PALEOMAGNETIC DATING AND STRATIFICATION OF THE LATE PLEISTOCENE KARADZHA SECTION – THE REFERENCE SECTION OF THE NEOPLEISTOCENE PARATETHYS

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The Late Pleistocene deposits of the Karadja section were studied. Both vector and scalar characteristics of its constituent rocks were obtained. The main paleomagnetic elements of the section were established: the Jaramillo paleomagnetic horizon and the boundary between the Matuyama and Brunhes zones. A number of anomalous horizons (excursions) were identified - these include Roksolany (Mono, Laschamp, etc.), Blake, Biwa I, Jamaica, and Biwa III. Such an abundance of dated levels, along with fission track dates and abundant fauna, allowed for confident correlation of the studied section with the oxygen isotope scale for the last 0.8 million years.

Keywords: anomalous horizon, fission track dating, Pleistocene, Matuyama-Brunhes boundary, Karadja section.

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1. INTRODUCTION

The study of the Karadja section was undertaken because it is the most complete and powerful (of those known) section of marine deposits of the Late Pleistocene. The main objective of the research was to find the maximum number of paleomagnetic boundaries in a single sequence - zones, horizons, anomalous horizons (excursions) - and thereby saturate the section with absolute dates. These dates, along with dates obtained by other methods (tracks, fauna), allowed solving at least two problems. The first is an attempt to identify the spectrum of secular variations of the geomagnetic field, and the second is to compare the Neopleistocene part of the section with the oxygen isotope scale and thereby finally resolve the issue of synchronicity (or asynchronicity) of Caspian Sea level fluctuations with those of the World Ocean.

Additionally, paleolithic artifacts have recently been found in the Karadja section [Zeynalov et al., 2022], which makes it even more important to establish the maximum number of dating levels in this section.

2. RESEARCH OBJECT AND DATING

The Karaja section is located on the shore of the Mingechevir reservoir (λ = 47 °E, φ = 40 °N) two kilometers east of the city of Mingechevir, Azerbaijan (Fig. 1). The entire section is an anticlinal fold 17 km long, which belongs to the Bogaz-Karaja-Karamaryam fold zone [Mamedov, 2002]. The northern monocline of the fold exposes a complete sequence of deposits with a thickness of 1000 m, corresponding to the time interval from the Early to Late Pleistocene inclusive. The Karaja section is classic and has repeatedly been subjected to various kinds of research [Fedorov, 1978; Trubikhin, 1987; Gurariy et al. 1986].

Fig. 1.

Fig. 2.

Most of the Pleistocene deposits of the Karaja section are strongly dislocated, but the very top, corresponding in age to the Middle and Late Valdai (about 50-10 thousand years ago) is not dislocated and represents two marine terraces of Late Pleistocene age, embedded in the underlying dislocated strata [Trubikhin, 1987].

The section is composed of marine terrigenous deposits - clays, siltstones and sandstones, and in the upper part often conglomerates as well.

Here (Fig.2) from bottom to top is exposed:

1. A complex of sediments, represented mainly by siltstones and clayey siltstones, brownish-gray with interlayers of sands with fauna *Apscheroni propinqua Eichw.* This stratum forms the southern slope of the Karaja ridge facing the city of Mingechevir. Thickness ~220 m.

2. In the overlying sediment complex, the nature of the stratum changes, and it is composed mainly of siltstones and sandy siltstones of variegated colors with interlayers of sands and sandstones. At the base lies a thick (5-7 m) layer of dense sandstone, and in the middle part two layers of volcanic ash. In this stratum, fauna *Hyrcania sp.* was found. Thickness ~ 250-260 m

3. The next sedimentary complex is double and lies on the underlying stratum with azimuthal unconformity. It is represented in the lower parts by conglomerates and sands, and in the upper part by brownish-gray layered siltstones and contains only freshwater mollusc fauna. Thickness ~ 50 m.

4. The overlying sediment complex represents a thick stratum of brownish-gray finely layered clays. At the base there are sands with pudding pebbles. Contains fauna *Didacna parvula Nal.* Thickness ~ 70 m.

5. The fifth sedimentary complex with sands and lenses of pebbles at the base represents a stratum of gray siltstones with interlayers of sands. Contains a layer of pinkish ash and fauna *Didacna aff. Rudis Nal.* Thickness ~ 40 m.

6. The next sediment complex is predominantly a coarse stratum of sands with lenses of pebbles and sandy siltstones. Only in the middle part of the stratum there is a layer of calcareous variegated siltstone. Here is fauna *Didacna pravoslavlevi Fed.* Thickness ~ 45-50 m.

7. Above the previous sediment layer, with deep erosion and pockets of 3-5 m span, lies a stratum of initially sands with lenses of pebbles, then sandy siltstones and clays with fauna *Didacna trigonula Vekil.* Thickness ~ 80 m.

8. The next sedimentary complex with thick sands (~ 20-25 m) at the base represents a stratum of light brown sandy siltstones with interlayers of sands and pebbles. Thickness ~ 75 m.

9. Finally, the dislocated rock stratum is completed by interlayering of conglomerates, sands, siltstones, and light calcareous siltstones with fragments of marine mollusks. The rocks of the upper part of the stratum quickly flatten out and go under the water edge of the Mingechevir reservoir. Thickness ~ 100 m.

10. The section is completed by deposits of two marine terraces with pedestals ~ 25 and 35 m above the average level of the Mingechevir reservoir. They are constructed uniformly. Basal pebbles overlie the dislocated deposits. Carbonate siltstones lie on them. Upward, the latter are replaced by siltstones and sandy siltstones, and all this is covered by modern surface deposits. The thickness of terrace deposits is ~ 7 and 15 m respectively.

Figure 2 shows stratigraphic subdivisions: *ap* - Apsheron, *t* - Tyurkyan, *b* - Baku, *ur* - Urundjik, *hz* - Khazar, *gk* - Girkan, *hv* - Khvalyn. The wavy line (~~) - unconformity.

The first sediment complex, according to its lithological characteristics and mollusk fauna, corresponds to the maximum of the Late Apsheronian transgression. Its lower part, exposed on the southern slope of the Karaja ridge, is normally magnetized and corresponds to the Jaramillo horizon, the top of which is dated at approximately 1 million years [Cande and Kent, 1992].

The overlying strata (complex 2) corresponds both in its lithological characteristics and fauna to the regressive part of the Upper Apsheronian and lies entirely in the upper part of the Matuyama zone. Near its top, there is a layer of light gray volcanic ash, which (with a correction for the new spontaneous uranium fission constant) can be dated to approximately 0.8 million years [Ganzey, 1984; Faure, 1989].

The overlying complex 3, with azimuthal unconformity and erosion, is composed predominantly of freshwater deposits and corresponds to the Tyurkyan horizon. The Matuyama-Brunhes boundary (760-780 thousand years ago) passes through it.

The three sediment complexes lying above correspond to the lower part of the Neopleistocene. These are the Lower Baku, Upper Baku, and Urunjik complexes. In the middle part of the Upper Baku deposits (complex 5), corresponding to the maximum of the Upper Baku transgression, there is a layer of pink ash, dated (with a correction for the new constant) to about 500 thousand years ago [Ganzey, 1984].

In the overlying Urunjik horizon (complex 6), in its middle part, an anomalous horizon ("excursion") Biwa III with an age of about 380-390 thousand years ago has been established [Pilipenko and Trubikhin, 2012; 2015].

The overlying Lower Khazar deposits are bipartite and correspond to two transgressions of the Paleocaspian. In the deposits of the upper part of the Lower Khazar (complex 8), two anomalous horizons ("excursions") have been established: Jamaica (~ 220 thousand years ago) and Biwa I (~ 160-180 thousand years ago) [Chepalyga and Mekhailescu, 1985].

In the middle part of the overlying Upper Khazar deposits (Girkan), an anomalous horizon ("excursion") is found, which can only be the Blake "excursion" (~ 100-120 thousand years ago), since the Upper Khazar deposits are reliably dated and have an age of about 100 thousand years, as does the Blake "excursion" [Dodonov, 2002; Geochronology, 1974].

Finally, the section is crowned by two marine terraces embedded in the dislocated underlying strata. The older one has been studied in detail, and an anomalous Roksolany horizon with an age of ~20-40 thousand years has been established in it.

Thus, in the interval corresponding to the Brunhes zone, five anomalous horizons (excursions) have been established in one sequence. Of course, there may be more of them in this interval [Shkatova, 2015]. However, the established anomalous horizons (excursions) are sufficient to saturate the described section with additional datings.

3. SAMPLING AND PETROMAGNETIC AND PALEOMAGNETIC STUDIES

The described section was first sampled with a frequency of ~2 m per sample (about 500 blocks in total). Subsequently, the most interesting areas were detailed with a frequency of 0.2 m per sample and further up to continuous sampling. The selected blocks were cut into cubes with an edge of 2 cm, and petromagnetic and paleomagnetic studies were conducted on these cubes.

When conducting paleomagnetic studies, the examination of petromagnetic characteristics of the object usually aims to establish the ore mineral carrier of NRM (natural remanent magnetization). This provides insight into whether the NRM is synchronous or metachronous and the representativeness of the obtained paleomagnetic data. No less important is the use of petromagnetic characteristics for reconstructing the sedimentation environment and paleogeography of the studied sedimentary basin.

The composition, size, and concentration of ore minerals change in the section not randomly, but systematically, depending on their origin and sedimentation conditions. Thus, if the ore mineral has an allothigenic (detrital) origin, the petromagnetic characteristics will change vertically in a certain way, and in this case, one can reasonably assume the detrital nature of NRM and, accordingly, the representativeness of the obtained paleomagnetic data.

Magnetic susceptibility (K) and saturation isothermal remanent magnetization (SIRM– *Saturation isothermal magnetization*) were studied. Both parameters correlate well with each other throughout the section, reflecting the concentration of ferromagnetic material in the section depending on facies. The reason for fluctuations in these and other studied parameters is associated with sea level fluctuations dependent on climate changes and tectonic settings. This, along with the high sensitivity of petromagnetic parameters to the slightest fluctuations in sedimentation environment, most likely indicates the detrital nature of minerals – carriers of magnetization in the studied rocks. This is discussed in more detail in the works [Pilipenko et al., 2009a,b].

Fig. 3.

During the study of the pilot collection, samples were subjected to thermal demagnetization and alternating field. Fig. 3 shows Zijderveld diagrams and saturation magnetization curves. The bulk of the collection was subjected to thermal cleaning, resulting in the isolation of characteristic remanent magnetization (ChRM – *Characteristic remnant magnetization*), which is accepted as primary.

Since one of the objectives of this study was to identify the spectrum of secular variations (SV– *Secular variation*), the authors intend to examine the entire body of primary paleomagnetic and petromagnetic data in a subsequent paper. In the present work, we must limit ourselves to presenting the average paleomagnetic and magnetic mineralogical parameters across the section.

The values of the studied paleomagnetic and magnetic mineralogical parameters vary throughout the section, however, their average values are as follows: declination (*D* avg) – 1.5º; inclination (*I* avg) – 35º; NRM – (5–10)10^{-6}; A, m^2/kg; K·10^{-7}, m^3/kg.

4. DISCUSSION OF RESULTS

It is generally accepted that the last 0.8 million years (Neopleistocene) are characterized by sharp climate changes and, accordingly, continental glaciations and interglacials. During cooling periods, the water masses of the World Ocean were mobilized into continental glaciers, which led to a sharp decrease in the level of the World Ocean and open seas connected to it, that is, glacioeustatic transgressions and regressions occurred. As for closed water bodies like the Caspian Sea, until recently, the prevailing view was that closed water bodies behave in the opposite way. That is, if open water bodies (for example, the Black Sea) fluctuate synchronously with the World Ocean, then closed water bodies (for example, the Caspian Sea) fluctuate asynchronously. This point of view arose from a misunderstanding and continued to lead to misunderstandings in the process of its use. Initially, several major glaciations of a planetary nature were identified in the Pleistocene. These are Günz, Mindel, Riss, and Würm. During glaciation periods, water masses were mobilized into ice sheets, and the level of the World Ocean and seas connected to it decreased. During interglacial periods, the reverse process occurred. In works [Fedorov, 1978, etc.], it was established that during the Würm period, the level of the Caspian basin unexpectedly reached abnormally high values (more than +50 m). A number of mechanisms were invented to try to explain this strange phenomenon [Klenova, 1948, etc.]. However, for several decades now, there has been a simple explanation for this phenomenon. First, within the Würm (Valdai), there is a rather pronounced warming (3rd oxygen isotope stage), which should have raised the level of the Caspian basin. Secondly, before the beginning of the 3rd oxygen isotope stage, there was a phase of tectonic activation, which led to the uplift of the Caucasus and the blocking of the Kuma-Manych Strait by a layer of Burtas (Gudilovsky) loams. Prior to this, excess water from the Caspian was discharged into the Black Sea and further into the World Ocean. Now, the blocking of the strait and the impossibility of discharging excess water led to an abnormal increase in the absolute water level in the Caspian Sea basin.

Ignorance of these two factors led to the notion that open basins connected to the World Ocean fluctuate synchronously with it, while closed ones (like the Caspian) fluctuate asynchronously during climatic oscillations of cooling-warming [Klenova, 1948].

Let's examine our results from the Karaja section in light of this problem.

The Neopleistocene section begins here with the Tyurkyan horizon. Here it is two-membered, meaning there are two episodes of basin level rise expressed in facies. The Matuyama-Brunhes boundary passes through the middle part of the first of them. If we refer to the oxygen isotope scale, we can see that the Matuyama-Brunhes boundary passes through the middle part of warm stage 19 [Bassinot et al, 1994]. The next dated point is the transgression of the Upper Baku (pink ash - track dating). It is evident that this date corresponds to the maximum of warm stage 13. The position of the anomalous Biwa III horizon ~ 380 thousand years ago does not contradict the coincidence of the Urundjin transgression with warm stage 11. The position of the Jamaica and Biwa I anomalous horizons also correlates well with oxygen isotope stages 7 and 6. The position of the Blake anomalous horizon fits within the limits of warm stage 5, although in this section it is probably significantly reduced. However, regarding Blake and the Late Khazar (Hyrcanian - gk), there is more than enough data on the synchronicity of the Late Khazar with the Karangat of the Black Sea basin and oxygen isotope stage 5 [Popov, 1983; Geochronology, 1974]. The same applies to the last stage - the Great Khvalynian transgression. It falls on oxygen isotope stage 3. It is marked by the thoroughly studied Roxolany anomalous horizon (Odessa, Kerch, Taman, Karaja), absolute dating, and the Trans-Caucasian angular unconformity [Pilipenko et al. 2006, 2007a, b; Trubikhin and Pilipenko, 2015]. The results presented above are summarized in Table 1 . The following methods were used for dating: C^{14} [Dodonov et. al, 2000, 2001]; U/Th [Arslanov et al., 2002; Geochronology, 1974]; "Tracks" [Ganzey, 1984]; OSL [Pilipenko et al., 2006; 2007a, b]. Additionally, data from the following works were used in compiling the tables [Mörner et al., 2001; Paleolithic, 1984; Petrova et al., 1999; Pilipenko et al., 2005; Fedorov, 1963; Sharonova et al., 2004; Guyodo and Valet, 1999; Jonson, 1982; Tauxe and Shackleton, 1994].

Table 1.

5. CONCLUSIONS

1. The most complete and powerful Pleistocene section of the Paleocaspian - Karaja has been studied.
2. The main elements of the Pleistocene paleomagnetic scale have been established, which allowed, along with paleontological and absolute dating, to correlate the stratigraphic units of the Caspian scale with the corresponding units of the Black Sea region.
3. It turned out that these units are synchronous and, consequently, Caspian transgressions and regressions are glacioeustatic in nature and synchronous with fluctuations in the World Ocean level.

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Table 1. Comparison of Black Sea and Caspian glacioeustatic sea level fluctuations

Black Sea scale		IS stages	Caspian scale (Karaja)		
Anomalous horizon, date	Subdivisions		Subdivisions		Anomalous horizon, date
Roksolany C^{14} ~ 20–40 kyr	Surozh	No. 3 ~ 20–50 kyr	Khvalynian		Roksolany
Blake U/Th ~ 100–120 kyr	Karangat	No. 5 ~ 100–120 kyr	Upper Khazar (Hyrcanian)		Blake U/Th ~ 100 kyr
Biwa I U/Th ~ 160–180 kyr Jamaica OSL ~ 200–220 kyr	Uzunlar	No. 7 ~ 200–250 kyr	Lower Khazar	Kosog	Biwa I Jamaica
		No. 9 ~ 300 kyr		Singil	
Biwa III ~ 380 kyr	Ancient Euxinian	No. 11 ~ 400 kyr	Urundjik		Biwa III
	Chauda	No. 13 ~ 500 kyr	Baku	Upper	"Tracks" ~ 500 kyr
		No. 15 ~ 600 kyr		Lower	

Figure captions

Fig. 1. Geographic location of the Karaja section

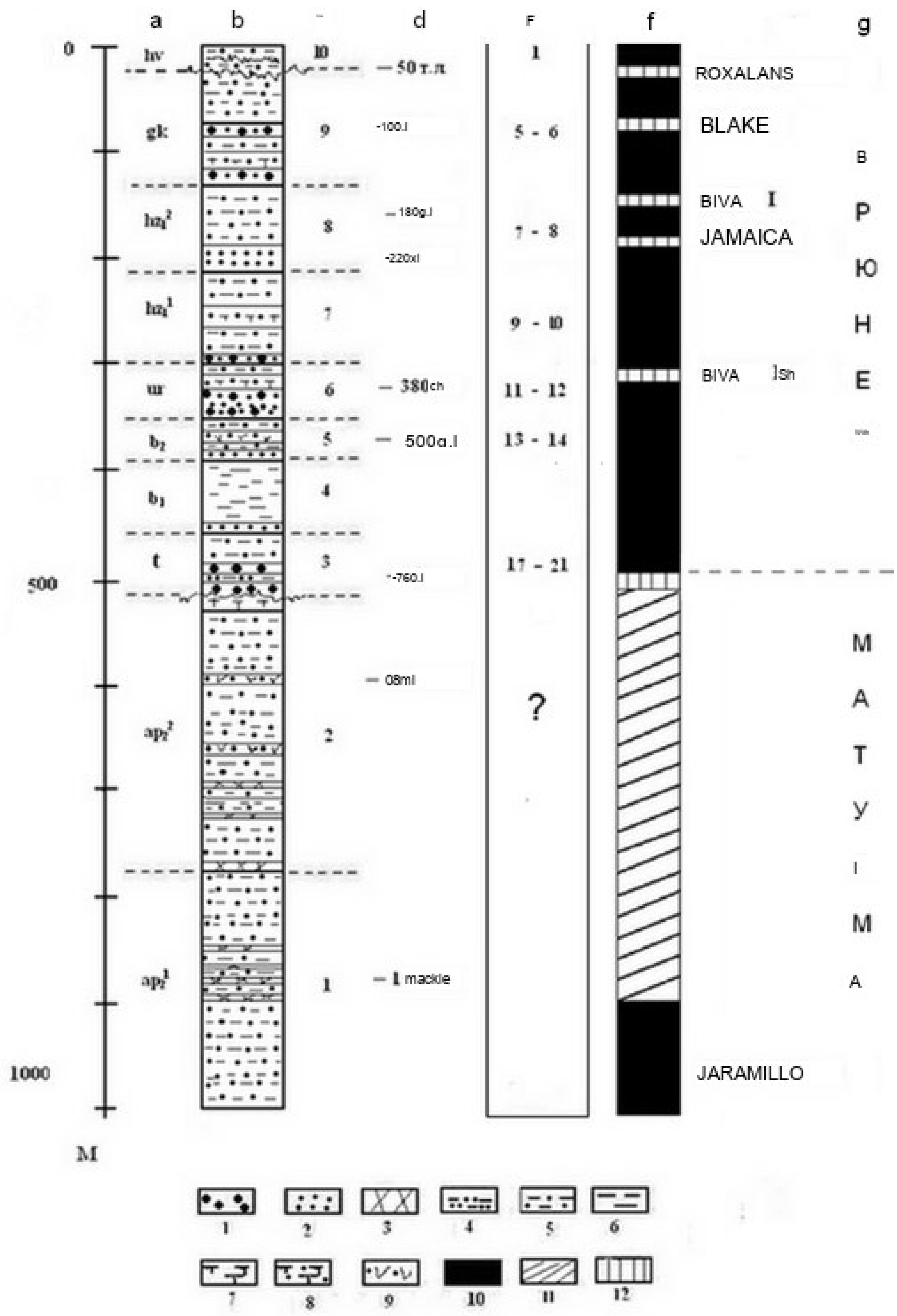
Fig. 2. Stratigraphic and lithological columns of the Karaja section:
a – stratigraphic column; *b* – lithological column; *c* – numbers of sedimentary complexes; *d* – approximate dates (radiological and paleomagnetic); *e* – IS stages; *g* – excursions (anomalous horizons), *f* – zones and horizon; 1 – pebbles and conglomerates; 2 – sands and sandstones; 3 – sandstones; 4 – sandy siltstones; 5 – siltstones; 6 – clays; 7 – calcareous clays; 8 – calcareous siltstones; 9 – volcanic ash; 10 – normal polarity; 11 – reversed polarity; 12 – anomalous polarity.

Fig. 3. (*a*) Right – Zijderveld diagrams.

On the left – curves of complete demagnetization of NRM (natural remanent magnetization) by alternating field. The y-axis represents the NRM value (100%). The x-axis represents the percentage of NRM remaining after demagnetization

(*b*) Curves of isothermal remanent magnetization in a constant magnetic field. The y-axis represents the SIRM (saturation isothermal remanent magnetization) value, taken as unity during stepwise magnetization in a constant magnetic field. The x-axis represents the magnetic field intensity *B* (*T*) [Pilipenko et al. 2009a, b].

Fig. 1.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-760.l
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Fig. 2.

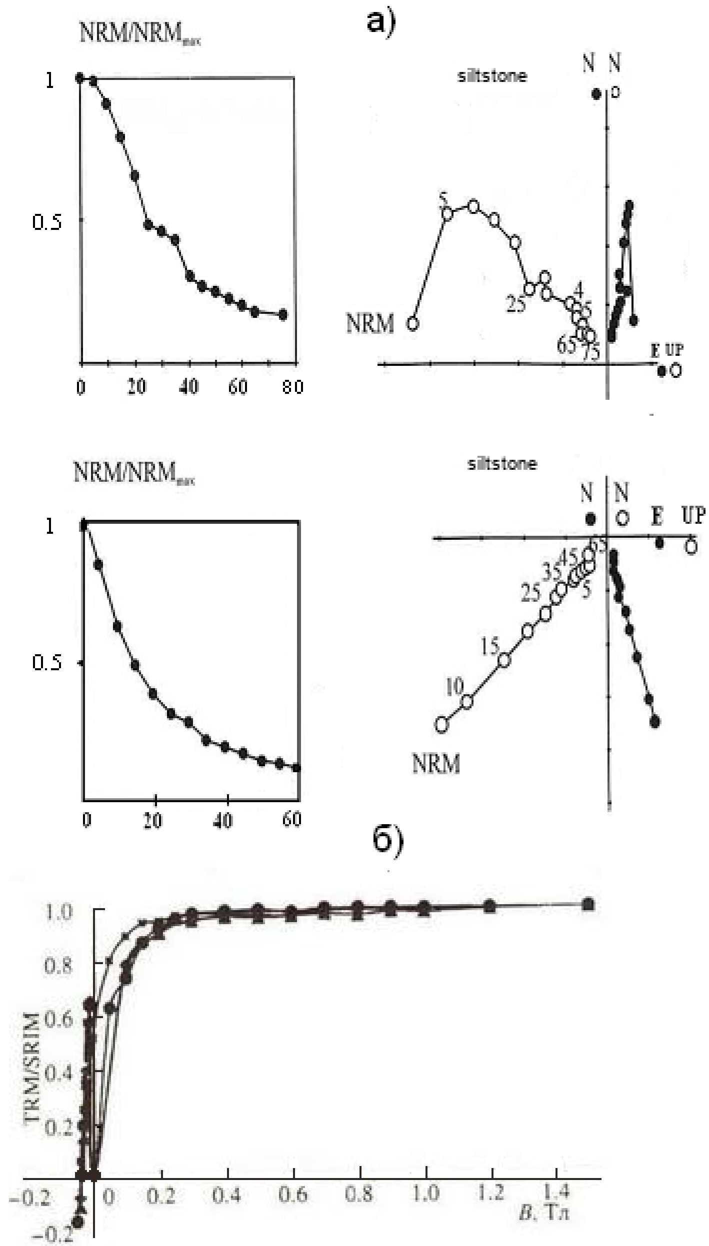
a)
NRM/NRM$_{max}$
1
0.5
0
20
40
60
80
siltstone
N N
NRM
5
25
65
75
E UP
NRM/NRM$_{max}$
1
0.5
0
20
40
60
siltstone
N N
E UP
NRM
10
15
25
35
45
5
б)
TRM/SRIM
1.0
0.8
0.6
0.4
0.2
-0.2
-0.2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
B, Тл

Fig. 3.