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Middle–Upper Miocene Volcanic Ashes of the Kerch–Taman Region

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Abstract—Results of the detailed study of Miocene volcanic ashes from Kerch and Taman peninsulas are presented. Based on the distribution of pyroclastics in the rocks under consideration, the Sarmatian and late Meotian stages of volcanic activity are distinguished. In close association with other geological data, results of the first microprobe analysis of the volcaniclastic materials are analyzed. It has been revealed that Sarmatian ashes are characterized by rhyolitic composition, whereas upper Meotian ashes correspond to dacites and rhyodacites. Decrease of silicate content and increase of alkalinity in the studied pyroclastic rocks are traced from ancient to younger sediments. The upper Meotian volcanics are noted for higher concentration of potassium. The predominantly vitroclastic Kerch–Taman ashes with a low content of calcium and high contents of potassium and sodium most likely belong to a single magmatic center. Stages of volcanic events and petrochemical similarity of composition of the magmatic products suggest that the studied ash material belongs to volcanic centers of the Lesser Caucasus.

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INTRODUCTION

Within the Kerch–Taman region, volcanic ashes are known in Middle–Upper Miocene clayey sediments of the relatively deep-water facies. Previously, the presence of interlayers of pyroclastic material was noted by N.I. Andrusov, V.P. Kolesnikov, N.N. Karlov, G.A. Lychagin, L.S. Belokrys, I.S. Chumakov, and others. Detailed investigations of the volcanic ashes were conducted by Belokrys (1981) and Chumakov et al. (1992). Belokrys published the first data on chemical compositions of the upper Sarmatian volcanic ashes of the Kerch Peninsula (based on the analysis of two samples). Chumakov et al. carried out the radiometric dating of a series of ash interlayers in Kerch and Taman peninsulas by fission track and K–Ar methods. These works revealed the sharp predominance of volcanic glass grains in the ash composition. The general grain size distribution pattern of the pyroclastics was defined. Intervals with the maximum ash content were outlined in the sections. The further study of the ash interlayers needs detailed petrochemical investigations, which would allow us to estimate quantitative proportions of different magmatic components (major, secondary, and minor) in the rock, establish the type of the initial silicate melt, trace temporal changes of the pyroclastic material composition in time, and most reliably define the affiliation of the ash material to ancient volcanic centers. In this paper, the first obtained results of the high-precision (microprobe) petrological study of the ash interlayers are described in close connection with other geological data.

DISTRIBUTION IN ROCK SECTION

Volcanic ashes in the Kerch–Taman region are encountered in the Sarmatian and Meotian clayey sediments (Belokrys 1981; Chumakov, 1992) (Fig. 1).

Sarmatian Stage. In the studied rocks, the oldest interlayer of volcanic ash, first found by G.A. Lychagin, is located at the top of the Lower Sarmatian in the Adzhel'skaya gully section in the central part of the Kerch Peninsula. According to Chumakov et al. (1992), this ash horizon (~7 cm thick) is mainly composed of sand-sized (>0.1-mm fragments up to 80%) vitroclastic material grains (up to 97%) with the radiometric age of 12.24 ± 0.97 Ma (12.43 Ma, averaged from two determinations) (sample 8). According to the mollusk assemblage (determinations by N.P. Paramonova), clays hosting the ash interlayer belong to the Zbruch Beds crowning the Lower Sarmatian section in this area (Chumakov et al., 1992). In other Lower Sarmatian sections in Kerch and Taman peninsulas, ash interlayers were not found possibly because of their poor exposure.

The next volcanic ash interval is found in rocks of the upper part of the Sarmatian. The presence of ash interlayers in these rocks was established by Belokrys (1981) in the Kop-Takyl section in the southeast of Kerch Peninsula. In the coeval rocks in Taman Peninsula, volcanic ashes were found in the Mt. Zelenskii section by Chumakov et al. (1992) and Shcherbakova in a quarry near the Fakel Pansion (sample 20). The ash interlayers have a thickness of up to 1–1.5 cm (usually, a few millimeters), and they are dominated by particles of the silt-pelite size. Rocks of the upper part of the

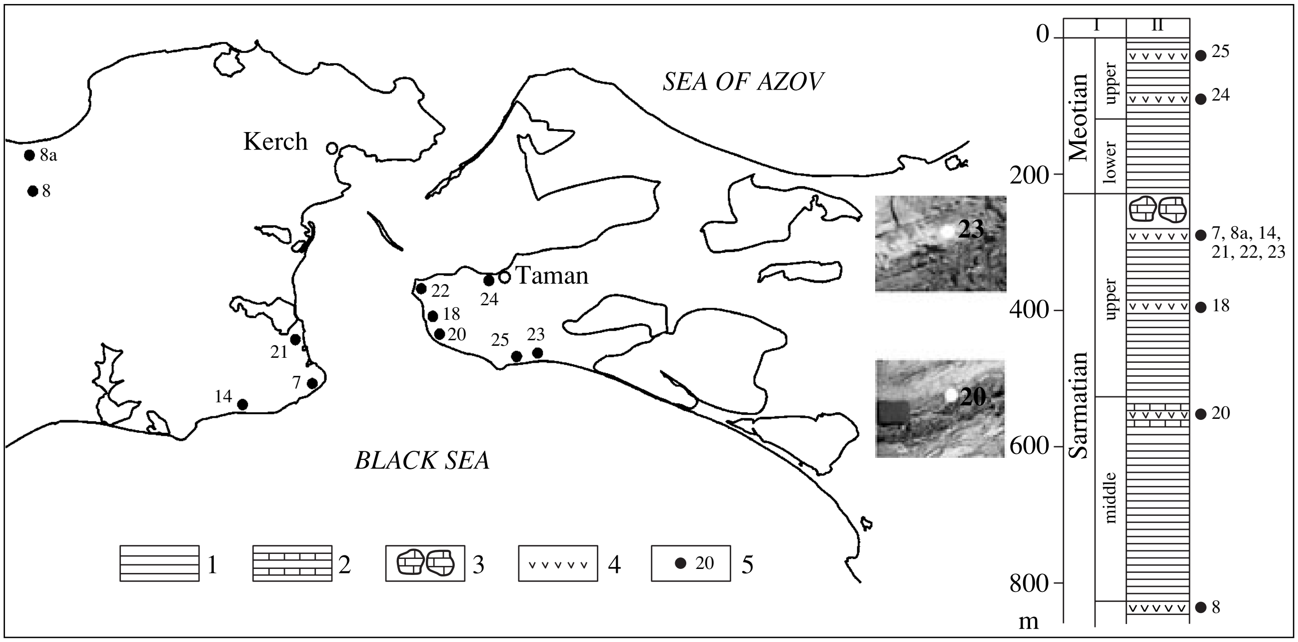

Fig. 1. Location of volcanic ash interlayers in the Middle–Upper Miocene clayey rocks of the Kerch–Taman region. (I) Stratigraphic age; (II) composite section. (1) clays, in places with carbonate rock interlayers; (2) frequent alternation of carbonate rocks and clays; (3) biohermal bryozoan limestones; (4) volcanic ashes; (5) location of the studied ash interlayers in area and sequence and sample numbers. In Kerch Peninsula: (8, 8a) Adzhel gully, (7, 14) Kop-Takyl Cape, (21) Settlement of Zavetnoe; in Taman Peninsula: (18) Popov Kamen Cape, (20) Zelenskii Mt. (Fakel quarry), (22) Tuzla Cape, (23, 25)—Zheleznyi Rog Cape, (24) Settlement of Taman.

Middle Sarmatian are represented by frequent alternation of clayey and fine-grained carbonate rocks. The abundance of carbonate interlayers in these rocks hampers the search of thin ash horizons. According to the preliminary unpublished data of D.I. Golovin, the K–Ar dating of volcanic ash (sample 20) from the upper part of the Middle Sarmatian yielded an average value of 12 Ma.

The upper Sarmatian sediments are marked by a high content of ash. Volcanic ashes are known in the lower and upper parts of these rocks. In the lower part of the upper Sarmatian, Belokrys (1981) found numerous thin pyroclastic strata in the Kop-Takyl and Podmayachnoe sections in Kerch Peninsula. In similar rocks in Taman Peninsula, ash interlayers occur in the Popov Kamen Cape section. In this area, Chumakov et al. (1992) distinguished two ash horizons (1.5–3 cm thick) with the fission track age of 11.19 ± 0.74 (sample 18) and 10.58 ± 0.75 Ma. The lower interlayer almost completely consists of fragments of volcanic glass larger than 0.1 mm in size. The base of the upper horizon is characterized by an accumulation of biotite flakes.

The presence of ash interlayers in the upper part of the upper Sarmatian has been pointed out by many researchers (Andrusov, 1961; Kolesnikov, 1940; Karlov, 1957; Belokrys, 1981; Chumakov et al., 1992). Volcanic ashes of this stratigraphic level are characterized by noticeable thickness (up to 12 cm, average 5 cm), predominant sand–silt size of grains, and occurrence near the base of the Mitridat Beds (bryozoan biohermal limestones). In Kerch Peninsula, ash interlayers are present in the upper part of the upper Sarmatian in the Kop-Takyl (samples 7 and 14), Zavetnoe (sample 21), Adzhel gully (sample 8a), Takyl-Burun, Ortaul, and other sections. Based on the radiometric dating (Chumakov et al., 1992), ashes in these sections are estimated at 9.75 Ma (samples 8a, 7, and 14).

In Taman Peninsula, Rostovtseva et al. found ash interlayers in the upper part of the upper Sarmatian in the Tuzla and Zheleznyi Rog sections (samples 22 and 23).

In the Tuzla Cape section, volcanic ash (sample 22) makes up a lenslike interlayer (3–5 cm) at the contact of reefal bryozoan limestones (Mitridat Beds) with the underlying clays.

In the Zheleznyi Rog Cape area, two ash interlayers were first found in upper Sarmatian rocks during the lithological investigation in 1997. The interlayers are separated by a clay unit 4–5 m thick. The white ash interlayers (~5 cm thick) consist of volcanic glass fragments of the sand-silt size with traces of ferrugination at the top and base. The interlayers are located 115–120 m below the base of brecciated clays (10 m) occurring in this section at the base of the upper Meotian. Clays underlying the lower ash interlayer (sample 23) contain the upper Sarmatian diatom assemblage with *Achantes brevipes Ag.* The overlying ashes include diatomaceous species of *Thalassiosira Cl.* family typical of the Meotian (determinations by T.F. Kozyrenko).

Based on the distribution of siliceous flora in the section, the ash horizons can be attributed to the upper part of the upper Sarmatian and compared with vitroclastic interlayers near the base of the Mitridat Beds. In the Zheleznyi Rog section distinguished by the absence of reefal bryozoan limestones in the upper Sarmatian rocks, these ash interlayers can serve as reference and correlation units. We also found traces of redeposited pyroclastics in thin sections of clays from the upper part of the upper Sarmatian (4 m below the base of the bryozoan limestones) in the Mt. Zelenskii section.

Meotian Stage. Only one ash interlayer of the Meotian sequence was known previously in the Zheleznyi Rog section of Taman Peninsula (Andrusov, 1961; Chumakov et al., 1992). Recent detailed lithological investigations yielded new data on the distribution of pyroclastic rocks in the studied rocks (Rostovtseva and Goncharova, 2006). Near the Settlement of Zavetnoe in Kerch Peninsula, abundant vitroclastic admixture was found in clay interlayers at the base of the upper part of the Lower Meotian. In Taman Peninsula, ash interlayers were first found in the upper Meotian rocks in the Taman Stanitsa and Popov Kamen Cape sections. Ashes in the Taman Stanitsa (sample 24, 12 m above the top of the Gastropod Horizon 0.9 m thick) and Popov Kamen Cape sections are encountered in the lower part of the upper Meotian. The ash horizon in the Zheleznyi Rog section of Taman Peninsula (sample 25) known from Andrusov (1961) is situated in the upper part of the upper Meotian based on the development of monospecies assemblage of diatoms with *Actinocyclus octonarius Ehr.* in the Meotian–Pontian transitional beds (Radionova and Golovina, 2004). The average radiometric age of this interlayer is 8.40 ± 0.30 Ma (Chumakov et al., 1996). These ash interlayers (1–3 cm thick) are dominated by particles of the silt-pelite size. The nearly complete absence of volcanic ash interlayers in the Meotian sediments in Kerch Peninsula (Belokrys, 1981) is probably related to the abundance of shallow-water sediments (detrital limestones) and the existence of unfavorable hydrodynamic conditions for the burial of fine vitroclastic sediments in the studied area of the basin at that time.

In general, based on the distribution of pyroclastic material in the Middle–Upper Miocene rocks, we can distinguish two (Sarmatian and late Meotian) stages of volcanic activity. The oldest magmatic events were episodically manifested at the end of the early Sarmatian. Magmatic eruptions took place during 3.8–4 Ma. The vitroclastic ashes of the Kerch–Taman region are represented by interlayers (generally, from a few millimeters to 5–7 cm thick; up to 12 cm in some places) with particles of the silt-pelite or sand-silt size.

CHEMICAL COMPOSITION

We studied the chemical composition of 11 volcanic ash samples taken from all of the known Sarmatian–Meotian stratigraphic levels of the pyroclastic distribution. Among them, six samples were studied at certain points and in areas with a Camscan 4DV electron microscope (equipped with Link no. 10000 energy-dispersive device) in the Laboratory of Local Methods for the Study of Materials (Department of Petrology, Geological Faculty, MGU). For other samples, we used previous data on the complete silicate chemical analysis carried out in the VIMS laboratory (Shcherbakova, 1999).

The results show that all ashes under consideration belong to acid magmatic rocks. Based on the content of silica, they can surely be divided into two groups (Table 1). The first group includes the Sarmatian ashes with the rhyolitic composition. The second group includes the upper Meotian dacites and rhyodacites. All the ashes are vitroclastic formations with the content of volcanic glass reaching 92–95% or more.

The *Sarmatian* ashes have the following composition (%): silica 74–77%, alumina 12–14%, and alkaline components 6–8%. The ashes mainly belong to the subalkaline or alkaline petrochemical types of volcanics with the predominance of potassium over sodium. The Na_2O/K_2O ratio changes from 0.49 to 0.89. The content of CaO is 0.58–1.54%. Fragments of volcanic glass are mainly presented by transparent colorless flyer-shaped and splintery grains. Brownish particles with flame-shaped structure are noted in some places (Fig. 2). Crystalloclasts are commonly present as quartz, plagioclases (more rarely, potassium feldspar), and biotite flakes. Separate zircon grains are also encountered. The plagioclases have intermediate and basic compositions (nos. 41–63) frequently characterized by zonal structure (Table 2). Enrichment of the plagioclases with Ca, typical of high-K magmatic rocks, is one of the specific features of the studied volcanics. The biotite composition is as follows (%): alumina ~14–16, iron (FeO_{tot}) 16–21, and titanium oxide 3–5% (Table 3). Ashes of the later phases of the Sarmatian volcanism contain high-Fe and low-Ti biotite varieties.

The *upper Meotian* ashes have the following composition (%): silica 66–69%, alumina 17–19%, and alkali metals 7–13% (Table 1). The ashes commonly correspond to subalkali and alkali types of magmatic varieties with the content of potassium oxide equal to or higher than that of sodium oxide. The Na_2O/K_2O ratio varies from 0.29 to 1.01. The content of calcium oxide is 0.48–2%. As opposed to the Sarmatian ashes, Meotian vitroclastics generally occur as platy (elongated) or isometric slag-type highly porous (pumice-type) formations (Fig. 2). Flame-shaped tuff particles are also observed. Along with volcanic glass fragments, grains of quartz, acid and intermediate plagioclases (nos. 10–50), potassium feldspar, and biotite are also present (Table 2). Biotite is enriched in titanium (6.01–6.15%) (Table 3).

The study of petrochemical peculiarities of the Kerch–Taman ashes revealed temporal changes in the chemical composition of the pyroclastics. When pass-

Table 1. Chemical composition of Middle–Upper Miocene volcanic ashes of the Kerch–Taman region

Component	Sample no.										
	8	20	18	8a	7	14	21	22	23	24	25
SiO_2	74.69	77.47	75.17	75.34	74.37	76.13	77.28	77.83	77.64	66.94	66.87
TiO_2	0.16	0.18	0.23	0.14	0.36	0.14	0.20	0.10	0.07	0.46	0.45
Al_2O_3	14.02	13.26	13.49	13.40	13.16	12.90	12.63	12.67	12.78	17.37	18.88
FeO_{tot}	2.22	1.26	2.63	2.17	1.82	2.13	0.87	0.88	0.64	2.10	2.40
MnO	0.03	0.02	0.08	0.02	0.08	0.06	0.06	0.08	0.08	0.22	0.28
MgO	0.21	0.14	0.25	0.21	0.69	0.21	0.20	0.09	0.10	0.30	0.27
CaO	1.01	1.22	0.96	0.90	1.54	0.89	0.68	0.70	0.58	0.99	1.16
Na_2O	3.50	2.13	3.39	3.61	3.65	3.15	3.48	3.49	3.67	5.43	3.56
K_2O	4.16	4.32	3.80	4.21	4.33	4.39	4.60	4.16	4.44	6.19	6.13
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
abs. age	12.2	12.0	11.1	9.9	9.5	9.4	–	–	–	–	8.4
str. age	s_1	s_2	$s_{3\ bottom}$	$s_{3\ top}$						$m_{2\ bottom}$	$m_{2\ top}$

Note: (Samples 8, 18, 8a, 7, and 14) silicate analysis; (samples 20–25) volcanic glass, microprobe analysis; (abs. age) radiometric age (Ma), after (Chumakov et al., 1992, 1996); (–) no data; (str. age) stratigraphic age of host rocks, after (Chumakov et al., 1992; Popov and Zastrozhnov, 1998). Individual typical measurement values are shown. Analyses were carried out in laboratories of the Fedorovskii All-Russia Research Institute of Mineral Resources (VIMS) and the Geological Faculty (MGU).

Table 2. Chemical composition of feldspars from Middle–Upper Miocene volcanic ashes of the Kerch–Taman region

Component	20	21			22			23	25	
	An_{53}	An_{41}	An_{49}	An_{63}	An_{48}	An_{51}	Kfs	An_{55}	An_{10}	Kfs
SiO_2	55.06	58.63	55.86	52.35	56.52	55.50	65.49	53.95	63.60	65.47
TiO_2	0.03	0.08	0.21	0.10	0.05	0.13	0.12	0.06	0.55	0.02
Al_2O_3	28.42	25.70	27.13	29.00	27.21	26.83	19.01	29.13	18.72	18.90
FeO_{tot}	0.26	0.39	0.73	0.74	0.57	0.82	–	0.24	2.61	0.68
MnO	0.03	0.03	–	–	–	0.06	–	0.08	–	–
MgO	–	–	0.15	0.21	0.03	0.27	0.09	–	0.17	–
CaO	10.98	8.47	10.09	12.89	9.86	10.55	0.68	11.51	2.11	0.73
Na_2O	4.88	6.14	5.30	4.41	5.36	5.09	1.95	4.79	6.03	4.22
K_2O	0.34	0.56	0.53	0.30	0.40	0.74	12.66	0.24	6.20	9.98
Total	100.00	100.00	100.00	100.00	100.00	99.99	100.00	100.00	99.99	100.00

Note: (20–25) Sample nos.; (An_{53}) plagioclases; (Kfs) potassium feldspars, (–) component was not detected. Analyses were carried out with the electron microscope in the laboratory of the Geological Faculty, MGU.

ing from the ancient phases of volcanism to younger ones, the content of silica in the pyroclastics diminishes, while the alkalinity increases. The upper Meotian ashes are characterized by higher concentrations of potassium. Despite all differences in the content of components and morphology of the volcanic glasses, the Sarmatian and upper Meotian ashes also demonstrate similar features: low content of calcium and high contents of potassium and sodium. The content of potassium oxide usually exceeds that of sodium oxide. The ashes mainly correspond to K- and K–Na varieties of volcanics. These features indicate that the studied pyroclastic sediments are monotype formations related to a single magmatic source.

RELATION BETWEEN THE ASHES AND ANCIENT ERUPTION CENTERS

According to Belokrys (1981), the Sarmatian–Meotian volcanic ashes of the Kerch–Taman region are related to ancient eruption centers of the Lesser Caucasus. Chumakov (1992) and Shcherbakova (1999) suppose that volcanic centers of the Inner Carpathian (southern Transcarpathians) or Turkey should be con-

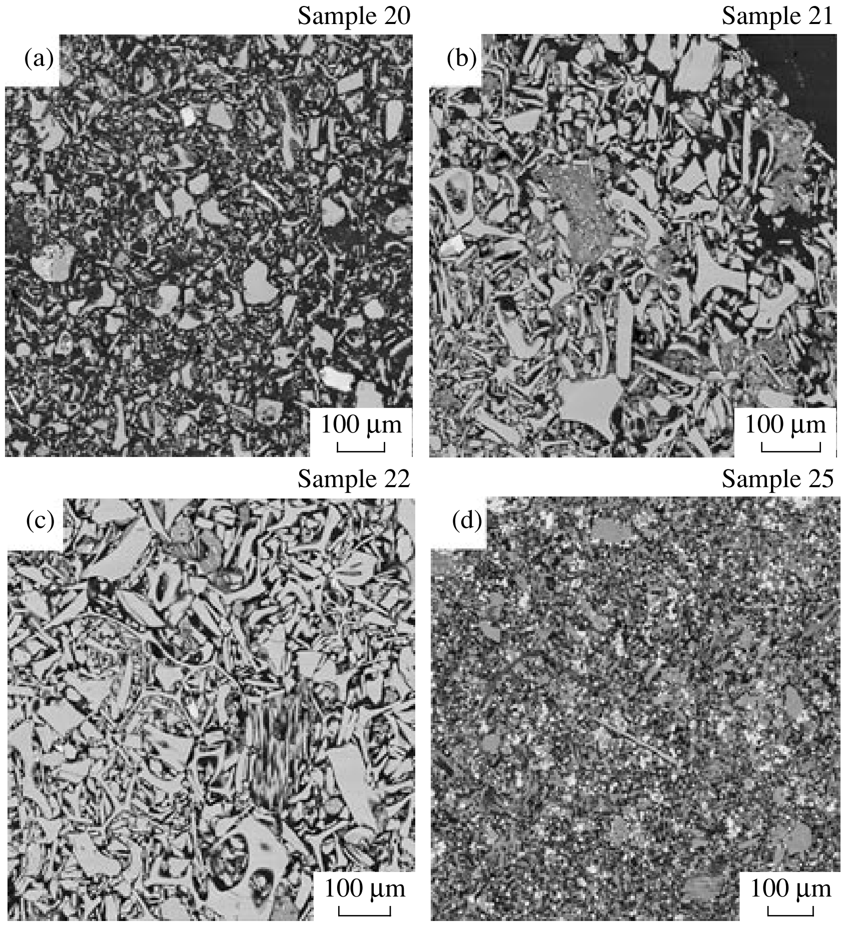

Fig. 2. Photomicrographs of volcanic ashes from Middle–Upper Miocene deposits of the Kerch–Taman region. (a) Middle Sarmatian, Zelenskii Mt. (sample 20); (b) upper Sarmatian, Settlement of Zavetnoe (sample 21); (c) upper Sarmatian (Tuzla Cape) (sample 22); (d) upper Meotian, Zheleznyi Rog Cape (sample 25).

sidered the initial source of the ashes. The affiliation of the Kerch–Taman ashes to ancient eruptive centers is differently interpreted, first of all, because the available petrochemical and radiometric data are still insufficient. The study of the chemical composition of the ashes made it possible to make additional comparisons of the pyroclastic sediments with the coeval volcanic rocks in some areas of the Alpine Foldbelt.

In terms of proximity to the Kerch–Taman region and timing of activity of acid volcanism, volcanic centers in the Carpathians, Turkey, and Caucasus are among the possible sources of the considered ashes.

In the *Carpathians*, the acid volcanism reactivated in the Lower Miocene (Eggenburgian). The last intense manifestations of acid volcanism took place in the early Sarmatian when volcanic activity produced a rock complex known as the “Upper Rhyolitic Tuff”. Powerful explosions occurred approximately from 13.5 to 11 Ma ago (Pécskay et al., 1995). The acid volcanism faded in the Meotian (Danilovich, 1976). According to (Sayanov and Peres, 1960), the distribution of pyroclastic rocks in separate horizons of the Miocene section of Moldavia testifies to the delivery of acid vitroclastics from the Transcarpathian region in the early Sarmatian–Meotian (Table 4). One of the areas of wide distribution of acid volcanism in the Sarmatian was the Beregovskoe Kholmogor’e region, where thick ignimbrite piles were accumulated as a result of large-scale volcanic eruptions. The radiometric age of the Beregovskoe Kholmogor’e rhyolites and dacites is 12.8–12.2 and 10.5 Ma, respectively (Seghedi et al., 2001). The chemical composition of rhyolites and dacites of this region is reflected the major petrochemical features of the final cycle of acid volcanism in the Carpathians (Kostyuk, 1961; Danilovich, 1976).

Significant differences are observed in the succession of the distribution of acid vitroclastics transported from the Transcarpathian region to Moldavia and their accumulation in the Kerch–Taman region (Table 4). The development of ash interlayers in the upper parts of the middle and upper Sarmatian is a characteristic feature of Kerch and Taman peninsulas. However, they are absent in the areas adjoining the Carpathians. In contrast to the Carpathian Foredeep, pyroclastic materials

Table 3. Chemical composition of biotite from Middle–Upper Miocene volcanic ashes of the Kerch–Taman region

Component	20	22		23	24		25
SiO_2	39.23	38.05	38.89	35.33	38.61	38.61	37.71
TiO_2	5.28	4.84	4.09	3.23	6.01	6.06	6.15
Al_2O_3	14.82	14.39	14.48	16.32	14.67	13.67	15.17
FeO_{tot}	16.03	21.37	20.05	16.13	14.19	15.42	16.48
MnO	0.25	0.38	0.32	0.35	0.28	0.77	0.30
MgO	15.03	11.61	12.61	16.96	16.00	15.38	14.26
CaO	0.09	–	0.07	–	traces	traces	0.04
Na_2O	0.60	0.51	0.70	1.29	0.93	0.71	1.00
K_2O	8.67	8.85	8.79	10.39	9.31	9.38	8.89
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Note: (20–25) Sample nos, (–) component was not detected. Analyses were carried out with the electron microscope in the laboratory of the Geological Faculty, MGU.

Table 4. Distribution of pyroclastic rocks in Miocene sedimentary rocks of different regions

<table>
<tr><th colspan="4">Stratigraphic scale</th><th>Moldova*</th><th>Eastern Georgia**</th><th>Kerch–Taman region</th></tr>
<tr><td rowspan="9">Miocene</td><td colspan="3">Pontian</td><td>–</td><td>?</td><td>–</td></tr>
<tr><td rowspan="3">Meotian</td><td colspan="2">upper</td><td rowspan="3">+</td><td rowspan="3">+</td><td>+</td></tr>
<tr><td rowspan="2">lower</td><td>top</td><td>?</td></tr>
<tr><td>bottom</td><td>–</td></tr>
<tr><td rowspan="4">Sarmatian</td><td>upper</td><td></td><td>–</td><td>+</td><td>+</td></tr>
<tr><td rowspan="2">middle</td><td>top</td><td>–</td><td>+</td><td>+</td></tr>
<tr><td>bottom</td><td>+</td><td>–</td><td>–</td></tr>
<tr><td colspan="2">lower</td><td>+</td><td>–</td><td>+</td></tr>
<tr><td colspan="3">Badenian</td><td>+</td><td>–</td><td>–</td></tr>
</table>

Note: Pyroclastic rocks: (+) present, (–) not found, (?) assumed; * after (Sayanov and Peres, 1960); ** after (Skhirtladze, 1958; Aslanyan et al., 1982).

are unknown in pre-Sarmatian sediments of the Kerch–Taman region. In rhyolites and obsidians of Beregovskoe Kholmogor'e (typical varieties of the Sarmatian volcanics of the Carpathians), the contents of the major components differ from those in the studied ashes (Table 5; Fig. 3): rhyolites have lower concentrations of potassium oxide, while obsidians are distinguished by lower concentrations of sodium oxide. Danilovich (1976) found that all of the acid volcanic rocks of the Carpathian origin have similar mineral assemblages and chemical features, and they generally belong to magmatic rocks with normal alkalinity. The Inner Carpathians lack rocks similar to the Taman acid volcanics with the alkali components reaching 9–10%. Volcanic centers of the Transcarpathian region are located more than 1000 km away from the studied region. Sources of the Kerch–Taman ashes (up to 12 cm thick) with sand-sized particles were more likely located significantly nearer. Chumakov's supposition about the possible location of sources of the Kerch–Taman ashes in the southern Transcarpathian region (within Romania) is not confirmed by the available data. Andesite magmatism was widespread in the Sarmatian and Meotian in this area of the Carpathians (Apuseni Mts.) (Roşu, et al., 2004).

In *Turkey*, Miocene volcanism was spread in central and northern Anatolia (Milanovskii and Koronovskii (1973). In central Anatolia, the thickest interlayers of volcanics are known in the Kaishery area (Central Anatolian volcanic province). These rocks are found in the Upper Miocene–Quaternary Urgyup volcanosedimentary formation. The volcanics are usually represented by the products of large-scale acid tuffaceous–ignimbritic magmatism. Up to 10 ignimbrite horizons are outlined in the rocks. The radiometric age of the lower ignimbrite cover varies from 11.2 ± 2.5 to 7 ± 0.15 Ma (Temel et al., 1998). The rhyolitic and rhyolitic-dacitic

Table 5. Chemical composition of Miocene volcanics in different regions

Component	Carpathians*, after (Kostyuk, 1961)				Central Anatolia**, after (Temel et al., 1998)			
	1r	2r	3o	4o	5r	6r	7g	8g
SiO_2	73.91	74.00	75.66	76.92	75.54	71.12	79.59	76.89
TiO_2	0.16	0.15	0.23	0.23	0.16	0.31	0.11	0.86
Al_2O_3	14.94	14.14	13.34	13.65	14.12	14.98	12.89	13.68
FeO_{tot}	2.87	2.37	2.06	1.39	1.25	2.22	0.65	1.14
MnO	0.01	0.02	–	0.06	0.06	0.07	0.13	–
MgO	0.13	0.22	–	–	0.26	0.70	0.27	0.10
CaO	1.85	2.24	1.81	1.17	2.00	2.14	0.97	0.97
Na_2O	3.77	3.66	2.55	2.99	2.16	3.11	0.95	1.37
K_2O	2.36	3.20	4.35	3.59	4.45	5.35	4.44	4.99
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Component	Central Anatolia**, after (Temel et al., 1998)				Georgia*, after (Skhirtladze, 1958)		Armenia*, after (Abovyan et al., 1970)	
	9f	10f	11b	12b	13r	14o	15r	16o
SiO_2	58.79	60.80	41.13	40.07	75.96	75.64	74.48	73.86
TiO_2	n.d.	n.d.	3.31	5.29	0.42	–	0.21	0.12
Al_2O_3	25.92	24.47	19.97	14.06	13.38	11.75	14.66	12.70
FeO_{tot}	0.16	0.29	14.85	16.91	0.59	1.53	1.29	2.79
MnO	n.d.	n.d.	0.45	0.25	tr.	0.01	0.04	0.09
MgO	n.d.	n.d.	11.38	14.45	tr.	0.43	0.33	0.70
CaO	8.09	6.16	–	–	1.00	2.71	1.12	1.06
Na_2O	6.53	7.45	0.42	0.35	3.47	3.56	3.41	4.40
K_2O	0.51	0.83	8.49	8.62	5.18	4.37	4.46	4.28
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Note: (1–16) sample nos.; (r) rhyolite; (o) obsidian; (g) volcanic glass; (f) feldspar; (b) biotite. Samples: (1–4) Beregovskoe Kholmogor'e; (5–12) Urgyup Formation: (5, 7, 9, 11) Kavak Horizon (11.2 ± 2.5 Ma), (6, 8, 10, 12) Gordeles Horizon (7.8 ± 1.6 Ma); (13, 14) Koyundag and Inyakdag Mts.; (15, 16) Tsakhkunyatskii Ridge; (n.d.) component was not determined, (–) component was not detected; * complete silicate analysis, ** microprobe analysis.

ignimbrites are characterized by a high content of potassium oxide. In northern Anatolia, the volcanism is most prominent in the Galata area, where explosions of acid magmas (trachydacites, rarely dacites and rhyolites) occurred only in the Early Miocene (19–17 Ma), whereas the Late Miocene (<10 Ma) was marked by eruptions of alkaline basalts (Wilson et al., 1997).

Upper Miocene acid volcanics of central Anatolia and the studied ashes have different petrochemical features (Table 5, Fig. 3). Rhyolites and acid volcanic glasses of the Urgyup Formation are characterized by higher content of silica (up to 80%) and lower content of sodium oxide. The potassium content usually exceeds the sodium content. In the volcanic glasses, the Na_2O/K_2O ratio varies from 0.17 to 0.45. The difference is also noted in the compositions of feldspars and biotite encountered in the compared rocks. Volcanic centers of the Galata area produced basic volanics in the Late Miocene and, therefore, could not be the source of the Kerch–Taman ashes.

In the *Caucasus*, Miocene volcanics are widespread in southern Georgia and central Armenia (Milanovskii and Koronovskii, 1973). In southern Georgia, the Miocene volcanics are represented by the Goderdz Formation consisting of different (from basic to acid) volcanogenic rocks. According to (Skhirtladze, 1958), the formation is a product of multiple magmatic eruptions in the Late Miocene. In the areas adjacent to southern Georgia, the section includes ash interlayers in upper Middle Sarmatian, Upper Sarmatian, Meotian, and, presumably, Pontian. Such a distribution of pyroclastic rocks can be related to the stage-by-stage manifestations of explosive eruptions during the accumulation of sediments of the Goderdz Formation. This formation includes acid volcanics at the Settlement of Khertvesy as thick rhyolitic lava and obsidian piles with the radiometric age of 9.1 Ma (Aslanyan et al., 1982). Upper

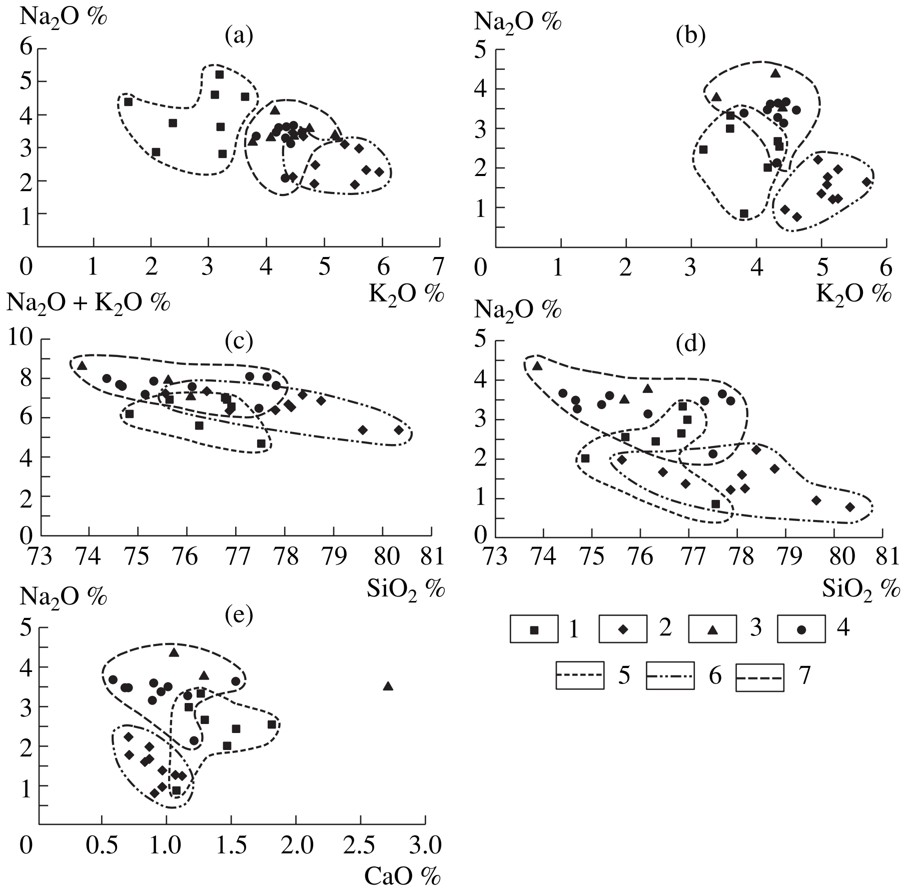

Fig. 3. Comparison of contents of major components in Miocene volcanics of different regions. (a) Rhyolites and Kerch–Taman volcanic glasses; (b–e) obsidians and volcanic glasses (Urgup Formation and Kerch–Taman region). Volcanites: (1) Beregovskoe Kholmogor'e, Transcarpathians (Kostyuk, 1961); (2) Urgyup Formation, Central Anatolia (Temel et al., 1998); (3) Lesser Caucasus (Skhirtladze, 1958; Abovyan et al., 1970); (4) Kerch–Taman volcanic glasses. Contours of fields of quantitative values of volcanics: (5) Beregovskoe Kholmogor'e, (6) Central Anatolia, (7) Lesser Caucasus and Kerch–Taman region.

Miocene acid effusives (rhyolitic and dacitic lavas and pyroclastolites) are known in the Erushet Highland, as well as the Arsian, Samsar, and Kechut ridges (Skhirtladze, 1958). In the central Armenian area, Miocene–Pliocene acid volcanics are sufficiently widespread in the Aiotsdzore, Tsakhkunya anticlinorium, and Sevan Basin regions (Abovyan et al., 1970). The Aiotsdzore and Tsakhkunya anticlinorium regions incorporate rhyolites and rhyodacites with an absolute age of 12.8 Ma (Aslanyan et al., 1982).

One can observe a significant similarity in the scenario of the Miocene volcanism in the Caucasus and in the stage-by-stage distribution of the Kerch–Taman ashes in the studied section (Table 4). Contents of the major components are similar in the ashes and acid volcanics of southern Georgia and central Armenia (Table 5). In different diagrams showing the petrochemical features of the studied rocks, fields of the major characteristics of volcanic rocks of the Kerch–Taman and Caucasian regions show mutual intersections (Fig. 3). Judging from the stage-by-stage manifestation of volcanism and petrochemical similarities of the magmatic rocks, volcanic centers of southern Georgia and central Armenia could be possible sources of the ashes.

The opinion of Chumakov et al. (1992) is very important in the discussion concerning the Caucasian volcanic centers as the possible sources of the Kerch–Taman ashes. According to this opinion, the Neogene aureoles of volcanic ashes reflect the predominance of western and southwestern (instead of eastern) winds in the Tethys and Paratethys realms. Therefore, the eolian transport of pyroclastics toward the west (from the Caucasus to Taman) looks unlikely. This idea was based on the following fact: ashes are absent in the Sarmatian section in western Georgia (in contrast to the eastern areas and Kura Basin). According to this concept, volcanic centers of the Lesser Caucasus could hardly serve as sources of the studied pyroclastics.

The study of the recent predominant air flows in the Black Sea region revealed their considerable complexity and seasonal variability (*Klimaticheskii atlas…*, 1962): the presence of westward winds most intensely blowing in the winter period and significantly weakly blowing or completely dying out in the summer season.

The existing distribution of air masses does not exclude the possibility of the delivery of pyroclastic material to Kerch and Taman peninsulas from the Caucasian territory in the past. The irregular distribution of pyroclastics in the western and eastern areas of Georgia could be related to unfavorable conditions for the burial of ash interlayers during the Miocene in the Rioni Basin. Thin ash horizons are best preserved in clayey sediments. Predominantly clayey–sandy and coarse-grained shallow-water sediments accumulated during the Sarmatian–Meotian in western Georgia (*Stratigrafiya SSSR…*, 1986).

Thus, results of our investigations suggest that the Kerch–Taman ashes are probably derived from the Caucasian volcanic centers situated within southern Georgia and central Armenian. Continuation of the comprehensive study of pyroclastic rocks of the Kerch–Taman region, elucidation of concentrations of microelements in the vitroclastic material, wide application of isotope methods, and further interregional correlations are needed to ultimately resolve this problem.

CONCLUSIONS

(1) The distribution of pyroclastics in Miocene sediments of the Kerch–Taman region indicate two (Sarmatian and late Meotian) stages of volcanic eruptions with a duration of ~3.8–4 Ma.

(2) The studied ashes belong to acid magmatic varieties. The Sarmatian ashes are characterized by the rhyolitic composition, whereas upper Meotian ashes correspond to dacites and rhyodacites. Decrease of silica content and increase of alkalinity are observed from ancient to younger rocks. The upper Meotian volcanics are characterized by high concentration of potassium. The ashes largely correspond to potassic–sodic and potassic (normal alkaline, subalkaline, and alkaline) varieties of volcanics with low contents of carbonates and high contents of potassium and sodium. The studied pyroclastic rocks most probably belong to a single magmatic center.

(3) Stages of volcanic activity and petrochemical similarities of magmatic products indicate that the Caucasian volcanic centers situated in southern Georgia and central Armenia are the sources for the Kerch–Taman ashes.

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