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MAGNITOSTRATIGRAPHIC STUDIES OF THE UPPER SARMATIAN-LOWER MAEOTIAN DEPOSITS IN THE PANAGIA CAPE SECTION (THE TAMAN PENINSULA, RUSSIA)

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In order to obtain the missing data on the magnetostratigraphy of transitional layers between the Sarmatian and Maeotian parts in the Eastern Paratethys, the authors studied the upper Sarmatian — the lower Maeotian deposits in the Panagia Cape section (the Taman Peninsula, Russia) using petromagnetic and magnetostratigraphic methods. The Panagia Cape section is located on the Black Sea coast of the Taman Peninsula. The total thickness of the studied sediments is about 29 m. The section is composed mainly of clays characterized by weak magnetization. Natural remanent magnetization is caused mainly by monoclinic pyrrhotite. Magnetic anisotropy was studied in order to substantiate the reliability of the results. Comparison with the ATNTS 2012 magnetochronological scale shows that the studied transitional layers between the Sarmatian and Maeotian parts probably correspond to the 4n, 3Bn and 3Br Chrones. The obtained results agree with biostratigraphic and radiometric data.

Keywords: petromagnetism, magnetostratigraphy, natural remanent magnetisation, magnetostratigraphy scale.

INTRODUCTION

The upper Miocene deposits identified on the Taman Peninsula are unique for conducting magnetostratigraphic studies of the Neogene sequences in the southern regions of the European part of Russia. Taman sections are well exposed and mainly composed of relatively deep-sea clay sediments that reflect a more complete geological record comparing to shallow water sediments. The magnetization of the Maeotian sediments of the Taman Peninsula was first studied by Pevzner M. and Chikovani V. (Pevzner and Chikovani, 1978). The authors showed that the lower and upper parts of Maeotian were magnetized reverse and normal accordingly. Recent biostratigraphic and lithological studies revealed an urgent need for a more detailed study of the sediments in question using magnetostratigraphy methods (Popov et al., 2016; Radionova et al., 2012). Petromagnetic and paleomagnetic studies of the Maeotian and upper Sarmatian deposits of the Popov Kamen Cape section located on the Black Sea coast in the southwestern part of the Taman Peninsula were described in our previous publications (Pilipenko, Trubikhin, 2014; Trubikhin, Pilipenko, 2011). It was shown that sediments of the upper part of the upper Sarmatian are magnetized mainly reverse but contain an interval of normal polarity in the middle of the strata. In the magnetochronological scale, the upper part of the upper Sarmatian of the Popov Kamen Cape section (Fig. 1) can be correlated with the C4r, C4An and C4Ar Chrons. In the top of the upper Sarmatian of the Popov Kamen Cape section, an interval of clays on uncertain polarity is distinguished, above which bryozoan limestones (bioherms) of the Maeotian base are traced. Bryozoan limestones are unsuitable for sampling for paleomagnetic studies. Thus, the sediments corresponding to the bottoms of the lower Maeotian and the top of the upper Sarmatian were not covered by magnetostratigraphic studies. So we assume that there is a stratigraphic ~0.6–0.8 Ma gap between the sediments of the upper Sarmatian and lower Maeotian. By magnetization, the overlying rocks of the lower and upper Maeotian correspond to the C3Br, C3Bn, C3Ar, C3An Chrons (Trubikhin, Pilipenko, 2011).

This work focuses at petromagnetic and paleomagnetic studies of deposits of the top of

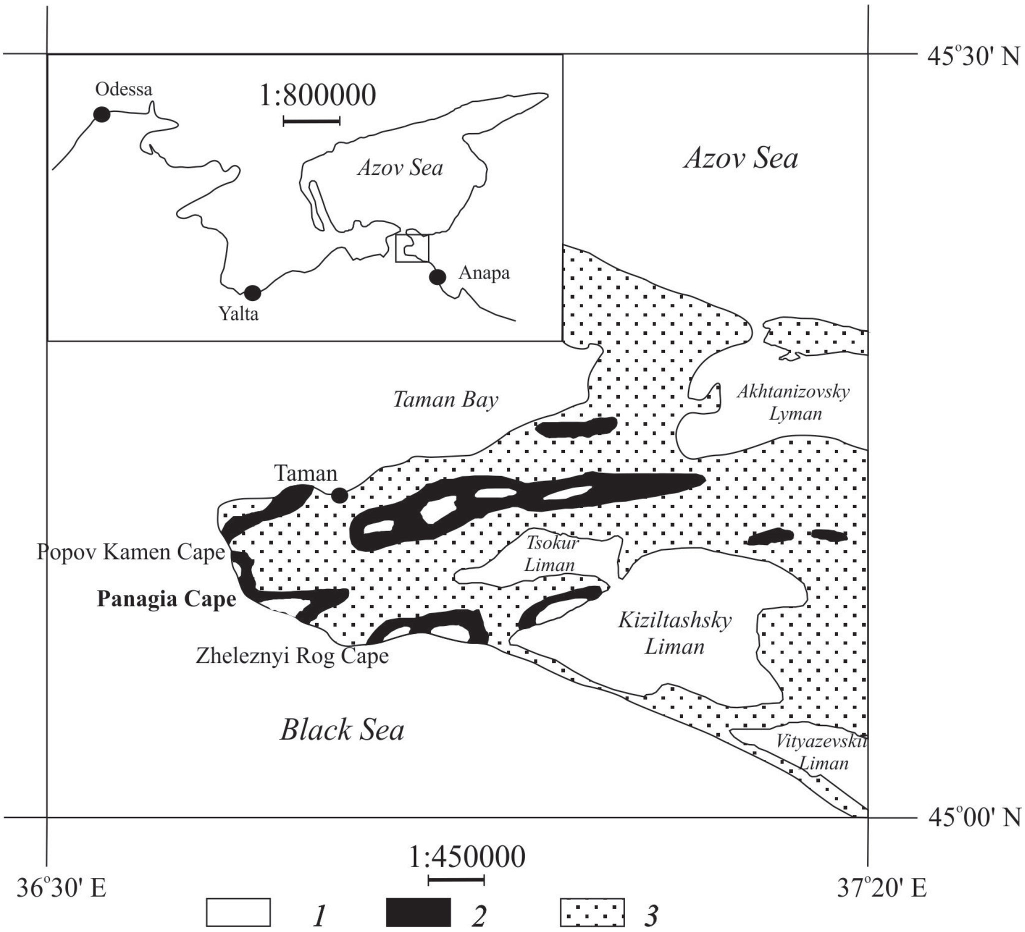

Fig. 1. Schematic geological map of the region under investigation. The square in the inset denotes the position of the studied region on the geographic map : *1* — pre-Maeotian; *2* — Maeotian; and *3* — post-Maeotian deposits.

Sarmatian and the base of the Maeotian Panagia Cape section located to the east of Popov Kamen Cape on the Taman Peninsula in order to obtain the missing data on the magnetostratigraphy of the transitional layers between the Sarmatian and Maeotian in the Eastern Paratetis.

OBJECT OF INVESTIGATION AND GEOCHRONOLOGICAL DATING

The Panagia Cape section is located on the Black Sea coast of the Taman Peninsula (φ = 45°09' N, λ = 36°37' E, Fig. 1) and composed mainly of clay sediments of Sarmatian and Maeotian age. At the base of the Maeotian strata there is the horizon of bryozoan limestones, which is a good lithological marker. Above in the lower Maeotian clays there are also separate horizons of bryozoan limestones with much lesser thickness. In the studied part of the section, the sediments outcrop exposes from the bottom to top (Fig. 2*a*):

Layer 1. Dark gray, dense thin-layered clays (~1 m).

Layer 2. Ferruginous clays, distinguished in the form of a horizon, traced by layering (~0.1 m).

Layer 3. Dark gray, thin-layered clays (~10 m).

Layer 4. Horizon of bryozoan limestones (bioherms) (~6 m).

Layer 5. Dark gray, thin-layered clays, with jarite efflorescence in the upper part (~4 m).

Layer 6. Dark gray, thin-layered, with fading of jarosite at the bottom (~8 m).

Layer 7. Lumps of bryozoan limestones (~1.3 m).

The total thickness of the studied deposits is ~29 m. By mollusk fauna, the deposits of layers 1–3 belong to the upper Sarmatian, and the deposits of layers 4–7 to the lower Maeotian (Radionova et al, 2012). In this section, the Maeotian mollusks are found both in the body of bryozoan limestones (layer 4) and in the clay deposited in their base. Therefore, all the carbonate formations are considered as part of the Maeotian strata (Goncharova et al., 2009).

In the studied part of the Panagia Cape section, bedding elements of the layers of the upper Sarmatian — lower Maeotian strike NW 319° and deep 12° in average.

In some sections of the upper Sarmatian deposits that outcrop on the Kerch and Taman Peninsula, there are remained layers of volcanic tephra (Chumakov et al., 1992). The K-Ar age of the tephta layer, located in the upper part of the upper Sarmatian in the Zheleznyi Rog Cape section of the Taman Peninsula,

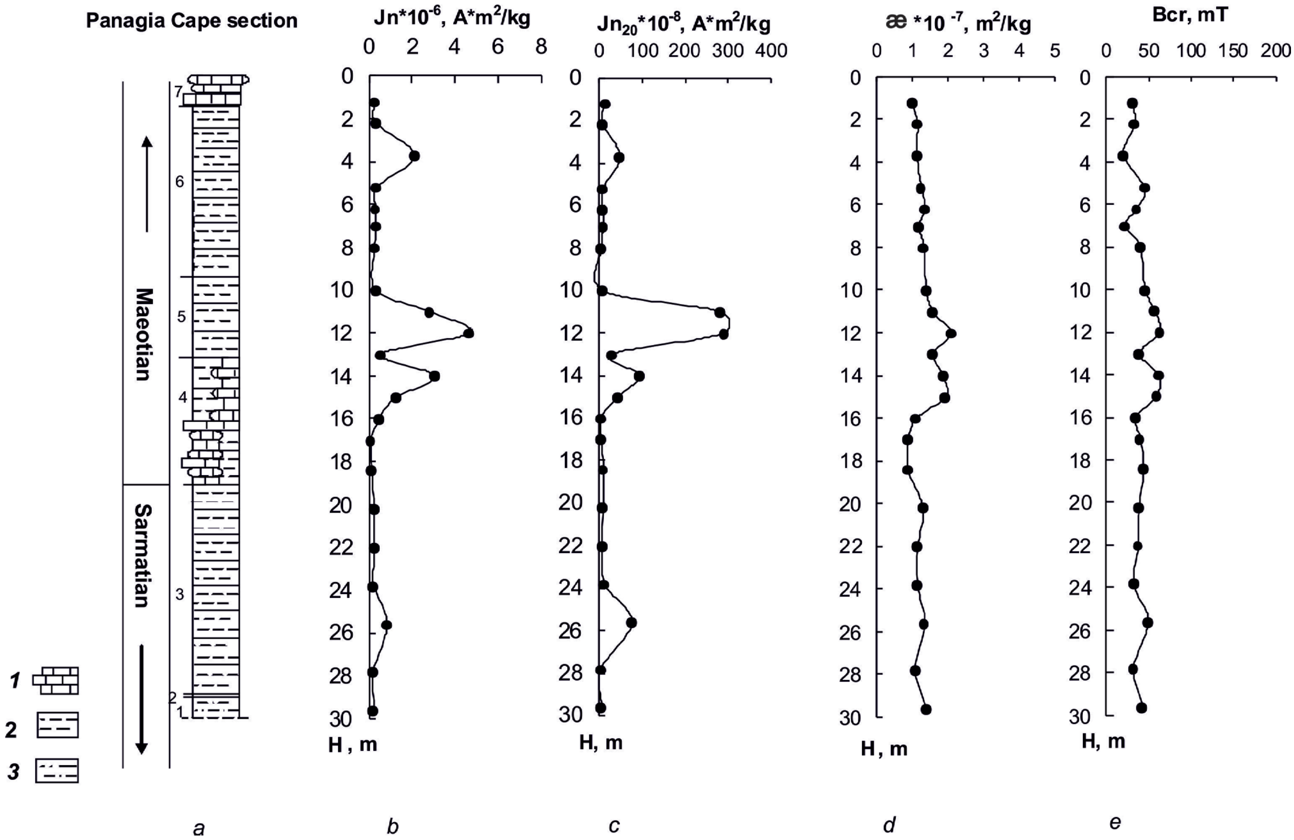

Fig. 2. Lithological column of the Upper Sarmatian and Lower Maeotian deposits of the Panagia Cape section (*a*). The numbers on the lithological column denote layers. The curves of variations in the mass magnetic characteristics as functions of the section's thickness H; natural remanent magnetization Jn (*b*); natural remanent magnetization Jn_{20} after the alternating magnetic field demagnetization at 20 mT (*c*); magnetic susceptibility æ (*d*), remanent coercitive force Bcr — (*e*): *1* — bryozoan limestones (bioherms); *2* — clays; *3* — aleurolitic clays.

was previously determined to be ~8.87 ± 0.27 Ma (Golovina et al., 2002), and ~8.69 ± 0.18 Ma by the Ar / Ar analysis (Vasiliev et al., 2011).

In the work (Chumakov et al., 1992), radiometric track dating of volcanic ash interlayer in the Popov Kamen section of the Taman Peninsula is given. This pyroclastic interlayer in the upper Sarmatian deposits lies about 40 m below the base of the bryozoan limestones found at the base of the Maeotian. Taking into account the new constant of spontaneous fission of uranium (For, 1989), the age of this volcanic ash may be ~8.5 ± 0.7 Ma.

In the clay deposits of the upper part of the upper Sarmatian of Panagia Cape section, there are valves of diatoms Navicula zichii together with oceanic diatoms Thalassiosira burckliana (LO 7.9 Ma), Th. grunówii (LO 7.9 Ma), Th. antique (FO 7.7 Ma) (Radionova et al, 2012). The valves of the oceanic diatoms Thalassiosira grunowii, which lived 8.9 to 7.9 Ma back, were found in the studied upper Sarmatian deposits 10–32 m below the base of Maeotian (Popov et al., 2016).

According to the micropaleontological data, the age of the border between the Sarmatian and Maeotian is slightly younger than that obtained by dating of tephra (Radionova et al., 2012).

SAMPLING FOR ROCK MAGNETIC AND PALEOMAGNETIC ANALYSES

Hand blocks of bedrocks (No. 1–21) of the studied lower Maeotian and upper Sarmatian deposits were sampled with an interval of ~1–2 m. Hand blocks oriented along the magnetic meridian were taken mainly on the bedding from freshly cleaned vertical walls of the section. Then, the hand blocks were sawn up into horizontal plates 2 cm thick from which three 2 cm cubic samples from each level were cut out. Totally, we analyzed 66 samples cut out from 22 hand blocks of the studded part of Panagia Cape section.

ANALYSING METHODS AND MAGNETICK PROPERTIES OF THE ROCKS

We measured standard magnetic parameters, which are natural remanent magnetization (Jn), mass magnetic susceptibility æ (Fig. 2*b*, 2*d*), and anisotropy of magnetic susceptibility (AMS). The entire experiment was performed on the basis of "Laboratory of the main geomagnetic field and rock magnetism" of the Schmidt Institute of Physics of the Earth, Russian Academy of Sciences (IPE RAS). The

Jn was measured with JR-6 magnetometer (AGICO, the Czech Republic); æ and AMS was measured with a Multi-Function Kappabridge instrument (AGICO, the Czech Republic). Before the experiment, all samples were weighed on a CAS scale (model CAUY 120, South Korea). The mass of the samples varied from 8 to 13 g, which was due to the imperfection of the samples shape.

Before demagnetization, the Jn was measured in free positions of a rotating sample and was normalized to the density of the samples. In this work, all of the used scalar parameters were normalized to density, and in what follows, the term “mass” will be omitted. Average for three samples from level Jn is demonstrated in Fig. 2*b*. In the studied part of the section, the value of Jn isn't homogeneous and varies from 0.3×10^{-6} to 4.7×10^{-6} A m^2/kg.

The values of æ vary along the section from 0.99×10^{-7} to 2.08×10^{-7} m^3/kg (Fig. 2*d*), which points to changes along the section in the concentration of particle NRM carriers by a factor of ~2 (Pan et al., 2001). The remanent coercitive force Bcr varies from 20 to 60.3 mT (Fig. 2*e*).

The thermomagnetic analysis of æ (T) was performed with a Multi-Function Kappabridge (AGICO, The Czech Republic) for seven powdered samples of sediments ~1 g in mass taken to study the composition of magnetic minerals — carriers of natural remanent magnetization, (Fig. 3): No. 2 (H = 3.7 m, lower Maeotian), No. 11 (H = 12 m, lower Maeotian), No. 10 (H = 13 m, transitional pack between Maeotian and Sarmatian), No. 9 (H = 14 m, transitional pack between Maeotian and Sarmatian), No. 19 (H = 25.6 m, upper Sarmatian). Thermomagnetic analysis of a characteristic sharp peak on the curves æ (T) — the so-called λ-peak (Nagata, 1965) showed that monoclinic pyrrhotite is the main carrier of magnetization. In sediments, pyrrhotite may be in detrital form (Quaternary ..., 1999). Initially, pyrrhotite of chemical origin is contained in the sediment in suspension, and can be considered as primary. As a result of lithification — the transformation of sediment into rock, there are the extraction of pore waters and the partial ordering of the structural arrangement of magnetic minerals and the formation of paleomagnetic record.

After heating, pyrrhotite turns into magnetite and maghemite, as indicated by the Curie points around 575–620°C on the heating and cooling curves and the increase in magnetic susceptibility on the cooling curve.

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY

In order to determine the true Jn directions, we studied anisotropy of magnetic susceptibility (AMS). To assess the AMS, the volumetric magnetic susceptibility of samples K were measured using a Multi-Function Kappabridge instrument (AGICO, the Czech Republic). The susceptibility tensor can be represented as an ellipsoid, having three main axes: K_1 — maximum, K_2 — intermediate and K_3 — minimum component of magnetic susceptibility ($K_3 < K_2 < K_1$). The spatial distribution of the projections of the AMS ellipsoid axes is shown in Fig. 4 (*a*). It can be seen from the figure that a part of the magnetic susceptibility tensor projections of axes K_1 and K_2 lies in the plane of the bedding, and the minimum axis K_3 is perpendicular to the bedding plane. The other part of the samples demonstrated an isotropic distribution of the main axes projections. The mean values of the parameters $L_{mean} = 1.002$ and $F_{mean} = 1.02$, the degrees of anisotropy $P'_{mean} = 1.024$ (Fig. 4*c–e*). Therefore, the rock samples possess a small planar anisotropy, which is a characteristic of normal sedimentary rocks.

PALEOMAGNETIC ANALYSES

In order to study the magnetization recorded in rocks of sedimentary origin, it is necessary to extract the part of the Jn that was magnetized in the period of accumulation and lithification of the sediment, i.e., to free the Jn from secondary components of magnetization. For this purpose, we used the alternation field demagnetization of the collection (three duplicates from each level). We used the AF Demagnetizer (Applied Physics Systems, USA) for three positions of the sample inside AC coils, the magnetic field of which could vary from 0 to 100 mT with a shielded from the external magnetic field. After each demagnetization step, the remnant magnetization was measured with a JR-6 magnetometer (AGICO, The Czech Republic) in three positions of a rotating sample. As noted above, the main carrier of magnetization of studied rocks is monoclinic pyrrhotite. The low initial Jn values are characteristic of samples of the collection. That is why for extracting the primary component of magnetization, the curves of demagnetization were measured for all the samples from initial values of Jn up to 45–60 mT with a step of 2.5–5 mT. It is seen from the Zijderveld diagrams (Fig. 5*b*) that an alternation magnetic field of ~20 mT removed the viscous component of magnetization. Apart from the viscous component, the Zijderveld diagrams contained a component whose direction was assumed to be characteristic.

After the viscous component of magnetization was removed Jn dropped by ~40 % (Fig. 2*c*). The remaining Jn20 after the demagnetization was rather strong, suitable for further paleomagnetic studies.

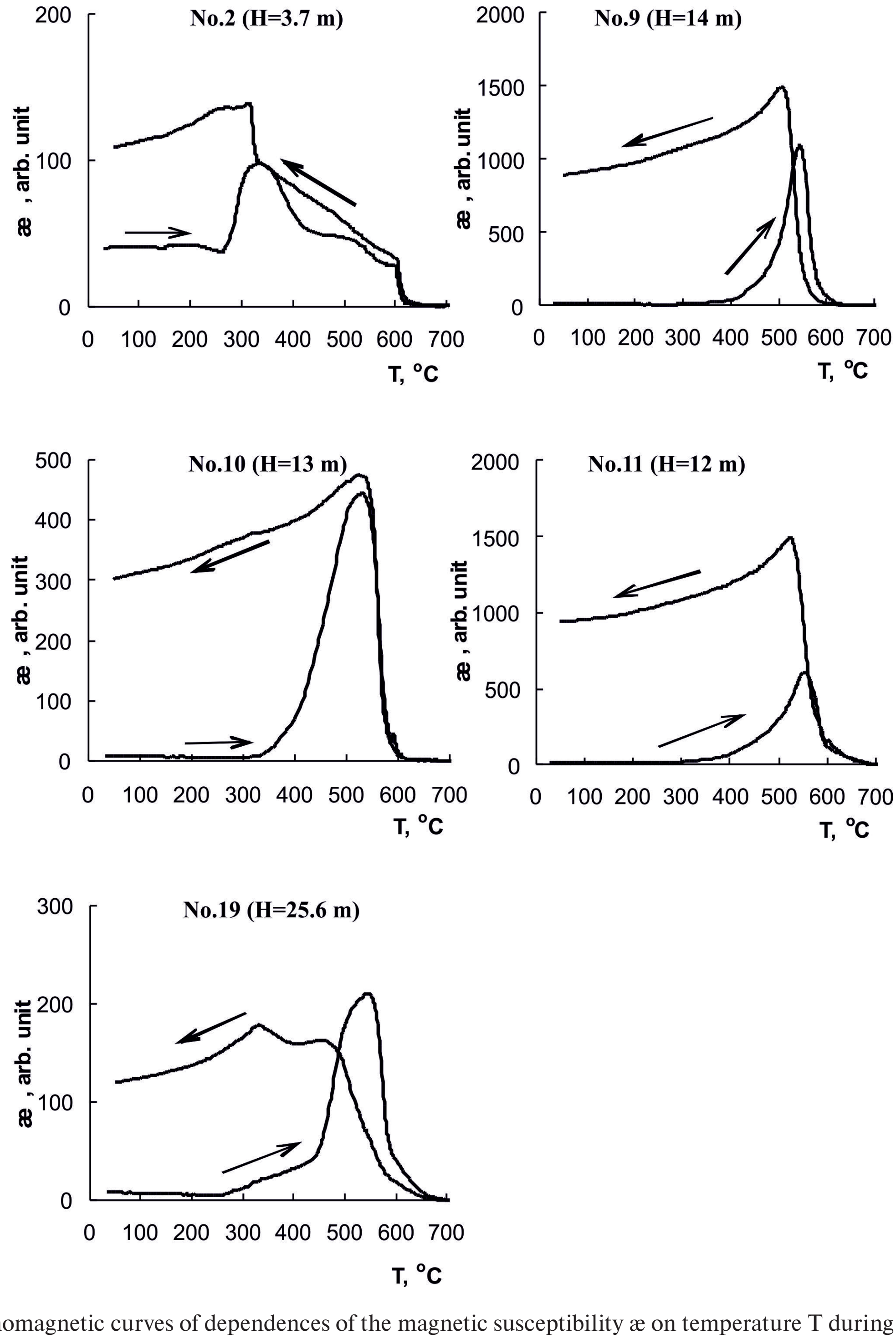

Fig. 3. Thermomagnetic curves of dependences of the magnetic susceptibility æ on temperature T during the heating — cooling cycle. The arrows denote the course of the curve.

RESULTS

The values of the declination D and inclination I of magnetization obtained after the AF demagnetization satisfactorily agree for three duplicates from one level (the mean concentration parameter of Fisher's statistics is ~103), which makes it possible to average them and construct curves of the dependences of I and D on the thickness of the section (Fig. 6*b*, 6*c*). The samples have positive and negative values of the inclination I, so the interpretation of the polarity sign must be cautious. However, based on declination D, a reasonable interpretation seems possible.

The studded part of the section is characterized by alternating intervals of normal (n) and reverse (r) polarity. Paleomagnetic characteristic of the upper Sarmatian in the most complete sections of Parathethys shows that the upper Sarmatian is localized within C4 Chron in the magnetochronological scale (Cande, Kent, 1992; Gradstein et al., 2012; Popov et al., 1996).

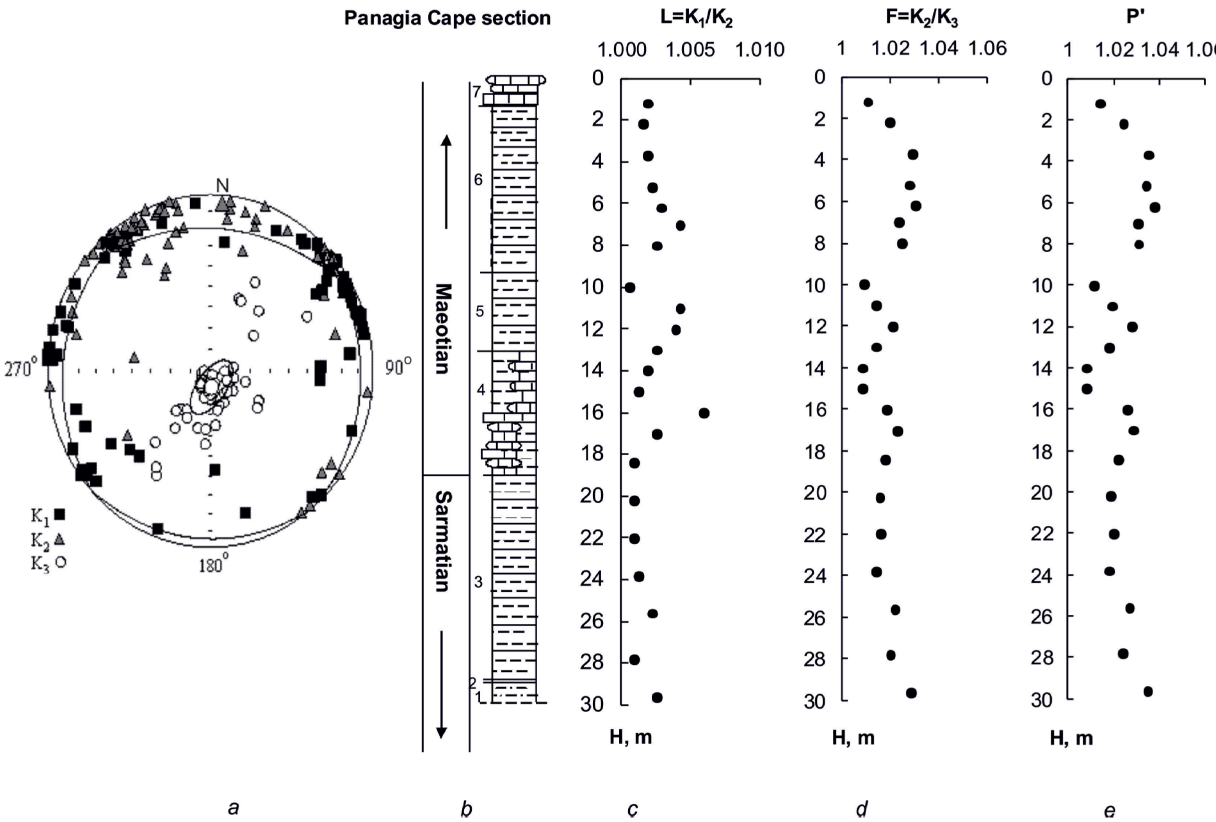

Fig. 4. Stereographic projections of the components of the magnetic susceptibility anisotropy ellipsoid (*a*). K_1, K_2, K_3 are the maximum, intermediate, and minimum components, respectively. The lithological column (*b*). Dependence of anisotropy parameters L= K_1/K_2 (*в*), F = K_2/K_3 (*c*) and degree of anisotropy P′ (*d*) on the section's thickness H.

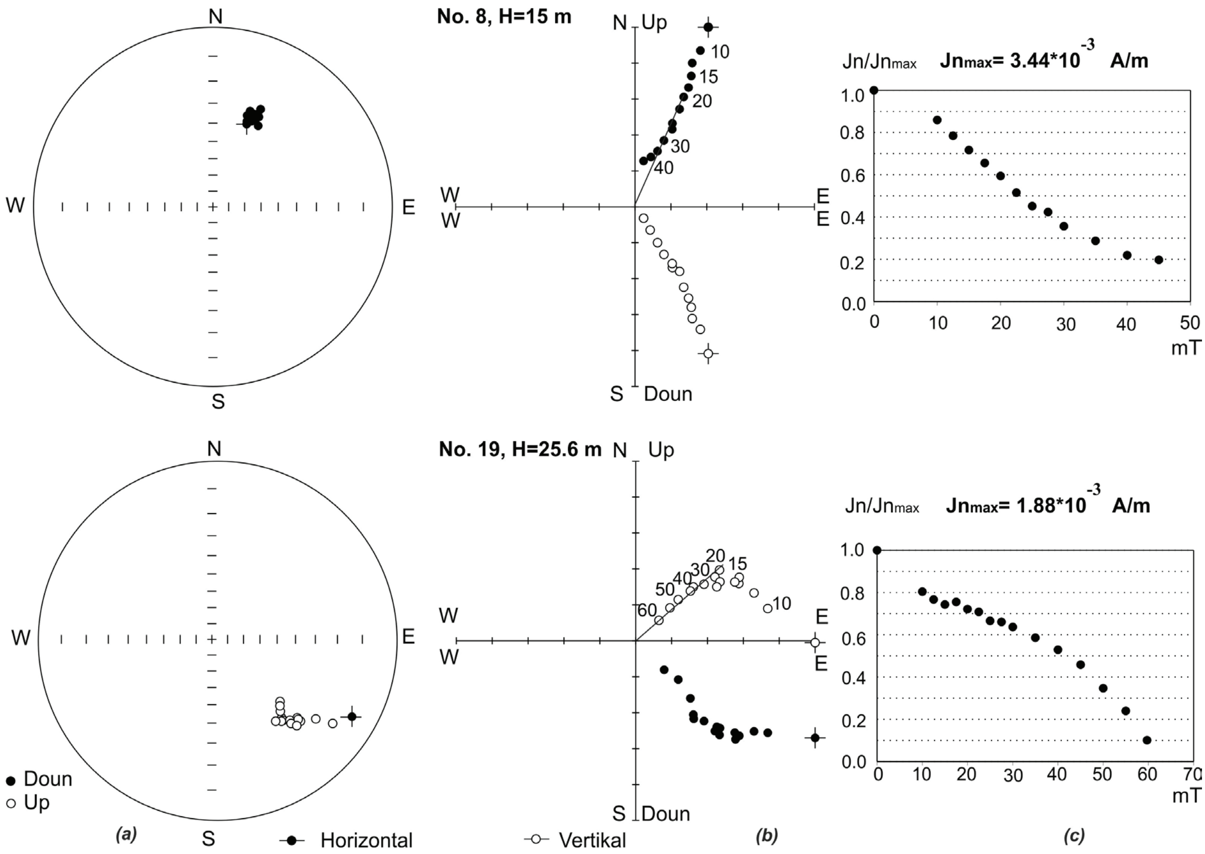

Fig. 5. Stereographic projections of natural remanent magnetization of vector Jn in the ancient coordinate system (*a*). Zijderveld diagrams (*b*). Curves of the Jn alternating field demagnetization for samples (*c*).

Leaving aside rare single sites, the sediments lying in the top of the upper Sarmatian part of the of Panagia Cape section are magnetized reverse and normal. The interval of normal polarity can be compared with the C4n Chron on the magnetochronological scale. The deposits in the bottom of the lower Maeotian are magnetized normal. Above, the transition zone and again normal polarity zone follow, which suggests that this interval may correspond to the C4n, C3Br and C3Bn Chrons.

The age of the boundary between the Chron C3 and the Chron C4 is ~7.3–7.4 Ma (Cande, Kent, 1992), and ~7.6 Ma by the ATNTS2012 scale (Gradstein et al., 2012), (Fig. 6e). According to our data, the deposits of layer 4, which include bryozoan limestones at the base of the Maeotian, are not younger than ~7.3–7.6 Ma. This conclusion is confirmed also by the presence of flaps of oceanic diatoms Thalassiosira grunówii in the underlying upper Sarmatian deposits, which existed 8.9 to 7.9 Ma back.

It was suggested earlier that there was the Chron C4n stratigraphic gap between the Sarmatian and Maeotian deposits in the Popov Kamen Cape section of the Taman Peninsula (Pilipenko, Trubikhin, 2015). Our study revealed that deposits of Panagia Cape section can be compared with the part of the Chron C4n.

CONCLUSION

For the first time the entire deposits of the top of the upper Sarmatian and lower part of the lower Maeotian of the Panagia cape section of the Taman peninsula including the interval of bryozoan limestones were studied by magnetostratigraphic methods. A complex of rockmagnetic and paleomagnetic studies of the ferromagnetic fraction composition and anisotropy of magnetic susceptibility was carried out to substantiate the reliability of the obtained results. Paleomagnetic study showed that the rocks in the top of the upper Sarmatian part of the Panagia Cape section were magnetized both normal and reverse. The rocks of the bottoms of the lower Maeotian are magnetized mostly normal. Comparison with the magnetochronological scale ATNTS 2012 leads to the conclusion that the studied part of the section may correspond to the C4n, C3Br and C3Bn Chrons. The obtained results correspond to the biostratigraphic and radiometric data.

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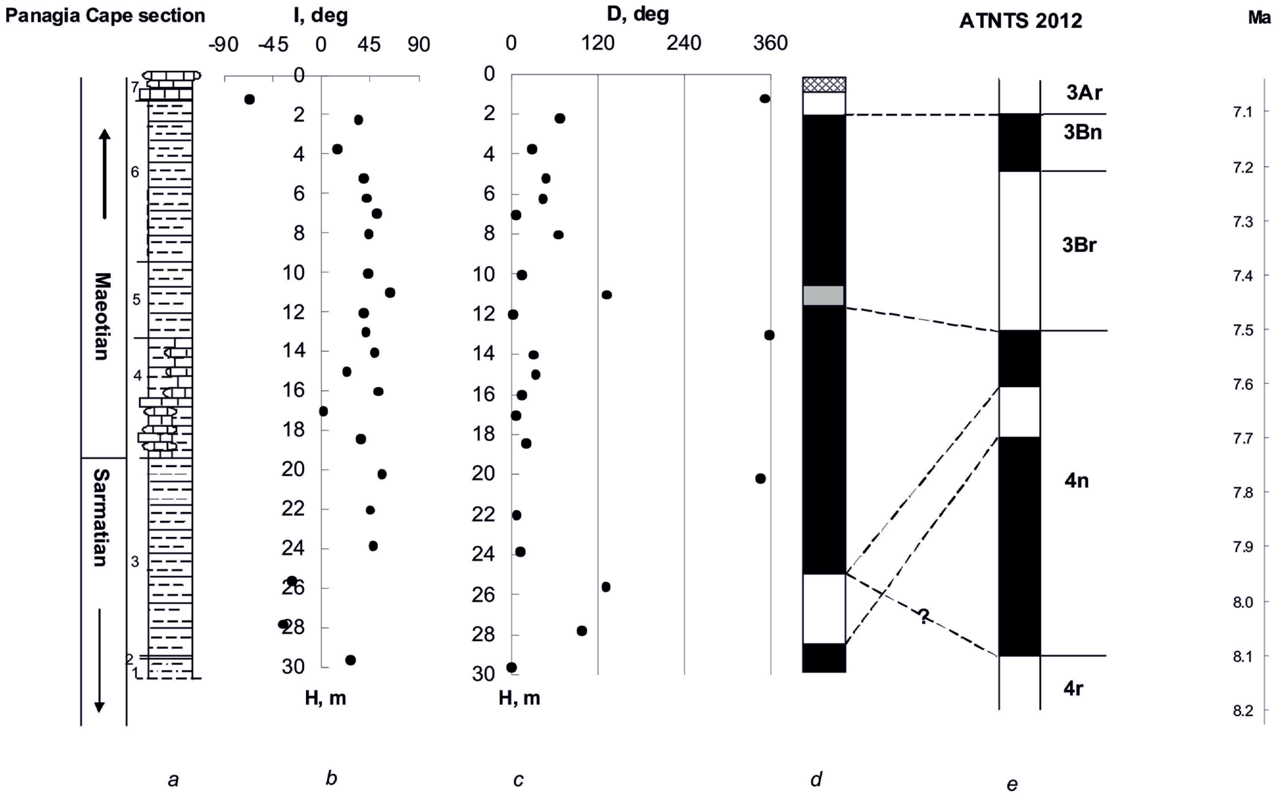

Fig. 6. Lithological column (*a*). The dependences on the section thickness H of the mean values of inclination I (*b*) and declination D (*c*) after the alternating field demagnetization and component analysis. Magnetochronological column (*d*). Comparison of the studied part of the upper Miocene sediments in the Panagia Cape section with the magnetochronological scale ATNTS 2012 (Gradstein et al., 2012) (*e*). Black colour denotes normal polarity of the magnetic field; white colour denotes reversed polarity of the magnetic field, grey colour denotes a transitional zone.

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