24. THE AGE OF TERRIGENOUS MINERALS OF THE BLACK SEA SEDIMENTS

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INTRODUCTION

The method for absolute dating of terrigenous minerals in marine sediments suggested and developed in the USSR (Krylov and Silin, 1959, 1963; Krylov et al., 1961) is used now successfully for the study of terrigenous sedimentation in sea basins. Comparison of these data with the age of the minerals in the rocks of the drainage areas can define the source of the sedimentary material delivered into different parts of the basin. This method was also used in the study of Recent and late Quaternary sedimentation in the Black Sea (Krylov, Avdzeiko et al., 1973; Krylov, Emelyanov, et al., 1973). Besides serving as an age mark and indicator of source areas of the terrigenous matter, it also proved valuable for solving problems of the paleogeography of the Recent basins (Krylov and Silin, 1963; Krylov, Emelyanov, et al., 1973). A similar method was used for similar purposes in examination of the drilling cores obtained during Leg 42B in the Black Sea.

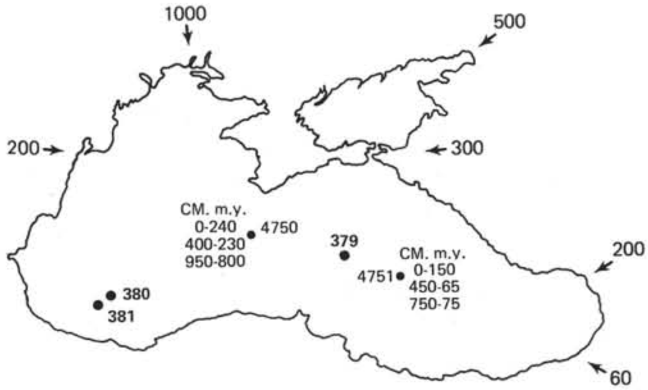

Figure 1. *Age of terrigenous minerals in the river suspensions and Black Sea sediments. Arrows show the age of terrigenous minerals in the river suspensions (m. y.) in the columns: left-depth of cores in cm; right-age of terrigenous minerals (m. y.).*

PREVIOUS RESEARCH

Knowledge about the age of sedimentary minerals mobilized in the Black Sea drainage area can be obtained from an analysis of river alluvium and beach sands which extend from the Danube River mouth to Batumi (Krylov, Avdzeiko, et al., 1973). The Danube River is a source of sedimentary material for Recent sediments, and contains terrigenous minerals with an age of 200 to 225 m.y. The oldest mineral load is derived from the rivers draining the Russian Platform rocks—the Southern Bug (1080-1260 m.y.) and the Dnieper (1165 m.y.). Beach sands of the Crimean coast are composed mainly of minerals whose age ranges from 185 to 340 m.y. Rivers of the Caucasus northwestern slope deliver terrigenous minerals 195 to 570 m.y. old, but their contribution to Recent basins is insignificant. The most powerful Caucasian rivers (Bzyb, Inguri, Rioni, etc.) transport minerals of younger age: 140-185 m.y. The minimal age of terrigenous minerals was identified for the river Chorokh—40 to 70 million years. In the early stages of the Black Sea Quaternary history, considerable sedimentary matter may have been supplied by the Don and Kuban. The age of terrigenous minerals in these river loads accordingly is 400 to 650 m.y. and 230 to 320 m.y. These data are schematically represented in Figure 1.

Studies of the age of the Black Sea upper Quaternary sediments show that the age of terrigenous minerals in the deep-sea muds in the upper Würm Holocene varies insignificantly, from 150 to 230 m.y. (Krylov, Avdzeiko, et al., 1973; Krylov, Emelyanov, et al., 1973). Sharp differences occur only for the interbeds of coarse-grained matter (silts and sands) extending into Würm deposits synchronous with melting of glaciers. In the eastern Black Sea sediments, terrigenous minerals are 65 to 75 m.y. old (Table 1), which indicates that formation of these interbeds is due to the Eastern Pontic river loads; in the central part, sandy-silt interbeds of terrigenous minerals (600 to 800 m.y.B.P.) may be linked to loads from the Russian Platform.

METHODS

The basic principles of potassium-argon dating of terrigenous minerals are described in early articles (Krylov and Silin, 1959, 1963; Krylov et al., 1961). The same methods were used in this study. Samples of sediments were treated with nitric acid for removal of carbonates and adsorbed potassium. Potassium was determined by dipicrilaminatic and flame-photometric methods; argon was determined by isotopic dilution, using a type MC-2M mass-spectrometer.

RESULTS

Data concerning the ages of terrigenous minerals from sites studied are given in Table 2 and shown in Figure 2.

The deposits of Hole 379A were formed during different epochs of sedimentation, both during the glacial periods, when sea level was lower than at present and the climate throughout the drainage area was cold and dry, and during the interglacial periods which were characterized by a rapid rise

TABLE 1
Absolute Age of Terrigenous Minerals in the Black Sea Bottom Sediments

Station	Depth (m)	Coordinates N.L.	Coordinates E.L.	Interval (cm)	Stratigraphic Layer	Type of Sediment	K (%)	$Ar \frac{cm^3}{g} \cdot 10^{-5}$	Age, (m.y.)
4750	2163	42°30′9″	37°34′3″	0-37	Hl_{III}	Pelitic mud	2.08	1.20	150
				435-493	W	Fine-grained sand	1.62	0.39	65
				720-760	W	Medium-grained sand	1.65	0.49	75
4751	2222	43°12′4″	33°48′	0-25	Hl_{III}	Pelitic mud	2.39	2.30	240
				59-115	Hl_{III}	Aleurite-pelitic ooze	1.94	0.95	125
				390-435	W	Pelitic mud	2.38	2.22	230
				946-966	W	Sand	0.82	3.10	800
4752	2214	43°32′9″	33°54′3″	0-25	Hl_{III}	Pelitic ooze	2.40	1.76	180
				770-790	W	Coarse aleurite	1.69	0.56	85
4754	1330	41°36′1″	29°23′7″	0-15	Hl_{III}	Pelitic mud	2.51	1.66	170
				170-185	Hl_{III}	Pelitic mud	2.36	1.42	150
				611-624	W	Pelitic mud	3.44	2.16	155
672	2215	42°31′3″	31°56′2″	0-29	Hl_{III}	Pelitic mud	1.90	1.24	165
				235-250	W	Coarse aleurite	1.65	5.15	600

Note: Designation of Stratigraphic Layer: Hl_{III} = recent sediments (u. Holocene); Hl_{III} = old Black sea sediments (m. Holocene); W = new euxinic sediments (Würm).

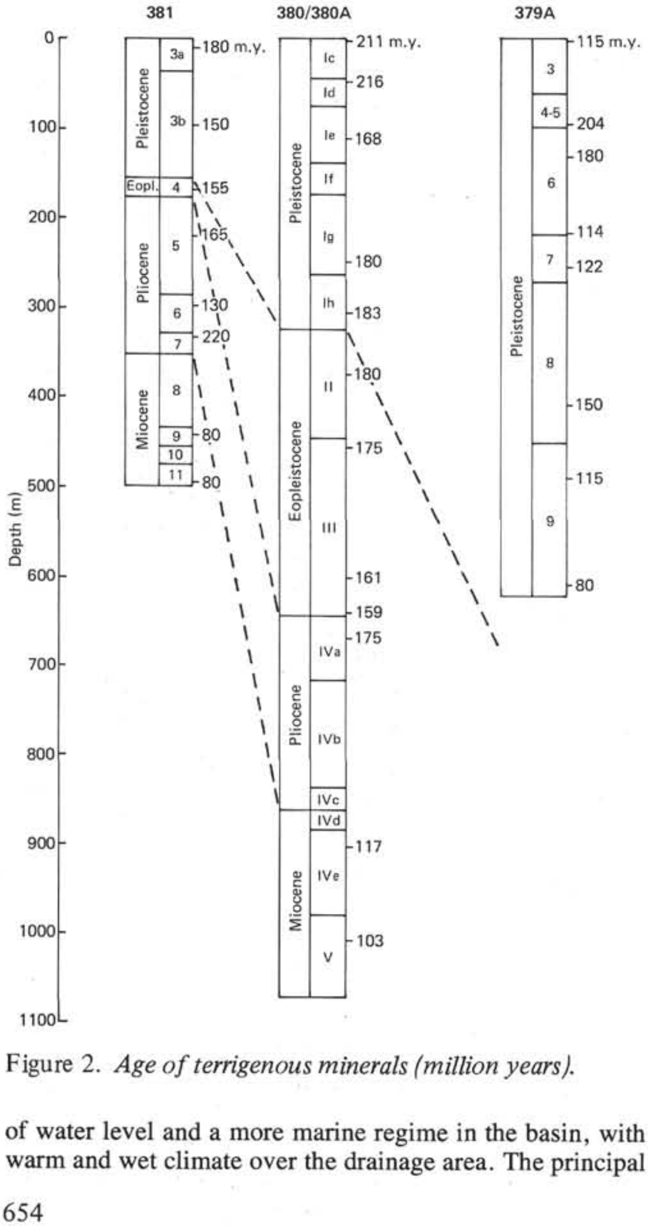

Figure 2. *Age of terrigenous minerals (million years).*

of water level and a more marine regime in the basin, with warm and wet climate over the drainage area. The principal part of the Pleistocene section consists of terrigenous deposits represented by aleuritic-pelitic and pelitic muds. The age of terrigenous minerals of these sediments in lithologic units of different ages shows small variations—from 204 to 114 m.y. The youngest (80 m.y.) occurs in Sample 379A-67-4, 110-120 cm (lower Pleistocene), in the sandy silt of a sample whose major portion consists of finely dispersed terrigenous matter. The data obtained enable us to discuss only the sources of the finest suspension delivered from the drainage area.

The age of terrigenous material formed during three glacial epochs (Würm, Riss, Mindel) is 114 to 180 m.y. almost the same age is noted for the terrigenous minerals in the finely dispersed deposits of the interglacial periods (115 to 204 m.y.). This indicates that during the Pleistocene there were no cardinal changes in supply sources for the sedimentation area. Additionally, this is supported by the mineral composition of sediments, which shows similar ratios of basic rock-forming minerals (Table 3).

The mineralogy study of the coarse-silt fraction (0.1-0.05 mm) shows that the terrigenous matter from this site is of mixed genesis. Moreover, it is characteristic of the southern drainage system loads at individual stages of units (or some parts of them); the material was delivered largely from the Caucasus (Trimonis and Shimkus, this volume). The sediments of the Riss glacial period (Unit 6) may be given as an example. In the coarse-silt fraction of terrigenous muds, the mineral composition changes repeatedly. This is expressed by considerable variations in the contents of monoclinic pyroxenes, epidote, opaque minerals, etc. There are large amounts of garnet in a number of beds. Zircon, tourmaline, and kyanite are often present; this is not characteristic of the southern drainage system loads. The ages of terrigenous minerals in two samples are 114 and 180 m.y. The age increase is probably connected with a larger admixture of sedimentary material transported from the northern source areas. The marked variation in the ages of the terrigenous minerals in other units also indicates the increasing role of sedimentary matter from the Caucasus drainage areas in the sedimentation at some stages of the Pleistocene.

TABLE 2
Absolute Ages of Terrigenous Minerals

Sample (Interval in cm)	Depth (m)	Unit	Age	Type of Sediment	K (%)	Ar ($\frac{cm^3}{g} \cdot 10^{-5}$)	Age (m.y.)
Hole 379A							
1-4, 115-125	5.65-5.75	3	Würm	Terrigenous mud	2.06	0.932	115 ±5
11-4, 135-143	98.35-98.43	4	Riss-Würm	Terrigenous mud	2.06	1.680	204 ±10
15-3, 45-58	133.95-134.08	6	Riss	Terrigenous mud	2.12	1.570	180 ±9
24-2, 0-18	217.50-217.68	6	Riss	Terrigenous mud	1.85	0.826	114 ±5
28-2, 82-93	256.32-256.43	7	Mindel-Riss	Terrigenous mud	1.87	0.887	122 ±6
45-4, 98-106	411.48-411.56	8	Mindel	Terrigenous mud	2.05	1.219	150 ±7
54-2, 20-34	493.20-493.34	9	Gunz-Mindel	Calcite-rich mud	1.83	0.826	115 ±5
67-4, 110-120	611.10-611.20	9	Gunz-Mindel	Terrigenous sandy silt	1.77	0.548	80 ±4
Hole 380							
1-3, 10-20	3.10-3.20	1c	Würm	Terrigenous mud	2.58	2.182	211 ±11
6-1, 93-105	48.43-48.55	1d	Riss-Würm	Terrigenous diatom-rich silty mud	2.34	2.029	216 ±11
13-1, 0-14	114.00-114.14	1e	Riss	Terrigenous mud	2.85	1.900	168 ±8
27-3, 1-13	250.01-250.13	1g	Mindel	Terrigenous mud	2.64	1.893	180 ±9
33-3, 95-110	307.95-308.10	1h	Mindel	Terrigenous silty mud	2.35	1.720	183 ±9
Hole 380A							
5-4, 61-74	375.61-375.74	II	Eoplei-stocene	Terrigenous mud	3.20	2.290	180 ±9
14-2, 62-77	458.12-458.27	III	Eoplei-stocene	Terrigenous mud	2.60	1.804	175 ±9
30-2, 38-50	600.38-600.50	III	Eoplei-stocene	Calcareous mud	2.48	1.650	161 ±8
34-3, 27-44	629.77-639.94	III	Eoplei-stocene	Marly calcareous mud	2.43	1.557	159 ±8
37-4, 1-14	669.51-669.64	IVa	Pliocene	Terrigenous mud	1.89	1.357	175 ±9
48-6, 41-53	776.91-777.03	IVb	Pliocene	Terrigenous mud	2.09		
62-2, 0-15	904.00-904.15	IVe	Miocene	Marly calcareous silt	2.54	1.005	117 ±6
73-3, 16-27	1010.16-1010.27	V	Miocene	Terrigenous silt	2.50	1.030	103 ±5
Site 381							
2-2, 124-144	12.24-12.44	3a	Mindel-Riss	Terrigenous mud	2.53	1.805	180 ±9
5-3, 115-135	42.15-42.35	3b	Mindel	Terrigenous mud	2.60		
11-2, 0-15	96.50-96.65	3b	Mindel	Terrigenous mud	2.56	1.540	150 ±7
19-1, 0-15	171.00-171.15	4	Eoplei-stocene	Carbonate silty mud	1.61	0.974	155 ±8
25-2, 40-55	220.40-220.55	5	Pliocene	Terrigenous mud	2.19	1.428	165 ±8
33-4, 120-135	300.20-300.35	6	Pliocene	Marly calcareous mud	2.08	1.044	130 ±7
37-2, 30-40	334.30-334.40	7	Pliocene	Terrigenous silty mud	2.00	1.764	220 ±11
48-6, 110-120	445.60-445.70	9	Miocene	Terrigenous silty mud	2.51	0.793	80 ±4
54-2, 5-16	495.55-495.66	11	Miocene	Siltstone	2.05	0.639	80 ±4

The coarse-grained material (Sample 367A-67-4, 110-120 cm) is 80 m.y. old, indicating that sedimentary matter from the southern drainage area is predominant there. It contains a relatively small proportion of clay minerals (especially illite), and is enriched in feldspar (Table 3). Of all the heavy minerals in the coarse-silt fraction, the predominant ones are monoclinic pyroxenes, opaques, epidote, as well as weathered rock fragments; feldspars (to a greater extent than quartz) are in the light fraction. This composition is typical of the Recent eastern Anatolian terrigenous province, supplied mainly with products of the destruction of Cretaceous igneous rocks and Quaternary effusive formation in Turkey. It should be expected that the interbeds of coarse-grained matter in other units, which were not dated, are genetically associated with the sedimentary material, mobilized in the southern part of the drainage area.

Holes 380, 380A, and 381 are closely spaced and their lithological units are of similar composition. Holes 380 and 380A had better recovery and were drilled in Pleistocene to Miocene sediments. At Site 381 these deposits are thinner. The principal portion of the Pleistocene sediments at both sites is formed of terrigenous aleuritic-pelitic and pelitic muds. The Pliocene sediments are more enriched in carbonate matter, especially at Site 380; in the Miocene strata laminated clays prevail.

Most of the samples from Holes 380 and 380A were studied because of their fine grain size of finely dispersed muds. The age of the terrigenous minerals for the Pleistocene

TABLE 3
X-Ray Diffraction Results for the Bulk Samples

Sample (Interval in cm)	Total Crystalline Components = 100%									
	Quartz	Feld-spars	Illite	Montmoril-lonite	Chlorite	Kaolin-ite	Calcite	Other Carbonates	Pyrite	Other Minerals
Hole 379A										
24-2, 0-18	13.5	13.2	24.2	12.1	22.2	tr.	14.8	0	0	tr.
28-2, 82-93	14.5	11.1	23.4	7.4	20.1	4.2	16.3	3.0	0	0
45-4, 98-106	15.0	11.6	19.6	12.4	15.2	2.4	23.8	0	0	0
54-2, 20-34	8.9	11.6	23.1	4.7	18.2	2.2	29.5	1.8	0	tr.
67-4, 110-120	19.3	39.4	8.0	9.5	8.9	0	14.9	0	0	tr.
Hole 380										
1-3, 10-20	14.8	5.9	38.6	7.9	8.9	0	18.8	5.1	0	0
6-1, 93-105	19.7	6.9	39.3	7.2	7 9	0	9.2	6.6	3.2	0
13-1, 0-14	10.2	5.6	51.1	3.9	11.7	0	9.7	7.8	0	0
27-3, 1-13	14.5	9.6	45.2	7.4	11.9	2.4	9.0	0	0	0
33-3, 95-110	13.4	9.2	53.7	2.1	9.3	tr.	4.1	8.2	0	0
Hole 380A										
5-4, 61-74	16.0	12.9	41.4	4.6	14.9	0	7.4	2.8	0	0
14-2, 62-77	24.4	6.7	24.0	12.4	9.3	2.7	20.5	0	0	0
30-2, 38-50	8.3	0	9.7	14.7	tr.	tr.	67.3	0	0	0
62-2, 0-15	11.5	7.8	28.8	7.9	3.9	0	0	37.1	2.0	0
73-3, 16-27	11.4	14.5	40.5	11.5	4.3	6.0	2.3	tr.	1.7	7.8
Site 381										
2-2, 124-144	17.4	7.2	38.1	9.1	11.5	3.9	4.2	8.6	tr.	0
11-2, 0-15	16.9	2.1	27.9	23.6	7.8	3.9	12.7	5.1	0	0
19-1, 0-15	4.8	tr.	5.3	9.5	3.1	0	53.5	23.8	tr.	0
25-2, 40-55	16.0	4.0	19.3	32.8	19.3	8.6	0	0	0	0
33-4, 120-135	5.4	tr.	4.7	6.3	0	0	73.5	6.7	3.4	0
37-2, 30-40	30.2	8.8	22.1	13.0	5.1	2.3	tr.	11.4	7.1	0
48-6, 110-120	6.7	20.0	30.1	12.2	20.8	7.8	0	0	tr.	2.4

ranges from 161 to 216 m.y.; the oldest age is common for the upper part (Würm and Riss-Würm). The Pliocene clays contain terrigenous minerals with an age of 159 to 175 m.y., but fine-silt sediments of the Miocene are 103 to 117 m.y. old. Thus, on the whole, the site shows gradually decreasing age of terrigenous minerals from young deposits to older ones.

The mineral composition of the Pleistocene samples studied varies insignificantly. Only Sample 380-30-2, 38-50 cm contains authigenic calcite as a major component (Table 3). The Miocene deposits are notable for their relative increase of feldspar relative to quartz. If these data are compared with Recent loads from the north (mainly the Danube) and the south (the Sakarya), the mineral composition of Miocene sediments is more similar to the Sakarya sedimentary matter, in which the domination of quartz by feldspar is characteristic. The Danube loads, as is generally known, contain 1.5 to 3 times more quartz than feldspar. One may assume that the delivery of sedimentary material into this area during the Miocene was mainly from the southern part of the drainage area, but later (during Pliocene) the terrigenous material from the northern areas also increased. The increasing role of the Danube loads occurred during the Pleistocene. The age variation of terrigenous minerals in deposits from Holes 380 and 381, in our opinion, is in accordance with these changes.

In Hole 381 the samples are represented mainly by aleuritic-pelitic and pelitic muds. A portion of them is composed of almost exclusively terrigenous matter ($CaCO_3$ <10%), and in only two samples is calcite a predominant mineral (Table 3). The age of terrigenous minerals in Pleistocene sediments is 150 to 180 m.y. These sediments correspond to the lower part of the Pleistocene in Holes 380 and 380A, where the terrigenous minerals are the same age (about 180 m.y.). In Pliocene deposits the ages range from 130 to 220 m.y., and the mineral composition there also varies (Table 3). It is interesting that younger age corresponds to terrigenous minerals included with the calcareous sedments (micrite). The formation of calcareous oozes was probably linked to a considerable reduction of the sedimentary material supply into the basin from the drainage area. In the northern parts of the basin as well as in the area of Site 380, the increase in the absolute age values of terrigenous minerals was accompanied by an increase in importance of the terrigenous suspensions, transported from the northern part of the drainage area.

Aleurolites (siltstones) and aleuritic-pelitic muds of the Miocene (Units 9 and 11) consist of the youngest terrigenous minerals (80 m.y.B.P.). These data, as those of Site 380, suggest that sedimentation during the Miocene in this part of the basin was under the prevailing influence of material from the southern drainage area. It is characteristic that here the quartz content decreases sharply, and feldspars occur in greater abundance (Sample 380-48-6, 110-120 cm). The clay mineral ratios are also different (Table 3).

SUMMARY

Variation in the age of terrigenous minerals from Hole 379A sediments indicates that in this part of the basin the supply of sedimentary material during the Pleistocene changed repeatedly. The ages obtained, as well as the mineral composition of sediments, indicate that large quantities of sediments were delivered into this area not only from the coast of Turkey, but also from the northern drainage area and from the Caucasus. The increase in the ages of the terrigenous minerals correspond to periods of increasing influence of sedimentary matter from the northern drainage areas. The formation of coarse-grained interbeds of sands and silts and probably most of the turbidites was, however, connected with the accumulation of only the southern sedimentary material.

In the southwestern part of the Black Sea (Holes 380, 380A, and 381), terrigenous sedimentation during the Pleistocene, as well as during the late Neogene, occurred with unequal and changeable supply of sedimentary matter from the surrounding drainage areas. Besides supply of material from the south and the southwest, considerabwe material was supplied from the north (Danube) and also partly from the Russian Platform. The increases in the age of the terrigenous minerals correspond to the periods of the increased removal of material from the northern areas. Judging by these data there was substantial delivery of sedimentary material from the north at some stages of the Pliocene, and it notably increased at the end of the Pleistocene (Riss-Würm and Würm). One can consider in more detail the changes in sources of sedimentary matter supplied given areas (sites) of the Black Sea at different periods by studying the changes in the ages of the terrigenous components, within the limits of precision of the analysis (Table 2).

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