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THE BLACK SEA. STATE-OF-THE-ART AND PROTECTION

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Abstract. The Black Sea is situated in the Northern Hemisphere, in the temperate zone, by its geographical coordinates (40˚55' and 46º32' north latitude, 27º42' and 41º42' east longitude). Because of its limited connection with the Planetary Ocean, and lying within the European continent, we can consider it a continental sea. Its main morphometric elements are – area of the sea waters of 421,638 km² (without of 38,000 km² of the Azov Sea), maximum depth 2,245 m, average depth 1,288 m, water volume 529,955 km³, shore length 4,869 km, hydrographic basin 2,402,119 km² and it covers 21 states. Concerning the genesis and evolution of the sea depression, there have been issued more hypotheses about the age of the Black Sea, among which more interesting one say that the sea was formed in the Precambrian, in the medium-upper Mesozoic and in medium Neozoic and finally, assuming it was formed in the Quaternary era. The morpho-bathymetric configuration allows the identification of the main morphostructural units that characterize most of the tectonic sea basins' type – shelf (continental platform), marginal depression (the continental base) and abyssal zone (the abyssal field). The climate conditions, hydric balance with the variation of the water oxygen level, hydrogen sulphide and eutrotrophication are also presented. Policies for the management of the Black Sea environment were developed through many projects.
Keywords: Black Sea, morpho-hydrographic configuration, hydrological characteristics

1. INTRODUCTION

Through its geographical coordinates (40°55' and 46°32' north latitude, 27°42' and 41°42' east longitude), the Black Sea is placed in the northern hemisphere, the temperate zone, and due to its limited connection with the Planetary Ocean and being located inside the European continent, we can consider it as *a continental sea*.

The connection with the Mediterranean Sea is made through the Bosphorus Strait, the Sea of Marmara, the Dardanelles Strait and further the Aegean Sea dotted with numerous islands.

The main morphometric elements. The surface area of the marine waters is 413,490 km^2. If the surface area of the Sea of Azov, of 38,000 km^2, is included, as is found in many studies, it is obvious that the surface area increases accordingly (Gastescu, 1996, 2005).

The maximum depth is 2,245 m, according to other sources 2,212 m is in the central-southern part on a profile that would approximately unite the cities of Yalta on the Crimean Peninsula (Ukraine) and Sinop on the Asia Minor peninsula (Turkey). The average depth is 1,288 m (according to other sources 1,278 m). The volume of water at normal level is estimated at 538,124 km^3.

The maximum length from west to east is 1,150 km, between the ports of Burgas (Bulgaria) and Batumi (Georgia); the maximum width between the Gulf of Odessa (Ukraine) and the mouth of the Sakarya River (Turkey) is 600 km, and the minimum between the Yalta peninsula and Cape

Burun is 300 km. The Crimean Peninsula in the north and Cape Burun in the south divide the Black Sea basin into two compartments, western and eastern, which influence and individualize the circulation of sea currents (Roventa 1967).

The length of the coastline is 4,869 km (excluding the shores of the Sea of Azov) and is distributed, within the riparian countries, as follows: Ukraine 1756 km; Russian Federation 421 km; Georgia 322 km; Turkey 1,700 km; Bulgaria 404 km; Romania 256 km.

The Black Sea (including the Sea of Azov) has a drainage basin area of 2,863,119 km^2. If the area of the two seas is excluded, the effective area drained by the Black Sea and the Sea of Azov is 2,402,119 km^2. Of this effective drainage area, the Danube, with its 817,000 km^2, occupies 34%, followed in order of size by the Dnieper (Dnepr) with 504,000 km^2 (21%), the Don with 422,000 km^2 (17.6%), the Kızı1 Irmak with 77,100 km^2 (32%), the Dniester (Dniester) with 72,100 km^2 (3.0%), and the Southern Bug with 63,700 km^2 (2.6%) (Stanchev et all., 2018) (Fig. 1).

Fig. 1. Black Sea basin

Regarding the coverage area of the 21 states in the Black Sea basin, it is noteworthy that the Russian Federation and Ukraine hold almost 49%, followed by Turkey with 10.7% and Romania with 9.98%. Regarding the territory of the respective countries, in relation to the same basin, we find that Romania, the Republic of Moldova and Hungary fall entirely within its limits, followed by Ukraine (98%), Austria (97.4%), Slovakia (96.3%), Bosnia - Herzegovina (91%), Serbia (87.1%), etc.

Most of the basin is located in Eastern and Central Europe, under the influence of a temperate continental climate, where precipitation is on average between 400-700 mm/year, except for the Carpathian area where the average is higher (Sorocovschi, 2018).

It is worth noting that the Danube in its upper and middle course, with the rivers that drain the Alpine and Dinaric mountainous area due to the influence of the temperate oceanic climate, benefits from more significant precipitation, a fact that is also reflected in the water flows, respectively in the liquid runoff module.

2.RESULTS AND DISCUSSIONS

2.1. Genesis and evolution of the marine depression

Over time, several hypotheses have been issued about the age of the Black Sea depression, assessing that it was formed in the Precambrian, in the Palaeozoic, in the Mesozoic, in the Paleogene-Neogen (lower and middle Neozoic) and, finally, in the Quaternary.

The processing of data obtained from drillings carried out on the continental and abyssal slope of the Black Sea and the Mediterranean Sea, gave the opportunity to specialists to state that the two marine depressions were trapped between two Epiproterozoic platforms (East European and African-Arabian) that were part of the Tethys Sea, today its remains, isolated by subsequent paleogeographic evolution (Neprochnov and Ross, 1975).

Geological and geographical data on the Black Sea and surrounding areas confirm the existence of a continental mass during the Palaeozoic, in the sense of structures of the Caucasian and Anatolian type that extend underwater, suggesting that in the Mesozoic and Neozoic this space was subjected to pressures in the north-south direction.

Also, the lack of granitic layer and the thinning of the earth's crust at 18-24 km in the central part of the Black Sea and the deposition of sediments directly on the basaltic layer, indicate not a compression as mentioned above, but a distension. This fact would be explained by a process of subcrustal and subaerial erosion.

The evolution of the marine basin in the Quaternary, for 600,000 years, was characterized by periods when the marine waters were sometimes salty, sometimes brackish or fresh, with repercussions on the fauna (Guilcher, 1979).

Regarding the lithological structure of the seabed, according to drillings from the last 50 years, it is noted, as mentioned, the presence of a basaltic layer in the abyssal zone over which unconsolidated sediments are deposited, which towards the edge are arranged on the edges. The sediment deposition rate in the central-basaltic part was estimated at 15 cm/1000 years (Banu, 1961).

2.2 Morphostructural characteristics

The morphobathymetric configuration allows the identification of the main morphostructural units that characterize most tectonic marine basins.

Thus, from the coast to the centre of the Black Sea, the following are distinguished (Fig. 2) Ross et al., 1975:

» *the shelf (continental platform),* which is delimited starting from the isobath of -100 m and up to -200 m depending on its interference with the continental slope; the largest development of the shelf is in the northwestern part, reaching 200 km wide in the Gulf of Odessa and very narrow on the southern coast; the total surface of the shelf occupies about 30%; within this unit, submarine valleys belonging to paleo-rivers are highlighted;

» *the continental slope* almost uniformly wraps the central area, but with slope values varying between 8°-10° and sometimes between 20°-22° in the southeastern part; submarine canyons are evident on the slope, mostly the continuation of submarine valleys on the shelf, most of which are along the shores of the Crimean Peninsula, the Caucasus Mountains and Anatolia, which were carved during periods of low levels of the Black Sea; landslides of slightly consolidated sediments caused by earthquakes also occur on the slope; the occupied surface area is about 27%;

» *the marginal depression (continental shelf)* represents the transition zone to the abyssal one and is characterized by low slopes with several irregularities formed by the slid material, small hills and most importantly, the abyssal cone of the Danube located in the northwestern part; this morphostructural unit occupies about 31%;

» *the abyssal plain* located in the centre of the Black Sea with a greater extension in the eastern part, is characterized by depths of over 2,000 m, the field of deposits determined by turbidity currents; the occupied surface is about 12%.

The marine shore presents differentiations that are in direct relation to the relief of the neighbouring units (mountains, plateaus and plains), namely:

» *a fringed, steep and rocky coastal area* in the southern (Turkey) and eastern (Georgia, partially Russia) part;

» *a rectilinear, low coastal area with bays,* lagoons and deltas in the northern (except for the Crimean coast) and northwestern (Ukraine and Romania).

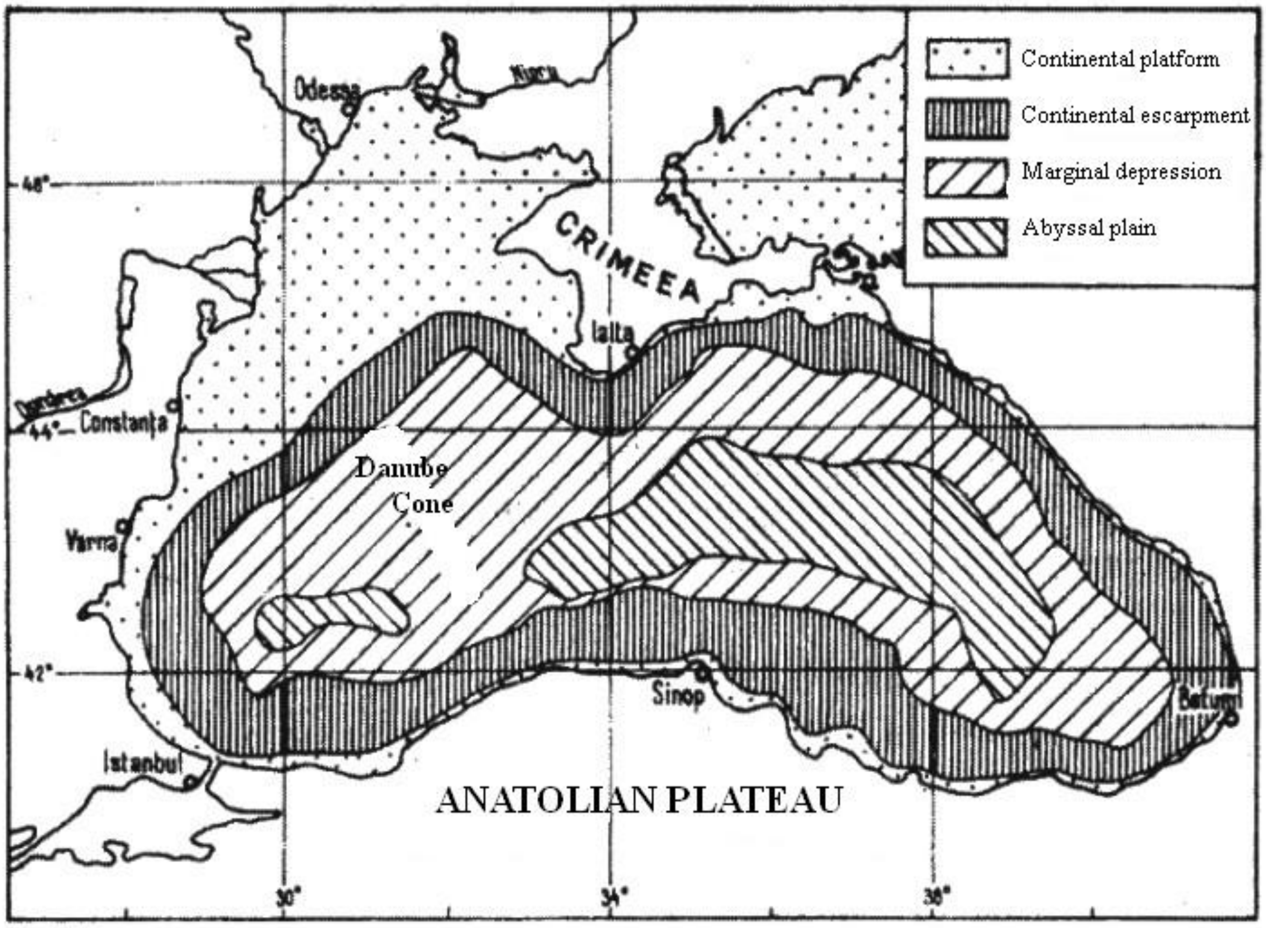

Fig. 2. Black Sea – main morphostructural units (after Ross et al., 1975)

The Black Sea has only one island, in the western part*, Șerpilor Island*, located 45 km away from the town of Sulina (48°15'53" north latitude and 30°14'41" east longitude) with an area of 17 ha, maximum height of 42 m, made up of sandstones and quartz conglomerates of Lower Jurassic age, the same as in Northern Dobrogea, genetically belonging to this morphological unit.

2.3. Climatic conditions

The Black Sea is located in the temperate zone with some subtropical influences on the southern shores of Crimea, Bulgaria and Rumelia (Turkey), a dry subtropical climate, and the shores of the Caucasus and Anatolia by a humid subtropical climate.

The average annual air temperature increases from the northwest (10-11°C) to the southeast (15.5°C); also, in the same direction increase the temperatures in January (from -2°C to 8°C) and July (from 23°C to 24°C) (Gastescu et al., 2016).

The average annual precipitation increases from the northwest (365 mm / year at Sulina) to the southeast (2,685 mm/year at Batumi). In a fairly large area of the marine area, in the western part precipitation is less than 300 mm / year, and in the northwestern part on the continental shelf is recorded only 200 mm/year.

*The water temperatu*re at the surface is close to that of the air with small differences due to the inertia of the aquatic environment in the process of accumulating and releasing heat energy.

Thus, *the average annual temperature* is 11°C in the northwest (Odessa Gulf) and 16°C in the southeast at Batumi; in February it varies from 0°C in the northwest when in the harsher winters and ice forms on the shore, to over 8°C in the southeast, and in August it increases in the same direction from 19°-20°C in the northwest to 24°C in the southeast. The values of the thermal amplitude demonstrate the accentuation of the continental character of the water area from the southeast (Batumi) to the northwest (Odessa).

Seasonal variations in water temperature in depth reach, through convective mixing, up to 60-80 m in winter and are reduced to 20 m in summer; from these depths, the water temperature drops very little to the bottom, within the limits of 7-9°C.

The presence of a 5-20 m thick layer at a depth of 60-80 m is noted, in which the temperature is lower by 1-2°C due to the descent of colder winter waters from the surface (Fig. 3).

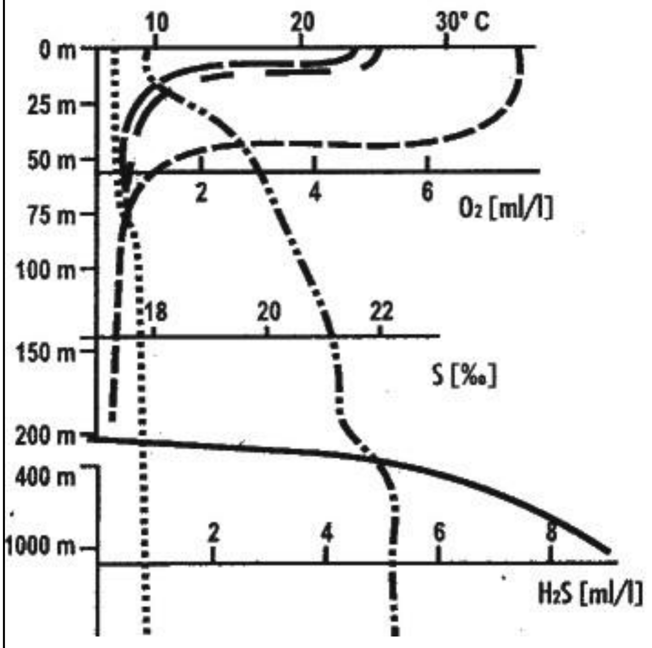

Fig. 3. Diagram of the vertical distribution of average temperature, oxygen (O_2), salinity (S) and hydrogen sulfide (H_2S) values in the Black Sea

2.4. Water balance and level variations

The water balance of the Black Sea is influenced by its continental position and its connections, on the one hand, with the Sea of Marmara (further with the Aegean Sea and the Mediterranean Sea) and, on the other hand, with the Sea of Azov, and the main components and the share of precipitation, both at the inlets and at the outlets, reflect this situation (Tab. 1).

Thus, the largest share of inputs is held by the fluvial input (42.2%), and of outputs, by evaporation loss (49.4%). Among the fluvial sources, the Danube, with its 404 km³, covers 60.3%, the Dnieper 15.6%, the Dniester 2.9%, from which it emerges that almost 80% of the fluvial input is from the northwest, without taking into account the Don and the Kuban which flow into the Sea of Azov and, therefore, their contribution to the Black Sea balance is lower. In addition, the waters of the Dnieper, in the lower course, have been transformed into a chain of reservoirs, and part of the Don waters are used for irrigation and other uses, which reduces the contribution to the marine water balance (Table 1).

As for the exchange with the Sea of Marmara, it takes place with slightly salty/brackish water at the exits (losses) on the surface and with salty water at the entrances (inputs) on the bottom, over the Bosphorus threshold, contributing to the increase in *the volume of anoxic water*.

The structure of the balance does not affect the entire water volume of the Black Sea, but only the superficial layer, between 0 and 200 m. Most of the water volume, below 200 m, is separated from the surface by sudden changes in temperature and salinity. There is, however, a rather slow exchange of water between the two water layers, but without changes in the thermal, saline regime, and living environments (Bratescu, 1942).

The long-term variation in water level reflects climatic variations from the Quaternary to the present, a characteristic of continental seas. It is estimated that the level was about 80-100 m lower than the current one, 18,000 years ago, during the glaciation (Digens and Ross, 1972).

With the melting of the glaciers after the last glaciation, the level began to rise at rates of 2-3 m in hundreds of years, alternating with short periods of stagnation or slight decline, so that about 8000-9000 years ago, the level was still 20 m lower than the current one.

The establishment of the connection with the Mediterranean Sea about 9000 years ago led to the beginning of the process of equalizing the sea level and reaching the 0 level.

Referring to the current period, as a result of the general trend of increasing the level of the Planetary Ocean caused by the effect of *global warming*, an increase in the level at a rate of 18-20 cm/100 years is also observed in the Black Sea.

Table 1. Water balance of the Black Sea (ECOSIN Firm, 1990)

	Inputs					Outputs			
	Riverflow	Precipitations	Marmara Sea	Azov Sea	Total	Evaporation	Marmara Sea	Azov Sea	Total
Annual averages									
m	338.0	237.7	176.0	49.8	801.5	395.6	371.0	33.4	800.0
%	42.0	29.7	22.0	6.2	100.0	49.5	46.4	4.2	100.0
Maximum volumes									
Kmc	492.0	322.3	274.0	71.0	-	484.0	540.0	46.0	-
%	145.6	135.6	155.7	142.6	-	122.3	145.6	137.7	-
Year	1970	1981	1950	1979	-	1951	1980	1949	-
Minimum volumes									
Kmc	246.0	170.0	96.0	35.0	-	289.0	250.0	21.0	-
%	72.8	71.5	54.5	70.3	-	73.1	67.4	62.9	-
Year	1949	1948	1980	1973	-	1985	1950	1932	-

2.5. Chemical features

Salinity depends on the isolation or connection with the Mediterranean Sea and varied greatly. If we consider the period close to our days, the Holocene, when the Black Sea was isolated, it is found that by establishing the connection with the Mediterranean, the salinization process begins. This process takes place through the surface flow of fresh water towards the Mediterranean and the depth of salt water towards the Black Sea. It is estimated that the salinization process, which took place 1000 years ago, took about 6000 years to reach the current concentration, including the distribution over depth. The average salinity in the surface layer is 18‰, and the total salinity of the water volume is about 22‰.

The salinity of the water at the sea surface varies depending on the season, being higher in summer and lower in winter by 0.5-0.6‰, due to the reduction of the input from rivers and the greater mixing of the water layer, the effect of waves. Also, the salinity at the surface is much lower in coastal areas, as a result of the input of freshwater from rivers, reaching 4-7‰ (for example in front of the Danube Delta), compared to the central area where it is 18‰.

In depth, the salinity increases from the surface (10-18‰), towards the depth, reaching 22‰ at about 1000 m and up to 25‰ at the bottom in the central area, the sudden increase in salinity occurring between 25 and 50 m depth. Regarding the salinity balance, the contribution of the main components, it is noted that 90% of the total volume of salts comes from the Mediterranean Sea.

Oxygen and hydrogen sulphide (H_2S). Due to the configuration of the basin in relation to the Sea of Marmara and the Mediterranean Sea, in the Black Sea, 7000 years ago, a process of accumulation of hydrogen sulphide began. This harmful gas, formed at the bottom, as a result of the decomposition of organic substances, increased in volume, rising to the upper layers to the detriment of dissolved oxygen.

From the sketch presented in Fig. 4, this increase in the level of hydrogen sulphide to a depth of 100-200 meters at the current stage is observed.

It is estimated that 90% of the water volume of the Black Sea is anoxic (loaded with H_2S), the largest volume of this kind in the Planetary Ocean. It is known that only some species of bacteria live in this volume of water, so the water layer capable of carrying out vital processes with dissolved oxygen is the one above (10%) and is constantly decreasing.

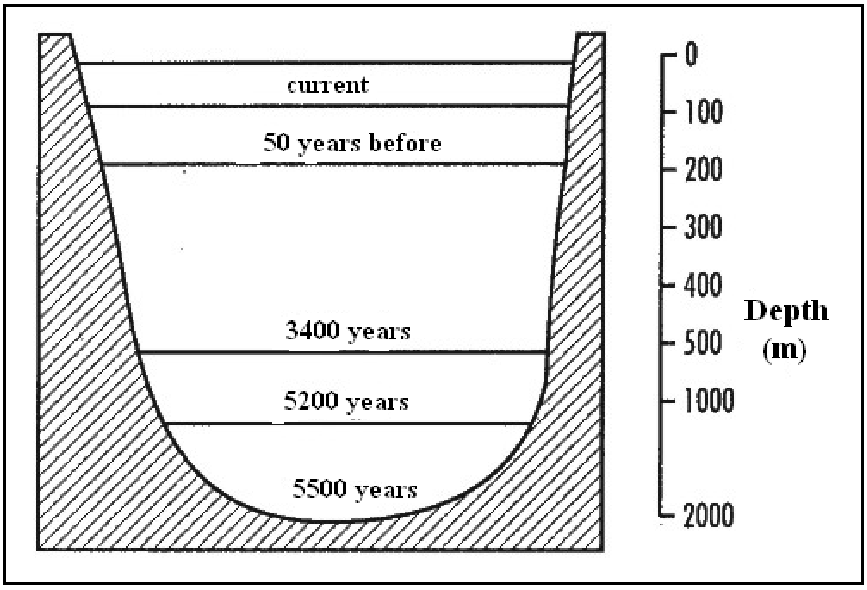

Fig. 4. Evolution of the anoxic water layer (with H_2S) in the Black Sea

The ratio between temperature, dissolved oxygen, salinity and hydrogen sulphide, in the vertical distribution determines a certain stratification of marine waters from the surface to the bottom.

It is also worth mentioning here that the Black Sea basin includes 21 states, industrialized to varying degrees and is populated by about 192 million inhabitants, of which 81 million are located in the Danube basin.

2.6. State of water quality in the biologically productive horizon

The polluted waters of the rivers in the hydrographic basin, as well as the intense navigation, the exploitation of useful mineral substances and the discharge of waste, sewage, toxic substances from all socio-economic activities in the coastal area, lead to a very high polluting potential.

Thus, the current situation has determined some ecological imbalances that have drastically reduced the potential of the natural resources of the riparian states and obviously, lead to an ecological catastrophe of the Black Sea as a whole (Miller, 1963).

Among the numerous aspects that lead to the degradation of the *euphotic* horizon in the Black Sea, the following are highlighted: *eutrophication, chemical and microbiological pollution.*

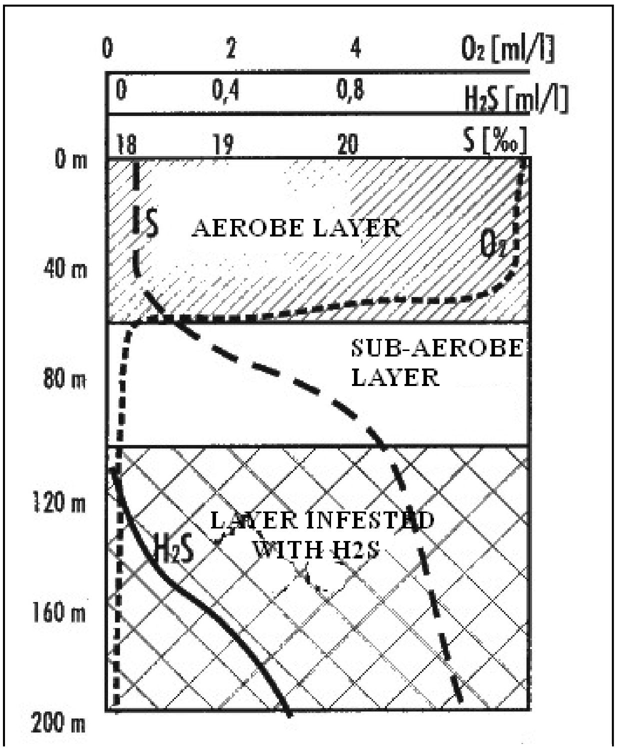

Fig. 5. Water stratification in the 0-200 m horizon

Eutrophication is registering alarming growth rates in the northwestern part of the Black Sea, due to the corresponding fluvial input. It is estimated that the Danube annually discharges 60,000 tons of phosphorus and 340,000 tons of inorganic nitrogen, these nutrients increasing in the last 50 years as a result of the use of fertilizers in agriculture and detergents in household activities (Fig. 5).

The consequence of the increase in nutrients is the explosion of *phytoplankton* (water bloom), especially on the northwestern shelf, where they are easily and quickly recycled. If in the short term the eutrophication of the water is beneficial, in the long term it has a devastating effect. Thus, in the euphotic horizon, transparency fell from 50-60 m, in the 1960s, to 35 m and even below 10 m in coastal waters. The decrease in transparency and the reduction in light penetration caused a great reduction in macrophytes, an important component *of the marine ecosystem* and a major commercial resource, in return it favoured the explosion of *nanoplankton* with low value in the *trophic chain, of the biomass of jellyfish and polyps* that reached 1 kg/m^2, offshore and 5 kg/m^2 on the shelf.

Eutrophication also has a negative final effect on the fish fauna; thus, out of 26 commercial species from the 1960s, 6 species remained, and in insignificant exploitable quantities (Gomoiu, 1996).

The disappearance of some native and valuable species, both ecologically and economically, was due to the penetration of *opportunistic and predatory species* brought in by the ballast waters of ships and which found ecological niches that allowed them to expand greatly. The most relevant example is the gastropod *Rapana thomosiana* brought in 1940 from the Japanese waters and which destroyed the oyster population. In recent years, the demand for Rapana in Japan has led to the intensification of its fishing and therefore, to the reduction of the stock (Antipa, 1941).

Chemical and microbiological pollution is the consequence of metal discharges through the rivers in the northwestern part and especially through the Danube. Monitoring of the quality of the Danube waters since 1989 highlights the fact that this river discharges through its annual liquid flow into the Black Sea 1000 tons of chromium, 900 tons of copper, 60 tons of mercury, 4500 tons of lead, 6000 tons of zinc and an impressive quantity of 50,000 tons of oil.

Regarding synthetic organic pollutants such as pesticides, of which D.D.T., although not yet approved, has been found to be present in various fish.

Other ways of polluting marine waters are the discharges of toxic waste, dredged sludge and other industrial and domestic pollutants on the continental shelf, which produce a significant impact on *the benthic layer*. Added to this is pollution with oil residues in the area of ports, on maritime navigation routes, in the vicinity of oil exploitations or in the Bosphorus Strait (Mee, 1994).

Eutrophication, chemical and oil pollution favour the growth of the anoxic layer loaded with hydrogen sulphide. Investigations carried out in the northern part of the Black Sea, although contradictory, have revealed that compared to 1970, the boundary between *the oxic and anoxic horizons* sometimes reaches 30 meters below sea level.

3. CONCLUSIONS

Due to the critical ecological situation of this basin and the political changes that occurred after 1990 in the riparian countries, especially in the former socialist countries, it was possible to implement several programs aimed at a better database, coordination of reconstruction policy and ecological management.

In this regard, we mention *the Convention for the Protection of the Black Sea*, from 1992, which was signed and ratified by the governments of the 6 riparian countries and which entered into force in February 1994. This convention provides for the establishment of the *Black Sea Commission* and a series of protocols on protection against pollution sources and regulation of discharges of oil residues or toxic substances. The Commission, based in Istanbul, is tasked with developing criteria for the prevention, reduction and control of pollution, on the one hand, and their implementation, on the other.

To achieve these goals, the riparian governments appealed to *the Global Environment Facility (GEF)* financed by the World Bank, which became operational in Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine, to develop a three-year program (1992-1996) on the Black

Sea, through which technical assistance would be provided in the design of an Action Plan for the implementation of the above-mentioned convention.

The GEF (Global Environment Facility) program for the Black Sea, approved by national coordinators (ministries for the environment) had three main objectives:

» strengthening and creating regional capacities for the management of the Black Sea ecosystem;

» developing and implementing a policy and framework for the assessment, control, and prevention of pollution, maintaining and improving biodiversity;

» facilitating and preparing investments for a healthy environment.

To implement the program, working groups were established on certain issues in which institutions and specialists, non-governmental organizations and representatives of the economic sectors involved participated.

The working groups operated through seminars or pilot stations and were distributed by country as follows: unforeseen reactions (Bulgaria); routine pollution monitoring (Turkey); special monitoring programs, biological effects and human health (Georgia), common standards and methodologies for integrated coastal zone management (Russian Federation); fisheries (Romania).

To these were added 3 working groups that belonged directly to the Istanbul Coordination Commission with the following objectives: management information; advisory group on the harmonization of environmental quality criteria, legislative standards and enforcement; group for environmental economic studies.

The GEF program for the Black Sea was correlated with other regional programs in the Black Sea hydrographic basin such as: EROS 2000 Black Sea (European River System), NATO's Science for Stability, Cooperative Marine Ecosystem Modelling as a Management Tool for the Black Sea, The Application of Tracer Techniques for the Study of Processes and Pollution under the auspices of IAEA, Horizon 2020 Coastal European Project and many others in which are implied institutions belonging to UNO, World Bank, etc.

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