6. BLACK SEA SEDIMENTARY FRAMEWORK[1]

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This paper summarizes results from important previous Black Sea sedimentary studies in order to provide background information useful for the interpretation of data from Leg 42B drilling. The information presented is basically derived from *Atlantis II* Cruise 49 (Degens and Ross, 1974) by the Woods Hole Oceanographic Institution and from cruises of the research vessels *Akademik S. Vavilov, Vityaz,* and *Academik Shirshov* of the Institute of Oceanology of Academy of Sciences of the Soviet Union (summarized by Shimkus and Trimonis, 1974). A listing of important literature concerning the biology, geology, chemistry, and geophysics of the Black Sea has been compiled by Laking, 1974.

BLACK SEA DRAINAGE AREA

The drainage area of the Black Sea is about 1,864,000 km^2 (Figure 1) of which approximately 85% belongs to the Russian Platform, and about 15% to high mountain areas. Generally low relief is found on the Russian Platform and Walachian Lowlands to the north and west. The rivers (Danube, Dnester, Bug, Dneper, Don) draining these areas have low velocity and limans at their mouths (see Shimkus and Trimonis, 1974, for a more detailed discussion). In the southwest, south, and east, the Black Sea is surrounded by mountainous regions (Balkan, Pontic, and Caucasus mountains). In contrast with the wide, large rivers of the north and northwest, this area has numerous small, but extremely erosive, rivers. As shown by Table 1, all rivers deposit a total of about 150 million tons of solid material per year into the Black Sea. This number should be considered as a minimum value, because the quantity of sediments transported by the Turkish rivers is probably larger than 17 million tons per year. The importance of organic productivity and river detritus to the sediment budget of the Black Sea can be seen from Figure 2. Based on the data of Table 1 and Figure 2, the Danube is presently by far the most important river draining into the Black Sea.

REGIONAL GEOLOGY

The Black Sea is located between the Paleozoic Russian Platform and the Mediterranean geosyncline which was folded during the Alpine orogeny. The Russian Platform represents a peneplain surface of Paleozoic, Mesozoic, and Tertiary sedimentary rocks (Figure 3). White chalks, marls, and argillaceous and sandy sedimentary units of Mesozoic and Tertiary age dominate the middle and southern part of the platform. The old crystalline Ukranian massif rising above the general level of the Russian Platform consists of gneiss, crystalline, schist, phyllite, chlorite schists, quartzite, and granitic rocks.

In its upper course, the Danube (Figures 1 and 3) runs through the Jurassic rocks of the Suebian Alb, the Tertiary rocks of the Bavarian molasse, the granitic and metamorphic rocks of the Bohemian massif and, most important, the complex series of the eastern Alps. The fluvial and eolian sediments of Quaternary age found in the Hungarian and Walachian Lowlands influence the middle and lower course of the Danube. The northern drainage of the Danube, the Carpathians, consists of Cretaceous and Tertiary flysch deposits, as well as Paleozoic gneisses and crystalline schists. The southern effluents of the Danube are mainly derived from the Balkans, which are distinguished by granites and crystalline schists.

The Pontic Mountain range south of the Black Sea can be divided into a western part dominated by flych deposits of Cretaceous and Eocene ages, and a more mountainous eastern region, which has an extensive distribution of Upper Cretaceous and Eocene volcanic rocks, and individual crystalline massifs.

The drainage area to the northeast and east is in the Caucasus Mountain range, which contains a large variety of rocks. The lower Caucasus has abundant Pliocene and Quaternary volcanic rocks, whereas the central Caucasus consists of Precambrian gneisses, mica and chlorite schists, and silicic intrusive rocks. The drainage area of the northeastern Caucasus comprises a chalk-flysch and clay-flysch facies of Cretaceous age.

The Crimean mountains, which are the southwestern extension of the Caucasus, are basically formed of Jurassic and Tertiary rocks. A flysch facies dominates the Middle Jurassic section, whereas the Upper Jurassic region is characterized by micritic and coral limestone. The area towards the northern Caucasus consists of limestones and mudstones which grade into carbonate flysch or sandy-argillaccous rocks. The widely distributed Neogene strata are mainly composed of sandy argillaceous sediments with some carbonate rocks.

HYDROGRAPHY AND BATHYMETRY

The Black Sea is an eliptical basin with an area of 423,000 km^2, a volume of 534,000 km^2, and a maximum depth of 2206 meters. The basin has four main physiographic regions: shelf, basin slope, basin apron, and abyssal plain (Figure 4). Maximum development of the shelf is west of the Crimean Peninsula, where it is more than 190 km wide. Along the mountainous coast of Turkey, eastern Russia, and south of

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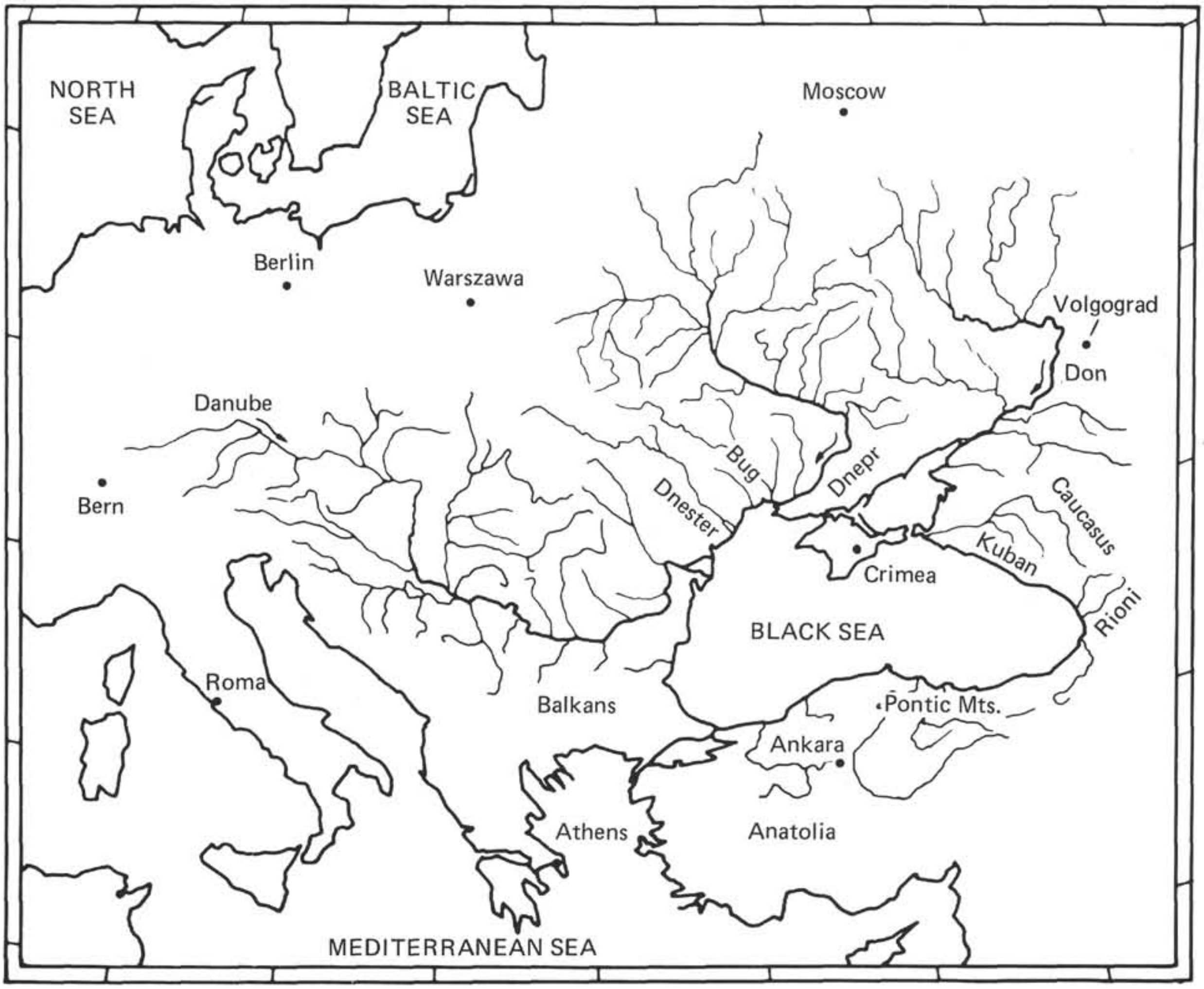

Figure 1. *Drainage area of the Black Sea (from Müller and Stoffers, 1974).*

the Crimean Peninsula, the shelf is narrow and hardly exceeds 20 km in width. The slope can be of two types; either a steep slope that is highly dissected by submarine canyons, or a relatively smooth slope. The latter is limited to the broad shelf west of the Crimean and southwest of the Sea of Azov.

The most distinctive depositional feature of the basin apron (gradient between 1:40 and 1:1000) is the Danube fan, which divides the abyssal plain into two unequal parts. The abyssal plain has a gradient of less than 1:1000, and is better developed in the eastern part of the basin.

BLACK SEA SEDIMENTS

The sediment pattern in the nearshore zone of the Black Sea is governed by surface and longshore bottom currents and wave action. In the deep basin, the sediment pattern is controlled by an isolated cyclonic current system and bottom morphology. Large quantities of detritus from the Danube, Dneper, etc. are deposited and trapped on the broad western shelf, whereas the terrigenous material derived from the geosyncline drainage areas (Pontic and Caucasus mountains, and Crimean peninsula) easily crosses the narrow shelf and enters the deep basin, often in the form of turbidite deposits. Textural analyses of cores from the western and eastern basins reflect these differences in the shelf morphology. A rather uniform sedimentation pattern of mainly fine-grained material predominates in the western basin, whereas abundant turbidites and silty material in the cores off the eastern coast indicate high variability in the sedimentation pattern (Figures 5a and b).

Recent sedimentation in the Black Sea is governed by the deposition of terrigenous allochthonous material of low carbonate content and the autochthonous production of large quantities of biogenic carbonate material (coccolithophorids). The surface distribution of grain size and carbonate content in the surface sediments is shown in Figures 6a and b. The highest clay and carbonate content is in central areas of the western and eastern basins. Because the biogenic constituents are composed of clay-sized calcite, the total carbonate content, as well as the amount of the $>2\mu m$ fraction, increase simultaneously with the coccolith portion.

On the basis of grain size, carbonate, and organic carbon content, 12 genetic types of modern Black Sea sediments can be distinguished (Figure 7).

MINERALOGY

Rock fragments, carbonate material, quartz, feldspars, heavy minerals, phyllosilicates, zeolites, iron sulfides, and amorphous silica have been detected in the Black Sea surface sediments (Figures 8 and 9). Rock fragments are generally rare, but a distinct pattern exists with volcanic and metamor-

TABLE 1
Liquid and Solid Discharge of Rivers in Black Sea Basin
(from Shimkus and Trimonis, 1974 – original source of data given in their paper)

Rivers	Liquid Discharge (km^3)	Solid Discharge (10^6 tons)
Platform area of drainage system, plains rivers		
Dneper	52	2.12
Southern Bug	3	0.53
Dnester	10	2.50
Don	28	6.40
Subtotal	93	11.55
Geosynclinal-platform area of drainage system, mountain-plains rivers		
Danube	198	83
Kuban	12.8	8.4
Subtotal	211.8	91.4
Folded mountain area of drainage system, mountain rivers		
Rivers from Kerch Strait to Batumi	41	–[a]
Rivers of Georgian Coast		
Bzyb'		0.60
Kodori		1.01
Inguri		2.78
Rioni		7.08
Chorokh (Goruh)		15.13
Others		2.40
Subtotal	41	29(?)
Rivers of Turkish Coast	25	17[b]
Rivers of Bulgaria	3	0.5[b]
Subtotal	28	17.05[b]
Total	373.8	149.45

[a]No amount given.
[b]Very approximate estimate made on basis of liquid discharge.

phic rock fragments being more abundant in the eastern part of the Black Sea. The main carbonate minerals are biogenic calcite and aragonite (coccolithophorides and molluscs). Aragonite is restricted to the shelf areas, whereas calcite predominates in the deeper parts of the Black Sea. The amount of detrital calcite, mainly present in the coarse-silt fraction, is generally less than 15%.

Dolomite occurs only in minor amounts in the western region of the Black Sea. The quartz and feldspars content in the sand fraction, generally decreases from west to east. Illite, smectite, kaolinite, and chlorite were detected in the $<2\mu m$ fraction. Illite is the most common clay mineral in the Black Sea surface sediments, and is mainly found in the north. Smectite predominates in the sediments off the Anatolian coast.

Heavy mineral studies reveal six provinces (Figure 9b):

I. Danube province (northwestern Black Sea): garnet, epidotes, green hornblende, staurolite, kyanite, zircon.

II. Bosporus province (southwestern Black Sea): epidotes, garet, amphiboles (green, brown, alkalic hornblende) pyroxene chloritoid, rutile, titanite.

III. West Anatolian province (southwestern Black Sea): amphiboles (actinolite, brown hornblende, crossite), epidotes (zoisite) pyroxene, garnet, zircon, rutile.

IV. East Anatolian and South Caucasian province (southeastern Black Sea): pyroxenes, amphibole, epidote, garnet, zircon.

V. North Caucasian province (northeastern Black Sea): epidotes (zoisite) green hornblende, garnet, pyroxene, zircon, tourmaline.

VI. Crimean province (off the Crimean peninsula): Amphiboles, epidotes, kyanite, garnet, staurolite, pyroxene, zircon, andalusite, rutile.

The mineralogy of the surface sediments clearly indicates the importance of provenance. A northern one is mainly influenced by the Danube which is characterized by a low calcite/dolomite and a high quartz/feldspar ratio. Garnet is the most abundant heavy mineral, and illite predominates in the clay fraction. In contrast, the southern distributive area is distinguished by a high calcite/dolomite and a low quartz/feldspar ratio and is related to the petrology of the individual source areas.

STRATIGRAPHY

Stratigraphic studies based on piston cores revealed three distinct sediment units which can be correlated over most of the Black Sea (Figure 10). These units were not observed in all the drilled cores, probably because of drilling disturbance and near-surface position of the units. The top unit (Unit 1), which is about 30 cm thick, consists of alternating white carbonate and dark lutite layers. The white layers consist almost entirely of coccoliths *(Emiliania huxleyi)*. The radiocarbon age at the base of Unit 1 is about 3000 years B.P.

Unit 2 is a dark brown jelly-like sapropel, having as much as 50% organic matter. Thin layers of inorganically precipitated aragonite often occur within this unit. Deposition of this unit was between 7000 and 3000 years ago.

Unit 3 is an alternating sequence of dark and light lutites consisting of clastic material with a low content of carbonate and organic matter. This unit comprises the main section of the piston cores, and although its base was not reached, a ^{14}C date of about 25,000 years B.P. was determined from a sample taken at the bottom of an 11-meter-long piston core.

The stratigraphic position and classification of Black Sea sediments is in some instances (see paper by Ross, this volume) a matter of confusion. However, the position and age of these three units is fairly clear (Table 2).

RECENT GEOLOGICAL HISTORY

The stratigraphic units encountered in the piston cores are closely related to the late Pleistocene-Holocene climatic changes. About 25,000 years ago, during the Würm (Weichselian) glaciation, the sea level was somewhat lower than today, thus isolating the Black Sea from the Mediterranean Sea (Figure 11). At that time, the Black Sea was an aerobic fresh water lake. Deglaciation eventually caused a rising sea level and permitted Mediterranean water to flow via the Borporus into the Black Sea. Between 9000 and 7000 years B.P., a gradual shift from a fresh water to a marine environment, and from an oxic to anoxic condition occurred. About 7000 years ago, the H_2S zone became well established and started to increase in thickness. During this period the dark organic-rich sediments of Unit 2 were deposited. Deposition of the coccolith ooze (Unit 1) and environmental conditions similar to today were established about 3000 years B.P.

ACKNOWLEDGMENTS

The writers wish to thank K.O. Emery and Elazar Uchupi for critically reviewing the paper.

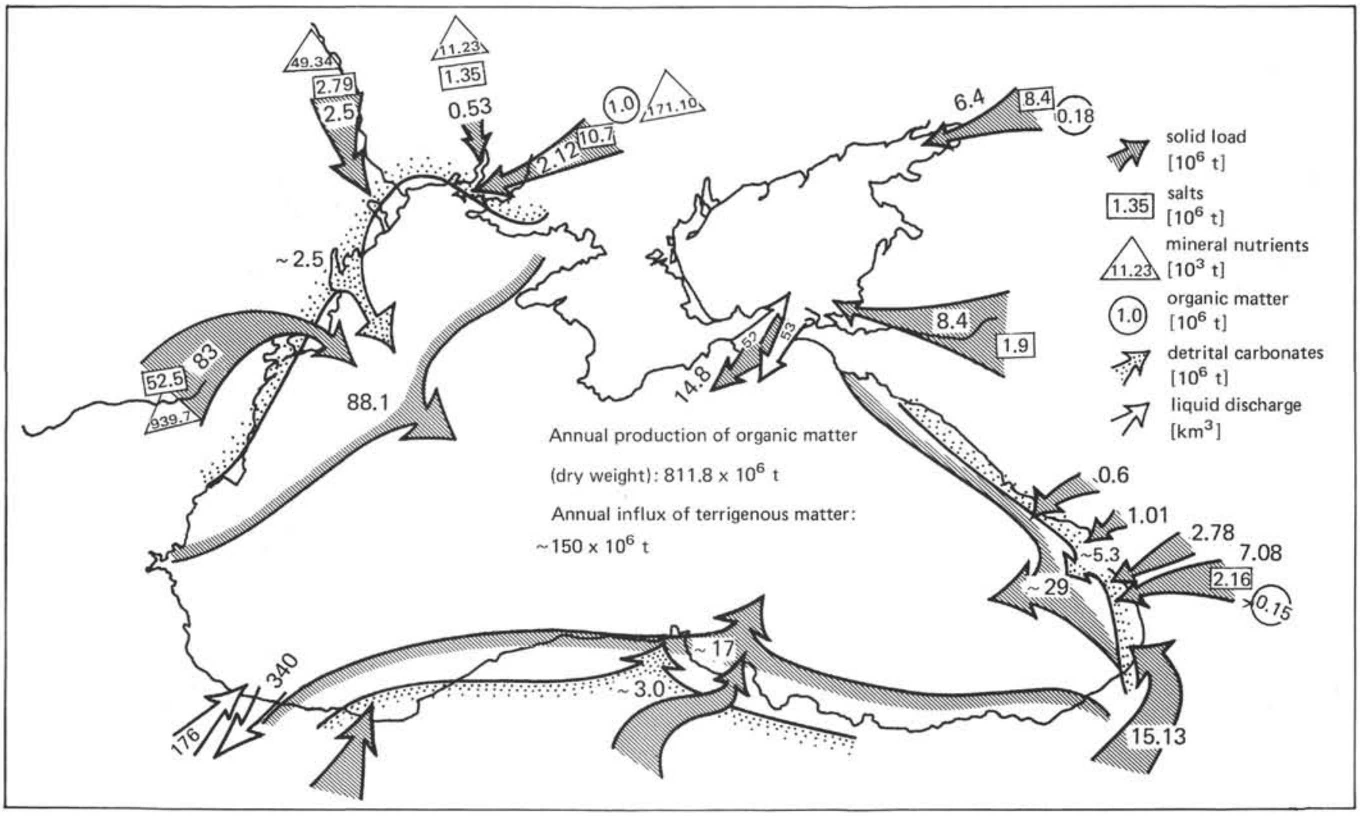

Figure 2. *Supply of sedimentary material to Black Sea basin on an annual basis (from Shimkuṣ and Trimonis, 1974).*

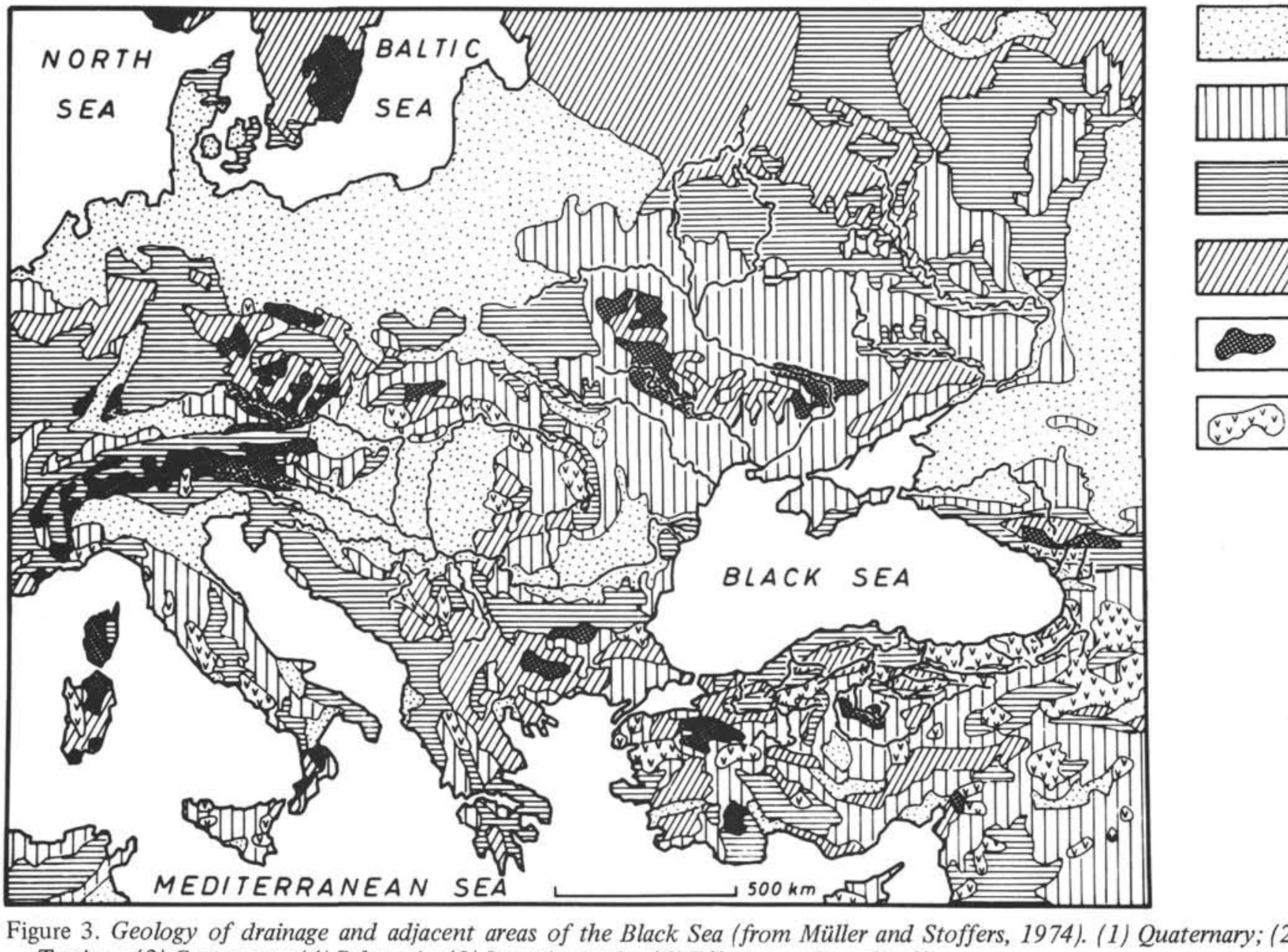

Figure 3. *Geology of drainage and adjacent areas of the Black Sea (from Müller and Stoffers, 1974). (1) Quaternary; (2) Tertiary; (3) Cretaceous; (4) Paleozoic; (5) Intrusive rocks; (6) Effusive rocks and tuffs.*

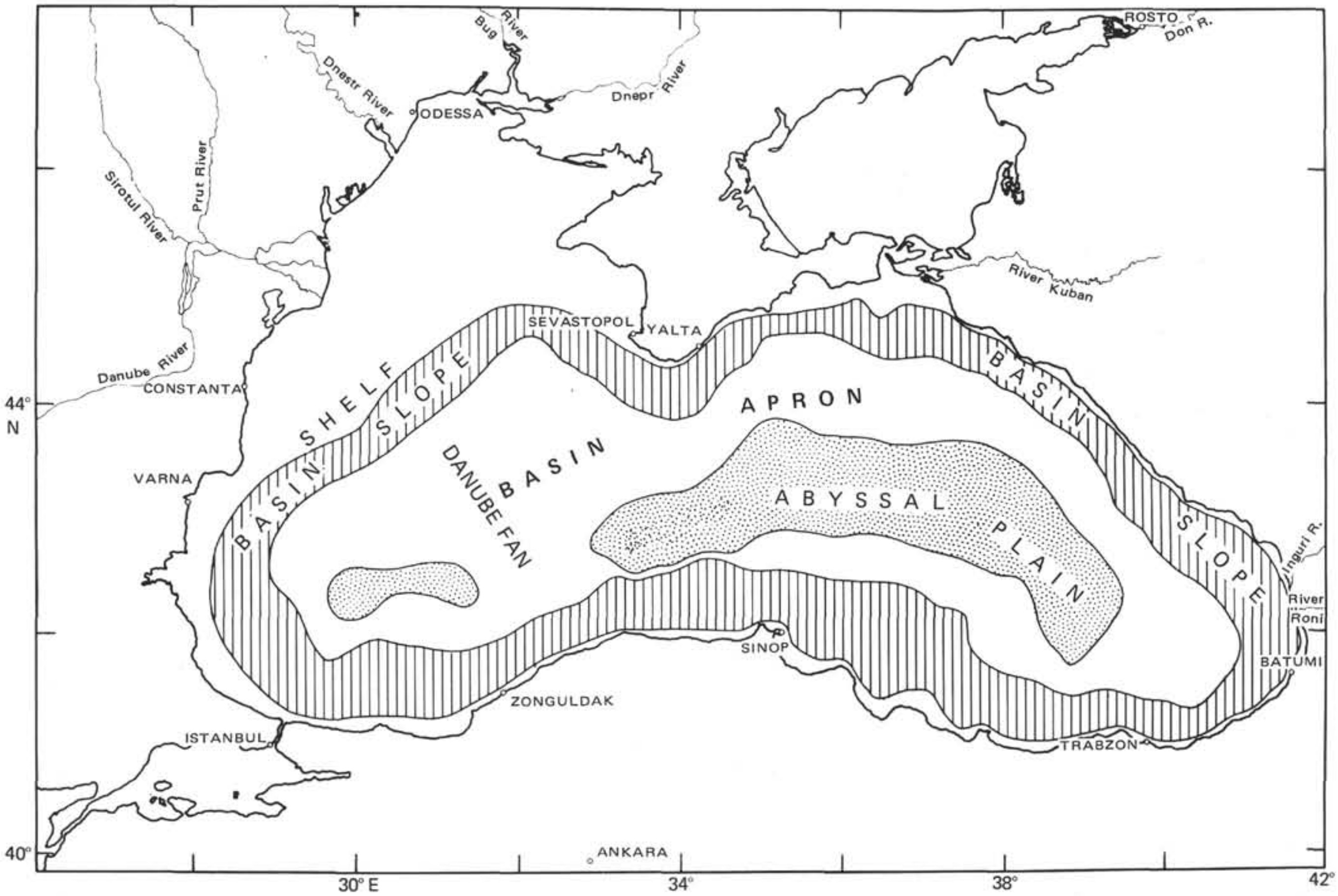

Figure 4. *Main physiographic features of the Black Sea (from Ross et al., 1974).*

The 1969 research expedition of *Atlantis II* into the Black Sea was funded by the National Science Foundation. The senior author of this paper was supported during the writing of this manuscript by a contract with the Office of Naval Research.

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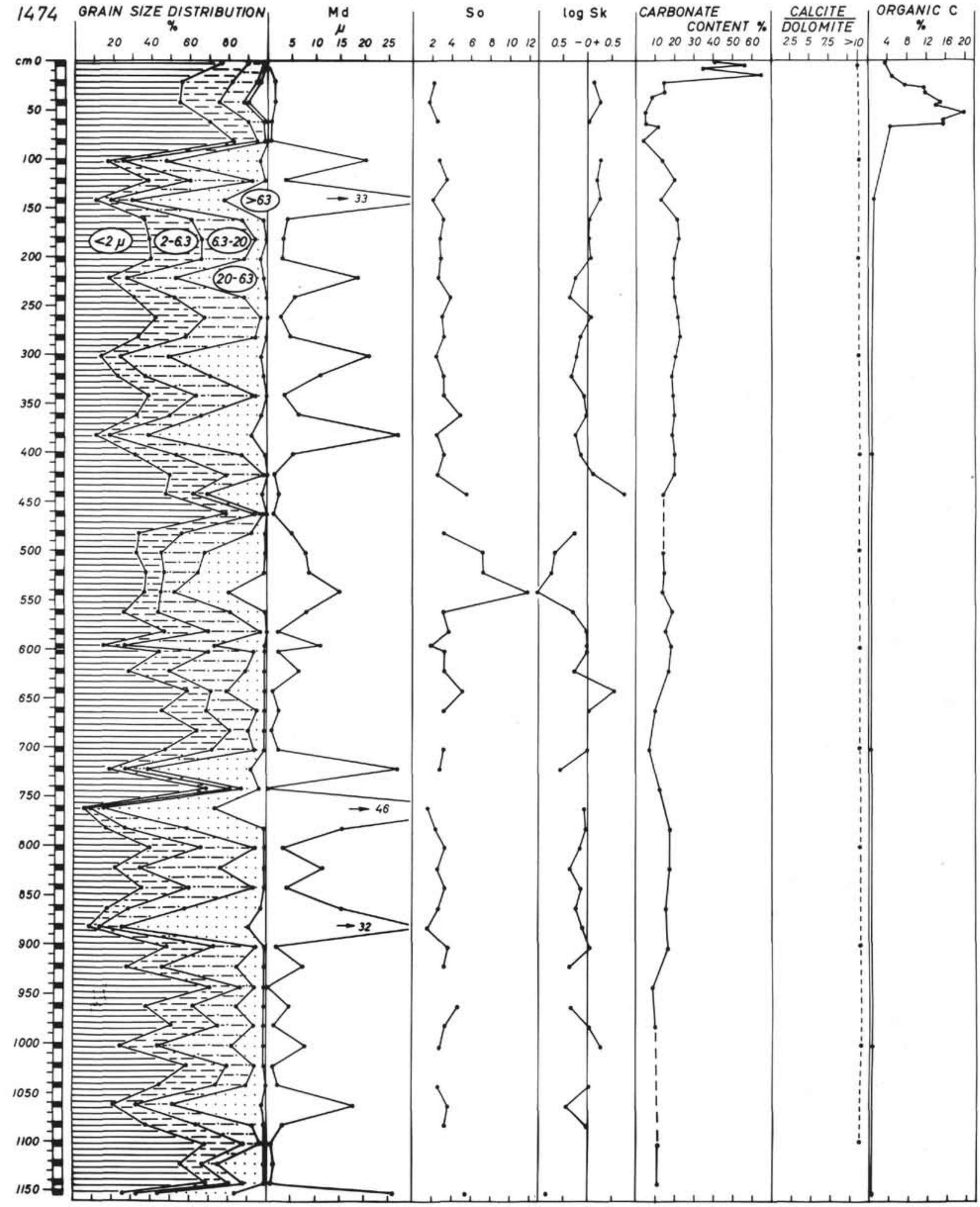

Figure 5a. *Grain-size distribution and other parameters of core* Atlantis *II-49, 1474 taken from eastern part of Black Sea.*

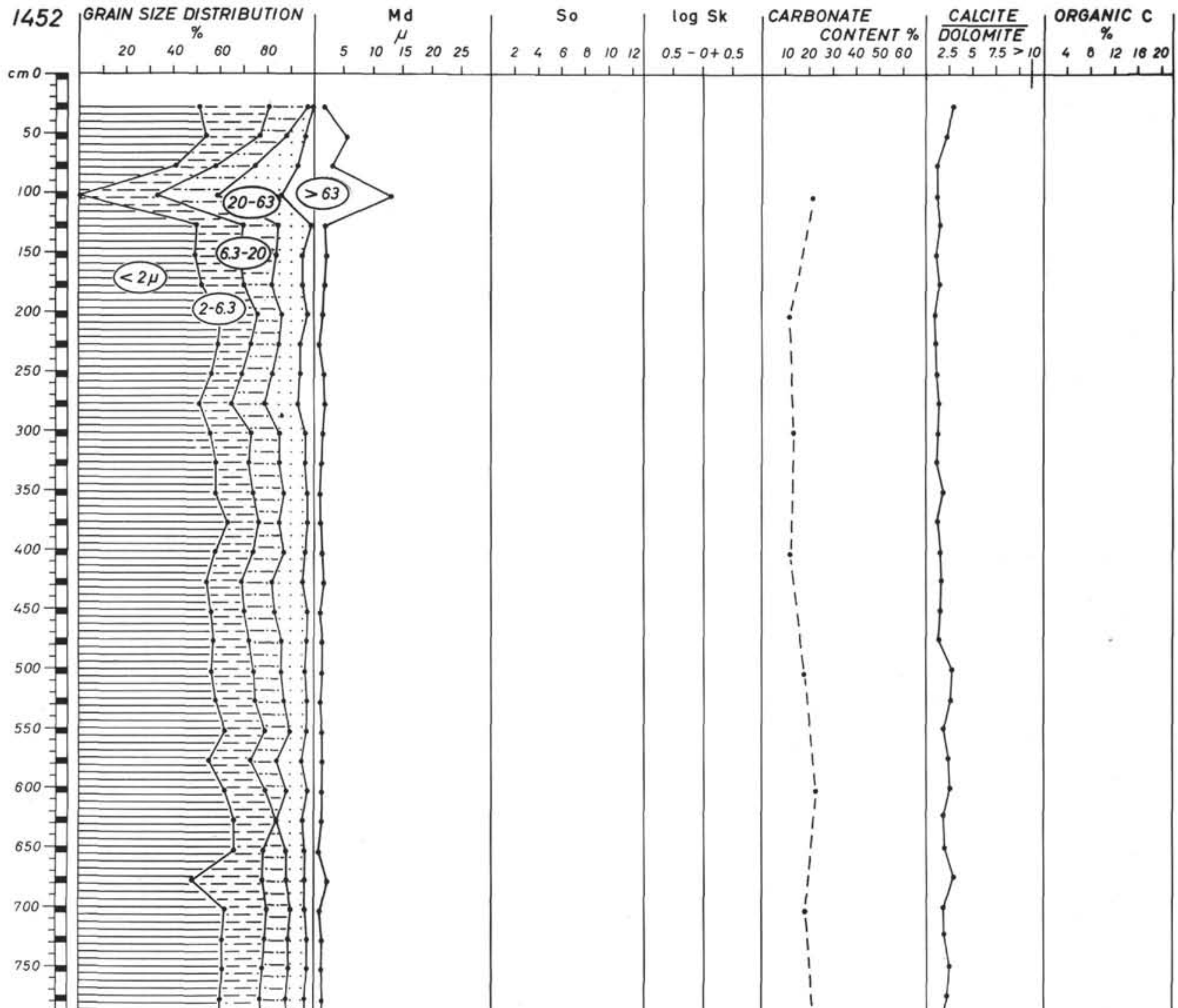

Figure 5b. *Grain-size distribution and other parameters of core* Atlantis *II-49, 1452 taken from western part of Black Sea.*

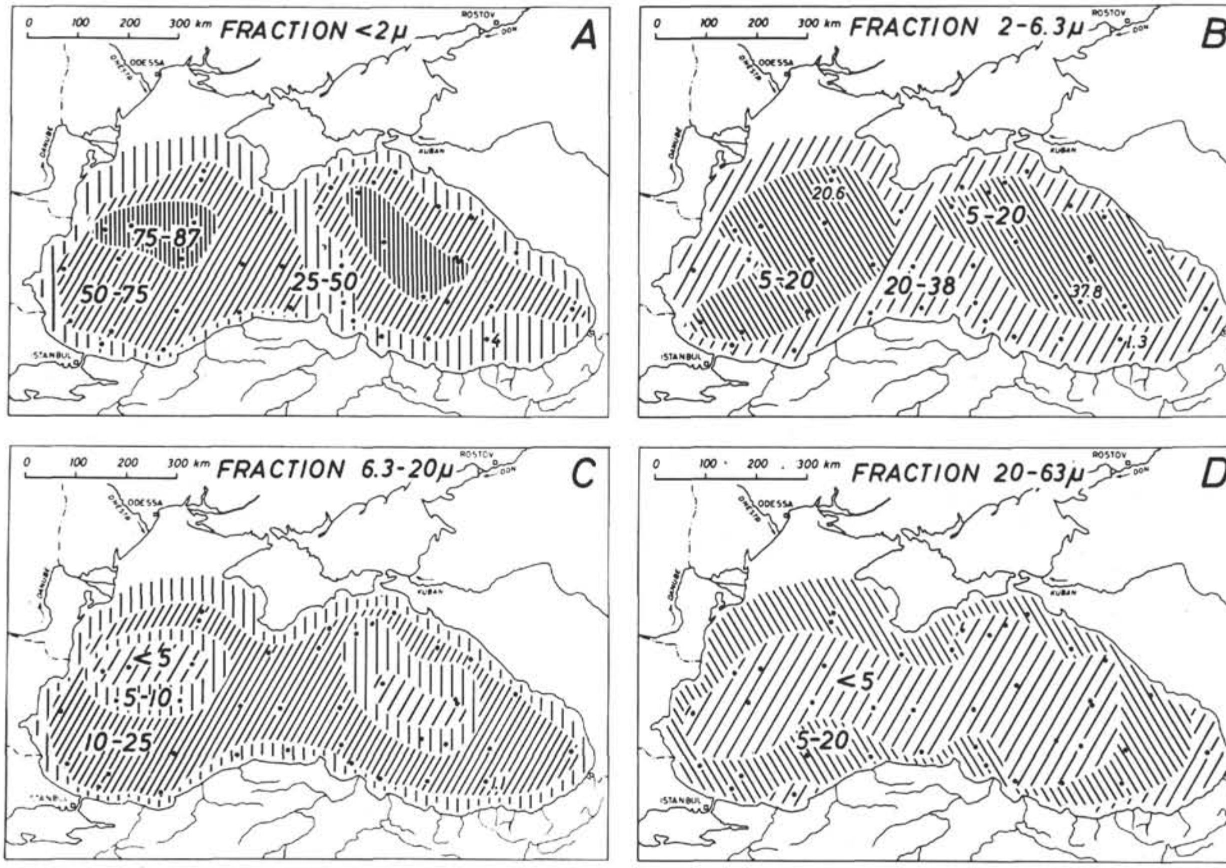

Figure 6a. *Grain-size distribution (in per cent) of surface sediments from Müller and Stoffers, 1974.*

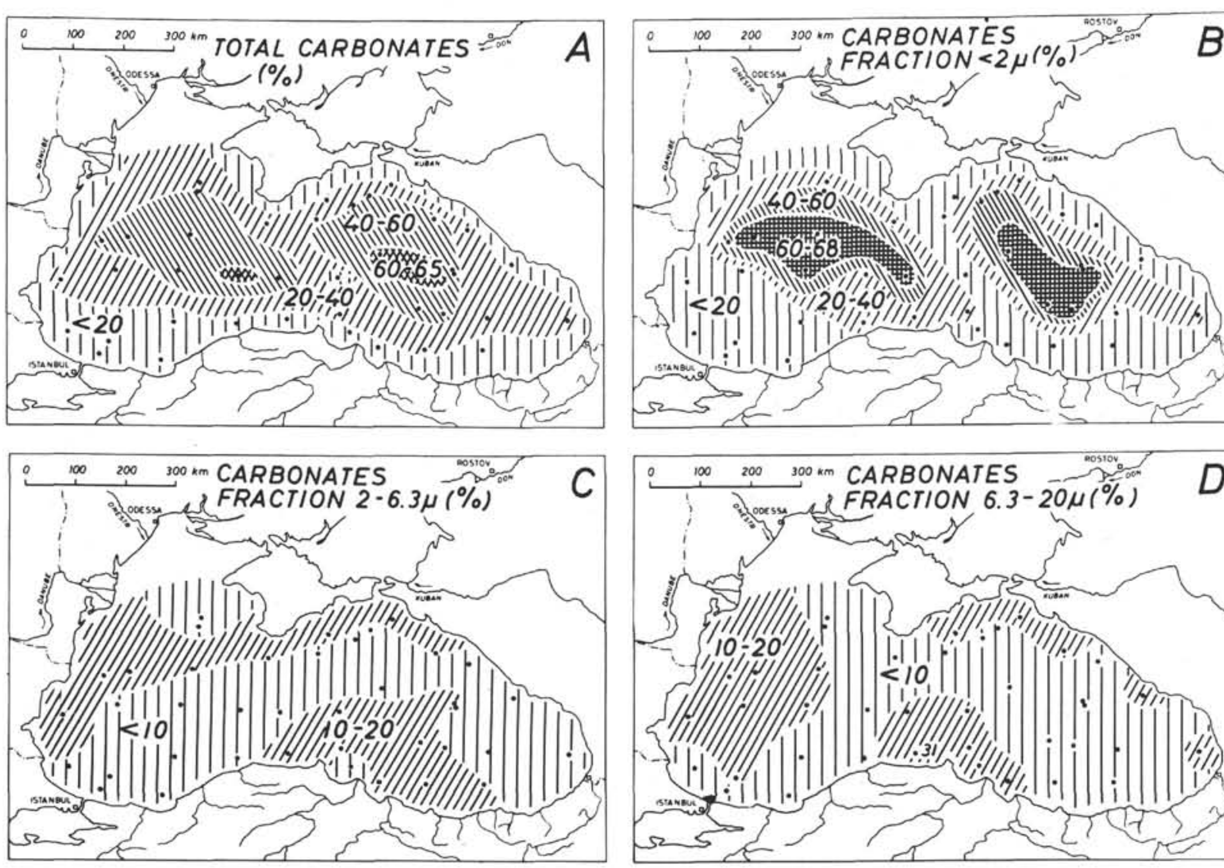

Figure 6b. *Total carbonate material and carbonate content of individual fractions, from Müller and Stoffers, 1974. Both figures based on anaylses of cores taken during R. V.* Atlantis *II Cruise 49.*

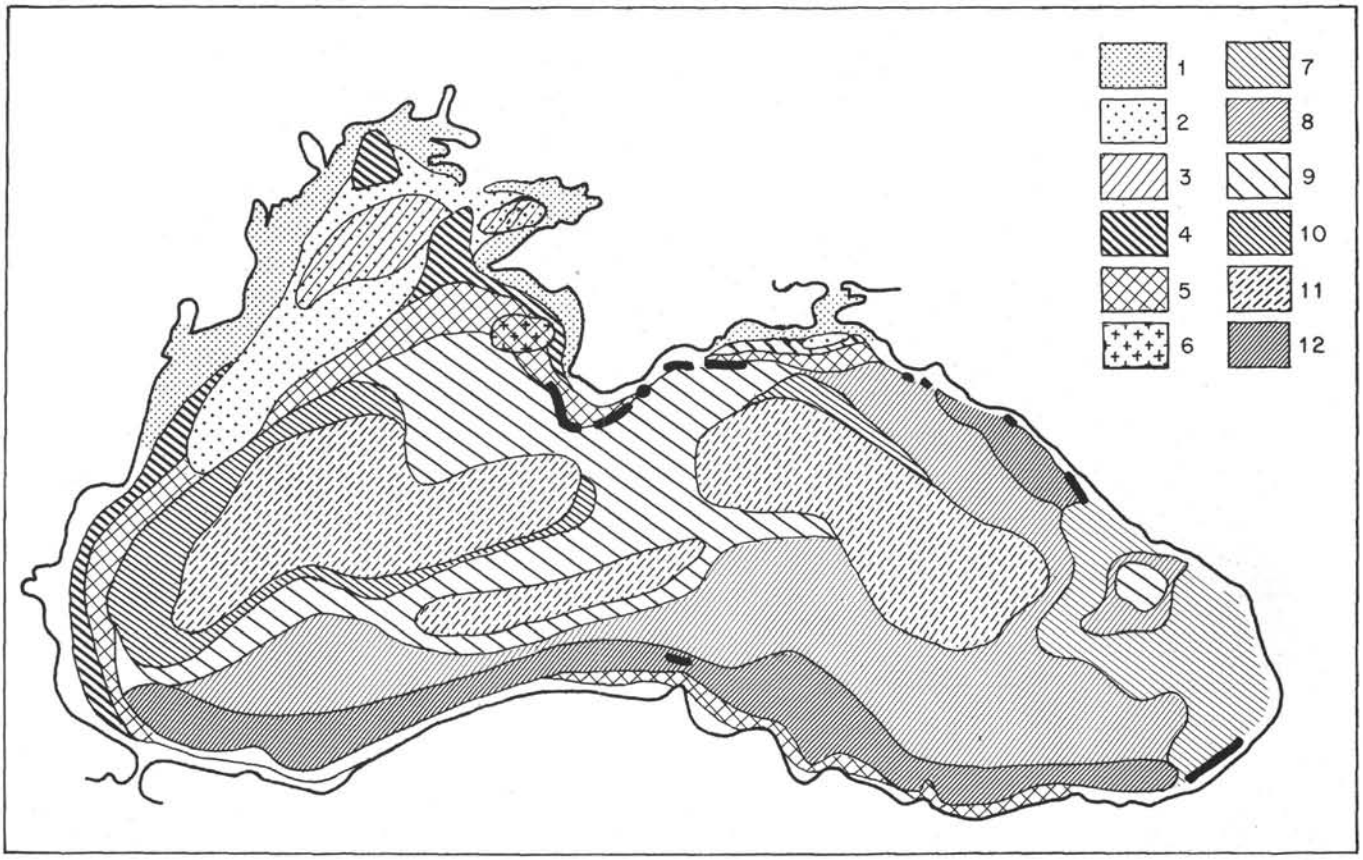

Figure 7. *Compositional-genetic types of modern Black Sea sediments, from Shimkus and Trimonis, 1974. Shallow-water sediments: (1) organogenic-clastic, very coarse-grained and coarse-grained sediments; (2) carbonate-rich shelly sediments; ($CaCO_3$ 50%); (3) sediments covered by overgrowth of Phyllophora; (4) carbonate-poor and carbonate-bearing, organogenic-terrigenous mytilid muds ($CaCO_3$ = 10-50%); (5) carbonate-poor and carbonate-bearing phaseolina muds concretions. Deep-water sediments: (7) carbonate-free terrigenous sediments ($CaCO_3$ content 10%); (8) carbonate-poor organogenic-terrigenous muds ($CaCO_3$ content = 10-30%); (9) carbonate-poor, organogenic-terrigenous, finely dispersed muds ($CaCO_3$ content = 10-30%); (10) carbonate-bearing, organogenic-terrigenous, finely dispersed coccolith muds ($CaCO_3$ content = 30-50%); (11) carbonate-rich (locally carbonate-bearing), finely dispersed coccolith muds rich in organic matter; (12) modern sediments of considerable diversity with predominance of carbon-poor organogenic-terrigenic muds.*

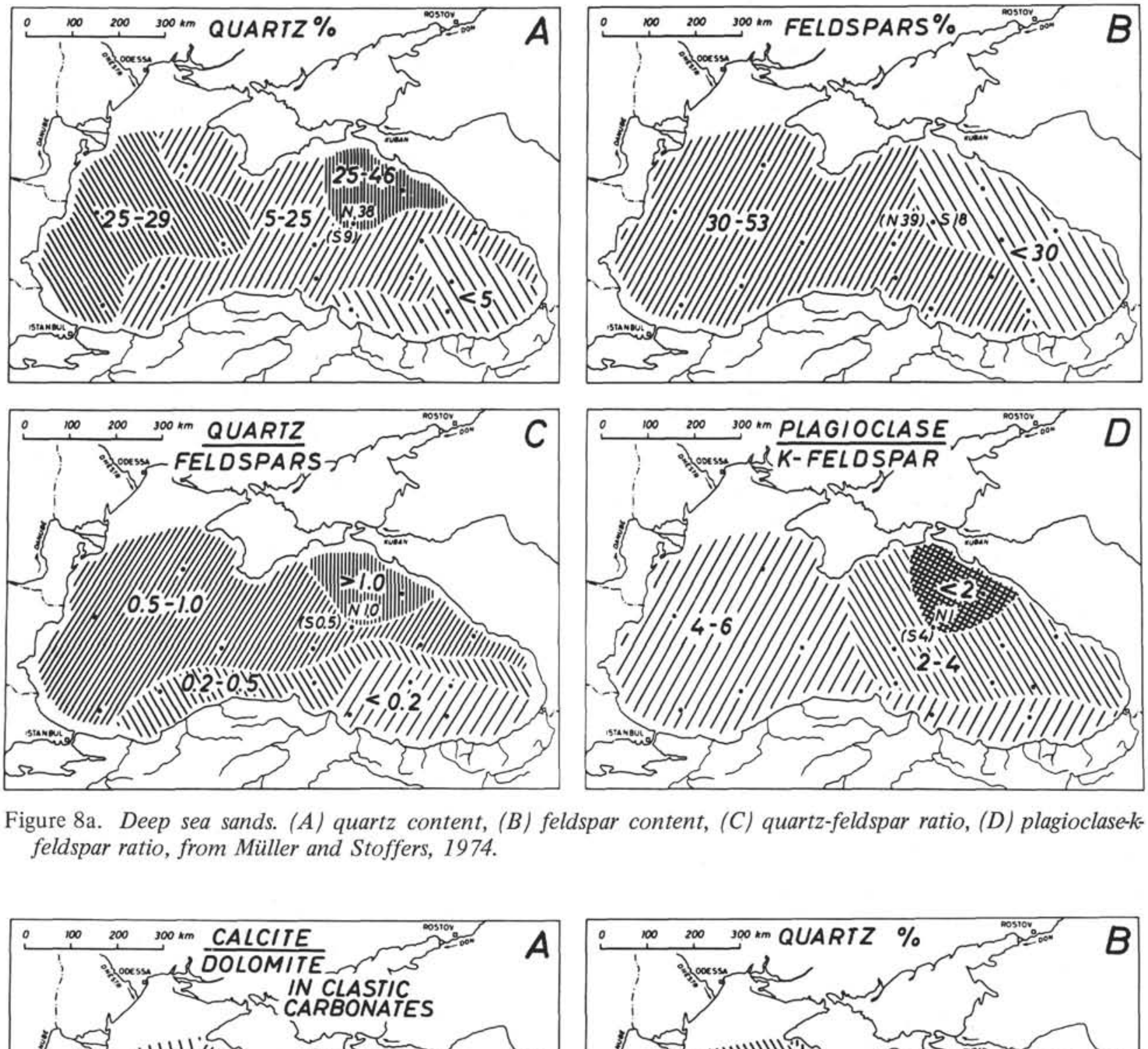

Figure 8a. *Deep sea sands. (A) quartz content, (B) feldspar content, (C) quartz-feldspar ratio, (D) plagioclase-k-feldspar ratio, from Müller and Stoffers, 1974.*

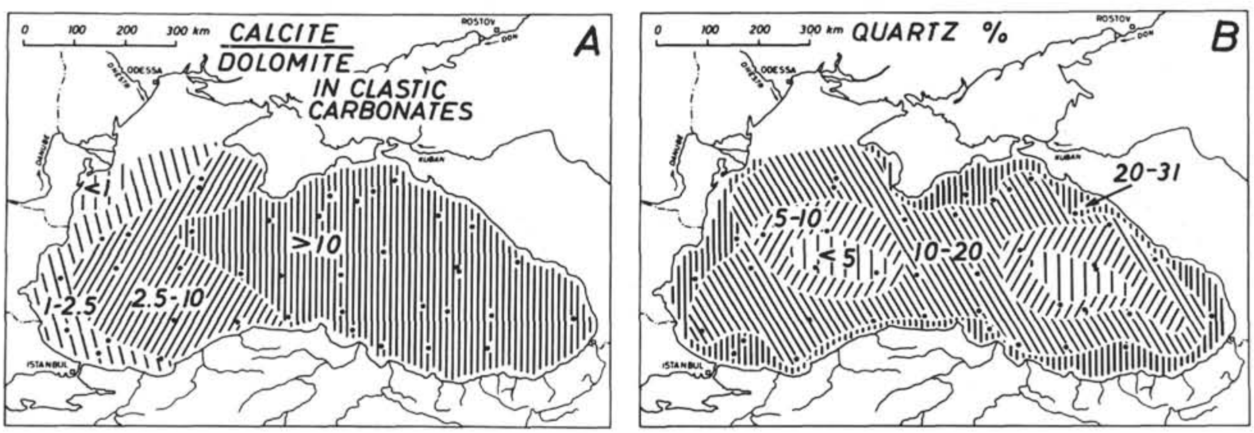

Figure 8b. *(A) Calcite/dolomite ratio in clastic carbonate material. (B) Quartz content in the surface sediments. Müller and Stoffers, 1974. Both figures based on analyses of cores taken during R. V.* Atlantis *II Cruise 49.*

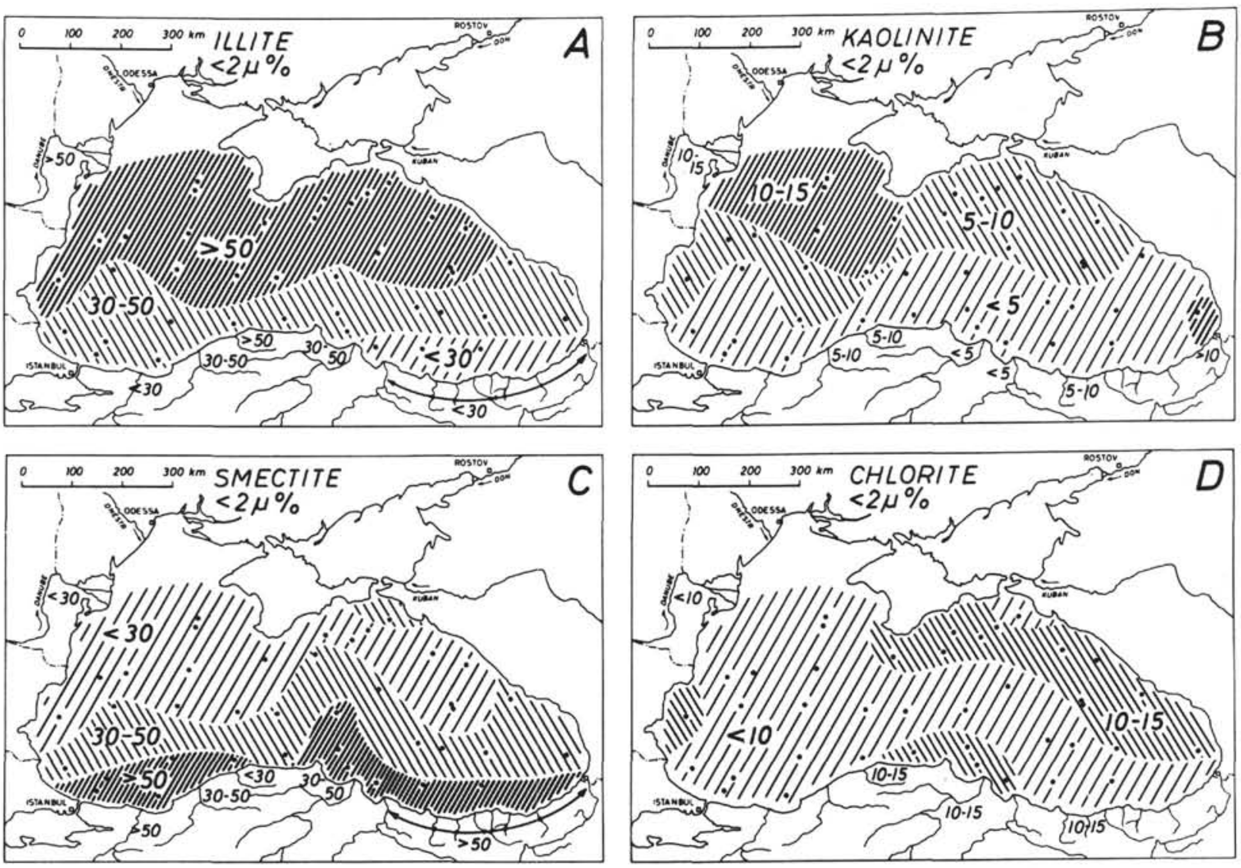

Figure 9a. *Clay mineral composition of fraction 2um. (A) illite, (B) kaolinite, (C) smectite, (D) chlorite, from Müller and Stoffers, 1974.*

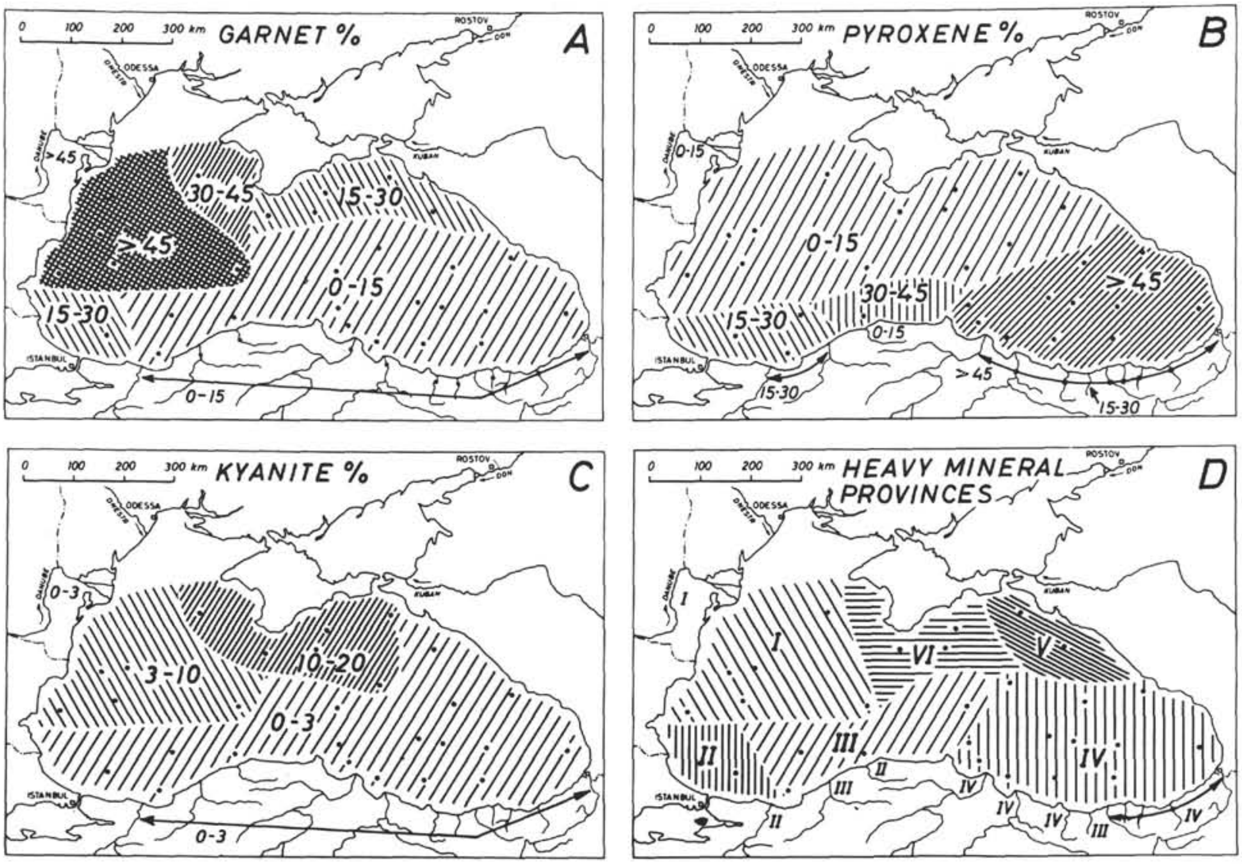

Figure 9b. *Heavy minerals and heavy mineral provinces of Black Sea sands. (A) garnet, (B) proxene, (C) kyanite, (D) heavy-mineral provinces I-IV, from Müller and Stoffers, 1974. Both figures based on anaylses of cores taken during R. V.* Atlantis *II Cruise 49.*

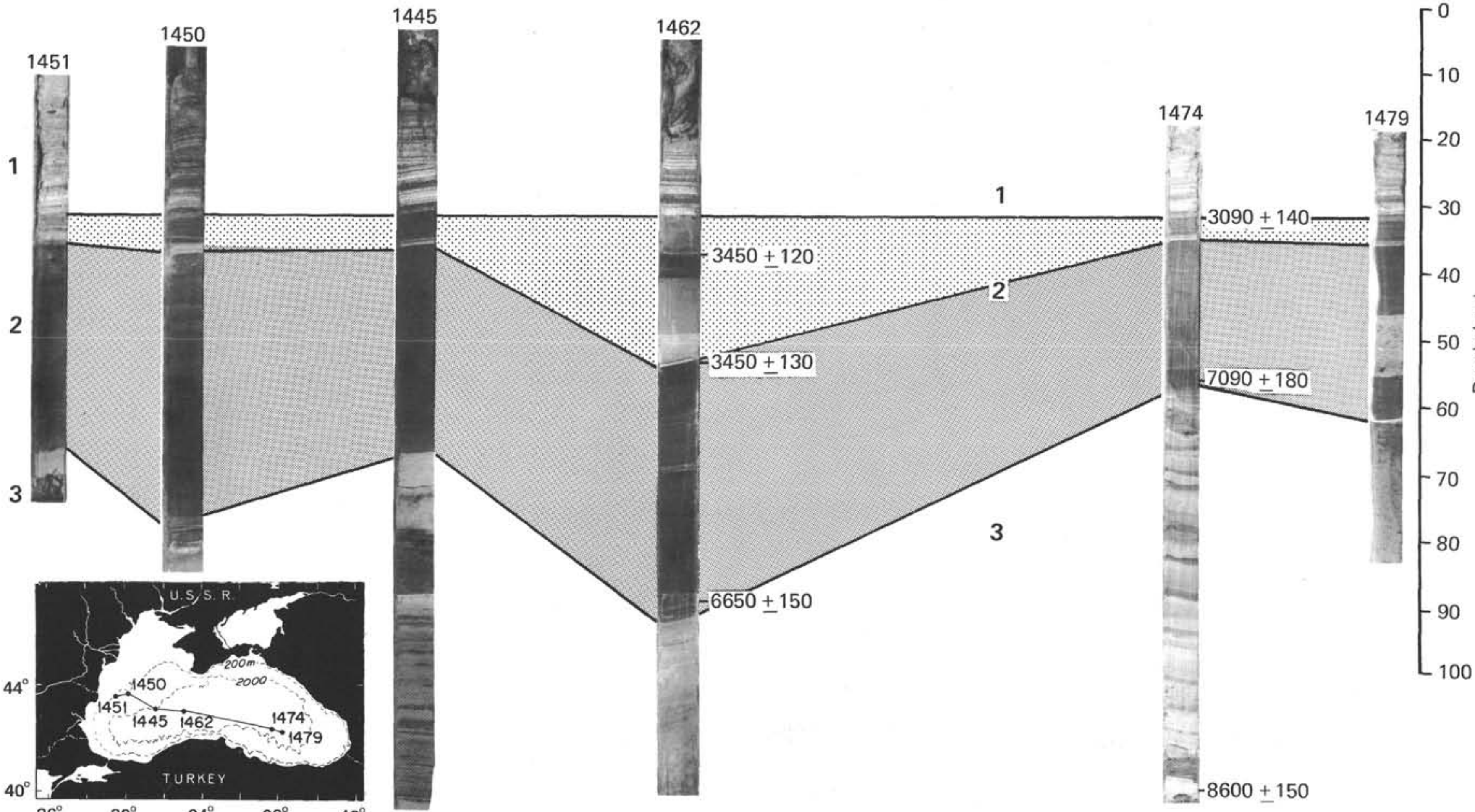

Figure 10. *Sediment profile of some cores (R. V.* Atlantis *II, Cruise 49), collected from the Black Sea (adapted from Ross, et al., 1970.*

TABLE 2
General Stratigraphy of Three Sedimentary Units Observed From Piston Cores

Arkhangel'skiy and Strakhov (1938)	Nevesskiy (1967)	Ross, Degens, and MacIlvaine (1970) (Sediment Units)	(Years B.P.)
Recent Deposits	Dzhemetinian	Unit 1 Coccolith ooze	1000
			2000
Old Black Sea beds	Kalamitian		3000
		Unit 2 Sapropel or organic-rich	4000
	Vityazevian		5000
			6000
	Bugazian		7000
Neoeuxinian Sediments	Neoeuxinian	Unit 3 Banded lutite	8000
			9000
			10,000
	Karkinitian		11,000
	-?-?-?-?-?		
	Tarkhankutian		25,000

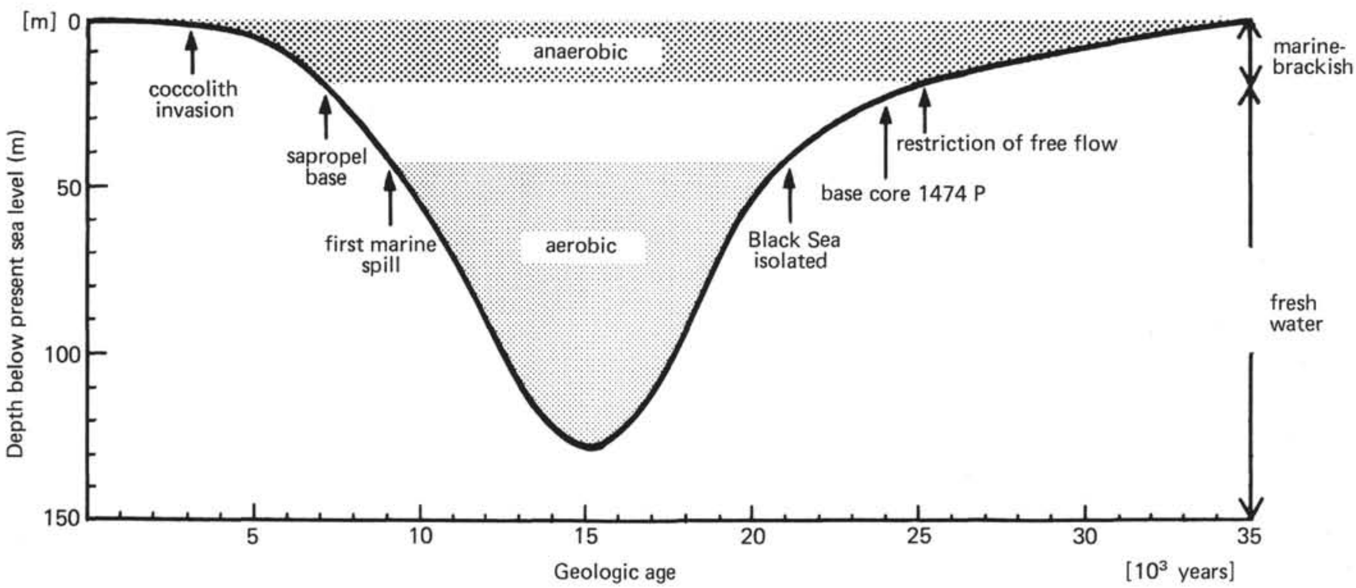

Figure 11. *Sea-level curve (after Milliman and Emery, 1968) showing major incidents in Black Sea History (from Ross and Degens, 1974).*