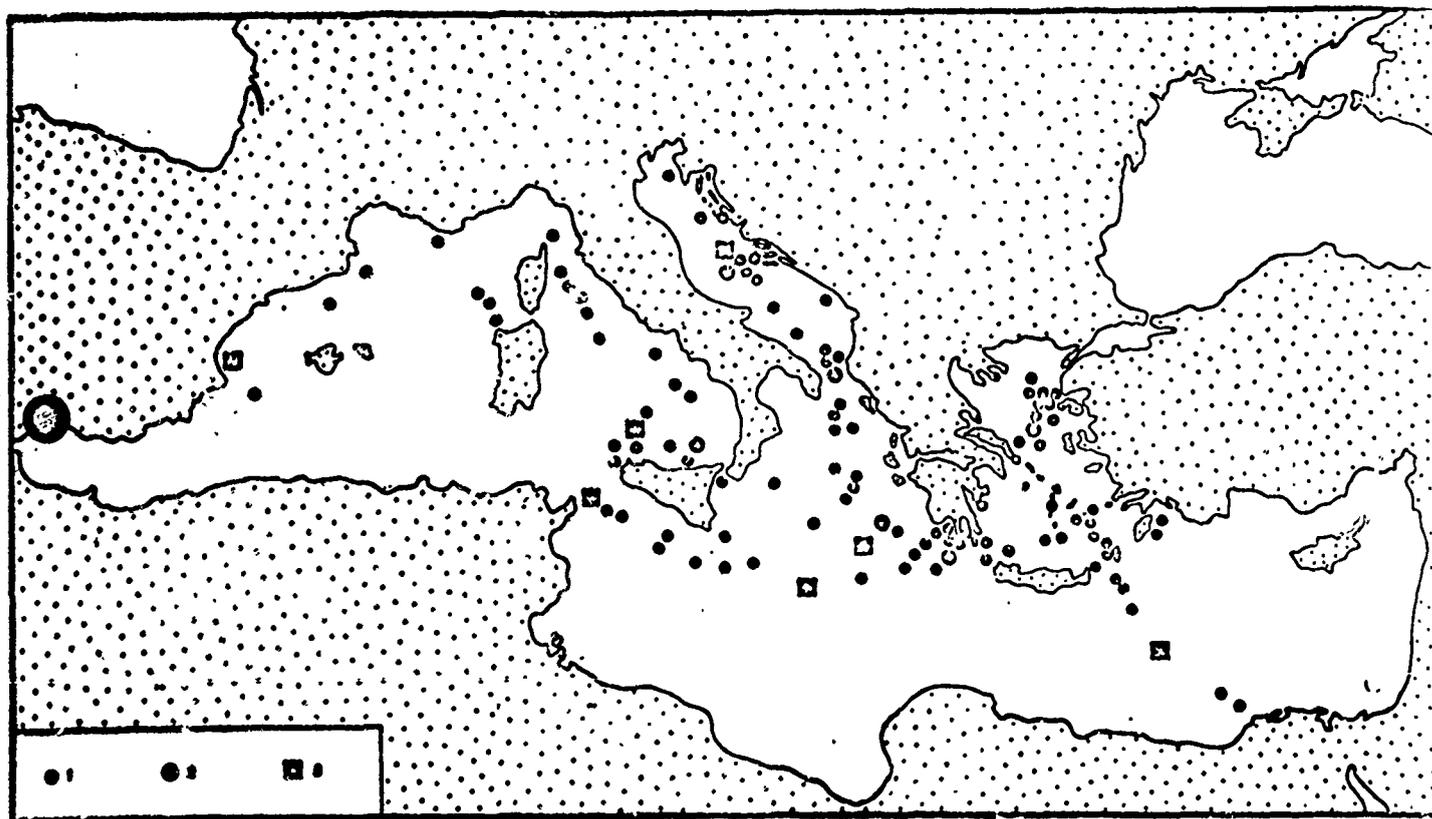


Figure 1. The distribution of the ichthioplankton collection station.

1 - suspended; 2 - daily; 3 - three-day ones.

As a result of the conducted work, materials have been collected on the quantitative distribution of the roe and larvae of many species of fish in the open waters of the /206 Mediterranean Sea during different seasons of the year. Special observation work was done on the feeding of the larvae under Mediterranean Sea conditions and certain peculiarities of the biology of the reproduction of the mass species of sea fish, common for the Black and Mediterranean Seas.

In the present report, certain sequence patterns of the ichthyoplankton distribution in the Mediterranean Basin and comparative data on the biology of reproduction of one of the mass types of fish species (Engraulis encrasicolus L) in the Black and Mediterranean Seas are being discussed.

The summer and autumn ichthyoplankton of the open regions of the Mediterranean Sea is distinguished by a diverse larvae species content.

According to quantity and frequency of encounter, all the forms of the summer and autumn ichthyoplankton can be categorized in three groups:

1. Those encountered everywhere in large concentrations (from 5-10 to 50 specimens under 1 m²).
2. Those encountered everywhere in concentrations from 1 to 15-20 specimens under 1 m².
3. Those rarely encountered as individual specimens.

Distributed everywhere and creating maximum concentrations in the plankton are the larvae of the gonostomidae family with the most numerous genera of Cyclothone and Vinceguerraia, of the Myctophidae with the genera Myctophum, Diaphus, Lampanictus, and of the Sudidae with the genus Paralepsis. The quantity of the Cyclothone sp., for example, reaches 40-50 specimens under 1 m² of the sea surface, of the Myctophum 20-30 specimens (in the 125-0 m layer). All these forms, like the remaining species of these families, are not represented in the fauna of the Black Sea.

Widely distributed, but encountered in lesser concentration, are the larvae from the family of Sparidae (2-15 specimens under 1 m² of sea surface), of the Serranidae (2-20 specimens) of the Syngnathidae (2-15 specimens) of the Bothide (1-2 specimens), of the Carangidae (2-3 specimens), and of the Labridae (2-4 specimens). May of the species of the enumerated families enter into the content of the Black Sea ichthiofauna.

To the third group belong the larvae of many species of fish which live in the Mediterranean Sea (Symphorus lactea, Lepidotrigla aspera, Corpos aper, Arentina sphyrana, A. lioglassa, Lepidopus caudatus, Cepola rubescen, Jchtiococaus ovatus, etc.), as well as those naturalized in the Black Sea (Thunnus thynnus, Sarda sarda, Mullus barbatus, Corvina umbra, Uranoscopus scaber, etc.).

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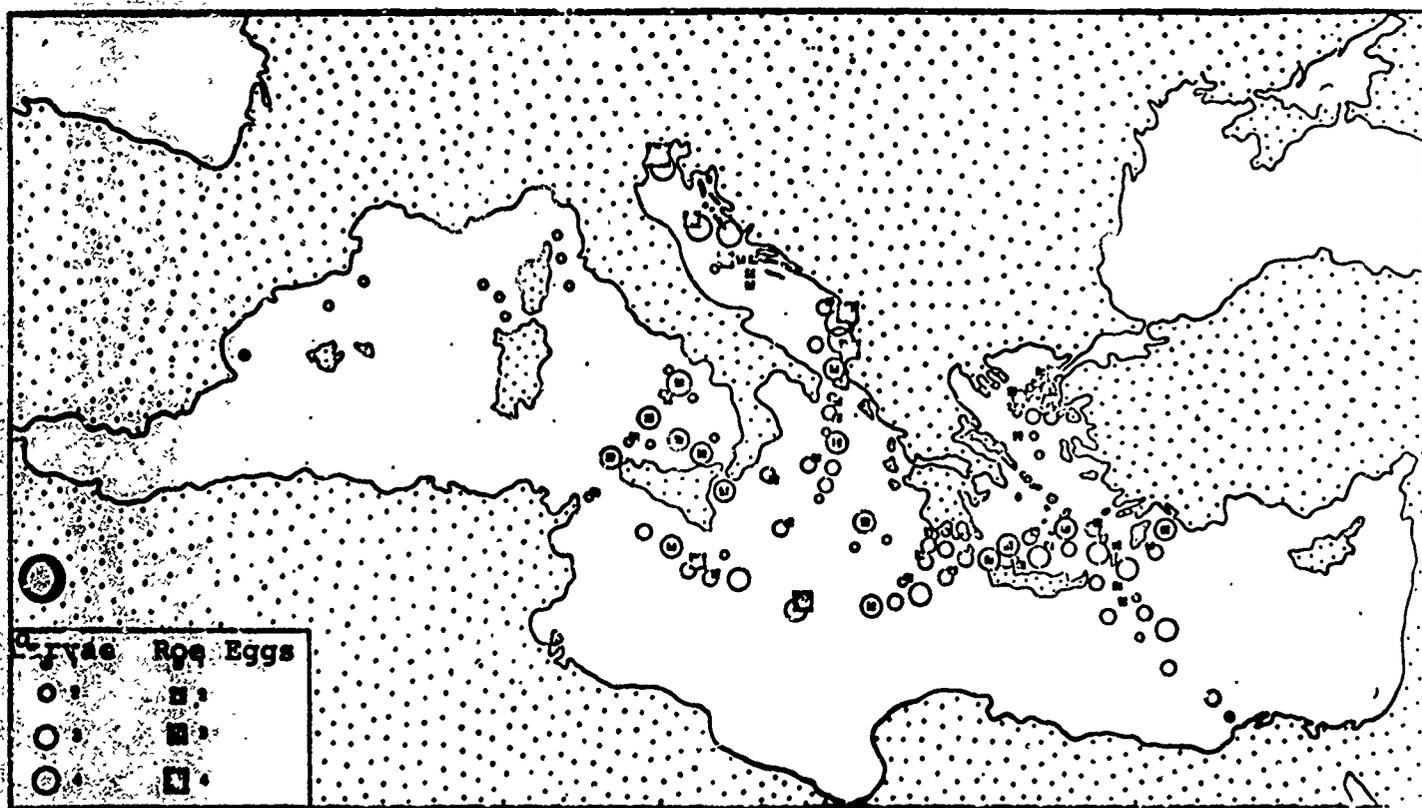


Figure 2. The distribution of the roe eggs and larvae (over all quantity according to station).

Roe eggs: 1 - 1-100; 2 - 101-500; 3 - 500-1000; 4 - >1000.

Larva: 1 - 1-25; 2 - 26-100; 3 - 101-500; 4 - >500

A considerable variety and abundance of larvae (from 100 to 500 specimens at the station) have been noted in the southern part of the Aegean Sea, in July of 1959 and in June 1960 in the central regions of the Mediterranean Sea, and of the same time in the Tyrrhenian Sea in August 1959. The maxima concentrations of larvae (more than 500 specimens per station) were observed in August 1959 in the northern part of the Tyrrhenian Sea and in June 1960 in the northern Adriatic (Figure 2).

Along with the varied species content of the larvae and comparatively high concentrations of individual forms in the summer and autumn plankton, the average quantity of larvae per unit volume (over all for all types) is considerably below the quantity of larvae in the Black Sea during the period of mass development of the pelagic stage of the fish.

For example, in 1958 in the Adriatic Sea the average quantity of larvae under 1 m² of sea surface in the 100-0 m layer comprised 4 specimens, in 1958 in the Aegean, Ionian and Adriatic Seas there were on the average 14 specimens in the 125-0 m layer and in 1960 in the same seas there were 12 specimens in the 150-0 m layer. An extremely low quantity of plankton in the Adriatic Sea in 1958 determined, it seems, by the lateness of the period of observation (August-September), when the spawning of all the summer-spawning forms terminates.

In the Black Sea the average quantity of larvae of the anchovies *stavrída* (two mass species) alone comprise in 1958 in the Prebosporus region in the 25-0 layer 51 specimens under 1 m² of the surface of the sea, in 1960 in the Sevastopol region it was 9 specimens, and 1961 it was 40 specimens under 1 m² (in the same region).

In the vertical distribution of the larvae a definite 208 sequence pattern can be observed. Their greatest quantity (overall for all species) is confined to the 25-50 m layer. The overall

larvae quantity also remains high at the horizons of 75, 100 and 125 m (Figure 3). The same 25-125 m layer is characterized by the most diverse species content. In the upper horizons (0-5 m) and below 200 m the over all quantity of larvae is not large and the species content (below 200 m) decreases by more than two times.

A certain difference in the vertical distribution has been determined only for the larvae of anchovies, the maximal quantity of which is confined to the 10-25 m layer.

It is characteristic that in these same layers (10-25 and 25-50 m) in the Ionian Sea the maximal quantity of zooplankton was observed (Greze, 1962). According to the data of A. A. Shmeleva (1962), during the summer season of 1958 in the Adriatic Sea the greatest concentration of zooplankton was noted for the 10-25 m layer.

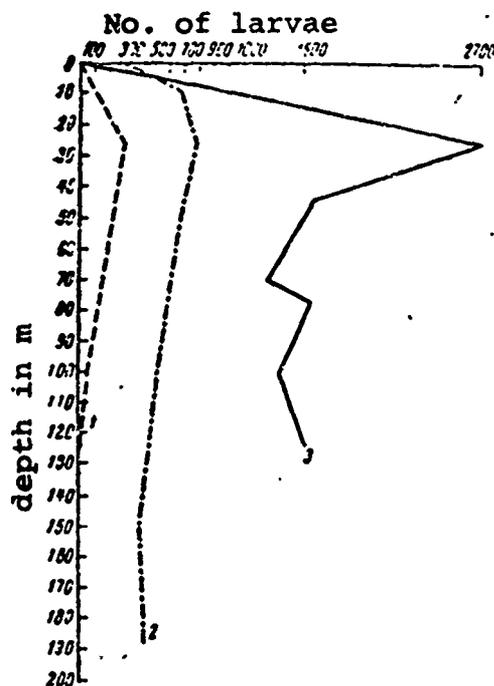


Figure 3. The vertical distribution of larvae (over all quantity for all species) according to years. 1 - 1958; 2 - 1960; 3 - 1959;

It is interesting to view the vertical distribution of larvae - on the one hand, those fish which did not penetrate

into the Black Sea, and on the other hand, those naturalized in the Black Sea.

Such typical Mediterranean forms, as for example, Cyclothone sp., Paralepsis sp., the species of the Myctophidae, and Coris julis (the naturalization of which in the Black Sea is doubtful) occupy a wide vertical area of distribution. Creating maximal concentrations in the 25-50 m layer, the same as the overwhelming majority of the Mediterranean species, these forms penetrate, according to our observations, up to the depth of 200 m, at the same time their quantity in all layers remains low (Figure 4). The wide vertical distribution spectrum of these larvae determines their existence under different temperature conditions, from 26-27° in the upper layers to 14-15° in the lower horizons of distribution. The year round reproduction period of these fish also testifies to the eurythermicity of the early stages of the development of the Cyclothone sp., Paralepsis sp. and species of the Myctophidae family.

Enormous vertical migrations of the larvae of many species in the Mediterranean Sea and, in particular, the larvae of Coris julis, were noted by Fage (1918). The high concentrations of the larvae from the family of Gonostonuidae, Myctophidae and Suidae at the depths down to 300 m were noted by Taning, Jespersen, and Ege, according to the materials of the Dutch Oceanographic Expedition.

A different character of vertical distribution is distinguished for the larvae of anchovies and stavrida, a species which was naturalized in the Black Sea, and larvae from their family of Sparidae, many species of which live and reproduce in the Black Sea. The vertical distribution of these forms is limited in the main by the 10-25 m layer. Below 50 m their quantity is insignificantly small and can be viewed as accidental catches made during the passage of the nets through the upper horizons (Figure 5).

The distribution of the larvae of anchovies, stavrida, and species of the Sparidae family is limited by the narrow amplitude of temperature fluctuation (20-26°). The reproduction of these species, as is well known, occurs only during the warmest period of the year. /209

The presented data on the vertical distribution of the larvae in the Mediterranean Sea is confirmed by the ideas of V.A. Vodyanitskiy (1930) on the naturalization in the Black Sea "only of such species of fish, which in all stages of development retain their place of habitation in the upper water layers or along the shores."

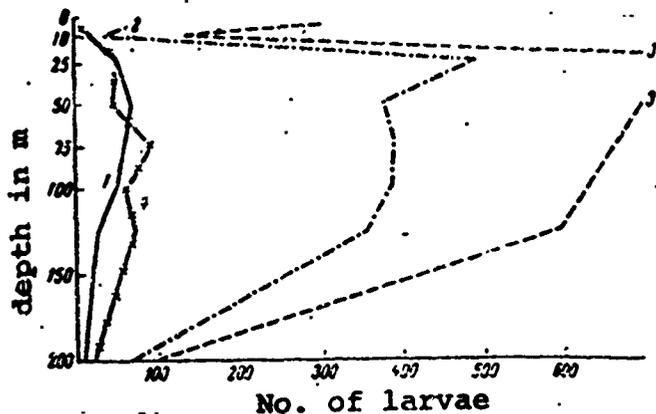


Fig. 4. Vertical distribution of larvae of the Coris julis (1), Cyclothone sp.(3), Paralepsis sp. (4), and the species of the Myxophidae family (2).

During the study of the distribution of the ichthioplankton in the Mediterranean Sea, the extremely small quantity of row developing in the plankton draws attention to itself. This peculiarity pertains only to the open regions of the sea, where the work was mainly conducted. At individual stations set up in

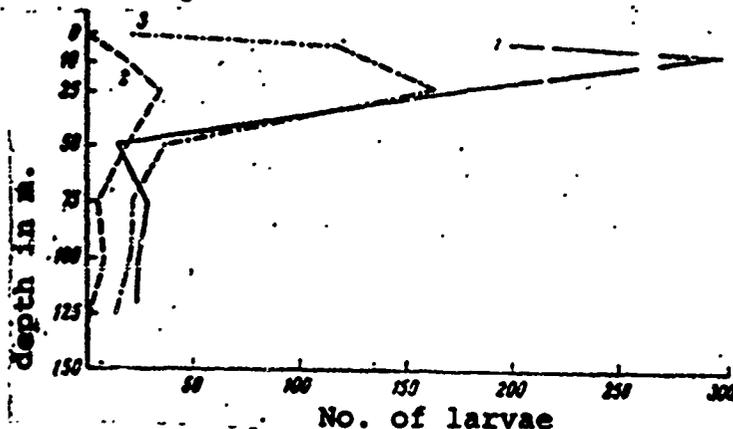


Fig. 5. Vertical distribution of anchovies larvae (1), stavrida (2) and the species of the sparadae family (3).

the coastal regions (for example, Venetian Bay of the Adriatic Sea, coastal region of Albania), the concentration of the roe in the plankton was comparatively high (approximately 50 specimens under 1 m^2 of the sea surface). At certain stations situated in the open regions of the Mediterranean Sea, at comparatively great depths (50-75-100 m) roe eggs of one or several related species were encountered, which were assigned temporarily to the Cyclothone genus. In all other regions of investigation, the roe eggs of different species of fish were encountered only as individual samples. It should be noted that in the materials of the Dutch oceanographic expedition, which also conducted its investigations mainly in the open regions, the pelagic roe eggs were also encountered extremely rarely.

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It is known that in the open regions of the Black Sea the concentration of pelagic roe eggs (first of all mass types - anchovies and stavridae) reaches considerable values (more than 1000 specimen 1 m^2 of the sea surface).

Such a peculiarity in the distribution of roe eggs in the Mediterranean Sea determines, it seems, the confinement of spawning areas of many species of fish to the coastal areas.

The clearly defined preference, during the procreative period, to the coastal regions is determined on one hand by the peculiarities of the biological and hydrological regimens of the Mediterranean Sea, and on the other, by the biological properties of every species.

In the present report certain comparative data on the biology of reproduction of one of the mass types of fish of the Mediterranean Basin, the anchovy (*E. encrasicholus* L.), will be discussed.

Occupying a wide area (from the Canary Islands up to 60° N Lat.), this species lives under considerable fluctuations in

temperature (from 8° to 26°) and salinity from 7-10 to 38-39‰).

Along with a large variety of habitat conditions one can detect the common reproductive traits of the species, which are, it seems, the main criteria of the spatial distribution and the quantity of the shoals in different sections of the area.

The spawning of the anchovies in the northern as well as southern latitudes takes place during the warmest time of the year. The duration of the reproductive period, besides the biological peculiarities of the species (the rate of roe deposition, the uneven maturization of the generations, which take part in the spawning), is determined by the water temperature. The development of roe eggs and larvae takes place when the water temperature is from 13° to 26° (with insignificant possible fluctuations in one or the other direction), the optimal conditions of development are created when the water is warmed up from 18°-20° to 25°-26°. In the northern regions of distribution (we have data mainly for the Zuider Zee) the temperature conditions which permit reproduction correspond to the period from May to August, with the spawning peak during the month of the maximal warm up of the water (June-August). During this period the predominating temperature of the surface layers is from 22° to 25°-26°.

The roe and the larvae of the anchovies are encountered under considerable fluctuations in salinity - from 7-10 to 39‰. Nevertheless, large concentrations of roe eggs and larvae have been noted everywhere for the sectors of the sea with decreased salinity (within the salinity fluctuation limits of the sea).

According to Redeke (1906) and Fage (1920), the distribution of the roe eggs and larvae of the anchovies in the northern regions of its distribution is limited by the isohaline of 30‰, and the maximal concentrations are confined to the regions with a salinity of no more than 15‰. The preference of the anchovies during the period of reproduction to the salty waters has been

noted by Ehrenbaum (1905-1909).

In the Zuider Zee, until it was separated, the spawning took place in the entire area under a salinity of 7 to 20‰, but the largest quantity of roe eggs and larvae was noted for the regions with a salinity of 9-15‰. (Redeke, 1906). The quantity of the roe eggs of the anchovies in the plankton, according to Redek's data was enormous (from 204 to 3780 roe eggs per 10 cm³ of water).

According to the observations of Fage on the distribution of roe eggs and larvae of the anchovies in the Mediterranean Sea, their spawning takes place only in the coastal regions mainly in the fishing area, where the fishing is based on the concentration of the reproducers along the shores during the reproduction period. On the basis of this Hjort (1912) assigns the anchovies to the coastal fish ("coast-water forms").

In the materials of our expeditions the roe eggs of the 211 anchovies were encountered very seldom, mainly in the Adriatic Sea. Comparatively large concentrations of the roe eggs of the anchovies (approximately 1500 samples per a 10-minute catch of ichthioplankton net) were detected in the Venetian Bay, above the depths of 30 m, under a minimal of the known values of salinity (34‰) for the surface waters of the Mediterranean Sea. Along the Albanian coast the roe eggs of the anchovies were encountered in noticeable quantities (up to 300 specimens per one 10-mile catch) in salinity of 37.0-37.5‰.

According to the materials of our expedition and bibliographical data, the distribution of the roe eggs and larvae of anchovies in the Mediterranean Sea is neither limited by the values of salinity, nor by the temperature of the water within the limits of its fluctuation during the spawning season. The salinity in the areas where the roe eggs and larvae are found fluctuates from 34 to 39‰, and the temperature from 15° to 25°.

Nevertheless, the noticeable and especially large concentrations of the larvae, as well as the roe eggs, are encountered close to the shores, above shallow depths, in the regions with a decreased salinity (34-37‰) for the Mediterranean Sea, when the water temperature is high (20°-25°).

Such a density of the roe eggs of the anchovies in the plankton of the Adriatic Sea is very small in comparison with the density of the roe eggs of this species in the Black and Azov seas during the period of the most intensive reproduction. The maximal concentration of the roe eggs in the Black Sea reached 33 thousand specimens per one catch.

A series of investigations has determined that the spawning of the anchovies in the Black Sea takes place on its entire territory, under the temperature of 13° to 26° and salinity from 9.7 to 19.3‰. In the coastal, as well as open regions, considerable concentrations of roe eggs and larvae are encountered (Nikitin, 1929; Vodyanitskiy, 1930; Puzanov, 1936; Malyatskiy, 1940; Mayorova, 1941; Kazanova, 1947; Dekhnik and Pavlovskaya, 1950; Dekhnik, 1954; Einarsson and Guertuerk, 1960). The spawning of the anchovies in the Azov Sea also occurs along its entire length, excluding the Taganrog Bay (Puzanov, 1936). The optimal conditions for the development of the roe eggs and larvae of the Azov Sea anchovies are considered by T. F. Dementyeva (1958) to be a water temperature from 22.5 to 24.0° and a salinity from 11.7 to 11.9‰.

On the basis of the presented data it becomes apparent that (within the confines of the area) in the seas with low salinity (from 7-9‰ to 20‰) this species is well distributed in the entire area of the sea during the spawning season, intensively reproduces in the coastal, as well as the open regions, and is one of the most numerous commercially caught fish of the Zuider Zee (until it's frozen over), and the Black and Azov Seas.

In the seas with high salinity (34‰-39‰) the spawning takes place close to the shores and, as was shown, mainly in places with decreased salinity, and the intensity of reproduction is not great. In these conditions the anchovies are the typical coastal form and do not create numerous shoals (Mediterranean and Adriatic Seas). The subspecies distinguished within the confines of the area of the *E. encrasicholus* L. on the basis of biological peculiarities (Fage, 1920; Aleksandrov, 1927; Puzanov, 1936) are united by the common traits of biological reproduction, characteristic for the species as a whole: the confinement of the spawning to the period of maximal warm up of the water, the clearly pronounced preference to the regions with decreased salinity, the wide distribution and large content of the shoals in the subsaline waters, coastal spawning, and the small content of the shoals in the seas with high salinity.

Therefore, one can assume, and not without basis, that the low salinity of the Black and Azov Seas was one of the most important factors determining the wide distribution and high content of the shoals in these water reservoirs.

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THE GROWTH OF CERTAIN NATURAL AND COASTAL
FISH IN THE SEAS OF THE MEDITERRANEAN BASIN

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by

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The majority of the fish permanently inhabiting the Black Sea are immigrants from the Mediterranean Sea. They differ from their Mediterranean kin by their slow growth. The slowing down of the growth in the Black Sea occurs in fish which prefer warmth as well as in those that prefer cold (Aleyeva, 1952, 1956, 1958; Burdak, 1956; Kalinina, 1962).

As was shown by Yu. G. Aleyev (1956), the main factor acting negatively on the growth of the majority of the Black Sea fish of the Mediterranean immigrant group, is the comparatively well pronounced continentality of the thermal regimen of these fish. The same author expresses the opinion that the action of the mentioned factor does not pertain to the fish living in the narrow coastal water zone.

The purpose of the present investigation was the study of the growth of those fish whose mode of life is to a greater or lesser degree connected with the coastal zone: Mullus barkakus L., Spicara smaris (L.), Diplodus annularis (L.), Gobius niger L. and Scorpaena porcus L. All these species live permanently in the Black Sea.

The comparative study of the growth of the coastal fish is the continuation of the investigations previously carried out by the Sevastopol Biological Station, of fish growth in the seas of the Mediterranean Basin (Aleyev, 1956, 1958; Burdak, 1956; Kalinina, 1962), which mainly pertain to the pelagic fish.

The collection of the materials was carried out in 1957-1962 by trawls and positioned gill nets by the expedition ship "Academician A. Kovalevskiy". The fish from the commercial fishermens' position nets were also analyzed.

The age determination of the fish was done according to the scales of the fish.

Among the discussed species of fish the one least connected with the coastal zone is the mullet (Mullus barbatus L.). Its roe is pelagic; its larvae and later young fish remain a long time in the pelagic area, and in the Black, Aegean and Adriatic Seas the young fish are encountered throughout practically the entire sea; this is borne out by the data collected when young fish were caught with the help of light during the period of the Mediterranean expeditions of the Sevastopol Biological Station on the expedition ship "Academician A. Kovalevskiy". At the age of one to one and a half months, when they are 4 to 7 cm long, the pelagic young fish approaches the shore and descends to the bottom.

The mature mullet lives at the depths of 5 to 100 m and is not directly connected with the narrow coastal strip. In the Black Sea it remains mainly at the depths of 20 to 30 m. In the Atlantic Ocean, according to Desbrosses' data (1936b), from September to March the mullet remains at the depth of 50 to 100 m.

In the Atlantic Ocean the mullet exists under conditions of an even thermal regimen with comparatively small seasonal changes.

As the mullet habitats become more distant from the ocean (as it advances further and further into the Mediterranean Sea and then into the Black Sea), its growth rate decreases perceptibly.

Table 1

Growth of the Mullus barbatus L. in different regions (absolute length in cm; number of specimens is shown in parentheses)

Female									
1	2	3	4	5	6	7	8	1	2
15,2 (603)	22,6 (372)	27,3 (100)	30,8 (92)	33,4 (61)	35,2	36,1 (14)	—	13,1 (413)	19,7 (192)
11,5	17,3	18,5	—	—	—	—	—	9,3	15,2
11,3 (5)	—	—	—	—	—	—	—	0,4 (4)	13,1 (2)
12,0	17,5	20,0	21,2	—	—	—	—	10,0	14,5
12,7 (393)	20,3 (1748)	23,8 (822)	25,9 (317)	27,0 (211)	27,9 (159)	28,7 (27)	29,3 (8)	12,6 (1411)	17,5 (921)
15,3	16,8	18,8	19,9	21,7	25,0	—	—	10,5	14,0
12,0 (62)	15,7 (33)	16,0 (15)	17,7 (8)	—	—	—	—	10,3 (33)	12,2 (36)
8,8	12,0	14,5	16,5	—	—	—	—	7,0	9,2
9,0 (5)	13,0 (18)	13,8 (20)	16,6 (14)	17,9 (4)	18,0 (3)	—	—	8,6 (17)	9,0 (21)
10,3 (8)	11,3 (20)	13,0 (32)	14,6 (31)	15,9 (10)	19,1 (1)	—	—	9,5 (32)	11,0 (25)

Male						Notes
3	4	5	6	7	8	
23,3 (97)	26,3 (42)	29,0 (23)	29,6 (17)	—	—	Northern Atlantic; Desbrosses, 1936.
16,5	—	—	—	—	—	Mediterranean Sea, Eastern Shore of Spain; Palanas a. Vives, 1956; Suau a. Planas, 1957
—	—	—	—	—	—	Bay of Lyons; our data.
16,5	17,5	17,7	30,0	—	—	Bonjules, Bougis, 1952.
20,4 (557)	22,31 (216)	23,3 (112)	24,2 (64)	24,9 (8)	25,5 (2)	Adriatic Sea, Western Adriatic; Scaccini, 1947.
15,6	16,6	17,7	—	—	—	Eastern Adriatic (Split) Bougis et Muzinic, 1958.
14,4 (11)	15,2 (1)	—	—	—	—	Albania, our data.
10,0	11,0	—	—	—	—	Black Sea, Caucasus, Danilevskiy, 1939.
10,8 (17)	12,7 (16)	15,0 (1)	—	—	—	Caucasus; our data.
12,6 (13)	12,5 (5)	—	—	—	—	Crimea, our data.

The lowest rate of growth of the mullet in the Black Sea is explained to a considerable extent by the continentality of the thermal regimen of this sea in comparison with the ocean (Aleyev, 1956). As was repeatedly noted (Danilevskiy, 1939; Lipskaya, 1959), during the winter period one observes a

weakening of feeding intensity of the mullet in the Black Sea, and during the coldest months of the year (January-February), its complete cessation. In the western part of the Mediterranean Sea the mullet continues feeding during the winter (Planas, Vives, 1956; Lipskaya, in print). The cessation of feeding during the winter period is also one of the causes of the mullet growth retardation in the Black Sea.

Bougis and Muzinic (1958), studying the growth of the mullet in the Mediterranean Sea, in the Bonjules region, and in the region of Split in the Adriatic Sea, have discovered that not all male specimens collected in the Split region acquire toward the end of their first year a year ring on their scales; all the young specimens collected in the Bonjules region had such a ring. Analyzing the winter water temperatures in these regions; the authors expressed the opinion that the variations in the ring formation are connected with temperature changes. For example, according to their opinion, the critical temperature for mullet is 12°. Below this temperature cessation of the growth is observed as well as formation of the ring. Under higher temperatures cessation of growth does not occur.

Comparing the obtained data on the growth of the mullet at the Crimea and Northern Caucasus with the growth in other regions of the Black Sea (Table 1), and taking into account considerable fluctuations of the average size of the age groups for different years (Ivanova, 1960), the Baïcan mullet at the age of three years (in 1953-1959) had an average size which fluctuated from 10.2 to 14.5 cm*, and one can conclude that no significant differences in the growth of the mullet from different regions of the Black Sea can be observed. In all the regions of the Black Sea great variability of growth can be observed within /215 each generation (Danilevskiy, 1939; Tikhonov 1957; Ivanov, 1960). It is possible that on the basis of these two factors (sharp

* The length of the body up to the end of the scale cover is given.

fluctuations in the average size for different years and the variability of the growth within the generations) one can explain the disparity of the results on average size of the yearlings, two-year olds, etc., obtained by different authors for different regions of the Black Sea. Nevertheless, as was noted by L. S. Ivanov (1960), there is a certain tendency towards an increase in the growth rate of the Black Sea mullet when it approaches the Bosphorus: "Specimens of the early (June) spawning of the Balkan red mullet do not differ in the rate of their linear growth from the Mediterranean population of the French coast, which spawns in May-June."

The smarida (Spicca smaridis (L.)) is a coastal fish which leads a demersal pelagic type of life. Here its life cycle is closely connected with the coastal zone. The smarida deposits benthonic roe at a depth of 15-20 m onto the sandy gravel grounds. The development of the roe occurs while it is firmly attached to the substratum. In June, 1962, in the region of Gelenzhik in the Black Sea, we discovered for the first time the deposits of smarida roe at the depth of 16 m. The roe was deposited onto shell sand, which consisted of remains of Cerithium reticulatum, Rissoa splendida, Phasionea pontica, Mytilaster lineatus, Gouldia minima and certain others. The larvae and young fish remain in the coastal zone. The life of the mature smarida is also connected with the coastal zone, even though certain seasonal displacements can be observed.

On the seasonal approaches of smarida to the shores of the Crimea and the Caucasus a decisive influence is exerted by the temperature factor (Zernov, 1913; Malyatskiy, 1936; Probatov and Moskvina, 1940; Grudinina, 1957; Smirnov, 1959, 1960, etc.) As was pointed out by V. A. Vodyanitskiy (1930), this is the most warmth-loving species among those that moved into the Black Sea. In the coastal regions of the Mediterranean and Adriatic Seas the smarida is encountered everywhere and is one of the main

objects of the coastal commercial fishing (Zei, 1951; Zupanovic, 1956).

Table 2

The growth of Spicara Smaris L. in different habitant regions (absolute length in cm; in parenthesis - number of specimens)

Female												
0+	1	1+	2	2+	3	3+	4	4+	5	1	1+	2
7,6 (5)	8,9 (2)	11,9 (15)	13,2 (55)								15,2 (5)	16,0 (3)
	8,6 (35)		12,7 (19)		13,5 (5)		16,9 (1)			8,7 (1)		15,6 (1)
6,4 (111)		8,9 (89)		11,9 (57)		13,1 (3)					9,7 (1)	
6,1 (112)		11,2 (79)		12,9 (17)		14,3 (10)					11,3 (1)	
	9,6 (67)		10,9 (25)		12,3 (20)		13,4 (3)		15,4 (5)			
	8,2 (25)		10,7 (64)		12,1 (23)		14,1 (5)		15,2 (3)			
					13,9 (2)		14,9 (7)					15,3 (1)
	8,5 (301)		12,3 (65)		13,7 (70)		14,1 (15)			8,1 (21)		14,1 (30)

Male										Notes
2-	3	3+	4	4+	5	5+	6	6+	7	
16,9 (5)	17,0 (3)									Mediterranean Sea, Eastern Shore of Spain; Lozano Cabo, 1953. Bay of Lyons; our data. Adriatic Sea, Albania; our data. Black Sea; Novorossiysk; our data. Batum; our data. Ayu-Dag; our data. Balaklava; our data. Sevastopol; our data.
			17,8 (2)		19,2 (1)					
12,1 (3)		13,6 (9)		14,3 (4)						
		16,6 (14)		17,1 (6)		19,7 (1)				
							17,7 (1)			
	13,0 (5)		14,4 (3)							
	15,7 (34)		16,0 (31)		17,9 (14)					
	15,7 (123)		16,9 (58)		17,1 (20)		19,4 (6)		19,3 (2)	

In conjunction with the varied thermal conditions of the Mediterranean, Adriatic and Black Seas, the Smarida spawns in these seas during different periods. For example, the spawning of the Smarida in the western part of the Mediterranean Sea begins in the second half of March and lasts until the third of April (Lozano Cabo, 1953; Planas, Vives, 1955). According to our data, already by the end of January in the Bay of Lyons individual large specimens of Smarida have gonads in the III-IV stages of maturity. The mass spawning of the Smarida in the

Adriatic Sea takes place in May-June (Zei, 1951; our data). In the Black Sea the mass spawning of the Smarida can be observed starting from the second half of June until the beginning of August.

As a result of different times of spawning the Mediterranean and Adriatic Smaridas are under better thermal conditions for a longer period than those of the Black Sea. Nevertheless, there is no sufficient difference in the rate of growth of the yearlings from the Mediterranean, Adriatic, and the Black Seas (Table 2). Beginning with the second year the Mediterranean Smarida is distinguished by a somewhat better rate of growth than those in the Adriatic and Black Seas. The Smarida of the Bay of Lyons and the population of the Spanish shores differ little in growth rate. In the latter case the average length of the females two years of age, according to the materials of Lozano Cabo (1953), is 13.2 cm, and for the Bay of Lyons (according to our materials) it is 12.7 cm. The Smarida from the Albanian and Yugoslavian waters differs just as little in its rate of growth (Zei, 1951). Nevertheless, the Adriatic Smarida lags in growth behind those in the Black Sea (Table 2).

In all three seas, beginning with the second year, the Smarida males are large as compared to the females.

The representative of the coastal bottom-dwelling pelagic fish is also the sea carp (Diplodus annularis (L.)). In the Black Sea it is distributed mainly in the narrow coastal strip, and prefers rocky grounds with abundant overgrowths of cystoseira, which abound with its favored food - the diatom algae. Here in the coastal zone the spawning also occurs. The roe eggs and larvae are planktonic. The young fish stay close to the shore. The area of the carp habitat in the Adriatic Sea is somewhat wider. In the region of Albania it is encountered several miles from the shore, on silty grounds, and is easily caught

by the trawls (in the Black Sea it is very seldom encountered by the trawls). Like the Smarida, the sea carp does not migrate far. The growth of the sea carp in the Black and Adriatic Seas is uneven (Table 3). Its faster growth is observed in the Black Sea (Salekhova, 1960).

If one compares the weight of the Black Sea form of carp with the Adriatic carp for the identical age groups, then the weight of the Black Sea forms exceeds by approximately two to three times that of the Adriatic forms. For example, the average weight of the females of the age of two years is 47.9 g in the Black Sea, and in the Adriatic Sea at the age of 2+ it is 23.2 g; the average weight of the females at the age of three years is 78.5 g in the Black Sea, and in the Adriatic Sea at the age of 3+ it is 31.0 g; and at the age of four it is respectively 112.3 and 35.6 g.

Table 3

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Growth of Diplodus annularis (L.) in the Black and Adriatic Seas (absolute length in cm; in parentheses - number of specimens).

Age	Female		Male	
	Black Sea	Adriatic Sea	Black Sea	Adriatic Sea
1	8,0 (100)	7,4 (37)	8,4 (398)	7,7 (52)
2	14,3 (180)	11,0 (36)	14,0 (360)	10,4 (17)
3	16,7 (295)	12,6 (17)	16,4 (238)	12,1 (3)
4	18,3 (243)	13,7 (6)	17,2 (139)	
5	19,4 (158)	13,9 (5)	18,2 (33)	15,5 (1)
6	20,8 (95)	---	19,3 (12)	
7	22,3 (16)	---	20,3 (2)	15,8 (1)
8	23,6 (8)	---	---	---
9	---	---	---	---
10	---	---	---	---
11	25,4 (1)	---	---	---

The larger size of this year's brood of the sea carp in the Adriatic Sea in September as compared to this year's Black Sea brood, caught during the same period in the Black Sea, is explained by the early date of the spawning of the Adriatic

forms (May-June). In the Black Sea the spawning of the carp usually starts during the second or third week of June and continues until the end of August. The earlier spawning of the carp in the Adriatic Sea as compared with the Black Sea, is confirmed by the materials collected during the period of the Mediterranean expedition of the Sevastopol Biological Station on the expedition ship "Academician A. Kovalevskiy".

The typical representatives of the narrowly coastal fauna are the Gobius niger L. and Scorpaena porcus L. The analysis of the Goby (Gobius niger) growth in the Mediterranean (Bay of Lyons), Adriatic (Albania) and Black (Bulgaria) Seas did not show any difference (Table 4). As can be seen, in all three seas for every age group the males have a larger size than the females.

Table 4

Growth of Gobius niger L. in the Mediterranean, Adriatic and Black Seas (length up to the end of the spinal cord in cm; in parentheses - number of specimens)

Age	Female			Male		
	Bay of Lyons	Albania	Bulgaria	Bay of Lyons	Albania	Bulgaria
0+	—	3,1 (5)	5,2 (15)	—	4,5 (4)	5,4 (9)
1	5,7 (4)	—	—	6,8 (2)	—	—
1+	—	6,9 (20)	6,7 (26)	—	7,2 (18)	6,9 (33)
2	6,4 (2)	—	—	7,7 (3)	—	—
2+	—	7,4 (8)	7,2 (8)	—	9,2 (8)	7,7 (13)
3	7,5 (1)	—	—	8,0 (3)	—	—
3+	—	8,9 (5)	8,4 (2)	—	10,1 (4)	8,7 (4)
4	9,6 (1)	—	—	9,4 (4)	—	—

During the analysis of the ruff (Scorpaena porcus) growth in the Black and Adriatic Seas no difference has been detected (Table 5).

Therefore, the fish population inhabiting the narrow coastal zone in different seas of the Mediterranean Basin does not show sequential differences in the rate of growth. The peculiarities

Table 5

The growth of the Scorpaena porcus L. in the Black and Adriatic Seas (length up to the end of the spinal cord in cm; in parentheses - number of specimens)

Age	Black Sea	Adriatic Sea
0+	---	4.4 (7)
1+	6.2 (5)	6.8 (2)
2+	8.9 (15)	9.6 (6)
3+	11.4 (26)	12.4 (5)
4+	13.1 (14)	14.0 (3)
5+	14.0 (5)	14.3 (1)

of growth, determined by specific traits of the temperature regimen of the Atlantic Ocean and Mediterranean, Adriatic, and Black Seas, are characteristic only for the fish whose way of life is not connected with the narrow coastal strip.

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LITTLE KNOWN LARVAE OF THE CONTRACAECUM
RAILLIET ET HENRY, 1912
FISH OF THE MEDITERRANEAN BASIN

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by

N. N. Naydenova

Larval forms that we attributed to the family Anisakidae Skrjabin et Karokhin, 1945, subfamily Anisakidae Railliet et Henry, 1912, genus Contracaecum Railliet et Henry, 1912, were discovered while studying nematodes, collected among the fish of the Mediterranean basin during the voyage of the "Academician A. Kovalevskiy" expedition ship in 1958-1960 (Nikolayeva, in print).

1. Contracaecum robustum Chandler, 1935.

These species, according to the information supplied by K. I. Skryabin, N. P. Shikhobalova, A. A. Mozgovoy (1951, 1953), were described for the first time by Chandler (Chandler, 1935), according to specimens collected from the kidneys of the Mugil cephalus and Fundulus heteroclitus in South and North Africa. Mozgovoy presents drawings of the cephalic and caudal ends of the body, according to Chandler. These drawings are incomplete, but by their appearance and the cited scale, Chandler described large larval forms of nematodes. The cephalic end of the larva is to a great extent similar to that of nematodes, discovered by us in the liver of the Mugil capito Cuv. These species have been mentioned for the first time in the Adriatic Sea. However, the host and the localization of the parasite are different. As we consider the study of these species as inadequate in regard to morphology, and the drawings incomplete, we give the description of these species.

Description. Young forms. Large, white parasites. The body is cylindrical, 13,420-32,860 μ m. The cephalic tip is blunt, the caudal tip is pointed. Maximum width is 0.555-1.140 mm; the width of the pharynx level 0.143-0.270 mm; the width at

the various system level - 0.270-0.450 mm; the width at the vertical level - 1.555-1.245 mm. The cutical is transversely striated, with intervals in the anterior tip of the body of 0.003-0.0045 mm, in the middle part of the body of 0.001-0.002 mm, at the caudal tip, 0.003 mm. The striated condition is especially noticeable at the cephalic tip, where deep cuticle folds form a cuticular "little collar" for a length of 0.150-0.225 mm. Additional transverse and lengthwise striation can be seen under greatly magnified glass. The cephalic tip is armed with a large "drilling" tooth 0.019-0.028 mm high in the form of triangular pyramid with a rounded top and with four hardly noticeable nipples. The excretion opening is located between the lateral ventral lip embryos. One can find it easily at the lateral position of the "drilling" tooth: it is located at the base of

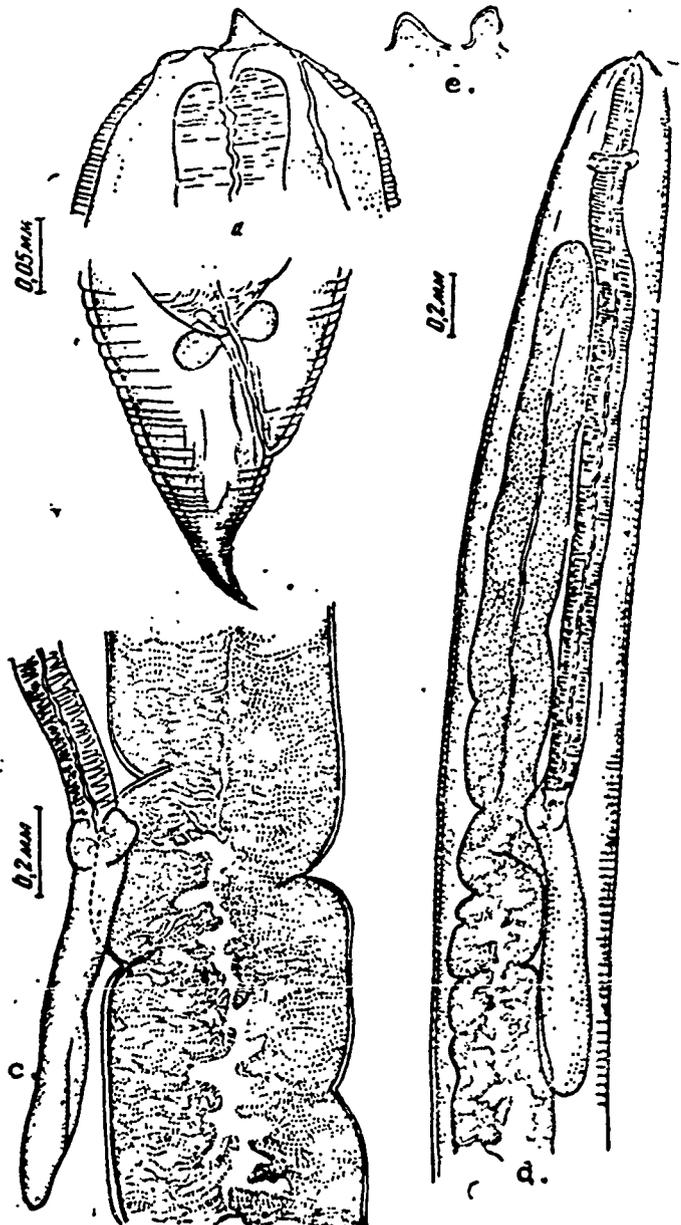


Figure 1. *Contracaecum robustum* Chandler, 1935.

[legend on next page]

Figure 1. [from previous page]. a. cephalic tip of the body; b. posterior tip of the body; c. anterior part of the alimentary trace; d. anterior tip of the body; e. the "drilling" tooth (dorsally and laterally).

the "drawn out" facet of the pyramid (Figure 1, a, e). The nervous system ring is located high, at a distance of 0.225-0.375 mm from the cephalic tip of the body. The aesophagus is narrow, of uniform width along all its length, 2,040-3,030 mm long and 0.081-0.192 mm wide (Figure 1, d). The ventricle is small, easily discernible, almost round, 0.078-0.195 mm long and 0.090-0.150 mm wide (Figure 1, c). The gastric appendage is in the form of a finger, transparent, 0.585-0.975 mm long and 0.090-0.180 mm wide. The intestinal appendage is bulky, densely colored, 1,635-2,880 mm long. It is wide near the ventricle (0.225-0.585 mm), and it gradually tapers towards the forward tip (0.078-0.165 mm). A relatively short trail is abruptly tapered as a thin projection 0.118-0.270 mm long (Figure 1, b). Sexual organs are not developed.

2. Contracecum collarae (Cobb, 1929.

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One nematode larva, according to morphology close to the immature phase of Contracecum collarae from the intestines of the Gibiomorus maculatus (Caribbean Sea), described by Cobb (Cobb, 1929), was discovered in the Box boops intestines (L.) and in the body cavity of the Mullus barbatus (L.). As Cobb, while describing the species, does not quote dimensional data and our larva is somewhat different than the C. collarae, we cite below the description and drawings according to our findings.

Description. Young form. Small nematode, 2,340-3,150 mm long. The body is soft, relatively fat, with the maximum width 0.195 mm, the body's width at the cephalic tip is 0.043-0.047 mm, at the nerve system's ring 0.097-0.099 mm, at the ventricle 0.112-0.119 mm, at the anus 0.056-0.059 mm. The cuticle is transversely striated with intervals of 0.001-0.002 mm at the cephalic and caudal tips of the body. The cuticle is of a

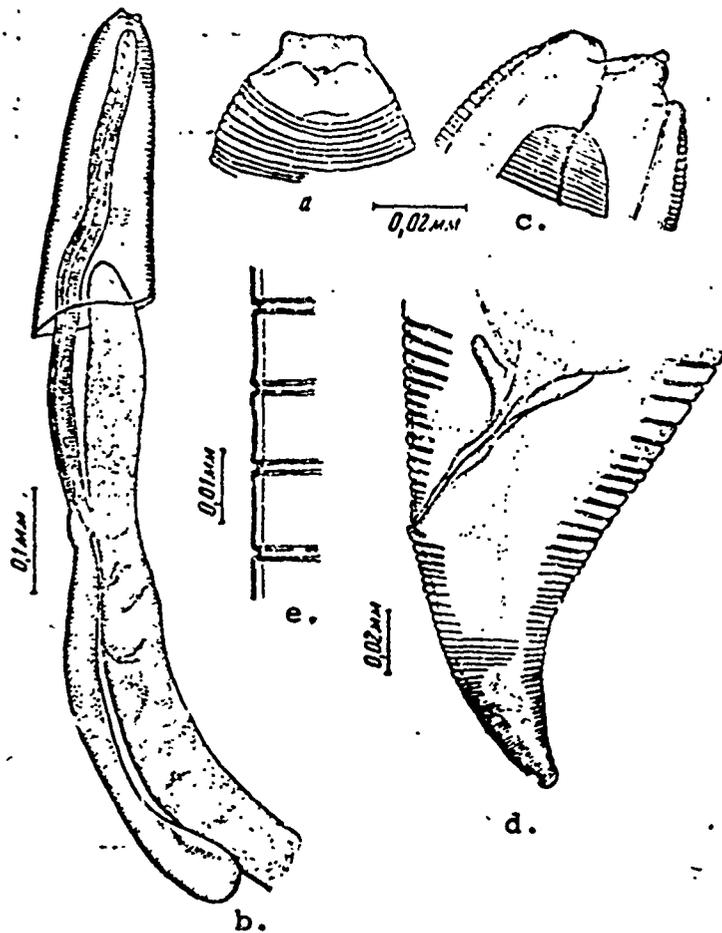


Figure 2. Contracaecum collarae (Cobb, 1912) Mosgovoy, 1951.
a. cephalic end of the body ventrally and laterally;
b. anterior end of body with esophagus and blind appendices;
c. tail end of the body laterally; d. crosswise serration
of the cuticula.

peculiar composition from the nervous system's ring and to the anal opening: flat cuticular rings 0.009-0.012 mm wide with somewhat inflated peripheries are separated from each other by 0.003-0.003 mm wide furrows (Figure 2, d). There is a tender longitudinal striation. The orifice is enclosed by three embryonic lips with four large protruding nipples on them: two on the dorsal and one on each of the lateral-ventral incipient lips. The "drilling" tooth, 0.004 mm high, with a rotund crown (Figure 2, c), is situated between the lateral-ventral lips, still not separated by a furrow. The narrow esophagus, 0.391- 223 0.419 mm long and of equal width along its entire extent (0.022-0.025 mm), is converted into a slightly elongated ventricle, 0.040-0.043 mm long and 0.030-0.031 mm wide. The ventricular appendage is transparent, as though inflated in its distal

portion. Its length is 0.347-0.391 mm and the width is 0.031-0.034 mm in the contracted portion and 0.047-0.053 mm in the expanded portion. The intestinal appendage is tinted more intensely, and it is 0.230-0.233 long and 0.043-0.053 mm wide. The nervous system's ring can be clearly seen at a distance of 0.189-0.192 mm from the cephalic tip of the body (Figure 2, b). The slit-like excretory opening is situated between the bases of lateral ventral lip embryos (Figure 2, a, c). The tail is short, cone shaped and is dorsally bent (Figure 2, d). The anus is situated at a distance of 0.081-0.084 mm from the rounded tip of the trail. Sexual organs are not developed. Forms described by us differ from the *Contracaecum collarae* by the following attributes: by dimensions of intestinal appendage (it is almost equal in length to the stomachic one, while the intestinal appendage of the *C. collarae* is three times longer than the stomachic) by a relatively longer trail and by an unusual cuticle textures over the greater part of the body. These species have been recorded in the Adriatic and Aegean Seas for the first time.

Inasmuch as we deal with a small amount of data, we only mark down indicated differences, without solving the matters pertaining to the degree of these differences.

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