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Caspian-type dinocysts in NE Turkey mark deep inland invasion of the Akchagylian brackish-water basin during the terminal Late Pliocene

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ABSTRACT

The paper presents new data on brackish-water Upper Pliocene and Lower Pleistocene deposits that were studied in the Demirkent (Kars) and Pekecik (Erzurum) sections, NE Turkey. The Demirkent section is situated in the southwestern slope of the Shirak Late Cenozoic intermontane basin near the Turkish-Armenian border. The Pekecik section is situated to the SW of the Demirkent in the southwestern slope of the Horasan intermontane basin. Both sections are composed of clays, silts, and poorly cemented fine-grained sandstones and contain the brackish-water dinocysts of the Akchagylian type. The age of the deposits is determined by combined analysis of associations of molluscs and small mammals, palynological spectra, including dinocysts and algae, and magnetostratigraphic data. The Demirkent and Pekecik sections are dated to the Late Pliocene (Piacenzian). The maximum spread of the Akchagylian transgression influenced the inland areas of NE Turkey prior to the early Gelasian. The pollen spectra demonstrate progressive aridisation during sedimentation of the lower part of the Demirkent section and the wetter and cooler climate during sedimentation of the lower part of the Pekecik section. The analysis of brackish-water dinocysts and fresh-water algae in different beds of the Demirkent section indicates gradual freshening of the basin probably due to the sea level fall. In the Pekecik section, the brackish-water dinocysts are found in the lower part that is covered by the lignite-bearing layers without signs of marine influence. Recent altitudes of the Akchagylian brackish-water deposits give a possibility to estimate magnitudes and average rates of the Quaternary uplift of the western Lesser Caucasus. The elevation of the Upper Pliocene deposits of Demirkent and Pekecik sections shows the uplift rate of ca. 0.6–0.7 mm per year during 2.6 Ma.

1. Introduction

The Akchagylian (Piacenzian – early Gelasian) transgression was one of the largest hydrological events in inland Eurasia during the late Cenozoic. The transgression spread far off the present shoreline of the Caspian Sea. The Akchagylian marine (brackish-water) deposits reached up to the city of Saratov along the Volga River valley and up to southern Urals in the north. In the east they are known in south-western Turkmenia, and in the west the Akchagylian sediments occur in Lower Kura Basin in Azerbaijan and in Eastern Georgia, in the Lori Highland and the south-eastern Kakheti (Uznadze, 1965; Shatilova et al., 2011). The chronology of the Akchagylian regional stage of the Caspian region of Eastern Paratethys is traditionally bracketed between ca. 3.5 and 2 Ma (Trubikhin, 1977; Semenenko and Pevzner, 1979; Nevesskaya and Trubikhin, 1984; Nevesskaya et al., 2005). Although the recent radiometric data suggested a younger age estimates for early Akchagylian

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(van Baak et al., 2019), the position of the highest water stand is reliably dated at the Pliocene-Pleistocene transition (Krijgsman et al., 2019). During the maximum of the Akchagylian transgression its level could exceed 50–150 m above the present world sea level, and decreased down to the present sea level by the beginning of Calabrian, as it is deduced from (Popov et al., 2010; Krijgsman et al., 2019). A search of the Akchagylian marine deposits in Lesser Caucasus and Eastern Turkey has the particular interest because of two reasons. First, these deposits can mark a way of connection between the Caspian and Mediterranean and define the origin of the Akchagylian fauna. Second, recent altitudes of these deposits give a possibility to estimate the Quaternary uplift of the region and its average rate.

During the 2017 field works, the authors found the Upper Pliocene brackish-water deposits in the Demirkent section that is situated in the south-western side of the Late Cenozoic Shirak Basin (Trifonov et al., 2020). The new data were obtained by studies of this section in 2019 and the new site of the Akchagylian brackish-water deposits was found and studied near the village of Pekecik (spelled “Pe-ke-gic”) in NE Turkey in 2019 and 2020. The obtained new data are presented in this paper.

2. Methods

To obtain age models for deposits exposed in sections of Demirkent and Pekecik, we sampled the sequences for faunal remains, collected palynological and magneto-stratigraphic samples, and studied them in the lab.

The maceration of pollen samples was performed by the method adopted in the Geological Institute of the RAS, which is a modification of the Grichuk’s separation method (Grichuk and Zaklinskaya, 1948), namely, the samples were additionally treated by sodium pyrophosphate and hydrofluoric acid. Pollen diagrams were constructed in Tilia 1.5.12 program, which allows to calculate the general spectrum (arborescent pollen + nonarborescent pollen + spores = 100%) and individual components as a portion of the total amount of pollen grains.

We used the results of our previous magneto-stratigraphic data on the Demirkent section (Trifonov et al., 2020). The palaeomagnetic samples in the Pekecik section were manually taken and oriented using a magnetic compass. Samples from loose deposits were strengthened by a non-magnetic silicate glue. The local magnetic declination was calculated using the IGRF model. The palaeomagnetic procedures were performed in the Palaeomagnetic laboratory of the Institute of Physics of the Earth of the RAS. All the samples were subjected to the stepwise alternating field (AF) demagnetization up to 130 mT with the AF-demagnetizer inbuilt in the 2G Enterprises cryogenic magnetometer. The remanent magnetization of samples was measured using the 2G Enterprises cryogenic magnetometer “Khramov”. The isolation of the natural remanent magnetization (NRM) components was performed with Enkin’s (Enkin, 1994) palaeomagnetic software package using principal component analysis (Kirschvink, 1980).

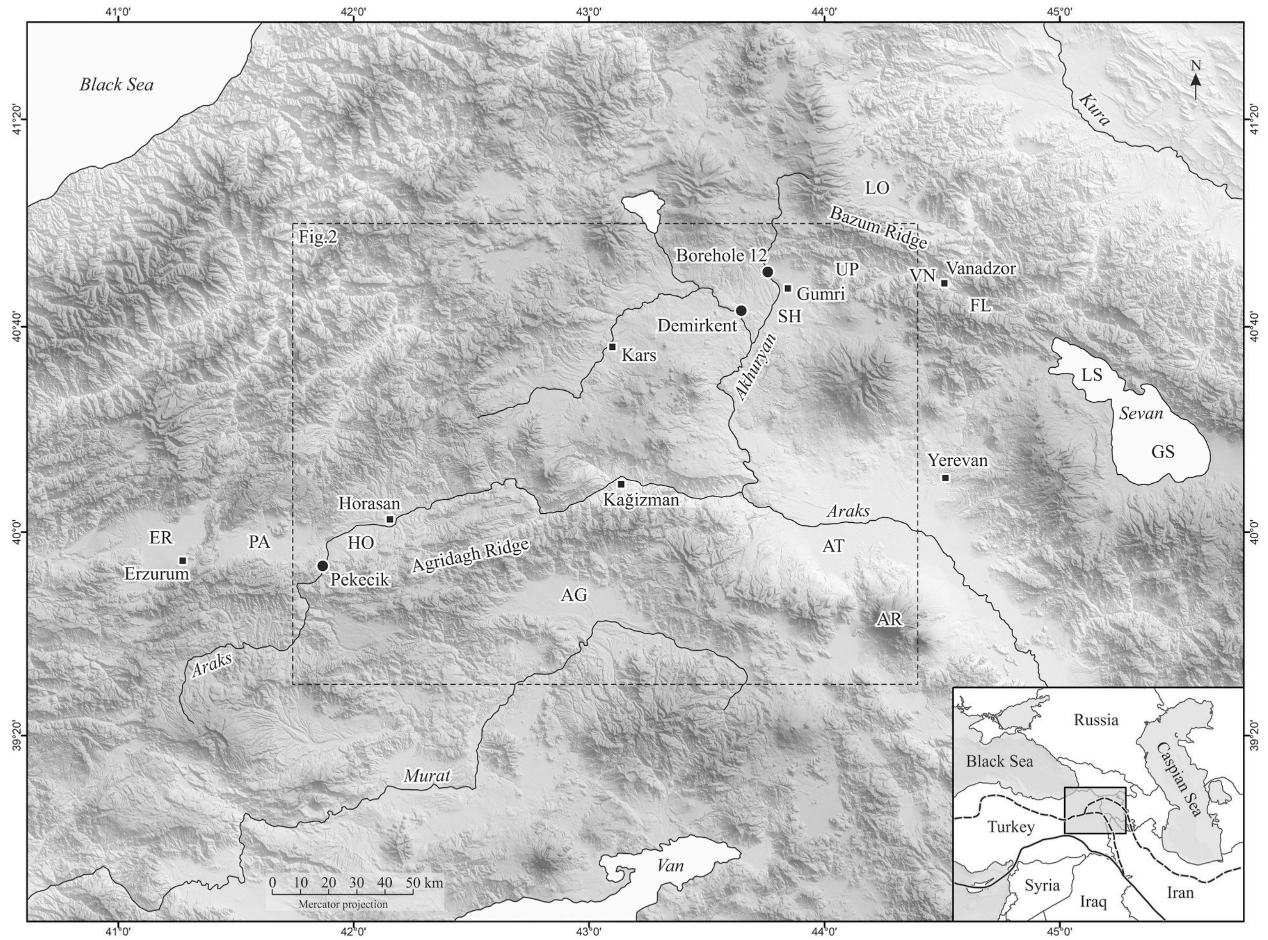

Fig. 1. Digital Elevation Model (DEM) of intermontane basins and their surroundings in NE Turkey and Armenia. Location of the Demirkent and Pekecik sections and the frame of Fig. 2 are shown. (AG) Agri Basin, (AR) Ararat Volcano, (AT) Ararat Basin, (ER) Erzurum Basin, (FL) Fioletovo Basin, (GS) Great Sevan Basin, (HO) Horasan Basin, (LO) Lori Basin, (LS) Lesser Sevan Basin, (PA) Pasinler Basin, (SH) Shirak Basin, (UP) Upper Pambak Basin, (VN) Vanadzor Basin. The Izmir–Ankara–Erzincan suture and its two eastern continuations are shown by dotted lines and the Neotethys suture is shown by solid line in the map fitted in the Fig. 1.

3. Geological setting

Two W–E-trending rows of the Late Cenozoic intermontane basins are situated in NE Turkey and Armenia (Fig. 1). The Shirak, Upper Pambak, Vanadzor, Fioletovo, Lesser and Great Sevan Basins represent the northern row. The Erzurum, Pasinler, Horasan and Ararat basins belong to the southern row. The Agridagh Ridge with the Late Quaternary Ararat volcano in the east borders the eastern Horasan and Ararat Basins to the south, and the W–E-trending Agri Basin is situated southward of the Agridagh.

The eastern continuations of the Izmir–Ankara–Erzincan ophiolite suture (Sengör and Yilmaz, 1981) control the structural position of the both rows of the basins. This suture bifurcates just to the west of the Erzurum Basin. Its northern branch is exposed in the north-western border of the Erzurum Basin and in the Bazum Ridge with the Neogene-Quaternary volcanic rocks occurring between these two sites. The Bazum ophiolites are traced intermittently along the northern coast of the Sevan Lake to the southeast up to the Araxes (Aras/Araks) River valley under the name of the Sevan-Hakari ophiolite zone (Knipper, 1975; Adamia et al., 2017). The island arc volcanic rocks were identified to the north of the ophiolite suture, in East Pontian (Turkey) and Somkheti-Karabakh (Georgia, Armenia, and Azerbaijan) zones (Okay and Sahintürk, 1997; Galoyan et al., 2018). Formation of the oceanic crust, represented by ophiolites, began in the Late Triassic, and the subduction began in the Bajocian and continued intermittently up to the Turonian-Campanian (Bagdasaryan and Gukasyan, 1985; Zakariadze et al., 1996; Knipper et al., 1997; Danelian et al., 2007; Galoyan et al., 2007, 2018; Rolland et al., 2010).

The southern extension of the Izmir–Ankara–Erzincan suture follows via the southern border of the Pasinler and Horasan Basins to the town of Kagizman (Fig. 2), where it turns to the south-east and runs along the south-western coast of the Urmieh Lake (Geological map of Turkey, 2002, sheets Erzurum, Kars and Van; Geological Map of Iran, sheet 1, 1978; Avagyan et al., 2017). It separates the Taurides and Iranian microplates and joins with the Neotethys suture. The latter strikes along the South Taurus (Bitlis) thrust zone in Turkey and continues along the Main Zagros thrust in Iran (Agard et al., 2005; Trifonov, 2016). The Neotethys suture is younger than the Izmir–Ankara–Erzincan and Sevan–Hakari sutures. The subduction began in the Taurus and Zagros in the Cretaceous, and the closure of the Neotethys relics and the beginning of the collision occurred at the Late Eocene–Oligocene (Akinci et al., 2016; Hessami et al., 2001).

The both rows of the Late Cenozoic basins are situated between two ophiolite zones extending the Izmir–Ankara–Erzincan suture to the east.

The Demirkent section is located in the south-western uplifted part of the Shirak Basin – N 40°42.897′; E 43°40.367′; H (the height a.s.l.) = 1570 m (Trifonov et al., 2020).

The Pekecik section is situated in the southern Horasan Basin drained by the Araxes River and its tributaries. The Araxes upper reaches are located in the south-western slope of the basin. The river flows to the north and turns down-stream to the east along the basin. The Pekecik site is situated in the N-trending upper segment of the Araxes valley to the west of the village of Pekecik – N 39°53.443'; E 41°51.672'; H = 1753 m. The Middle and Late Quaternary fluvial deposits compose the

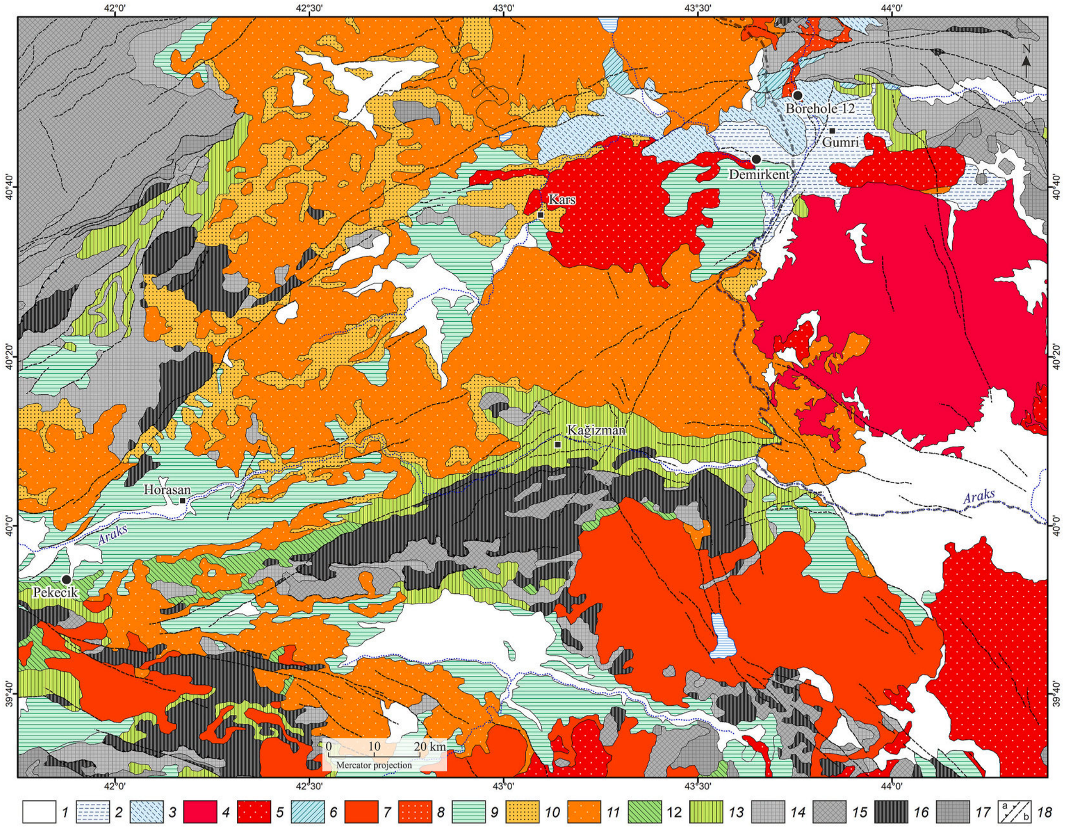

Fig. 2. Geological map of the Shirak, Horasan and the adjacent intermontane basins and their surroundings, after (Geological Map of Turkey, 2002, sheets Erzurum, Kars, Trabzon, and Van; Nalivkin, 1976; Trifonov et al., 2020), modified. (1) Fluvial deposits of the Middle Pleistocene to Holocene; (2) Arapi unit, the lower Middle Pleistocene; (3) Ani unit, the Calabrian; (4) volcanic rocks of the Aragats center (1.0–0.4 Ma); (5) volcanic rocks of the Calabrian and the lower Middle Pleistocene, including rocks of Mets-Sharailer Volcano (~0.9–0.5 Ma) and Arailer and Arteni Volcanoes (~1.35–1.0 Ma); (6) Karakhach unit (1.9–1.7 Ma); (7) Dacites, andesites, and trachyandesite of the upper Gelasian (~1.8–2.0 Ma); (8) basic lavas of the Gelasian (~2.0–2.3 Ma); (9) the Upper Pliocene deposits; (10) the Pliocene acid tuffs; (11) the Pliocene and possibly Messinian basic to acid volcanic rocks that can include the Lower Pleistocene lavas in the Akbaba and Kisir Highlands; (12) the Upper (?) Miocene volcanic rocks; (13) Paleogene (mainly Eocene); (14) Cretaceous; (15) Jurassic; (16) Mesozoic ophiolitic and ultrabasic rocks; (17) Paleozoic; (18) thrusts (a) and other faults and flexure-fault zones (b).

Araxes valley. The slopes of the valley are locally covered by the Lower Pleistocene (Calabrian) fluvial deposits. The Pliocene–Gelasian fine-grained clastic deposits are exposed in other parts of the basin.

The upper Miocene volcanic rocks bound the Horasan Basin to the north. The south-eastern border of the depression at the piedmont of the Agridagh Ridge bears the exposures of Middle-Upper Miocene terrigenous rocks and Lower Miocene evaporites. The ENE-trending fault separates Miocene deposits from the range where ophiolites are overthrust on Upper Cretaceous and Eocene terrigenous and carbonate deposits. In the south-west, the W–E-trending Agridagh Ridge slopes down, and a gentle sowneck separates the southern part of the Horasan depression from more south-eastern Agri depression. In this sowneck the flattened areas are composed of the Plio-Pleistocene sediments in combination with hilly occurrences of volcanic deposits. A weak NE-trending uplift bounds the Horasan depression from the west. This uplifted area is crossed by transverse faults and composed by Pliocene and in the south by Middle-Upper Miocene continental deposits.

4. Results

4.1. The Demirkent section

The 70-m thick Demirkent section was studied in 2017 (Trifonov et al., 2020). The section consists of clays, thin-bedded silts and fine-grained sandstones with interbeds of diatomaceous clay and silt (Fig. 3). In general, clays dominate in the lower part of the section and silt and sandstones are more abundant in its upper part. Palaeomagnetic samples (n = 49) that were collected from all layers of the section showed normal magnetic polarity. Data on palynology and normal magnetic polarity allowed the correlation of the sequence to the Upper Pliocene (Piacenzian). The eroded surface of the Upper Pliocene clayey-silty lacustrine deposits is covered by the 5–6-m thick fluviatile sequence (beds 1–4) that is represented by Gilbert-type progressive delta deposits with small-scale foresets. The dip direction of the foresets is to the east, indicating that in the area where this section is located, the basin is fed by rivers flowing from west to east. The gravel contains characteristic black obsidian pebbles.

4.1.1. Palynology

The preliminary study of four test samples from the lower 12 m of the section (clays, beds 10–14) surprisingly yielded spectra with characteristic marine dinoflagellates of Late Pliocene age that provided direct evidence of the deep inland influence of the Akchagylian transgression (Trifonov et al., 2020). Additional palynological sampling (13 samples) of a larger part of the Demirkent section (lower ~45 m) enables a more detailed palynostratigraphic model of the section. Four stages in the development of the basin and vegetation are documented by palynological data (Figs. 4 and 5). Palynological zones I-II reflect the vegetation during the formation of the lower clays (70–57 m from the top of the section, beds 14–10), palynozone III characterizes greyish brown clays and silts (52–46 m from the top, lower part of bed 9), and palynozone IV is confined to light silts (46–27 m from the top, upper part of bed 9 through bed 7).

Palynological zone I (samples 17–13) shows the dominant grass vegetation with Amaranthaceae, Asteraceae, Poaceae. Also occurs pollen of *Ephedr*a, Apiaceae, Fabaceae, and *Artemisia*. The arboreal group is dominated by pines. The conifers are represented by *Tsuga, Podocarpus, Cathaya, Picea, Cedrus*, and Taxodiaceae. The leaf trees are represented by sporadic pollen of Juglandaceae (*Carya, Juglans, Engelhardtia*, Betulaceae, *Fagus, Quercus, Carpinus*). The altitudinal zonation possibly existed in this time. The higher elevations were characterised by conifer forests with *Tsuga, Podocarpus*, *Cathaya, Picea,* and *Cedrus*, and the lower belts were covered by mixed forests with *Pinus,* Juglandaceae, *Quercus,* and *Carpinus*. The low elevations were covered by meadow-steppe vegetation. The arid climate is restored for this time. Here we also detect the occurrence of brackish-water dinocysts *Caspidinium rugosum* Marret (2004) type I and II, *Spiniferites ramosus* (Ehrenberg) Mantell, 1854, cf. *Impagidinium inaequalis* (Wall et Dale in Wall et al., 1973), cf. *Pontiadinium*, *Ataxiodinium* cf. *confusum* (Versteegh and Zevenboom, 1995), and fresh-water algae *Pediastrum, Botryococcus, Spirogyra,* and *Planctonites* that can bear brackish conditions.

Palynological zone II (samples 12–9) documents decreasing variability of conifers (sporadic records of *Pinus, Tsuga, Picea*). Broad-leaved trees are represented by *Carya, Juglans, Pterocarya,* and *Ulmus.* The grass group is dominated by pollen of Amaranthaceae and Poaceae. The share of Asteraceae is decreasing. The vegetation gains arid appearance with dominant open steppe coenoses. The climate grows cooler and more arid. The diversity of dinocysts decreases with only occurring *Caspidinium rugosum* type I and *Pontiadinium.*

Palynological zone III (samples 8–4) is characterised by spectra with decreasing diversity of trees. The spectra are dominated by Asteraceae and Amaranthaceae. Steppe and possibly semi-desert landscapes were widespread. The number of dinocysts is gradually decreasing. Represented forms include *Caspidinium rugosum* type I, and sporadic *Spiniferites ramosus* and *Spiniferites pannonicus* Sütő-Szentai, 1986. The share of freshwater algae Zygnemantaceae is increasing. Freshwater diatoms appear and their number increases up the section indicating a gradual strong freshening of the water basin.

Palynological zone IV (samples 3–1) shows a slight increase in the arboreal pollen mostly accounting for the pollen of pine. Single grains of *Tsuga, Abies, Picea, Betula, Alnus,* and *Quercus* occur here too. A notable increase in spores of *Botryococcus* is detected. No dinocysts were found. The water basin completely converts to the fresh-water mode. The plant communities are dominated by semi-desert vegetation. Mountain areas are covered by conifer forests.

In summary, the palynological data from Demirkent document a gradual evolution of the water basin from brackish-water conditions in the lower clayey part, characterised by Caspian-type dinocysts, into fresh-water conditions indicated by increasing numbers of freshwater algae up the section and occurrence of sporadic frustules of diatoms in the upper part of the studied sequence. The land vegetation gradually evolved from forest-steppe into steppe landscapes under conditions of progressing climatic aridisation.

4.1.2. Diatoms

Diatom algae were studied from the single level in the upper part of palynological zone III (47 m, palynological sample 13) to characterise the environmental conditions of the basin at the very end of its brackish-water stage. The association is dominated by mainly freshwater and freshwater to brackish-water benthic and epiphytic forms *Cymbella* sp., *Amphora* sp., *Hantzschia* sp., *Epithemia* sp., *Cocconeis* sp., *Nitzschia* sp., *Rhopalodia* sp., *Navicula* sp., *Pinnularia* sp., *Fragilaria* sp., *Staurosirella* sp., *Opephora* sp., and *Synedra* sp. Planktonic and plankto-benthic forms, *Ellerbekia* sp. and *Cyclotella* sp., are much less common. This combination of taxa indicates a shallow water basin densely overgrown with aquatic vegetation. The basin was strongly freshened with the salinity not exceeding 3–4‰.

4.1.3. Molluscs, small mammals, archaeology

Basic information of the molluscs, vertebrates and archaeology are given by Trifonov et al. (2020). The Demirkent sequence (beds 14–6) yields frequent shells of *Dreissena* concentrated in several shell beds. Especially abundant they are in the upper silty part of the section (bed 6). Here they locally form mass accumulations in a greenish silty matrix, often preserved with paired valves. Smaller, thin-shelled *Dreissena* from the lower part of the section markedly differ from the very large forms occurring in the upper, fluvial part of the section. Monospecific *Dreissena* assemblages of the lower part of Demirkent section indicate brackish and fresh-water lacustrine conditions of its accumulation. Bed 5 near the top of the fine-grained deposits yielded a relatively diverse assemblage of fresh-water gastropods and bivalves indicating conditions of a fresh-water lake.

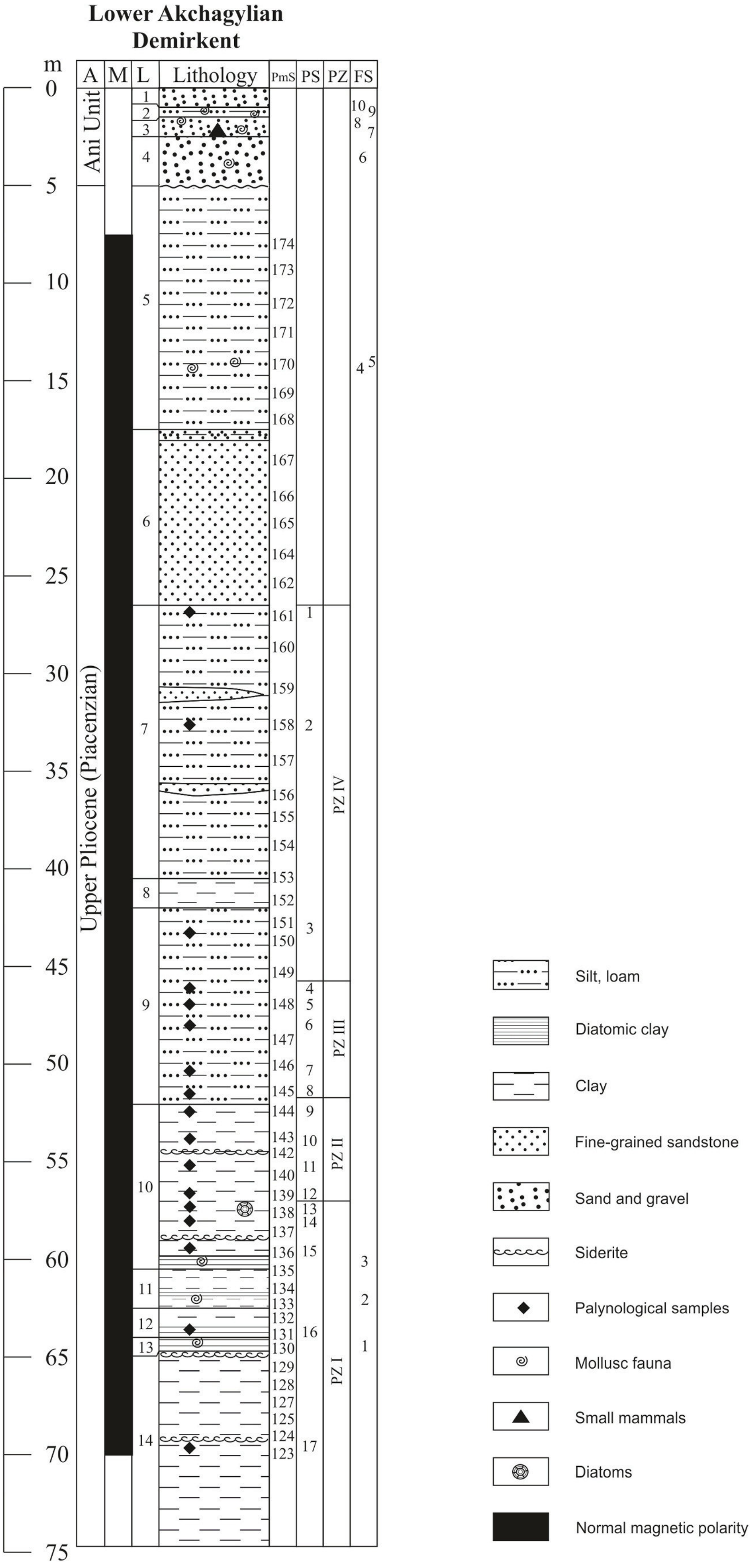

Fig. 3. Stratigraphic column of the Demirkent section. (A) Age, (M) magnetic polarity, (L) bed, (SM) number of palaeomagnetic sample, (SP) number of pollen sample, (PZ) palynological zone.

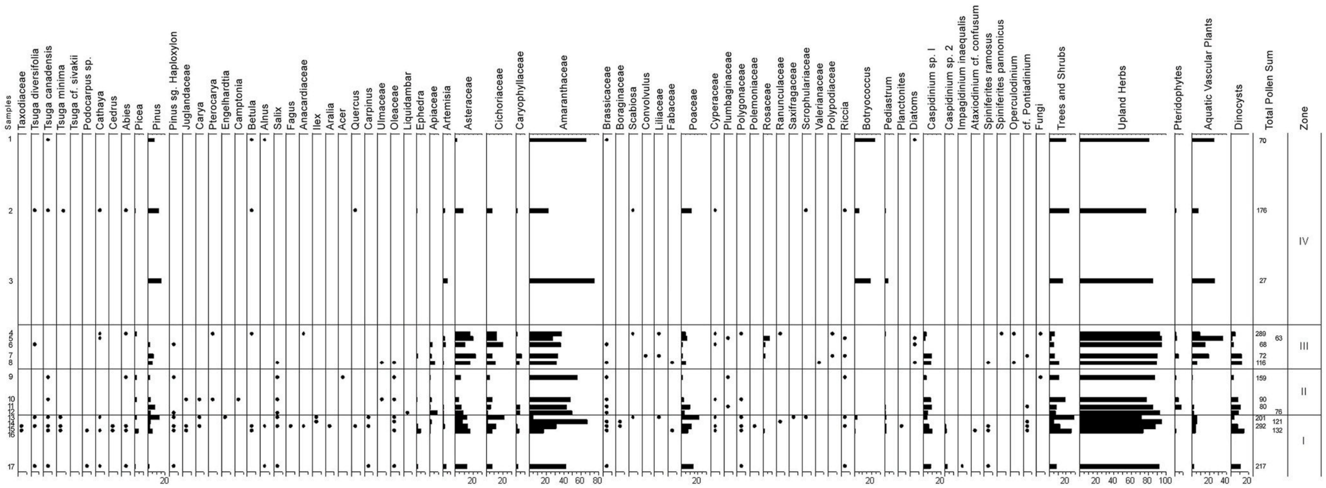

Fig. 4. Pollen diagram for the lower part of the Demirkent section.

The upper fluvial part of the section (beds 1–4) yielded an assemblage of freshwater gastropods and bivalves belonging to Hydrobiidae (*Falsipyrgula* cf. *sieversi* (Boettger, 1881), *F.* cf. *bakhtarana* (Schütt et Mansoorian, 1999)), Valvatidae, Planorbidae, Pisidiidae. *Dreissena* sp. The assemblage is similar to molluscan faunas of the Calabrian age (Ani unit) in eastern Turkey and western Armenia (Vasilyan et al., 2014; Tesakov et al., 2019).

The scarce small mammal assemblage from the upper part of the section (beds 3–4) contains *Prolagurus* cf. *pannonicus* (Kormos, 1930), Microtini cf. *Allophaiomys* sp., cf. *Ellobius* sp. These forms indicate the age of the late Early Pleistocene and the important role of open biotopes. E.V. Belyaeva found two flint tools, the side scraper and chisel-ended tool in the gravel (Trifonov et al., 2020). Based on all these data, the covering fluviatile deposits of Demirkent were correlated to the Ani unit of the mid-late Calabrian, Early Pleistocene age.

4.2. *The Pekecik section*

The stratigraphy of the Pasinler Cenozoic sedimentary basin was briefly reviewed by Irrlitz (1972). He attributed the basin infill at the southern rim of the basin to 500 m thick Pekecik Beds unconformably resting on ultrabasic rocks and grading from reddish conglomerates and green tuffites in the lower part to fine-grained lacustrine grey silts in the upper part of the section. Irrlitz noted the considerable uplift of the deposits dipping to the north and submerging beneath the younger Plio-Pleistocene sediments towards the basin centre.

The Pekecik area is also known by the former lignite mine occurring in the silty basin deposits to the west of the eponymous village. Ünay and de Bruijn (1998) described a small mammal fauna from three sample sites of about the same level in the mollusc-bearing grey mudstones associated with lignite in the mine. They referred the deposits to the Yolüstü Formation. The fauna with *Clethrionomys* sp., *Mimomys pliocaenicus* (Forsyth Major, 1902) and *Borsodia* sp. was dated to early Late Villanyian, i.e., the earliest Pleistocene in the modern usage. The lacustrine Yolüstü Formation was defined in more southern Hınıs Basin and dated to Pliocene and correlated to Late Miocene through Quaternary basin deposits of Eastern Turkey (Tarhan, 1991). The Erzurum sheet of 1:500000 geological map of Turkey (Geological Map. . ., 2002) mapped the deposits near Pekecik to undifferentiated clastic rocks of Late Miocene–Pliocene.

We studied sections of Pekecik 1 and 2 situated in ca. 600–1000 m to the W from the village of Pekecik. The Pekecik 1 section is described along the gully running from SW to NE. The Pekecik 2 section is described along the W–E-trending gully situated northward of the Pekecik 1, and on the slope and the top of the ridge extending NW from the gullies. The smaller Pekecik 3 section was studied in a gully ca. 500 m to NE from the Derebaşı village (Fig. 6). The sequences are described upsection.

Pekecik 1 section is divided into two units (Fig. 7).

Unit 1. Unit 1 is exposed in the upper part of the gully. It shows frequent alternation of differently grained deposits with several zones of different magnetic polarity. This unit consists of layers 1–3. The deposits dip to the NNW 350° with the angle 41°.

Conglomerates underlie at the base of the main part of the section with 10° angular unconformity (angle 51°).

1 1. The 5.5 m thick alternation of gravelites, sands, and partly ferruginous sandstones (N magnetic polarity in samples 17–25).

The 10 m thick unexposed interval.

2 2. The 0.5-m layer of brown lignite with mollusc shells at the base. Grey siltstones and sandstones; thickness is ca. 2.3 m. R magnetic polarity in samples 26–30.

The 4 m thick unexposed interval.

3 3. The 2 m thick alternation of loams, silts, sandstones, and gravelites. Two lower samples show N polarity and the last one (sample 34) shows R polarity.

Unit 2. The unit 2 deposits are exposed in the right bank of the gully and dip to the NNE 345° with the angle 17° (H28 in Fig. 7). The reason for the allocation of unit 2 is the finer character of the deposits (mostly siltstones, clays) and their stable N magnetic polarity.

The 5 m thick unexposed interval at the base. The thickness of gaps is calculated using dips of under- and overlying deposits.

1. Grey compact clay with rare gravel size clastic grains; thickness is 2.4 m.
2. Grey ferruginate sandy silt with pebbles of volcanic rocks up to 4–5 cm; thickness is 0.2 m. Fragments of shells of fresh-water molluscs.
3. Grey silts and sandy loam; thickness is 4 m. A layer enriched in shells of large thick-walled dreissenids in 0.8–1.0 m from the base and rarer fragments of shells above it.

The 15 m of unexposed thickness.

4. The ca. 2 m thick fine-grained upper part of the section is exposed in the left land-slided bank of the gully (H27 in Fig. 7) immediately above the technological levelled platform of the former mine. Here we

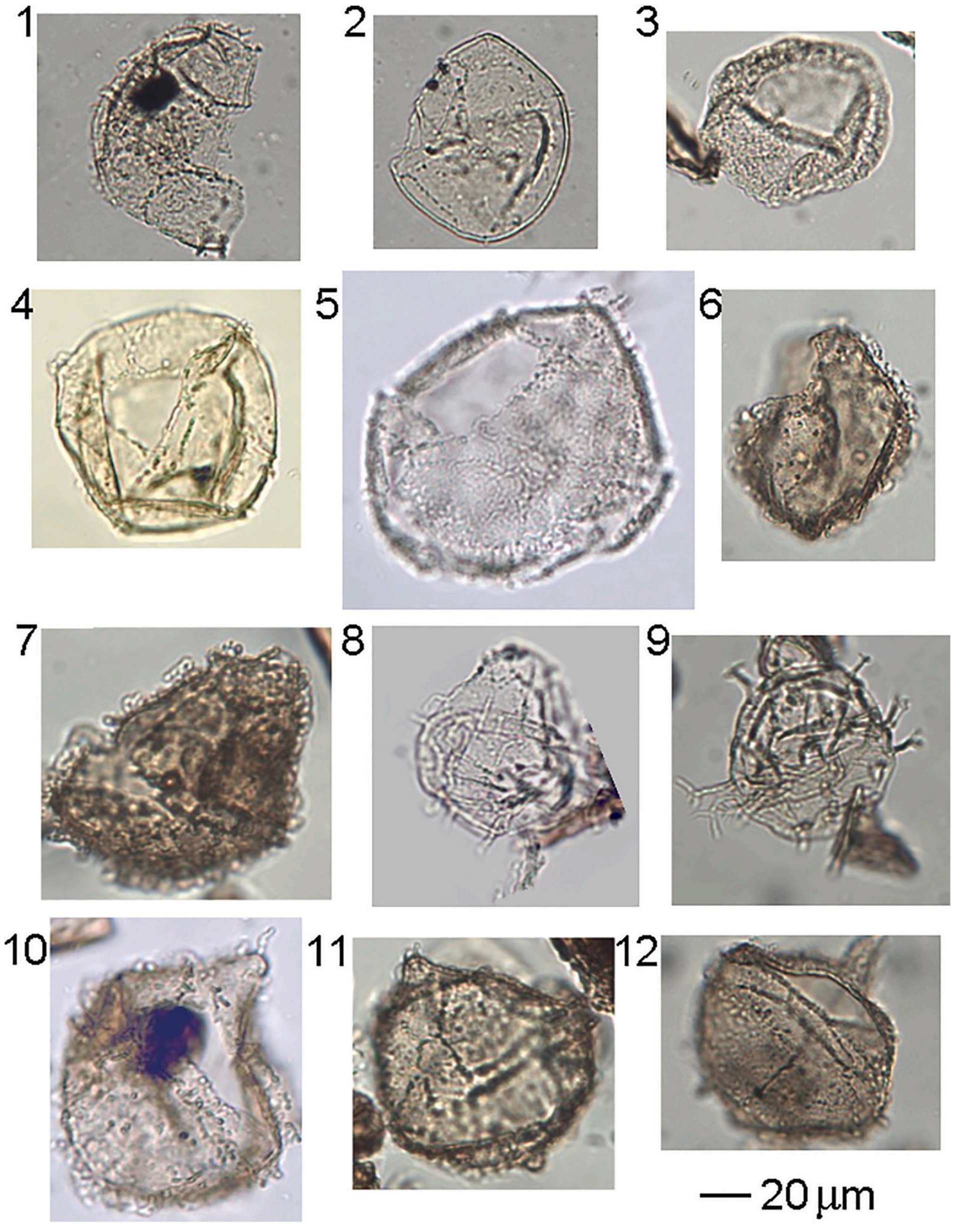

Fig. 5. Cysts of late Pliocene brackish-water dinoflagellates (1–12) from beds 9–14 of the Demirkent section: 1–5. *Caspidinium* sp. type 1; 6, 7. *Caspidinium* sp. type 2; 8. cf. *Impagidinium inaequalis* (Wall et Dale in Wall et al., 1973); 9. *Spiniferites ramosus* () ; 10–12. cf. *Pontiadinium* sp.

sampled light grey marly silt and sand with shells of molluscs and fish bones and lignite-bearing deposits processed in the adjacent former mine (palynological sample 2*).

The total thickness of Unit 2 in the Pekecik 1 section, considering the gaps, is 53 m.

Pekecik 2 section is divided into three units.

Unit 2. The lower part of the section was described from W (N39°53′38.1″ E41°51′29.8″ h = 1769 m) to E (N39°53′35.8″ E41°51′44.4″ h = 1715 m) down to the mouth of the Pekecik 2 gully (Fig. 6). The main part of the Pekecik 2 section is stratigraphically higher than Pekecik 1 section. We consider that the lower part of the section Pekecik 2, which was described in the gully, is a continuation of the Unit 2 of Pekecik 1 section and has N magnetic polarity (Fig. 7).

1. The 0.7 m thick silt.
2. The 2.4 m thick massive grey sandstone with the traces of wave ripples. It dips to ENE 73° with the angle 13° that is close to the average dipping in the described section (azimuth 70°, angle 13°).
3. The 2 m of grey silts with several layers rich in mollusc shells.

   The 1 m thick break of exposition because of landslides.

4. The 4 m thick grey clay with a lignite layer in the base. Several pollen and faunal samples were taken here. Possibly this layer corresponds to the layer 4 of the Unit 2 of the Pekecik 1 section. A fragment of an elephant tusk (cf. *Archidiskodon meridionalis* ()) was found in the lignite layer at this level (Fig. 7).
5. The 6 m thick grey silts with clay interbeds in the upper part.
6. The 0.5 m thick sands and the 0.5 m thick gravels.
7. The 3.2 m thick grey silts and clays with a layer of lignite inside. Several pollen samples and samples of fauna were collected here.
8 The 1 m thick siltstones and sandstones.

Total thickness of the Unit 2 deposits in the Pekecik 2 gully considering the gap of the closed part of section is 21.3 m. Thus the thickness of the unit 2 in the Pekecik 2 gully builds up by 15 m.

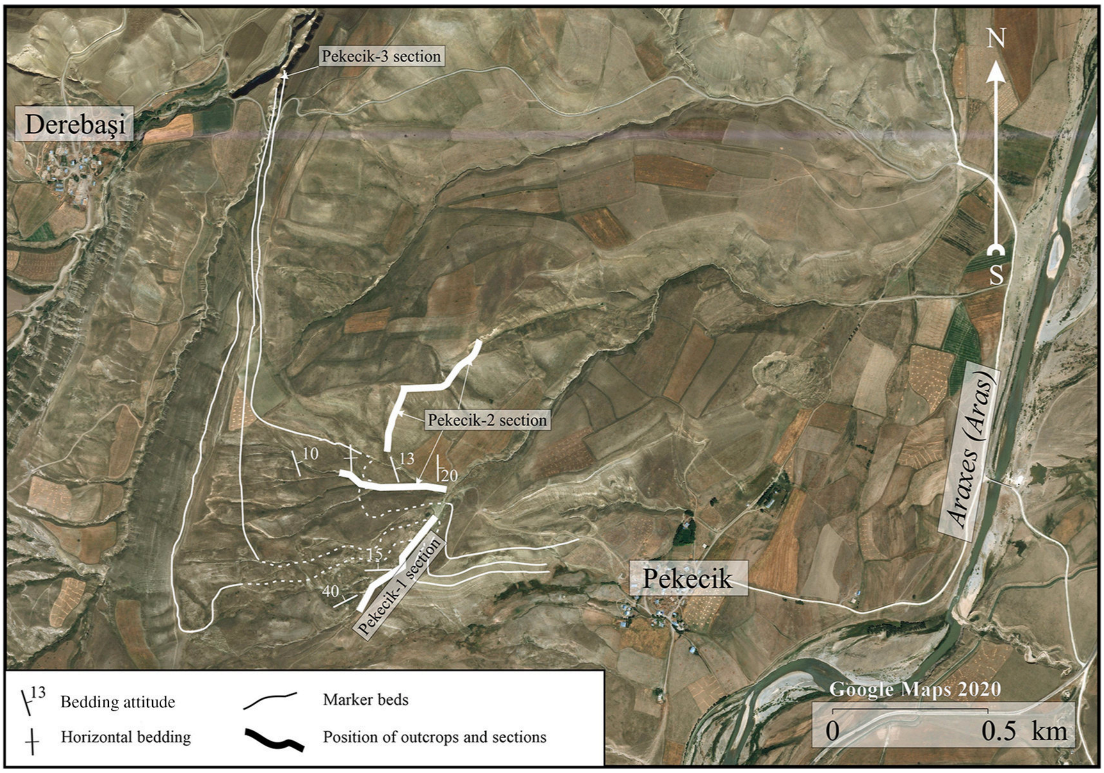

Fig. 6. Position of the Pekecik section in the southern part of the Horasan Basin.

Unit 3. The section is exposed above Unit 2 on the slope and the top of the ridge extending NW from the ravines with Pekecik 1 and 2 sections. The sediments are fine-grained and monotonous with predominant light grey silts.

1. The 12 m thick poorly exposed grey silts.
2. The 1.7 m thick grey silts and clays with R magnetic polarity.
3. The 0.5 m thick sand with N magnetic polarity in sample 68.
4. The 27 m poorly exposed grey silts.
5. Sample 70 from a small outcrop of grey silts show N magnetic polarity.
6. The 24 m poorly exposed grey silts.

Unit 4. The section is composed of generally more coarse-grained deposits with frequent changes in the character of sedimentation. All samples show N magnetic polarity.

1. The 0.5 m thick gravelites.
2. The 3 m thick grey locally ferruginous sands.
3. The 1.3 m thick clayey silts with lignite layer inside. A rodent tooth and samples of molluscan fauna were collected here.
4. The 0.6 m thick gravel.
5. The 5.4 m thick sands and silts with mollusc fauna and two layers of lignite.

Pekecik 3 section (N 39° 53.629: E 041°51.553; h = 1748 m) is a fragment of an extensive section exposed in the eastern bank of a valley situated westward of the Pekecik 2 section, in some 0.5 km to NE from Derebaşı village (upsection) (Fig. 6):

1. Green clay; 0.6 m (visible).

2 Brownish-grey sand; 1 m.
Gap, 2 m.

3. Brown sandstone; 0.8 m.
4. Silty marl, 0.3 m.
5. Grey and light brown silt with molluscs in the lower part of the layer; 1.8 m. Palynological sample 12 (with dinocysts).
6. Interbedding of black lignite and grey clay; 1 m.

The layer 5 of the Pekecik 3 section is correlated to the layer 3 of the unit 2 of the Pekecik 1 section.

4.2.1. Palaeomagnetism

The total of 58 palaeomagnetic samples yielded clear palaeomagnetic signals. The example of demagnetization diagrams are shown in Fig. 8. The majority of palaeomagnetic samples taken from the Pekecik 1 and the Pekecik 2 sections (Fig. 7) show normal polarity. We have found only two short intervals with R polarity.

The first reversed interval we can see in the middle part of the unit 1 of the Pekecik 1 section (samples #26–30). The lower part of the unit 1 in the Peketik 1 (samples #17–25) shows N polarity, the upper part turns back to R polarity again except one sample #34.

Sediments of the unit 2 in both sections were accumulated in conditions of normal polarity as we can see in the results of the analyses. All the samples have N polarity.

The rocks of unit 3 are poorly exposed. Only two short outcrops were sampled so we have no palaeomagnetic characteristic of the whole unit. The first well exposed interval has mainly R polarity (three samples of four). The second interval is characterized only by a single sample with N polarity. It is similar to the upper sample from the previous outcrop.

The unit 4 of the Pekecik 2 section is characterized with N polarity with all samples showing the same results.

Rock-magnetic properties. Thermomagnetic analysis shows the predominance of magnetite with Curie temperatures of about 580–600 °C as the main magnetic mineral in the studied samples from all parts of the section (Fig. 9A–C). Some amount of hematite or paramagnetic tails after 650 °C are identified on thermal curves of magnetic susceptibility as well. At cooling curves, many samples demonstrate the increasing of bulk magnetic susceptibility values, due to mineral transformations. However, no differences between samples with distinct types of

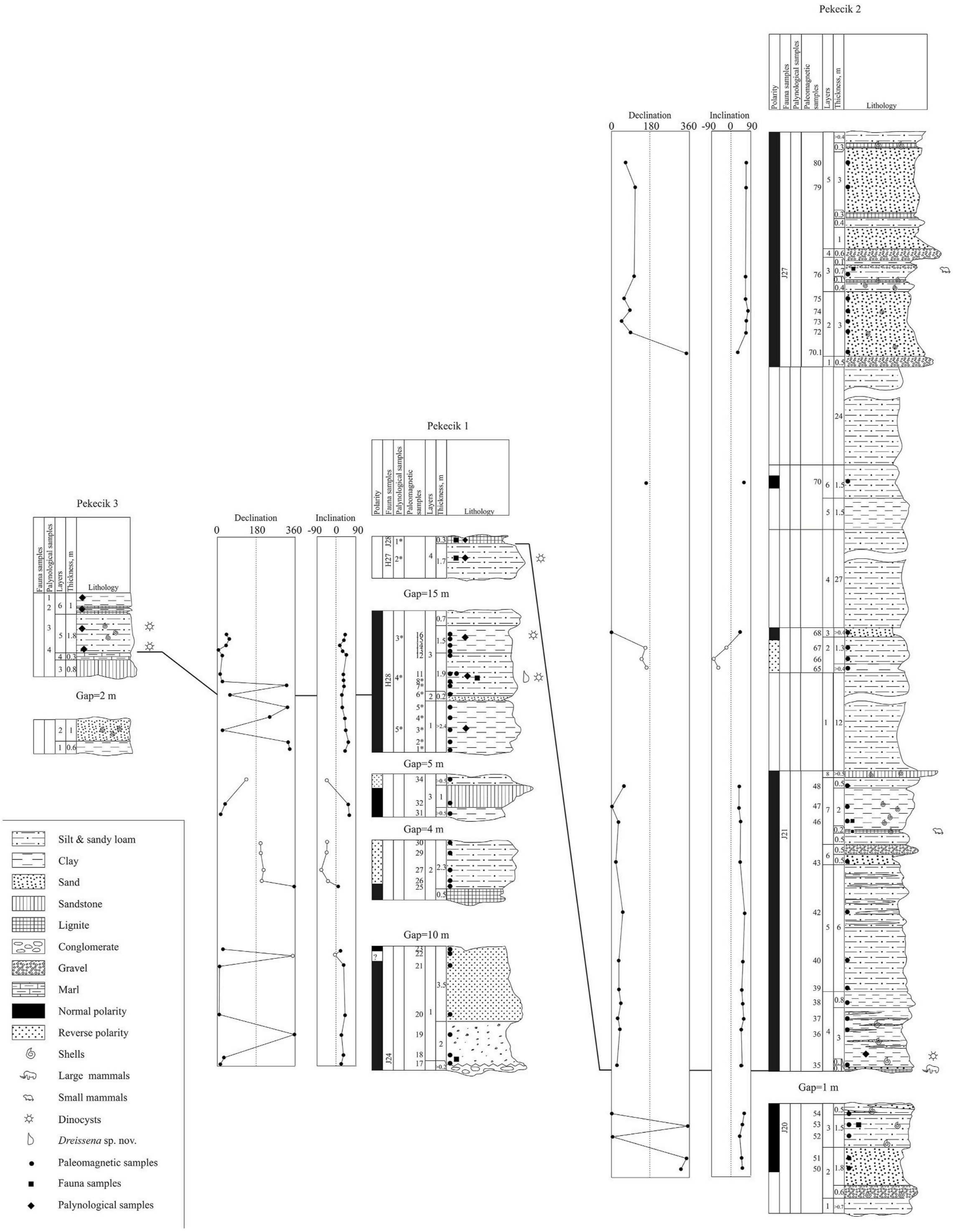

Fig. 7. Stratigraphic columns of the Pekecik section.

palaeomagnetic signal were found.

Hysteresis parameters Mrs/Ms and Hcr/Hc vary in the ranges of 0.13–0.28 and 2.56–3.57, respectively. On the Day-Dunlop plot (Day et al., 1977; Dunlop, 2002) samples of both normal and reversed polarity are located in the field of pseudo-singledomain grains of magnetite and titanomagnetite (Fig. 9D).

Correlation to standard Magnetic Polarity Time Scale. The results of the palaeomagnetic analyses show that all the units of the Pekecik section have stable normal polarity except for two short reversed intervals. Combined palaeomagnetic and biostratigraphic data suggest the correlation of the sediments of the Pekecik sections to the Gauss Chron (C2An), Late Pliocene, Piacenzian.

4.2.2. *Palynology*

Palynomorphs were obtained from 5 samples of the Pekecik 1 (Fig. 10a) section, from 4 samples from the Pekecik 3 sections (Fig. 10b), and from a single sample in Pekecik 2 section. Sampling locations are shown in Fig. 7.

In the diagram of Pekecik 1, the sample 5 shows a significant amount of pollen of grasses (91%) with dominant Asteraceae, Cichoriaceae, and

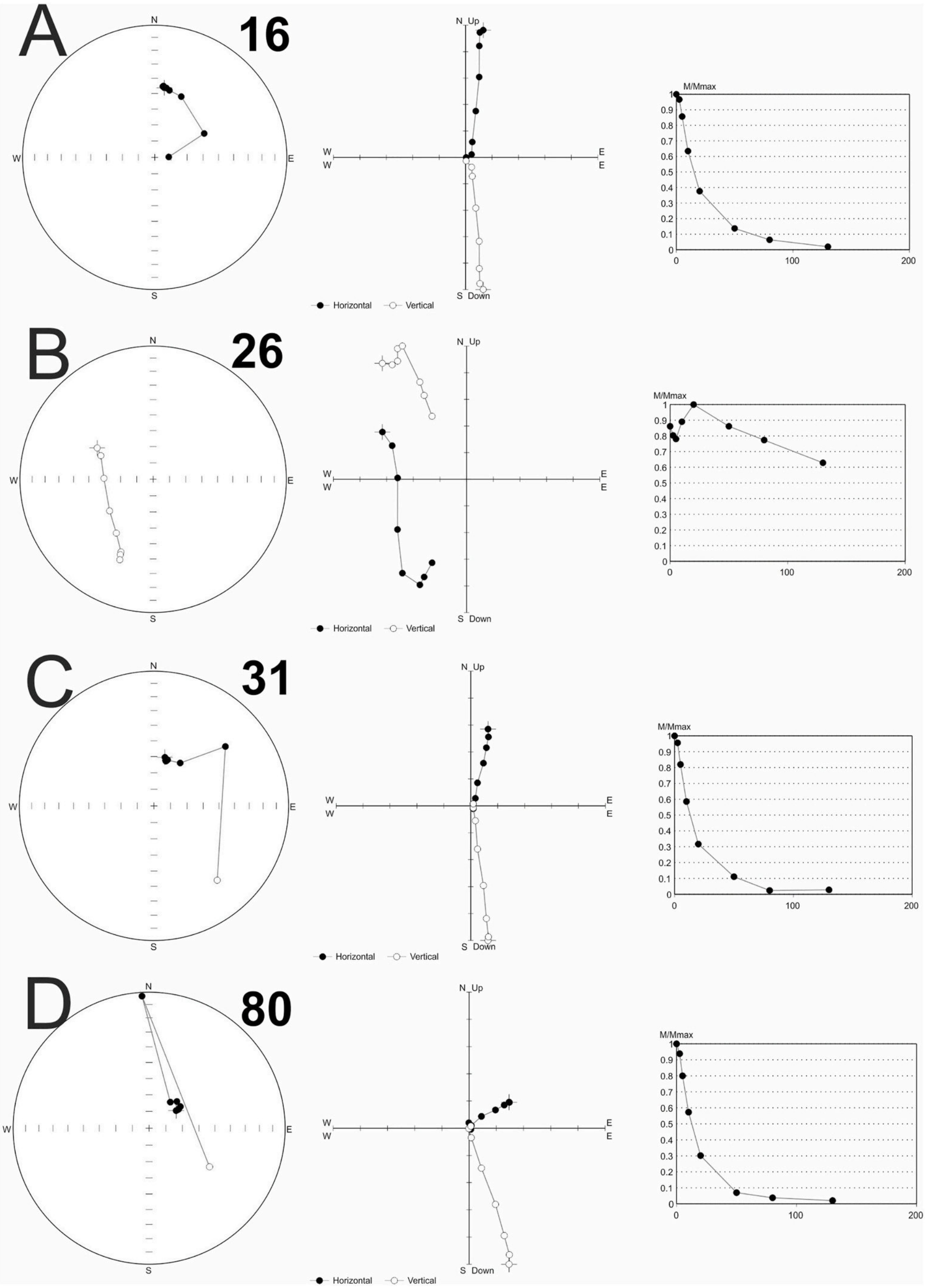

Fig. 8. Results of the palaeomagnetic investigation. A–D: Representative stereoplot, orthogonal plot and demagnetization path (samples 16, 26, 31, 80). Stratigraphic coordinate system.

Poaceae. Trees are represented by *Pinus* and *Alnus*. Sporadic spores of *Botryococcus* are present. The detected considerable expansion of meadow vegetation likely indicates an arid climatic interval.

Palynological spectra of samples 4 and 3 document increasing abundance and diversity of coniferous trees *Pinus*, *Abies*, and *Picea*. Other conifers are represented by *Tsuga canadensis, Tsuga minima, Podocarpus* sp., *Cathaya*, and Taxodiaceae. Grasses are dominated by Asteraceae, Amaranthaceae, and Poaceae. During this time, the forest vegetation expanded in the mountains. Steppe landscapes were widespread at lower elevations and in the foothills. The climate became wetter and cooler. The spectra contain spores of algae *Pediastrum*, *Botryococcus*, *Spirogyra*, Zygnemantaceae, and *Pseudoschizaea* (Fig. 11:1–5).

The sample 2 shows high content of pollen of grasses (65%): Asteraceae, Poaceae, Amaranthaceae, *Artemisia*, and *Ephedra*. Relatively high level of spores of fresh-water algae is mainly due to *Pediastrum*. This assemblage indicates expanding ranges of meadow-steppe plant associations under conditions of aridization.

Samples 4, 3, 2 document the presence of a dinocyst association with *Caspidinium rugosum* type I, *Spiniferites* sp., *Pontiadinium* sp., *Ataxiodinium* sp., *Achomosphaera* sp. *Algidasphaeridium* cf. *capillatum* Matsuoka et Bujak, 1988, *Polysphaeridium* sp. (Fig. 12), which clearly indicates the origin of the enclosing sediments in a brackish-water marine basin.

The sample 1 (lignite) contains pollen of riparian vegetation (*Sparganium*, *Typha*) and high content of spores of fresh-water algae *Spirogyra*

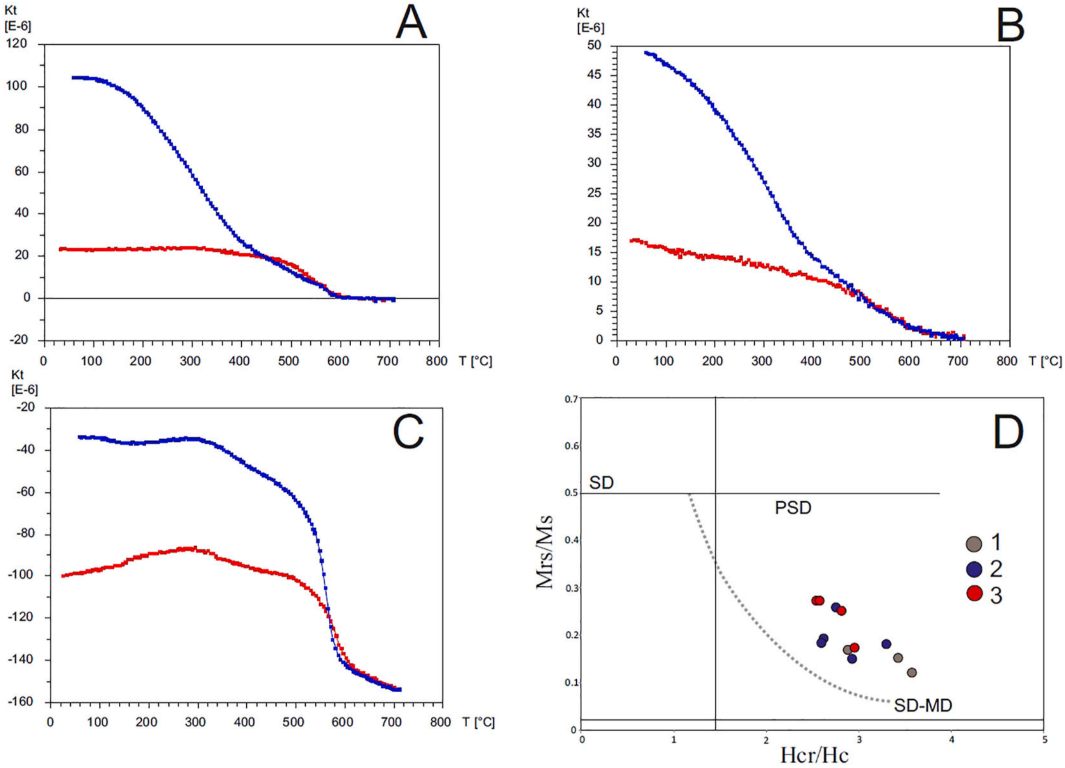

Fig. 9. A—C. Typical thermomagnetic curves of the magnetic susceptibility; red curve – heating; blue curve – cooling; T – temperature, K – magnetic susceptibility; A – sample 42, N polarity; B – sample 65, R polarity; C – sample 80, N polarity. D – Day-Dunlop plot. SD – single-domain area, PSD – pseudo-singledomain area; SD-MD – mixing curve of single-domain and multidomain grains shown after (Dunlop, 2002). Ms – saturation magnetization, Mrs – remanent magnetization; Hc – coercive force; Hcr – remanent coercive force. 1 – normal polarity, lower part of the section; 2 – normal polarity; upper part of the section; 3 – reversed polarity.

and Zygnemantaceae. *Ephedra* and dinocysts are absent. The climate was moderately cool.

All samples from Pekecik 1 (except sample 1 from lignite) yielded rare reworked pollen grains and dinocysts of Late Cretaceous age (Fig. 11: 6–10): *Extrapollis* sp., *Trudopollis* sp., *Pilosisporites* sp., *Systematophora* sp., *Heterosphaeridium cordiforme* Yun, 1981 (Zaklinskaya, 1963; Yun, 1981; Braman, 2001).

In the section Pekecik 3 (Fig. 10b), the lower sample 4 documents a significant amount of grass pollen (61%) with prevailing Asteraceae, Amaranthaceae, and *Ephedra*. The arboreal group is dominated by *Pinus*, with *Picea, Abies, Cathaya, Tsuga,* and *Podocarpus* represented by single grains. Spores of freshwater algae *Spirogyra, Pediastrum*, Zygnemantaceae are present. The single record of *Caspidinium rugosum* Marret, 2004 type I was found at this level. The composition of the spectrum indicates the existence of coniferous forests in the mountains. Lower elevations were covered with meadow-steppe vegetation. The sample 3 illustrates higher content of tree pollen (68%). Its higher diversity is characterised by the presence of *Cedrus, Betula, Carpinus, Tilia, Ulmus, Juglans,* and *Eunumus*. The role of Amaranthaceae pollen decreases. This pollen assemblage evidences a period of warming and humidification with mixed forests growing on the mountain slopes. The open spaces were covered with grassy steppes. The spectrum of sample 3 contains a relatively diverse assemblage of dinocysts (Fig. 12) *Polysphaeridium* cf. *zoharyi* (R.Rossignol) Davey et Williams, 1966, *Spiniferites* cf. *ramosus*, *Lingulodinium* sp., *Cleistosphaeridium* sp., aff. *Apteodinium* sp., *Pyxidinopsis* cf. *reticulata* Jiabo, 1978. The presence of dinocysts indicates conditions of a shallow brackish-water basin.

The single pollen sample studied from Pekecik 2 section comes from the clays near the base of the section (Fig. 7). Pollen of *Pinus, Abies, Tsuga, Podocarpus,* and *Cathaya* dominate in the assemblage. Single spores of fresh-water algae *Pediastrum*, *Botryococcus*, *Spirogyra* occur here too. The assemblage also includes a single record of *Spiniferites cruciformis* Wall et Dale in Wall et al., 1973, morphotype B sensu Marret et al. (2004). This form (Fig. 12: 3) can tolerate freshwater to brackish conditions.

In the spectra of the upper samples 1 and 2, taken from the upper layer of lignite and overlying grey clays. The spectra show higher content of pollen of pines and lower diversity of broadleaved arboreal plants. The numbers of freshwater algae *Spirogyra* and Zygnemantaceae are increasing. No dinocysts are detected here. The climatic situation becomes moderately cool.

The sediments of the sections Pekecik 1 and 3 were formed in more humid conditions than the sediments of the lower part of the Demirkend section. The spectra showed a higher amount of pollen of *Pinus, Abies, Picea*. The broadleaved group is less diverse. Pollen of Asteraceae and Poaceae dominates in the herbaceous group of the Pekecik 1 and 3, and Amaranthaceae dominates in the Demirkend section. The dinocyst assemblages are also not identical. The Pekecik assemblages show lower numbers of *Caspidinium rugosum* and higher content of *Polysphaeridium* sp., *Lingulodinium* sp., *Cleistosphaeridium* sp. The assemblage also documents the presence of cysts of *Pyxidinopsis* sp. and aff. *Apteodinium* sp. It is possible that the observed differences in the composition of dinocysts is associated with deeper water conditions in Pekecik dinocyst levels.

4.2.3. Molluscs

The lowermost part of the section Pekecik 1 (sample J24) yielded poorly preserved assemblage of freshwater molluscs with debris of *Valvata*, *Radix*, *Pisidium* and *Dreissena*. This sample also yielded numerous operculi of the Bithyniidae family with peculiar excentric (submarginal) nuclei. All other samples from Pekecik localities produced operculi with central nuclei. This may indicate both an older age of these deposits and a different ecological condition.

In the middle part of the section, in the right bank of the gully an assemblage of molluscs (sample H28) includes *Bithynia* sp. (operculum),

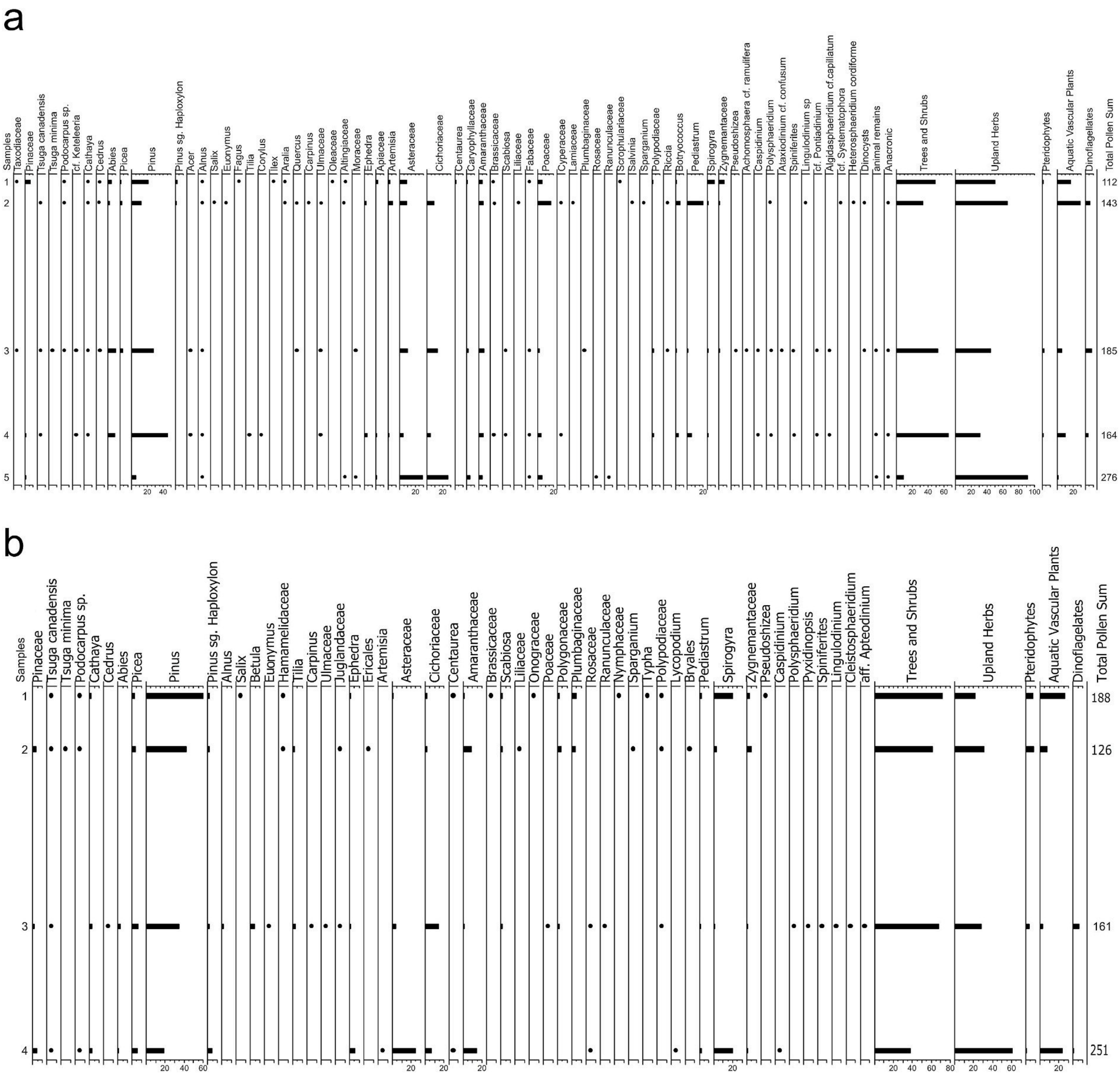

Fig. 10. Pollen diagrams for the Pekecik 1 (a) and Pekecik 3 (b) sections.

Valvata cf. *piscinalis* (O.F. Müller, 1774), *Caspicyclotus* cf. *armenicus* Schütt, 1991, *Radix* cf. *lessonae* (Issel, 1865), *Planorbis* sp., *Planorbarius* cf. *corneus* (Linnaeus, 1758), *Dreissena prediluvii* sp. nov., *Pisidium* sp., Pisidiidae gen. Two levels with molluscs were sampled in the left landslided bank of the gully in the upper part of the section. The first assemblage from silts and sands underlying lignites (H27) includes *Bithynia* cf. *applanata* Blanckenhorn, 1897, *Bithynia* sp. (operculum), *Valvata* cf. *piscinalis* (O.F. Müller, 1774), *Caspicyclotus* cf. *armenicus* Schütt, 1991, *Pseudamnicola* sp., *Radix* cf. *lessonae* (Issel, 1865), *Gyraulus* sp., *Dreissena* sp. and Pisidiidae gen. The lignite level (J28) yielded imprints and fragments of molluscs of the family Lymnaeidae gen. and of the genera *Planorbis* and *Anisus*, as well as *Bithynia* sp. (operculum).

A similar assemblage of molluscs was found in samples from the lower part of the Pekecik 2 section. Sample J20 yielded *Caspicyclotus* cf. *armenicus, Radix* sp. and nacreous fragments of Unionidae. Sample J21 – *Bithynia* sp. (operculum), *Valvata* cf. *piscinalis*, Valvaya sp. (close to V. sibirica), *Lymnaea* ex. gr. *stagnalis* (fragments of spire), *Lymnaea* sp., different Planorbidae and Pisidioidea.

The assemblage from the lignite layer is characteristic for the freshwater stagnant water bodies and has a broad chronological distribution. Other samples are close in composition of molluscs and probably have a similar age. These assemblages have common features with Plio-Pleistocene assemblages from northern Syria and Turkey. The absence of *Dreissena diluvii* that is characteristic for late Early – early Middle Pleistocene of the region, and the presence of its possible ancestral form give a possibility to assume an older age of the deposits.

Upper part of Pekecik 2 section (J27) yielded diverse assemblage of molluscs with *Bithynia* sp. (operculum), *Valvata* aff. *piscinalis*, *Falsipyrgula* sp., *Pseudamnicola* sp., *Lymnaea* ex. gr. *stagnalis, Radix* sp., *Gyraulus* aff. *horasanensis* (Schütt, 1991)*, Planorbarius* sp., Succineidae indet., *Pisidium* sp., Euglesidae indet., *Dreissena* sp. This complex is more diverse than in the lower samples. *Gyraulus horasanensis* originally described as a subspecies of *G. sibinjensis* from sand pit east of Horasan (Turkey). These deposits were attributed to the Late Pliocene (Schütt, 1991), now they can be correlated with the Early Pleistocene, however, some authors believe that they still belong to the Late Pliocene (Vasilyan et al., 2014). There is still insufficient data to identify the exact age of these deposits. Also, it was found in the Early Pleistocene deposits of Pasinler (Schütt, 1997; Vasilyan et al., 2014). Together with *Falsipyrgula* which was found here they may indicate a younger age of these deposits.

Below, we provide short remarks on the most informative species which were found in Pekecik 1 section with description of the new

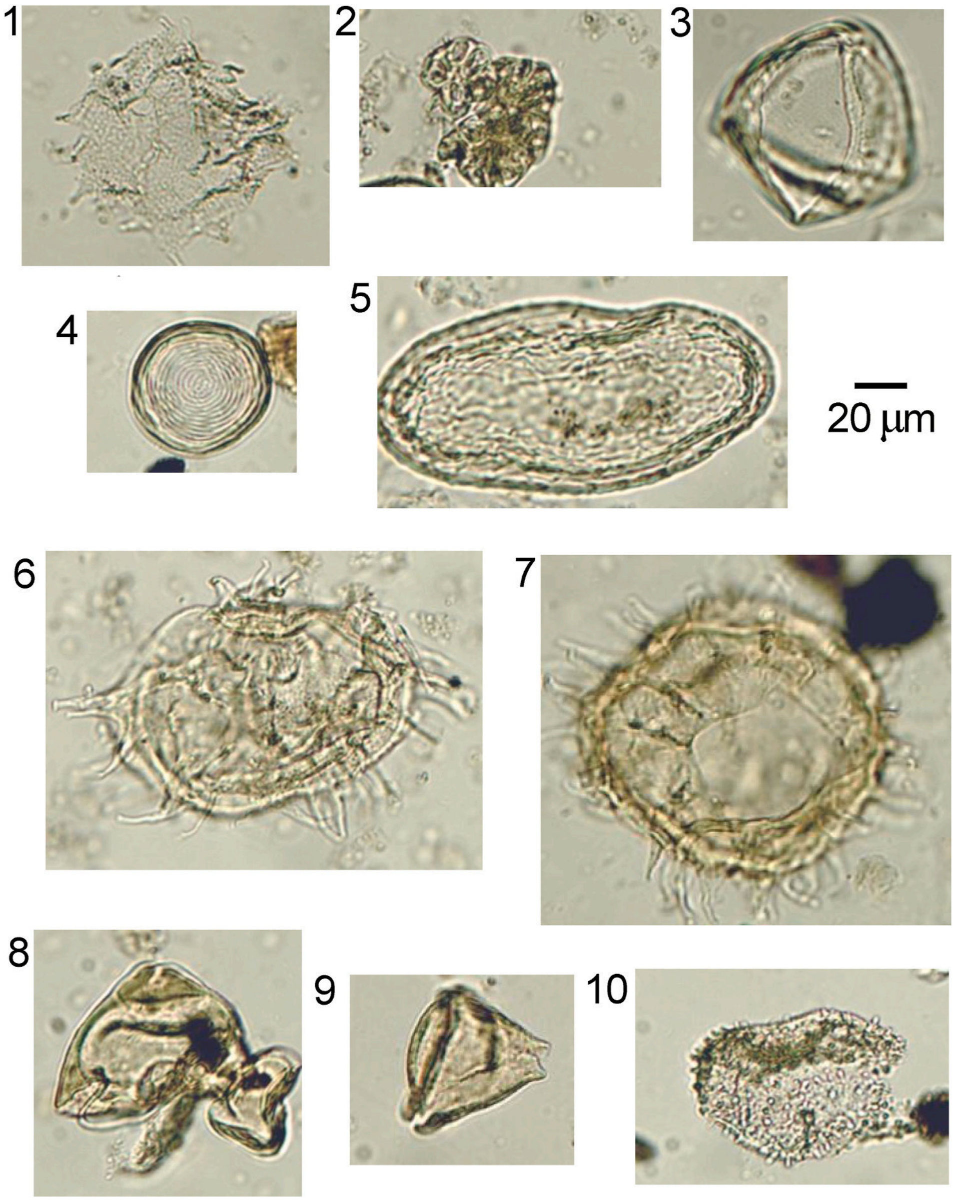

Fig. 11. Spores of algae (1–5) and redeposited dinocysts of the Cretaceous age (6–10) from the Pekecik section: 1. *Pediastrum* sp.; 2. *Botryococcus* sp.; 3. *Zygnema* sp.; 4. *Pseudoschizea* sp.; 5. *Spirogyra* sp.; 6. *Systematophora* sp.; 7. *Heterosphaeridium cordiforme* Yun (1981); 8. *Trodopollis* sp.; 9. *Extrapollis* sp., 10. *Pilosisporites* sp.

species of *Dreissena*. Species given in open nomenclature are represented by juvenile or poorly preserved shells.

Valvata cf. *piscinalis* (O.F. Müller, 1774) (Fig. 13: 1–5). The family Valvatidae is widespread in the Holarctic region. However, only five extant species of *Valvata* have been reported from Turkey: *V. cristata* O.F. Müller, 1774, *V. piscinalis* (O.F. Müller, 1774), *V. saulcyi* Bourguignat, 1853, *V. macrostoma* Mörch, 1864 and *V. kebapcii* Odabaşi, Glöer et Yıldırım, 2015 and 3 extinct species: *V. costata* Taner, 1973, *V. kavusani* Schütt, 1994 and *V. beysehirensis* Glöer et Girod, 2013 (Yıldırım, 1999; Haszprunar, 2014; Odabaşi et al., 2015). Our material is very close to *V. piscinalis* described from Pasinler Basin (Schütt, 1997), but umbo is slightly broader. In many shells, the spire is relatively low that is also noted in material from Pasinler Basin (Vasilyan et al., 2014). These features bring our material closer to *V. piscinalis alpestris* Küster, 1853, which is though slightly larger (Glöer, 2002). Also, our material resembles *Valvata saulcyi pliocaenica* Schütt, 1988 from the Early Pleistocene of the Orontes valley (Syria) which differs from nominal species in higher and more pointed spire. There are many forms which are close to nominal *Valvata saulcyi*, but bigger (up to 5.5 mm), while dimensions of *Valvata saulcyi* is 2–3 mm (Bourguignat, 1853; Bandel, 2010). Recent *Valvata saulcyi* which is illustrated by Odabaşi et al. (2015, Fig. 7) is close to our shells in morphology and differs from the form described and illustrated by Bourguignat (1853, p. 68, pl. 2, fig. 41, 42). All our morphotypes show a smooth transitional row. To clarify this issue, the study of type material is necessary. Prior to the revision of the type material the taxonomic assignment remains tentative.

Bithynia cf. *applanata* Blanckenhorn, 1897 (Fig. 13: 6–7). Our material (H27) is close to this species described from Syria (Blanckenhorn, 1897), but is slightly larger (up to 5.5 mm) and differs in less gracile shape of the shell. In addition, it resembles *Bithynia erzuruma* Schütt, 1991 which was described from Late Pliocene deposits near Çigdemli 23 km to the west of Erzurum (Schütt, 1991). It is close to *B. erzuruma* by shape of the shell and small size, but differs by the number of whorls (4 instead 5) and their more bulbous shape. Despite the small size, our shells are slightly larger with a lower number of whorls. In addition to shells, we also found multiple operculi. This form may represent a new species.

Caspicyclotus cf. *armenicus* Schütt, 1991 (Fig. 13: 8–10). This species

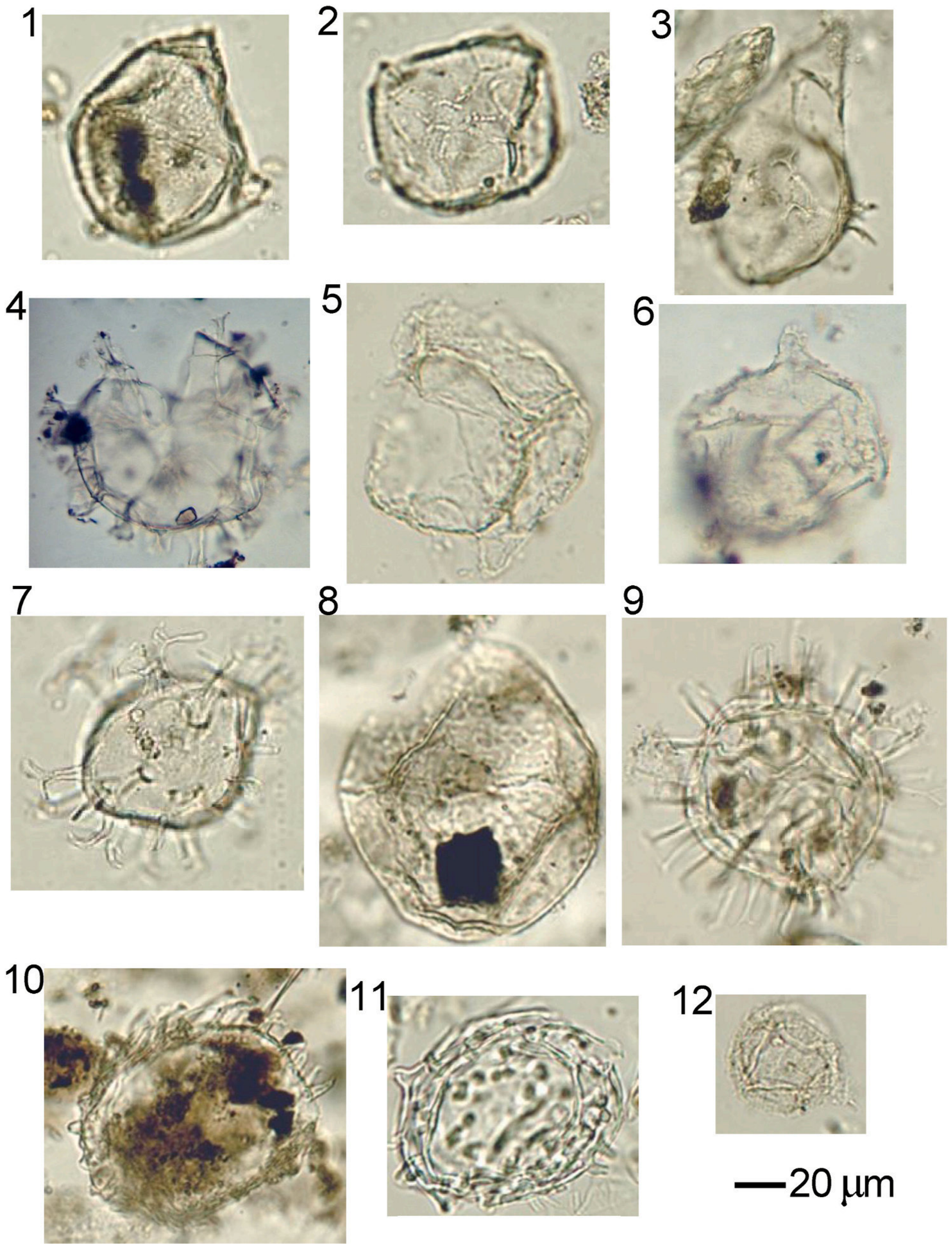

Fig. 12. Cysts of late Pliocene brackish-water dinoflagellates: 1, 2, 5, 7, 11, 12 – from the Pekecik 1 section; 3 - from the Pekecik 2 section; 4, 6, 8, 9, 10 - from the Pekecik 3 section: 1. *Pontiadinium* sp.; 2. *Caspidinium rugosum* Marret, 2004; 3. *Spiniferites cruciformis* Wall et Dale in Wall et al., (1973); 4. *Spiniferites furcatus* (Ehrenberg, 1838); 5. *Ataxiodinium* sp.; 6. aff. *Apteodinium* sp.; 7. *Achomosphaera* sp.; 8. *Pyxidinopsis psilata*? (Wall et Dale in Wall et al., 1973); 9. *Cleistosphaeridium* sp.; 10. *Polysphaeridium* cf. *zoharyi* (Rossignol, 1962); 11. *Polysphaeridium* sp.; 12. *Algidasphaeridium* cf. *capillatum* .

was described from a sand pit east of Horasan (Turkey) (Schütt, 1991). In our material we have one adult shell (H27) and three juveniles (H28). The adult one is close to Schütt's species by mastoid apex, broad umbo, and shape of the shell. But due to a slightly more compressed shape of the shell, it has a lower spire than the holotype. Due to this distinction, the taxonomic assignment is tentative.

Radix cf. *lessonae* (Issel, 1865) (Fig. 13: 15–16). Originally the species was described from sandy deposits near Baku (Azerbaijan) (Issel, 1865). Later Andrusov (1923) indicated its presence in a number of Apsheronian (Early Pleistocene, Calabrian) localities. Kolesnikov (1950) pointed out that this species is not widespread and occurs in the Lower Apsheronian. All researchers noted its small size of 5–6 mm, but some fragments also indicate larger shells. Shütt (1991) determined this species from a sand pit east of Horasan (Turkey) and noted its larger size. In our material, we have several fragments (H27) and few poorly preserved large shells (H28). Due to this, the assignment is tentative.

Pisidium sp. (Fig. 13: 17). One shell from H28 reminds *P. clessini* (Neumayr, 1875) by type of sculpture (well developed ribs), but its poor preservation precludes a precise identification. In the studied region, *P. clessini* was found in Pasinler and Denizli basins (Turkey) and in a sand pit near Gyumri (Armenia) (; Becker-Platen, Kuiper, 1979; Schütt, 1997).

Dreissenids. These bivalved molluscs are ubiquitous in Plio-Pleistocene lacustrine deposits of Eastern Turkey. The new dreissenid material from the Pekecik section provides evidence of a new species described below.

Class Bivalvia Linnaeus, 1758
Superorder Heterodonta Neumayr, 1883.
Order Venerida Gray, 1854
Family Dreissenidae Gray in Turton, 1840.
Subfamily Dreisseninae Gray in Turton, 1840.
Genus *Dreissena* Van Beneden, 1835
Dreissena prediluvii Frolov nov. sp.
Fig. 13: 18–23.

Type locality: Pekecik section, Erzurum Province, Eastern Anatolia, Turkey (N 39°53.443'; E 41°51.672'; H = 1753 m asl).

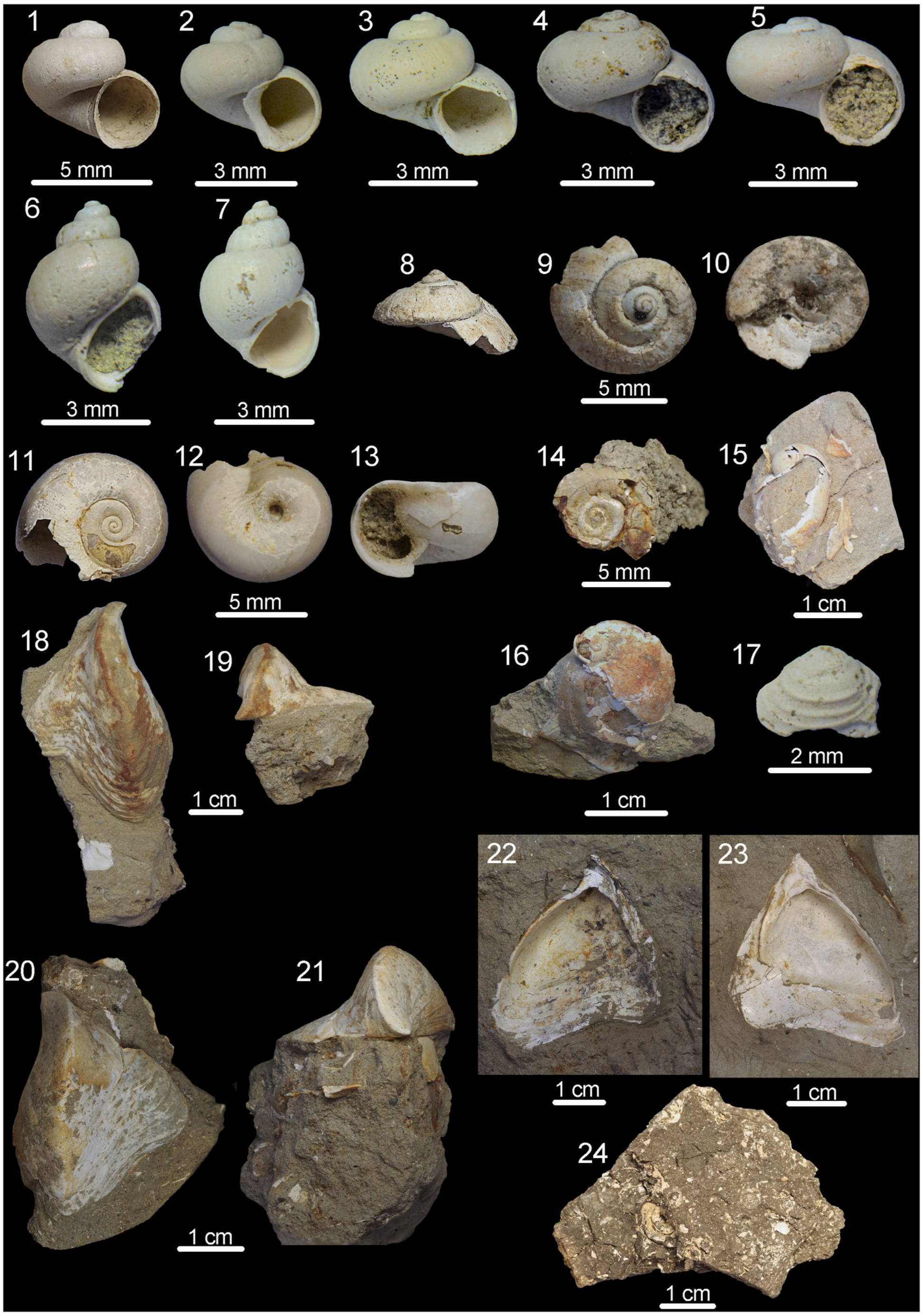

Fig. 13. Molluscs from the Pekecik section: 1–5. *Valvata* cf. *piscinalis* (O.F. Müller, 1774), 1. from sample H28, 2–5. from sample H27; 6–7. *Bithynia* cf. *applanata* Blanckenhorn, 1897, sample H27; 8–10. *Caspicyclotus* cf. *armenicus* Schütt, 1991, sample H27; 11–13. *Planorbarius* cf. *corneus* (Linnaeus, 1758), sample H28; 14. *Planorbis* sp., sample H28; 15–16. *Radix* cf. *lessonae* ((Issel, 1865), sample H28; 17. *Pisidium* sp., sample H28; 18–23. *Dreissena prediluvii* Frolov nov. sp., sample H28. 18–19. holotype, 20–23 paratypes; 24. lignite with shells and imprints of freshwater molluscs.

Holotype and type series: The holotype, GIN-1176-1 (Fig. 13: 18–19) is 26.9 mm in length (L) (wing-like protruding posterodorsal side slightly damaged), 41.7 mm in height (H), and 14.5 mm in shell convexity (SC). Paratypes, GIN-1176-2-1176-4 (Fig. 13: 20–23): no. GIN-1176-2 (Fig. 4: 20–21), L, 26.4 mm, H, 32.2 mm, SH, 14.7 mm; no. GIN-1176-3 (Fig. 13: 22), L, 29.4 mm, H, 39 mm; no. GIN-1176-4 (Fig. 13: 23), L, 25.3 mm, H, 36.3 mm. Most other specimens are damaged precluding accurate measuring.

All specimens of the type series are kept in collection no. 1176 of the Laboratory of Quaternary Stratigraphy of Geological Institute of the Russian Academy of Sciences, Moscow.

Type stratum: late Upper Pliocene, late Piacenzian.

Diagnosis: Large, thick-walled shell shaped as equilateral triangle with the ventral margin as the base, with wing-like protruding posterodorsal side. Keel well developed, angular. Shell exterior is smooth except growth lines.

Description: Shell is relatively large, shaped as a equilateral triangle with the ventral margin as the base. Shell is strongly thickened proximally, getting much thinner distally. Ventral margin has an S-shaped outline without noticeable angles, anterior part is concave, posterior part is rounded (convex). Anterodorsal margin is straightened and with a rounded angle merges into a concave (sometimes with angle) posterodorsal margin. Shell is relatively convex with slightly S-shaped angular keel smoothing near the posterior margin. Keel runs close to ventral margin. Ventral area drops abruptly to ventral margin, slightly convex. The dorsal area also drops abruptly, but then it flattens into a wing-like protruding. Concavity often forms at the bend coordinated with concavity on the posterodorsal margin. Umbo is pointed, distinctly prosogyrate, slightly bent. From the umbo view shell looks like a bird skull with a wing-like protruding at the posterodorsal side as a beak. The exterior side of the shell is smooth except for growth lines which are usually not visible in the anterior part of the shell and become rougher towards the posterior part.

The hinge apparatus is rounded triangular. Anterior muscle scars are usually clearly visible. Posterior muscle scars are not visible on our material. The ligamental suture takes a little more than half of the length of the anterodorsal margin.

Derivation of name: In allusion to possibly related and chronologically younger *Dreissena diluvii*.

Discussion: The Pliocene-Early Quaternary dreissenids of eastern Anatolia and adjacent areas of the southern Caucasus were studied by many authors, among others by Andrusov (1897), Blanckenhorn (1897), Seninsky (1905), Taktakishvili (1973), Babak (1983), Schütt (1988, 1991, 1997). Having consulted these sources, we could not find any fossil species of *Dreissena* morphologically identical or similar to *Dreissena prediluvii* sp. nov.

Among different species of the family Dreissenidae by the shape of a shell, our species is close to *Trigonipraxis madjerensis* Neubauer, Mandic, Jovanović et Harzhauser, 2020 (Early middle Miocene of Serbian Lake System) and to *Mytilopsis ornithopsis* (Brusina, 1892) (Early Pannonian) and *M. croatica* (Brusina, 1874) (upper Late Pannonian/Pontian) from Lake Pannon (Andrusov, 1897; Harzhauser and Mandic, 2010; Neubauer et al., 2020), the main difference of which is the presence of apophyses.

Several species are known from the Plio-Pleistocene in the studied region: *Dreissena diluvii* (Abich, 1859); *D. iconica* Schütt, 1991; D. buldurensis d'Archiae, 1859; *D. bukowskii* (Andrusov, 1893); *D. bourguignati* (Locard 1883) (= *D. chantrei* ((Locard 1883) by Schütt, 1993). *D. bourguignati* resembles our species, but it does not have wing-like protruding posterodorsal side. Of the listed species, the closest to our form is *D. diluvii* which was described from Pleistocene deposits of Armenia and occurs from Pasinler Basin (Turkey) to Yerevan and Gyumri (Armenia) (Abich, 1859; Andrusov, 1897; Akramovski, 1956; Schütt, 1997; Vasilyan et al., 2014). This species differs from our form in a thinner shell, less developed keel, angular only in the anterior third of the shell, less developed wing-like protruding posterodorsal side and straightened posterodorsal margin, usually without a concavity. It is worth noting that the degree of development of the posterodorsal wing-like protruding in *D. diluvii* is variable. noted that some shells have concavity at the bend of the dorsal area. Shells with a quite well-developed wing were also depicted in several works by Schütt (1991, Pl. 1, Fig. 8; 1997, Pl. 1, Fig. 10). It is likely that the shell depicted by Schütt as *Dreissena diluvii* (1993, Pl. 1, Fig. 13) refers to our new species. According to , the angle between anterodorsal and posterodorsal margins on his material is 95°–120°. According to Andrusov (1900), it can vary from 90° to 140°. These data allow us to assume an ancestral-descendant phyletic connection between Pliocene *D. prediluvii* sp. n. and *D. diluvii,* widespread in the Pleistocene of this region. Describing *D. diluvii,* Abich assigned this species to the genus *Congeria* and indicated the presence of apophyses (Abich, 1859, p. 517, Fig. 3). Schütt (1991) noted that rare shells with signs of formation of apophysis are found in the mass material from Horasan (Turkey).

Andrusov (1897), who studied the history and phylogeny of the Dreissenidae family, suggested that the genus *Dreissena* descends from the genus *Congeria* by reducing the apophysis. Later, transitional forms were found in various parts of Paratethys: for Pannonian, they were noted by Papp (1950), for the Dacian basin by Pană (1962), for the Euxinian by Nevesskaya (1962, 1967). Babak (1980) summarized these data and suggested that in different Paratethyan basins different *Congeria* species could give rise to *Dreissena* diachronically (but relatively fast) by reducing their apophyses. It characterizes *Dreissena* as a polyphyletic (paraphyletic) group. In modern taxonomy most of the species attributed by Andrusov to the genus *Congeria*, as well as mentioned by Papp, Pană, and Nevesskaya belong to the genus *Mytilopsis* (Nuttall, 1990), therefore it is considered an ancestor of *Dreissena* (Harzhauser and Mandic, 2010). Molecular phylogenetic studies challenge paleontological models. According to this data, modern *Dreissena* is monophyletic (Bilandžija et al., 2013) and, therefore, the loss of the apophyses could be a unique event.

4.2.4. *Fish*

Sampling points H27, H28, and J21 brought abundant cyprinid fish bones dominated by remains of scrapes, *Capoeta* sp.

4.2.5. *Herpetofauna*

The sampling point J21 produced about 30 bones of anuran amphibians mostly represented by the indeterminate fragments of the long limb bones. The fragment of ilium allows its assignment to ?Bufonidae indet. The fragmentary premaxilla and urostyle differ from other remains by their larger size. The premaxilla is similar in size and morphology to that of *Latonia*. The large urostyle, although incomplete, does not show any traces of transverse processes which are typical for the genus (Roček, 1994).

4.2.6. *Small mammals*

Small mammal remains were found in two levels of the combined Pekecik section: at J21, and at J27 in the upper part of the studied sequence. The site J21 yielded isolated molar teeth of a hamster *Allocricetus* sp. (2), and of voles *Mimomys praepliocaenicus* Rabeder, 1981 (n = 10), *Borsodia* ex gr. *praehungarica* (Schevtschenko, 1965) (6), *Pitymimomys* sp. (1). The small mammal fauna of Pekecik was first described in the literature by Ünay and de Bruijn (1998). After the study of this collection by A.S. Tesakov in MTA, Ankara in 2012, the revised list contains *Mimomys praepliocaenicus*, *Mimomys reidi* Hinton, 1910, *Borsodia* sp., *Pitymimomys stranzendorfensis* Rabeder, 1981, and *Clethrionomys primitivus* Popov, 2000. The evolutionary level of our new material and that stored in the collection of MTA are very close representing the same stratigraphic level. These materials are discussed jointly. The bank vole, *Clethrionomys primitivus* is close to the type form from the Bulgarian cave site of Varshets (Popov, 2000), the site correlated to early Late Villanyian and also documenting, in our view, *Mimomys praepliocaenicus* and *Pitymimomys stranzendorfensis.* Another record of earliest bank voles comes from the Late Akchagylian section Sablya in the North Caucasus (Tesakov, 1996). The most clear biochronological signal in the fauna is born by the large *Mimomys,* the reference evolutionary lineage of the European Plio-Pleistocene (Fejfar et al., 1998; Tesakov, 1998). Sinugrams of m1, m2, m3, M2 and M3 all place the fauna of Pekecik in the area of *M. praepliocaenicus,* a chrono-species of the lineage correlated to the uppermost Pliocene and lowermost Early Pleistocene (Rabeder, 1981; Tesakov, 2004). The large *Mimomys* of Pekecik plots (Fig. 14) between the faunas of Late Pliocene (as Shirokino and Rębelice Królewskie) and middle-late Gelasian faunal associations, Tegelen, Psekups, and Bicakci (Tesakov, 1998; 2004; van den Hoek-Ostende, 2015). The hypsodonty data on *Pitymimomys* (Tesakov, 2004) support the correlation and places the vole from Pekecik between the late Pliocene (MN16) *P. altenburgensis* Rabeder (1981) and earliest Early Pleistocene (MN17) *P. stranzendorfensis*. According to the evolutionary level of *Borsodia*, this form is more advanced than primitive rhizodont lagurines of Late Pliocene (*Borsodia novoasovica* Topachevsky et Scorik, 1977, Shirokino, MN16a), but less advanced than Early Pleistocene *B. praehungarica* from Kryzhanovka 3 (MN17). Taken together, these data indicate the correlation of the Pekecik fauna to the uppermost Late Pliocene, late Early Villanyian, MN16b or, as was suggested by Ünay and de Bruijn (1998), to the earliest Early Pleistocene, early Gelasian, the beginning of MN17 and Late Villanyian.

The site Pekecik 2, J27, produced a single second upper molar of *Mimomys* cf. *praepliocaenicus* intermediate in hypsodonty between molars of *Mimomys praepliocaenicus* from Late Villanyian faunas of Kryzhanovka 3 and *Mimomys pliocaenicus* from Tegelen (Tesakov, 1998, 2004). We thus tentatively refer this level to Early Pleistocene, early Gelasian, MN17. Predominantly normal polarity in deposits near the top

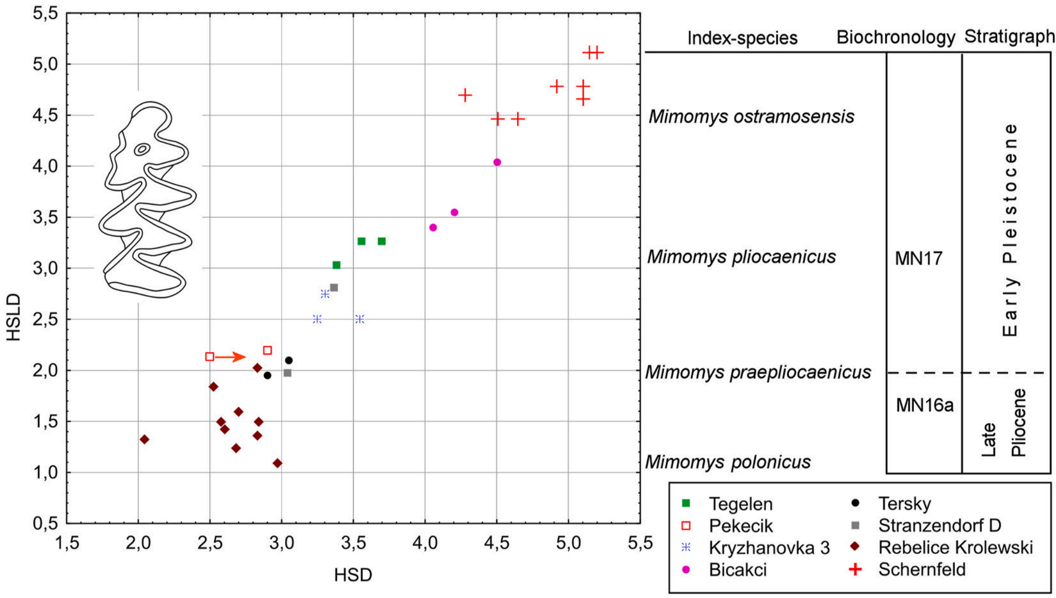

Fig. 14. Hypsodonty diagram (sinugram) of *Mimomys praepliocaenicus* from Pekecik in the sinumetric context of large *Mimomys hajnackensis-pliocaenicus* lineage in Late Pliocene-Early Pleistocene of Europe and western Asia. Data from (Rabeder, 1981; Tesakov, 1998; 2004; van den Hoek-Ostende, 2015).

of the studied section contradicts this inference. The scarcity of the material (n = 1), however, requires additional data for an unambiguous age model.

4.2.7. *Large mammals*

A smaller section near the base of the section Pekecik 2 yielded an isolated fragment of an elephant tusk in situ in the bed of lignite at the level correlated to member 4 of Pekecik 2 section. The specimen is 8.8 cm long and 12 cm in diameter. In the transversal and longitudinal cross-sections the dentine exhibits the characteristic pattern of Schreger bands. The specimen exhibits a V Schreger pattern near the cavity (=axis) area and an X Schreger pattern near the CDJ (Cement-Dentin Junction). The tusk displays a higher Schreger angle value near the CDJ (~109°) compared to the low angle value near the axis. Based on the data by Trapani and Fisher (2003) and Ábelová (2008), the studied specimen shows an obvious similarity to species of the genus *Archidiskodon* (=*Mammuthus*). Judging from the geological age of the source deposits we may suppose that it belongs to an early form of the southern elephant *Archidiskodon meridionalis.*

5. Discussion

The upper stratigraphic limit of dinocysts *Ataxiodinium* cf. *confusum* and *Pontiadinium* and spores of *Planctonites* that were found in the Demirkent section is the Upper Pliocene – Lower Pleistocene (Head, 1992; Williams et al., 1998; Lenz, 2000). *Spiniferites pannonicus* appears at the end of the Late Pliocene in the sediments of the western Caspian region in Azerbaijan (Richards, 2018). It is thus likely that the fine-grained and normally magnetised sediments of the Demirkent section containing the dinocysts and algae were deposited in shallow waters of the brackish Early Akchagylian (Late Pliocene) transgression of the Caspian Sea. In the more eastern, Armenian part of the Shirak Basin, the Akchagylian marine molluscs were found in the borehole 12 near the Marmashen Monastery at the depth range of 198–115 m (Zaikina et al., 1969; Sayadyan, 2009). The Upper Akchagylian deposits are absent in the Demirkent section that was uplifted before the Ani unit sedimentation (mid-late Calabrian).

In general, the pollen spectra of both studied sections reflect the features of the Late Pliocene – earliest Pleistocene vegetation of Eastern Turkey, which is characterised by temperate flora with predominance of coniferous forests with the participation of *Sciadopitys, Podocarpus, Cedrus, Tsuga, Picea, Abies* in the highlands, mixed forests with *Pinus, Acer, Quercus*, Juglandae, *Carpinus, Ulmus* at the middle elevations, and wide spread of the steppes with Asteraceae, Amaranthaceae, Poaceae, and *Ephedra* in the low mountains and on the plains (Işik et al., 2011; Trifonov et al., 2020).

However, a comparison of the palynological spectra of the Demirkent and Pekecik sections shows that the sediments of the Pekecik section were formed in somewhat wetter and cooler conditions than the studied deposits in the lower parts of the Demirkent section. The spectra of Pekecik show higher content of pollen of conifers (*Pinus*, *Abies*, *Picea*) and a lower diversity of pollen of broad-leaved species. Contrary to the record of Demirkent, no pollen of Juglandaceae (*Juglans*, *Carya*, *Pterocarya*) have been found in Pekecik and the grass group is dominated by pollen of Asteraceae and Poaceae. It is unclear if this difference indicates a slightly younger age of the Pekecik combined section than the lower part of the Demirkent section or if it reflects local paleoenvironmental distinctions. The small mammals of the Pekecik 2 section provide additional clues. Biochronologically this fauna belongs to early Late Villanyian, zone MN17a (the subzone of *Mimomys praepliocaenicus*). According to published accounts (Rabeder, 1981; Tesakov, 1998, 2004), the age range of this species correlates to the latest Late Pliocene and early Early Pleistocene (latest Picenzian and early Gelasian). The transition between Early and Late Villanyian of the European biochronological scheme is close to Pliocene - Pleistocene transition. The predominantly normal magnetic polarity of the Pekecik section indicates its correlation to a later part of the Gauss Chron. Therefore, bio-magnetostratigraphic analysis suggests that both Pekecik and the lower part of the Demirkent section belong to the uppermost Upper Pliocene. The molluscan fauna of the Pekecik section does not contradict this conclusion.

The obtained data show that the Akchagylian transgression of the Caspian Sea spread up to Shirak and Horasan intermontane basins in eastern Anatolia. Identification of described deposits of the both basins as the direct continuation of the Akchagylian basin of the Caspian Sea is based on the following evidence. The deposits contain the brackish-water dinocysts characteristic for the Akchagylian basin. Their accidental occurrence in these deposits is excluded, because they are present only at certain levels and their numbers decrease upwards parallel to the increase of numbers of fresh-water algae. The deep inland presence of the Caspian type dinocyst assemblage in the latest Pliocene is the direct indication of the invasion of Akchagylian waters. The results of our dating of the deposits correspond to the maximum highstand of the Akchagylian transgression, when its level could reach 50–150 m a.s.l. (Krijgsman et al., 2019).

According to our data, the transgression influenced inland regions of eastern Anatolia in the latest Piacenzian near the boundary with the early Gelasian. The end of the Akchagylian transgression with its level lowered down to the level of the world ocean occurred only by the late Gelasian (Popov et al., 2010).

The discovery of sediments interpreted as the brackish-water Akchagylian deposits of the Caspian Sea in the Demirkent and Pekecik sections allows us to estimate the magnitude and average speed of the Quaternary tectonic uplift of these territories. The current elevation of the top level of the Lower Akchagylian (Upper Pliocene) sediments is 1565 m in the Demirkent section. If the Akchagylian Sea level was 50–150 m a.s.l., the later tectonic uplift reached ca. 1515–1415 m and its average rate was ca. 0.6 mm per year. This value varies somewhat depending on local tectonic movements and is 0.6 ± 0.1 mm per year for the Shirak Basin and its frame (Trifonov et al., 2020). The top of the Akchagylian sediments is 1753 m in the Pekecik section. They were deposited not later than 2.6 Ma, when the Akchagylian Sea level could also reach 50–150 m a.s.l. Correspondingly, they were uplifted to ca. 1600–1700 m. This gives the average rate of the Quaternary uplift of 0.7 mm per year.

The studies in NW Armenia gave the relative uplift rate of the eastern Lori Basin more than 1 mm per year during 0.6 Ma and testify to the more rapid uplift of the adjacent ridges (Trifonov et al., 2016). The uplift probably accelerated during the Quaternary.

6. Conclusions

Two described sections of the fine-grained deposits of Upper Pliocene-Lower Pleistocene transition demonstrate penetration of the Akchagylian transgression of the Caspian Sea to NE Turkey. The brackish-water origin of the studied deposits is proved by the presence of characteristic dinocysts of the Caspian type. The age of the deposits is estimated by a combined analysis of faunal remains of molluscs and small mammals, palynological spectra including dinocysts and algae, and data on magnetostratigraphy. Both Demirkent and Pekecik sections are dated to the Late Pliocene (Piacenzian) at the boundary with early Gelasian. Our data show that the maximum pulse of the Akchagylian transgression reached Eastern Anatolia in terminal Piacenzian.

The number of brackish water dinocysts decreases up the Demirkent section and finally they disappear. The number of fresh-water algae increases in the same layers. These data indicate a gradual freshening of the brackish-water basin due to disconnection from the Akchagylian basin after its level fall. The dinocyst assemblage recorded in the lower part of the Pekecik section possibly represents the same highstand transgression event. The upper part of the Pekecik section is composed of lignite-bearing beds without signs of marine sedimentation.

Recent altitudes of the Akchagylian brackish-water deposits give a possibility to estimate the Quaternary uplift of the western Lesser Caucasus. The elevation of the top of the Upper Pliocene deposits of the Demirkent section is 1565 m that shows the average rate of uplift ca. 0.6 mm per year during 2.6 Ma. The elevation of the top of the Upper Pliocene part of the Pekecik section is 1753 m that gives an estimate of 0.7 mm per year during 2.6 Ma.

Data availability

All mollusc specimens are kept in collection no. 1176 of the Laboratory of Quaternary Stratigraphy of Geological Institute of the Russian Academy of Sciences, Moscow.

Authors contributions

Alexandra Simakova: Methodology, Investigation, palynology, biostratigraphy, field sampling. **Alexey Tesakov**: Conceptualization, Writing- Reviewing and Editing, Investigation, study of small mammals, biostratigraphy, field sampling. **Hasan Çelik**: Investigation, regional geology, field logging, Project administration. **Pavel Frolov**: Investigation, molluscs, biostratigraphy, field sampling. **Evgeniya Shalaeva**: Visualization, Investigation, field logging, Data curation. **Sergey Sokolov**: Investigation, neotectonics, field logging and sampling, Data curation, Visualization. **Yaroslav Trikhunkov**: Investigation, neotectonics, Data curation, field logging and sampling, Visualization. **Vladimir Trifonov**: Conceptualization, Writing- Reviewing and Editing, Investigation, neotectonics, field logging. **Dmitry Bachmanov**: Visualization, compilation of geological maps. **Anton Latyshev**: Formal analysis, paleomagnetism. **Pranav Ranjan**: Investigation, proboscidean remains. **Olga Gaydalenok**, Investigation, field logging. **Elena Syromyatnikova**: Investigation, herpetofauna. **Galina Kovaleva**: Investigation, diatom analysis. **Maria Vasilieva**: Investigation, field logging and sampling, laboratory treatment of diatom samples.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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