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Late Pliocene Gilbert Type Delta and Early Pleistocene Drainage System Changes in the Erzurum Basin, NE Turkiye

H. Çelik[a], V. G. Trifonov[b], A. S. Tesakov[b, *], S. A. Sokolov[b], P. D. Frolov[b, c], A. N. Simakova[b], E. A. Shalaeva[b], E. V. Belyaeva[d], A. A. Yakimova[b], E. A. Zelenin[b], A. V. Latyshev[e], and D. M. Bachmanov[b]

[a] *Firat University, Engineering Faculty, Department of Geological Engineering, Elâzığ, 23119 Turkiye*
[b] *Geological Institute, Russian Academy of Sciences (RAS), Moscow, 119017 Russia*
[c] *Laboratory of Macroecology and Biogeography of Invertebrates, Saint-Petersburg State University, St. Petersburg, 199034 Russia*
[d] *Institute of the History of Material Culture, RAS, St. Petersburg, 191186 Russia*
[e] *Institute of Physics of the Earth, RAS, Moscow, 123995 Russia*
**e-mail: tesak-ov@yandex.ru*

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Abstract—The Late Pliocene Gilbert-type delta is described in the western Erzurum Basin (NE Turkiye) and its position in the Late Cenozoic development of the basin is defined. The Erzurum Basin originated no later than Late Miocene between two Mesozoic ophiolite zones, continuing the Izmir–Ankara–Erzincan suture. In the Late Miocene–Pliocene, the basin was filled with fine-grained clastic and carbonate sediments of lacustrine-lagoon type. The Gilbert-type delta formed at the top of these deposits in the western part of the basin. The delta consists of 11 wedge-shaped bodies of clay, silt, sand, and gravel that were deposited as foresets of different phases of the delta development. The foreset bodies are dipping at 5° to 35° E. Some bodies underwent soft sediment deformation. The delta deposits are dated to Late Pliocene based on remains of small mammals and molluscs, palynological, and magneto-stratigraphic analysis. The delta eroded surface is overlain by alluvial pebbles dated to Early Pleistocene by archaeological finds. The Erzurum Basin is the westernmost member in a row of intermontane basins that continues to the east with the Pasinler, Horasan, and Agri basins that are drained by the Araxes River and its tributaries. It is likely that the paleo-Araxes River spread to the west in Late Pliocene and the studied delta was formed by its upper reaches that flowed into the water body of the Erzurum Basin. The delta deposits were covered by coarse alluvium in Early Pleistocene when the Erzurum Basin was tectonically isolated from the Araxes drainage system. In the latest Early Pleistocene or early Middle Pleistocene, the paleo-Araxes upper reaches were captured by the Euphrates River upper reaches that drain the Erzurum Basin now. The Upper Miocene and Pliocene deposits of the Erzurum, Pasinler, and Horasan Basins are similar and were accumulated in a single basin of sedimentation. Therefore, it can be assumed that the deposits of the upper Pliocene, containing the Akchagylian marine biota in the Horasan Basin, extended into the Erzurum Basin. However, the assumption that the upper reaches of the Euphrates River and the Erzurum Basin were the channel, through which the open sea biota entered the Akchagylian basin, is very unlikely for two reasons. Firstly, the Erzurum basin was limited by the described delta of the river, which flowed into it from the west. Secondly, the upper reaches of the Euphrates penetrated into the Erzurum Basin after the completion of the Akchagylian stage of sedimentation.

Keywords: Erzurum Basin, Gilbert type delta, small mammals, molluscs, palynology, magneto-stratigraphy, Acheulian, Late Pliocene, Pleistocene, river capture

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INTRODUCTION

Gilbert-type delta was first described by Gilbert (1885) for deposits formed by coarse grained fluvial clastics, where the river debouches into stagnant water of a lacustrine or marine environment. Wedge-shaped bodies of sediment and sensitive recorders of short-term base-level changes (Nemec, 1990) in this type of deltas reflect coeval tectonic activities of faults bounding margins of the reservoirs. Their clear sand intervals form operable quality reservoirs for oil and gas both in marine and lacustrine environments that has led to numerous studies of this type of deltas (Gobo et al., 2015).

Although Gilbert (1885) described deltaic coarse-grained sediments on freshwater coasts, the majority of subsequent studies (e.g. Corner et al., 1990; Nemec,

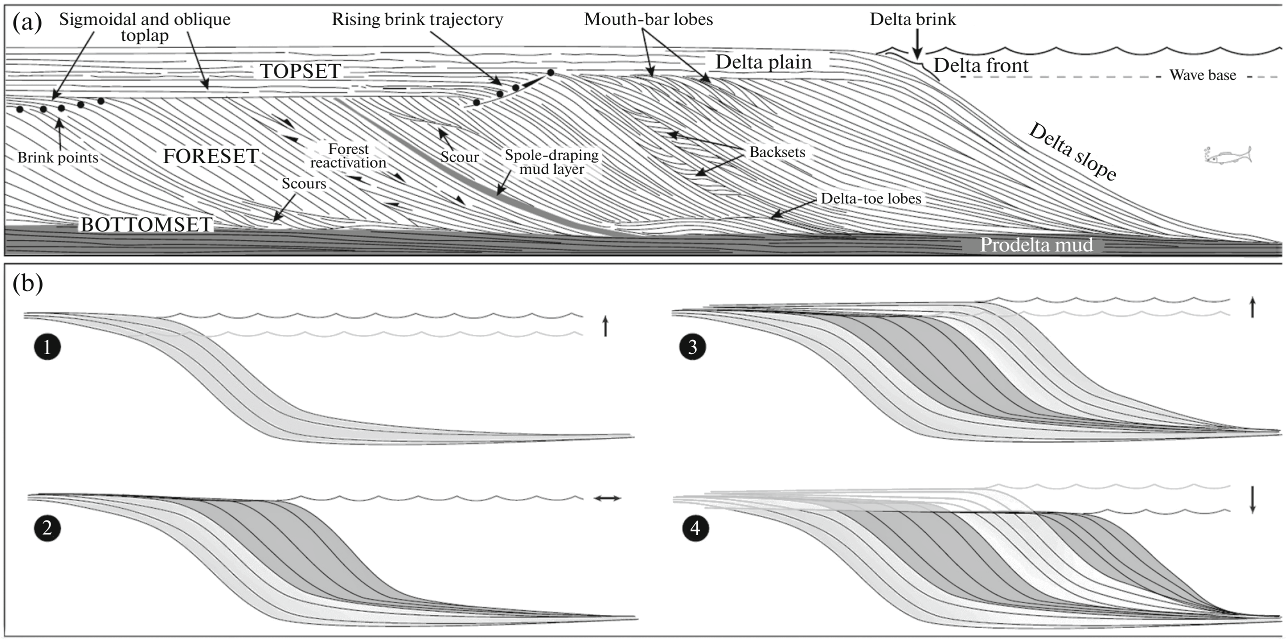

Fig. 1. Principal elements of a Gilbert-type delta and its development. (a) Schematic longitudinal cross-section of a Gilbert-type delta, depicting its characteristic tripartite architecture and other common features (Gobo et al., 2015). (b) Schematic cartoon portraying the growth of a Gilbert-type delta subject to short-term base-level changes, with a sigmoidal toplap formed during base-level rise (cases 1 and 3) and an oblique toplap formed base-level stillstand or fall (cases 2 and 4). Note that the sigmoidal brink-zone architectural record of base-level rise tends to be erased by fluvial incision during a subsequent baselevel fall (Gobo et al., 2015).

1990; Eilertsen et al., 2006; Bell, 2009; Eilertsen et al., 2011; Bijkerk et al., 2014; Gobo et al., 2014, 2015; Leszczynski and Nemec, 2015; Dietrich et al., 2016; Lang et al., 2017; Vellinga et al., 2018; Winsemann et al., 2018) show that deltas studied in marine margins were also evaluated as Gilbert type due to their tripartite (Gilbert, 1885) architectures. Many researchers (e.g. Kazancı, 1990; Ilgar and Nemec 2005; Alçiçek, 2007; Ghinassi et al., 2009; H. Alçiçek et al., 2015) have also studied these types of delta in lacustrine environments.

There are three major sedimentary divisions (Fig. 1a) in this type of deltas. These three divisions, known as tripartite, were first described by Gilbert (1885) as upper, middle and lower divisions. These are from top to base: (I) topset, represented by fluvial delta plain sediments; (II) foreset, consisting of prograding delta slope deposits with a basinward dip; (III) bottomset, consisting of suspended subhorizontal sediments settled in delta front (Nemec, 1990; Smith and Jol, 1997; Okazaki et al., 2020). Oblique or sigmoidal toplap geometries (Fig. 1b) of this type of deltas are particularly important as they reflect short term relative or eustatic water level changes (Soria et al., 2003; Gobo et al., 2014, 2015).

The present paper aims to unravel two tasks. The first task is to describe the structure and composition of the Upper Pliocene Gilbert type delta developed in a lacustrine/lagoon environment at the western margin of the Late Miocene–Pliocene Erzurum Basin (Fig. 2). A smaller part of this delta, which is covered by Quaternary alluvial sediments, is exposed in a sand quarry that gives a spectacular 3D exposure that has nether been studied so far in such details. The results may be useful in the study of the other, in particular, large deltas, promising for the search for hydrocarbons.

The second task arises from the fact that the Erzurum Basin is the western member of the W–E-trending array of intermontane basins in NE Turkiye. In the Horasan Basin, located to the east, the uppermost Pliocene part of the section contains marine dinocysts of the Akchagylian aspect (Simakova et al., 2021) that indicates a connection between the Horasan Basin and the main Akchagylian water body. The similarity of the Pliocene deposits of the Horasan and Erzurum Basins implies a presence of the marine Akchagylian in the Erzurum Basin too. An assumption was declared that the biota of the open sea could penetrate into the Akchagylian basin at the end of the Pliocene through the upper reaches of the Euphrates River and Erzurum Basin. The study of the delta, its structural position and relationships with the upper reaches of Euphrates help to test the validity of this assumption.

The delta was studied and documented during the 2017–2019 and 2021–2022 field seasons.

GEOLOGICAL SETTING

The Erzurum Basin is a flat intermountain plain located at altitudes of 1750–1800 m and rising to 2000 m in the NW (Fig. 2). The eastern part of the basin is drained by weakly incised riverbeds of the Karasu

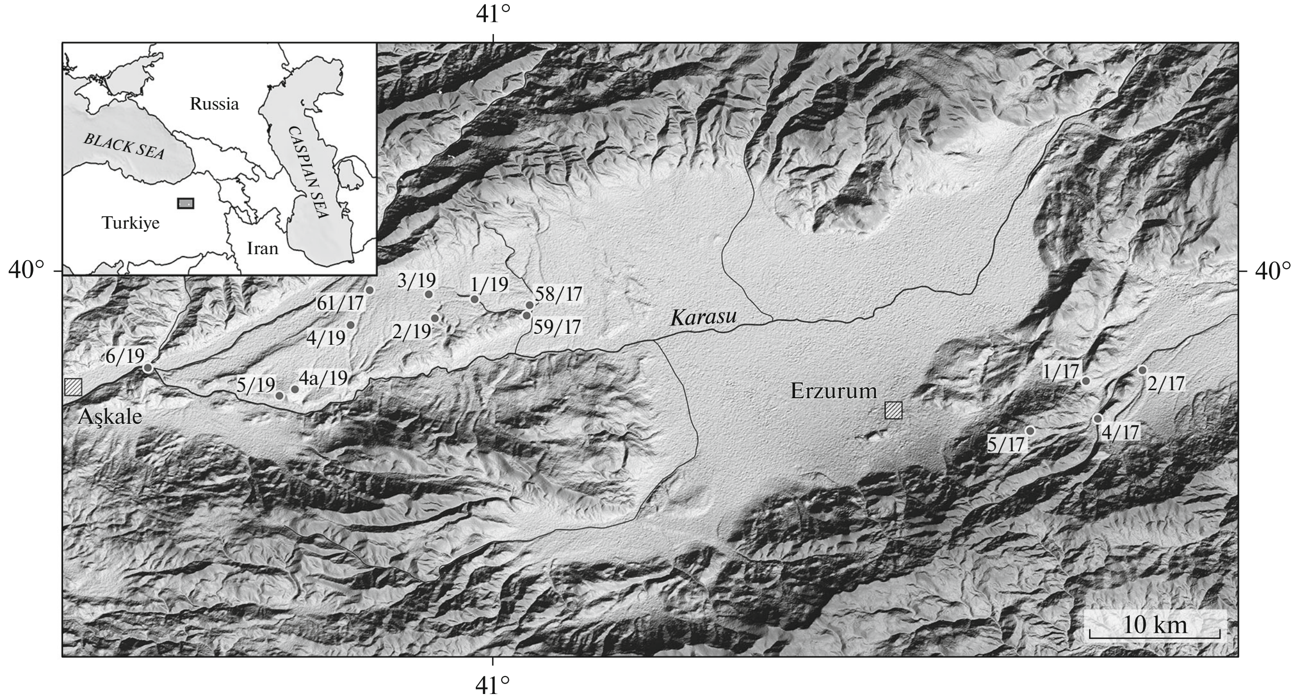

Fig. 2. Topographic model of the Erzurum Basin and its surrounding with main sites of observation.

River and its numerous tributaries, which merge into a single valley of the Karasu (upper Euphrates) River. Its incision increases westwards, downstream. The southeastern part of the basin is covered mainly by the Quaternary lacustrine and alluvial terrigenous sediments, and the Pliocene and, possibly, in places by Upper Miocene terrigenous and rarer carbonate deposits exposed in the western and northwestern parts (*Geological Map of Turkey*..., 2002) (Fig. 3).

The late Cenozoic Erzurum Basin is formed on a heterogeneous basement. In the northwestern surrounding of the basin, the thrust nappes are composed of ophiolites, clastic, and carbonate rocks of the Lower and Middle Jurassic, predominantly carbonate deposits of Upper Jurassic–Lower Cretaceous, and Cretaceous pelagic limestones. These formations are covered with unconformity by the Eocene volcanics of predominantly andesitic composition and the lower-middle Miocene acid volcanic formations.

The ophiolites are the eastern continuation of the Izmir–Ankara–Erzincan suture (Sengör and Yilmaz, 1981) and are continued by the ophiolites of the Bazum Ridge of Armenia (Fig. 4). The latter are traced intermittently along the northern coast of the Sevan Lake to the south-east up to the Araxes (Aras) River valley under the name of the Sevan-Hakari ophiolite zone (Knipper, 1975; Adamia et al., 2017). To the south of the Sevan-Hakari zone, near the town of Vedi and in the Zangezur Ridge, fragments of tectonic nappes thrusted from this zone are preserved (Knipper and Sokolov, 1976). The same thrusted ophiolite nappes are known to the east of the Erzurum Basin north of the town of Horasan (Geological Map of Turkey, 2002, Kars Sheet). The island arc volcanic rocks were identified to the north of the ophiolite suture, in East Pontian in Turkiye (Okay and Sahintürk, 1997) and Somkheti-Karabakh zone in Georgia, Armenia, and Azerbaijan (Galoyan et al., 2018). Dating of the ophiolites, associated blue schists, and island-arc volcanics shows that formation of the oceanic crust, represented by ophiolites, began in the Late Triassic, and subduction began in the Bajocian and continued intermittently up to the Turonian–Campanian (Bagdasaryan, Gukasyan, 1985; Zakariadze et al., 1996; Knipper et al., 1997; Danelian et al., 2007, 2010; Galoyan et al., 2007, 2018; Rolland et al., 2010; Sosson et al., 2010).

The southern extension of the Izmir–Ankara–Erzincan suture branches off near the western termination of the Erzurum Basin (Fig. 3). It is identified to the SW of the basin (southward of the town of Aşkale) and follows to the east up to the town of Kagizman, where it turns to the SE, runs along the south-western coast of the Urmieh Lake and joins with the Neotethys suture (*Geological Map of Iran*..., 1978; *Geological Map of Turkey*..., 2002). It was suggested that the ophiolites of this southern branch, exposed in the NW Iran, are allochthonous and obducted from the Sevan-Hakari suture (Avagyan et al., 2017). However, the structural position of the ophiolites of the southern branch between the Taurides and Iranian microplates indicates that the southern branch is an independent ophiolite zone. The more southern Neotethys suture strikes along the South Taurus (Bitlis) thrust zone in

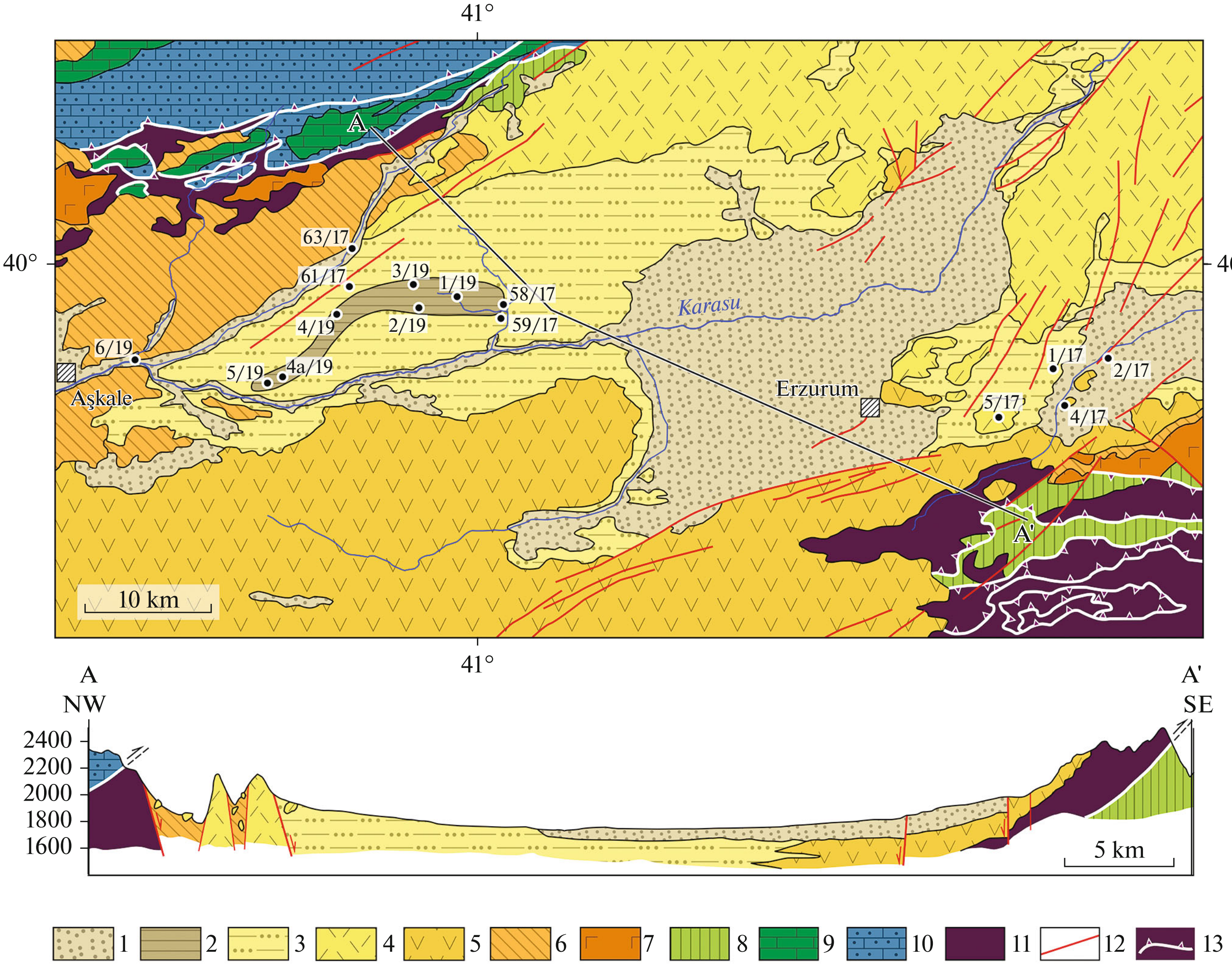

Fig. 3. Geological map of the Erzurum Basin and its surrounding, and a profile along line A–A', after Geological Map of Turkey..., 2002, modified. 1—Quartemary undifferentiated continental clastic rocks; 2—Quartemary alluvium; 3—Upper Miocene—Pliocene clastic, rarer carbonate rocks; 4—Upper Miocene—Pliocene volcanic rocks; 5—Upper Miocene basalts and andesites; 6—Lower-Middle Miocene evaporites and rarer limestones; 7—Paleogene volcanic and rarer clastic rocks; 8—Upper Cretaceous clastic and carbonate rocks; 9—Lower Cretaceous limestone; 10—Jurassic clastic and carbonate rocks; 11—Mesozoic ophiolites and associated basic and ultrabasic rocks; 12—active faults; 13—overthrust.

Turkiye 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. In the Taurus and Zagros, the subduction began in the Cretaceous, and the closure of the Neotethys relics and the beginning of the collision occurred at the Late Eocene–Oligocene (Hessami et al., 2001; Akinci et al., 2016).

The Erzurum Basin is situated in the angle between the two eastern extensions of the Izmir–Ankara–Erzincan suture and has a complicated outline. Its rectilinear north-western boundary is formed by the zone of reverse and/or reverse-strike-slip faults that is expressed in topography by an escarp. Closer to this zone, the Upper Miocene–Pliocene silts and marls, that occur nearly horizontally within the basin, dip at 30°–50°, and in some places, up to 70° (Fig. 5). Large unrolled boulders and blocks of the Miocene volcanic rocks composing the north-western side of the fault zone appear within the sedimentary sequence (Fig. 6). This indicates that the fault movements occurred during the sedimentation.

The Erzurum Basin sediments are bounded to the Mio-Pliocene volcanic formations of mainly basic and intermediate composition in the northern side of the basin. In the south-eastern side, the same dark basaltic andesites, andesites, and light acid tuffs are combined with the Pliocene terrigenous deposits. These formations compose a low NE-trending sawneck, ruptured by young longitudinal faults and separating the Erzurum Basin from the Pasinler Basin located to the east.

The faults of the south-eastern basin border turn to the SSW, forming the southern boundary of the Erzurum Basin. The uplifted southern side of the fault

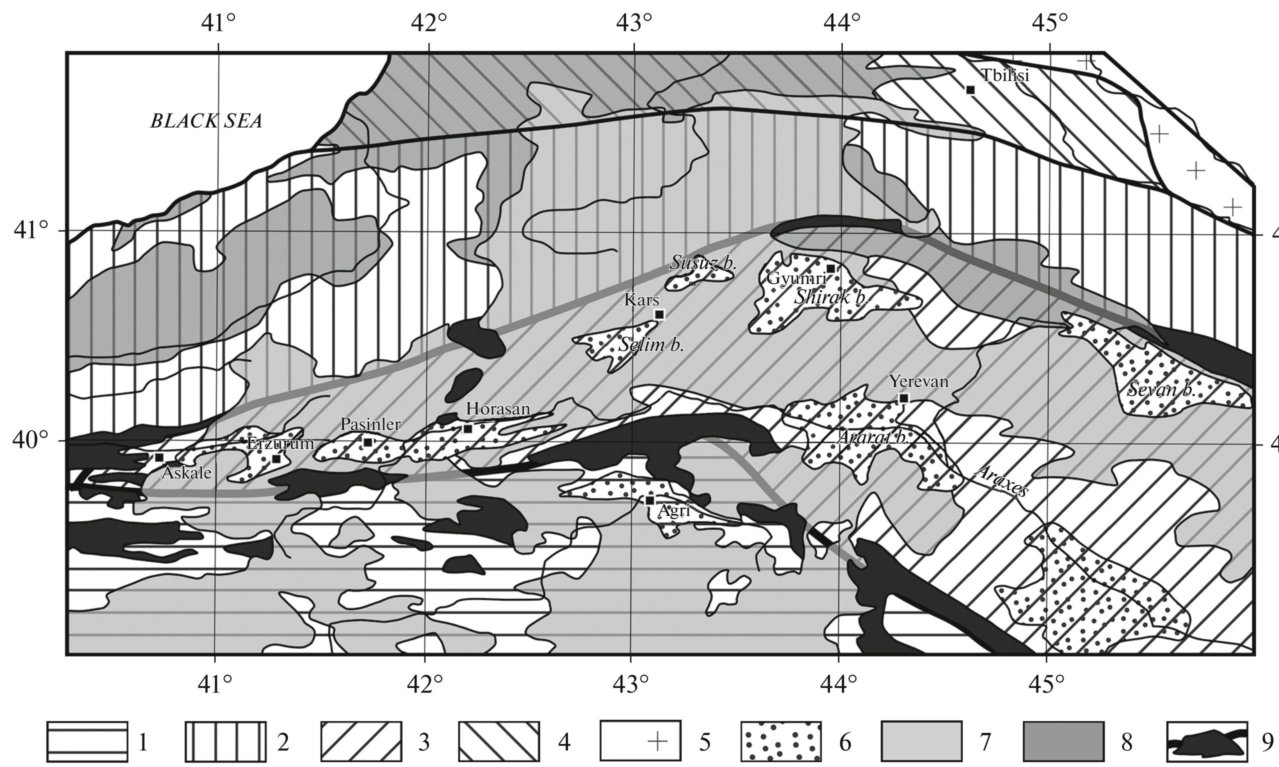

Fig. 4. Tectonic scheme of Eastern Turkiye, Armenia, Georgia, and NW Iran. 1—Taurides; 2—Eastern Pontian and Somkheti-Karabakh zones; 3—Iranian micro-plate and smaller lithosphere blocks of the Armenian Highland; 4—Adjaria–Trialeti zone; 5—Trans-Caucasus Massif; 6—Late Cenozoic intermontane basins; 7—Late Cenozoic volcanic fields, 8—Eocene volcanic belt including intrusions; 9—Sutures and ophiolites.

zone is composed of the Miocene volcanic rocks, which differ from the volcanic rocks of the northern and eastern borders of the basin by stronger secondary changes. To the west, the same Miocene volcanics form a tectonic uplift in the southern Erzurum Basin.

METHODS

In a detailed field study of clastic deposits of the delta, special attention was paid to two circumstances. Firstly, sedimentation phases were distinguished. In the central part of the delta, they are indicated by wedge-shaped bodies with different dips of layers at contacts. Secondly, in the peripheral parts of the delta, changes in dip of layers in the wedge-shaped bodies and their relationships to horizontally layered sediments of a reservoir, where the delta opened to, were studied. The structure and composition of the delta deposits and their relationships to the deposits of the reservoir, where the delta opened to, were studied by H. Çelik together with E.A. Shalaeva, S.A. Sokolov, and V.G. Trifonov. The latter analyzed the drainage system changes related to the Quaternary tectonic movements in the region.

To date the delta deposits, the found faunal remains of molluscs and small mammals were determined, samples were taken for palynological and magneto-stratigraphic analysis. Molluscs were collected and examined by P.D. Frolov and the found small mammals were identified by A.S. Tesakov. Remains of small vertebrates were collected in the field by a standard methods of wet screening of fossiliferous sediments using mesh size of 0.5–1 mm, and subsequent sorting of the concentrate in the laboratory. E.V. Belyaeva found and studied archaeological lithics. The palynological samples were collected and examined by A.N. Simakova. Samples were processed according to the method adopted in the Geological Institute of the RAS, which is a modification of Grischuk'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.

Palaeomagnetic samples were taken manually and oriented using a magnetic compass by S.A. Sokolov. Samples from loose deposits were strengthened by 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

Fig. 5. Steep dip of the Upper Miocene–Pliocene deposits near the north-western boundary of the Erzurum Basin (site 61/17).

the Earth of the RAS by A.V. Latyshev. 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). The quality of palaeomagnetic signal varies from sample to sample. Nevertheless, the majority of studied samples were suitable to define the palaeomagnetic directions.

The study follows the International chronostratigraphic chart for subdivisions of Pliocene and Pleistocene.

RESULTS

Structure and Composition of the Delta

The longitudinal W–E-trending cross section of delta deposits is exposed in the road cut to the west of the village of Paşayurdu (site 58/17, N 39°58.75′; E 41°01.3′. H = 1793 m). The section is composed of thin and medium bedded clay, silt, fine-grained sand and soft sandstone, and rare coarse grained sand and gravel. They form 11 wedge-shaped bodies, corresponding to different phases of the delta development (Figs. 7 and 8). The bodies-phases are distinguished by different dips of layers in their contacts appearing as unconformities. The phases I–XI representing different sedimentation stages of the delta development had initially typical tripartite divisions of a Gilbert type delta. Toplap division of some of these phases have been eroded by subsequent currents due to the base level changes. The lower parts of the foreset have been obscured due to the modern weathering and talus. The bottomset is not exposed. The observed oblique and sigmoidal topset can be interpreted in terms of base level changes occurred at the time of deposition of the visible part of this delta (Table 1). Foreset beds are dipping east at a variety of angles ranging from 5° to 35°. Most of beds show soft sediment deformation structure (SSDs) especially at the high angle parts of the cycles (Fig. 9) mainly due to oversteepening and gravity slidings. The zig-zag shaped deformation as seen in the phase I is similar to the seismogenic SSD (Fig. 9a).

Fig. 6. Block of volcanic rocks in the Upper Miocene–Pliocene deposits near the fault zone in the north-western boundary of the Erzurum Basin (site 63/17).

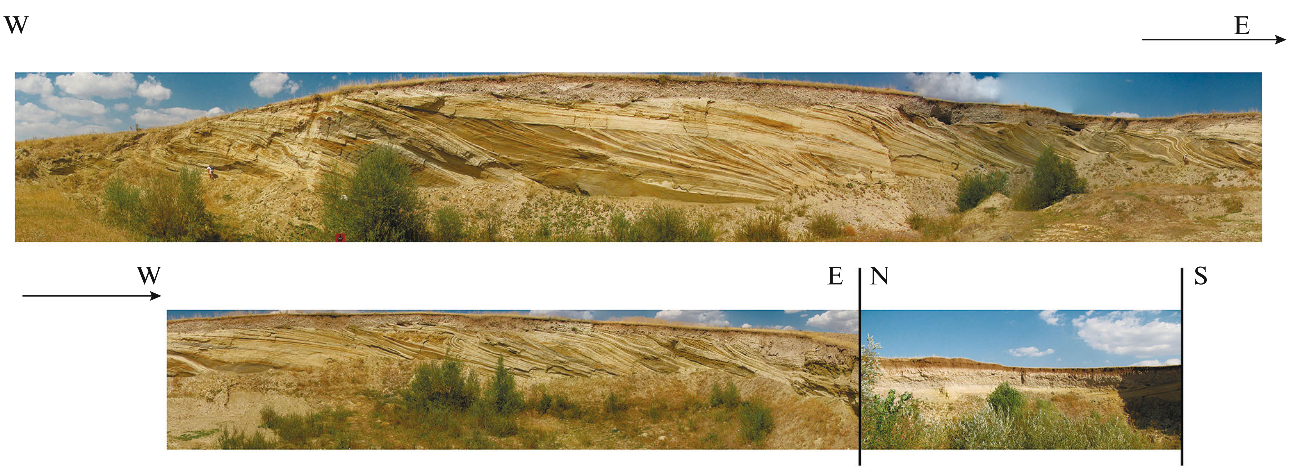

Fig. 7. Photo-profile along the Upper Pliocene delta (site 58/17). The lower picture continues the upper picture to the east.

Foreset beds erosion occasionally led to clayball formation (Fig. 9c).

The surface of the delta series is covered by an alluvial member that consists of pebbles with lenses of sand and gravel (phase XII of the delta development). The member represents the latest fluvial incision with an erosional base consisting of poorly sorted and clast supported gravels. B-axis imbrication shows that river waters continue to flow to the east during the formation of these deposits (Fig. 10).

A large sandpit has been excavated just to the north of the western part of the described section and pro-

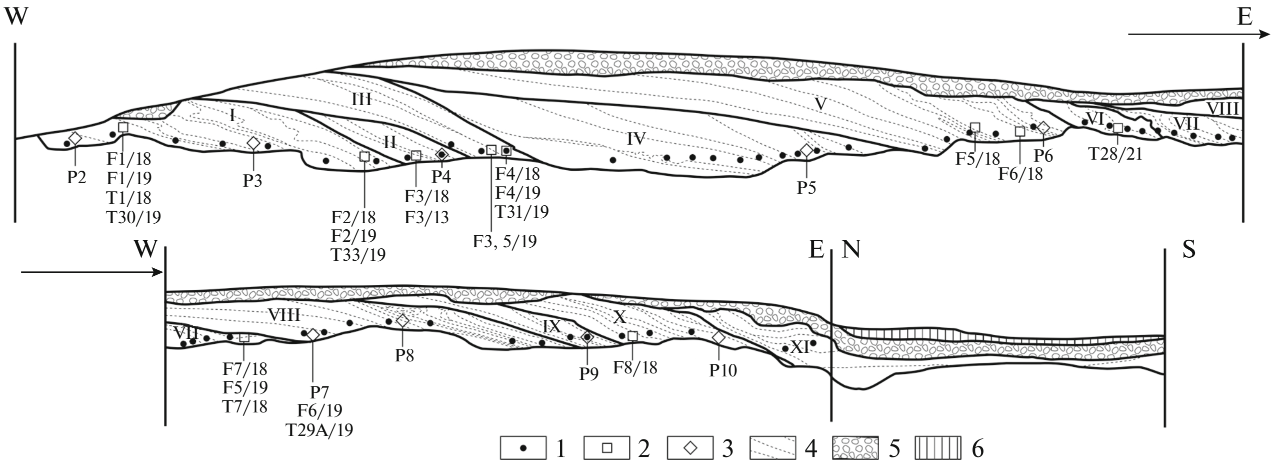

Fig. 8. Principal geological profile along the Upper Pliocene delta, corresponding to Fig. 7 (site 58/17). I–XI—forsets of prograding delta. 1—paleomagnetic samples; 2—faunal samples (F, molluscs, T—small mammals; 3—pollen samples; 4—boundaries within foresets; 5—pebbles of the bed XII; 6—cover loams.

vides the 3-D exposure of the delta. The southern wall of the quarry is parallel to the near-road outcrop and repeats its composition. The eastern wall demonstrates a view of the delta parallel to the strike of the bedding planes (Fig. 11). In this aspect the succession appears horizontal except the gravel-filled lenticular channel at the base of bed 11.

The more gentle dip of the delta deposits relative to the near-road outcrop is seen in the northern wall of the pit (Fig. 12). It could be an expression of the fan-like form of the delta, because of which the northern wall demonstrates the view of the delta along the strike of foreset beds. But the gentle dip of layers both in the northern and eastern wall that are situated under an angle relative to each other proves that the dip of layers really decreases to the north.

The described relationships are seen in the northern side of the weakly incised valley of the northern tributary of the Karasu River. The layer 12 of the road cut outcrop (site 58/17) is the cover of this valley terrace and the delta deposits compose the terrace base. The southern periphery of the delta is exposed in the southern side of the valley to the NW of the village of Çiğdemli (site 59/17; N 39°58.432′; E 41°01.191′. H = 1822 m). The following section is exposed there under the recent soil from the top downsection (Fig. 13):

1. Horizontally bedded soft sandstones and silts; thickness is ca. 7 m;

1.1. Light brownish-grey silts and fine-grained soft sandstones with vague stratification; thickness is 1.8–2 m.

1.2. Light brownish-grey fine-grained thin-bedded sandstones and silts with thin interbeds of grey coarse sandstone; thickness is 1.2–1.3 m.

Table 1. Water level changes of the Erzurum water basin during the delta development in the studied location related to the topset types of the phases

No.	Phase intervals	Topset type	Water level change
1	I–II	?	? (eroded)
2	II–III	Oblique	Fall
3	III–IV	?	? (eroded)
4	IV–V	Oblique	Fall
5	V–VI	?	? (eroded)
6	VI–VII	Sigmoidal	Rise
7	VII–VIII	Sigmoidal	Rise
8	VIII–IX	Sigmoidal	Rise
9	IX–X	Sigmoidal	Rise
10	X–XI	Sigmoidal	Rise
11	(I–XI)–XII	Oblique	Fall

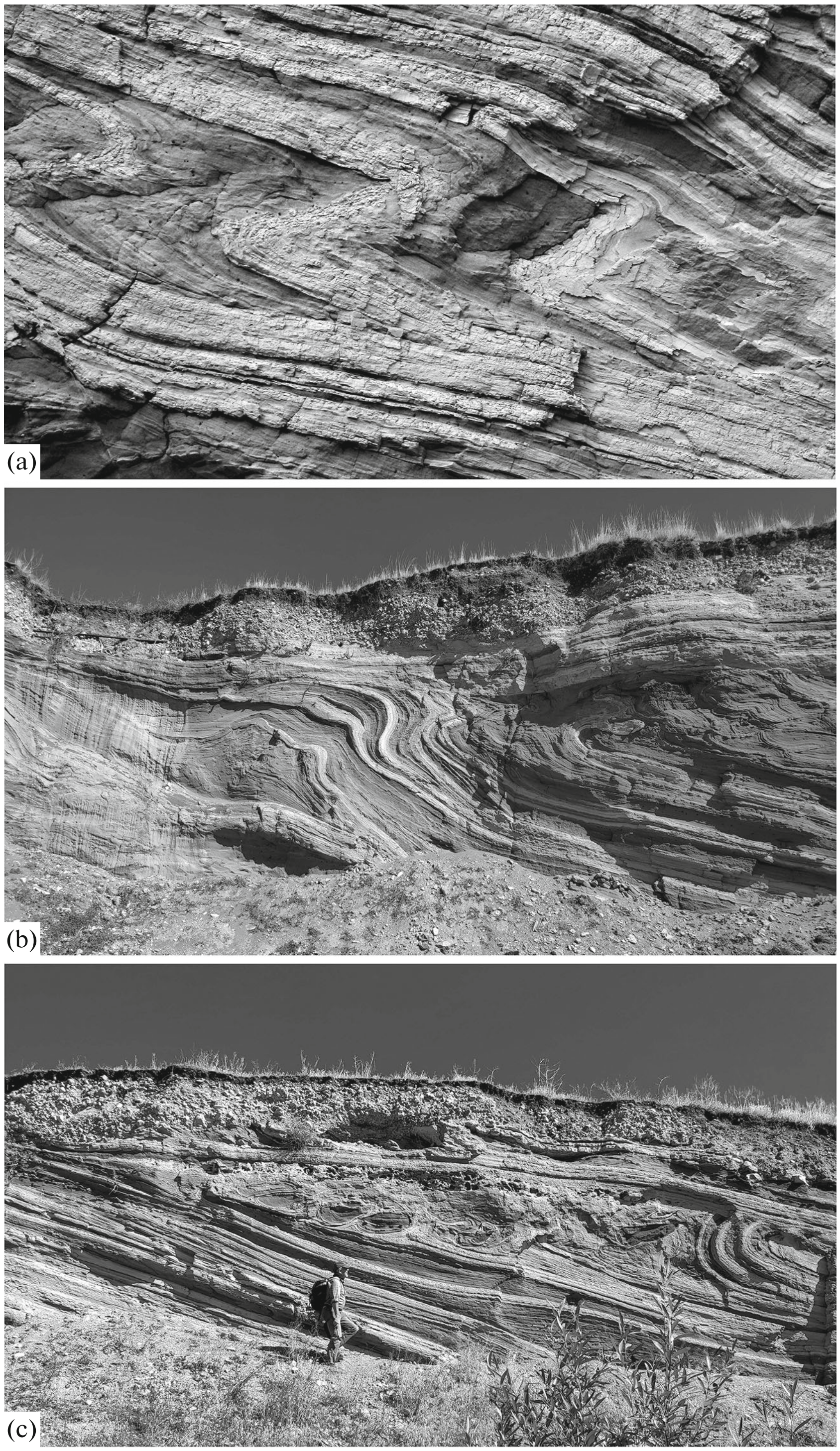

Fig. 9. Soft sediment deformation in the delta deposits (site 58/17), (a) zig-zag deformations in sediments of the foreset phase I; (b) soft sediment deformations in sediments of phase VI; (c) clay balls in top beds of phase VIII.

1.3. Darker brownish-grey sandstone with thin interbeds of light more fine-grained deposits; thickness is 0.5–0.6 m.

1.4. A layer of the 1.2 type; thickness is 1.4–1.5 m.

1.5. A layer of the 1.3 type; thickness is 0.8–1.0 m.

1.6. A layer of the 1.2 type; thickness is 1 m. The content of coarser sandstones increases in the lower part of the layer.

2. Grey cross-bedded coarse soft sandstones with interbeds of more fine-grained clastic deposits;

Fig. 10. Bed 12 of the site 58/17 having poorly sorted and mainly clast supported fabric, horizontally overlying the older phases with an erosional base. Clast imbrication (b-axis) shows easterly palaeoflow (white arrows).

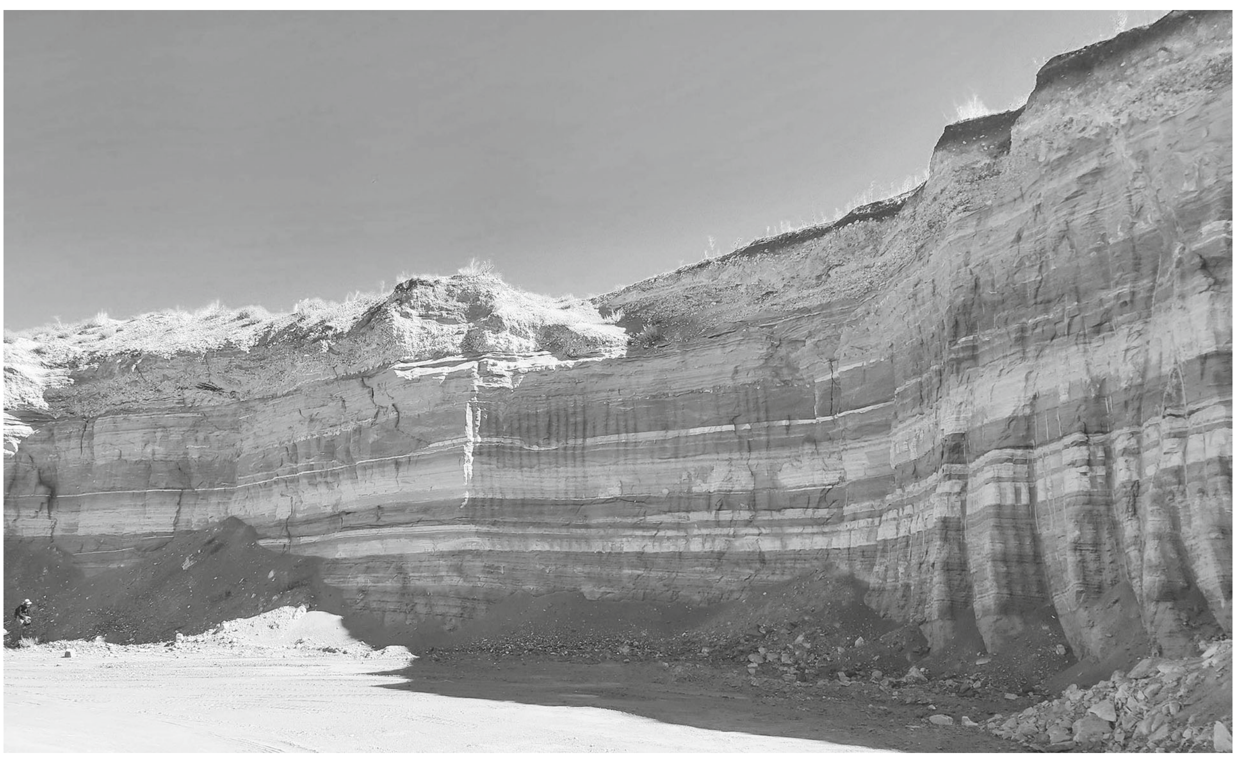

Fig. 11. The eastern wall of the quarry located just to the north of the outcrop 58/17: A view to the delta deposits along the strike of the foreset.

Fig. 12. The northern wall of the quarry located to the north of the outcrop 58/17: The outcrop demonstrates the gentler dip of layers than the section shown in Fig. 7.

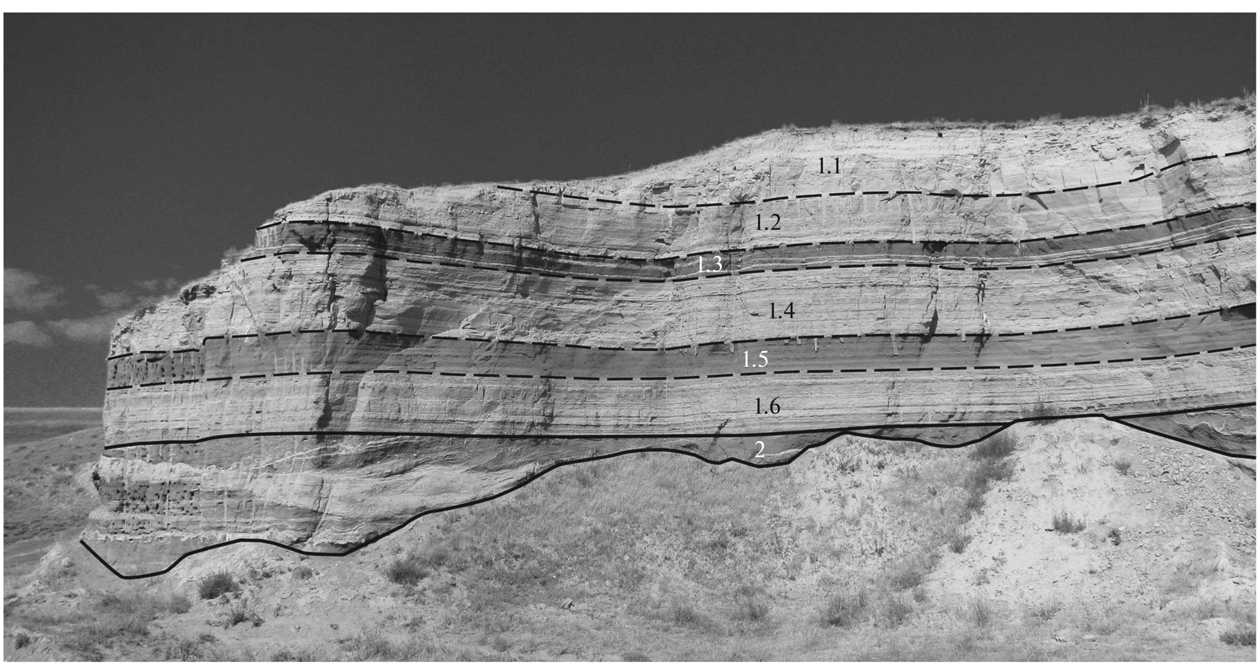

Fig. 13. The outcrop of the southern periphery of the Upper Pliocene delta near the village of Çiğdemli (site 59/17). The boundaries and numbers of layers are shown.

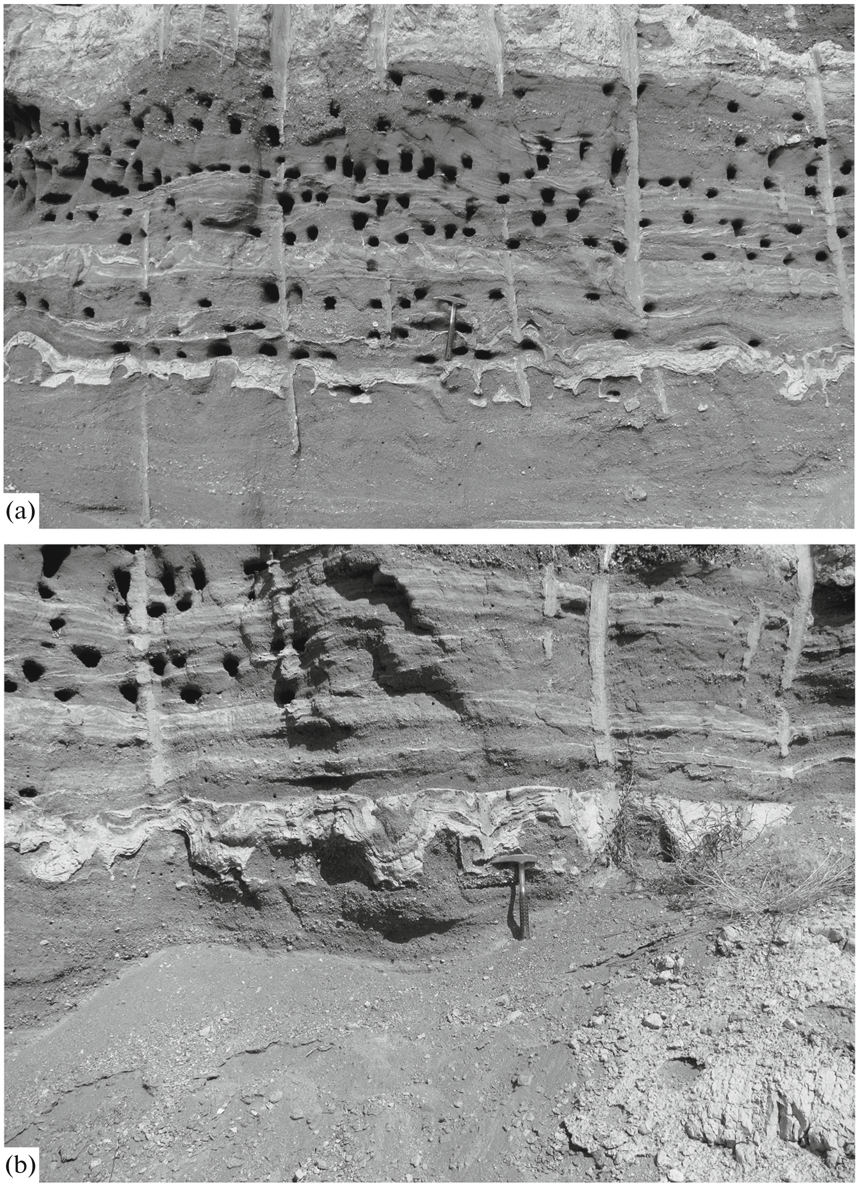

Fig. 14. Intrastratal deformation (seismite?) in the lower part of bed 2 of the southern periphery of the Upper Pliocene delta near the village of Çiğdemli (site 59/17).

thickness is 3 m. Thin fine-grained interbeds participate in the cross-bedding. The complicated intrastratal deformation of the seismite type disturbs the lower layers of the unit (Fig. 14). All beds of the section contain shells of molluscs and some bones of smaller vertebrates.

The described section of the southern periphery of the delta is located ca. 30 m above the section of the axial part of the delta. However, horizontally bedded layers of unit 1 have a tectonic dip to the NE at angles of 2°–3°, due to the uplift of the south-western part of the Erzurum Basin. This allows us to correlate the sections of the southern periphery and the axial part of the delta and consider the unit 1 of the southern section as a stratigraphic analog of the axial section. The layer 2 of the southern section may represent the earlier stage of the delta development.

Dating of the Delta Deposits and Their Paleoenvironmental Evaluation Faunal Data (Molluscs and Small Mammals)

Molluscs. Molluscs have been collected from several levels throughout almost the entire studied section, from the phase I (sample F1) and to phase X (sample F8). Samples 1, 7, and 8 yielded single shells of fresh water pond snail *Radix,* which also sporadically occurs along the entire section. The other samples contain both land and frewhwater molluscs, and some

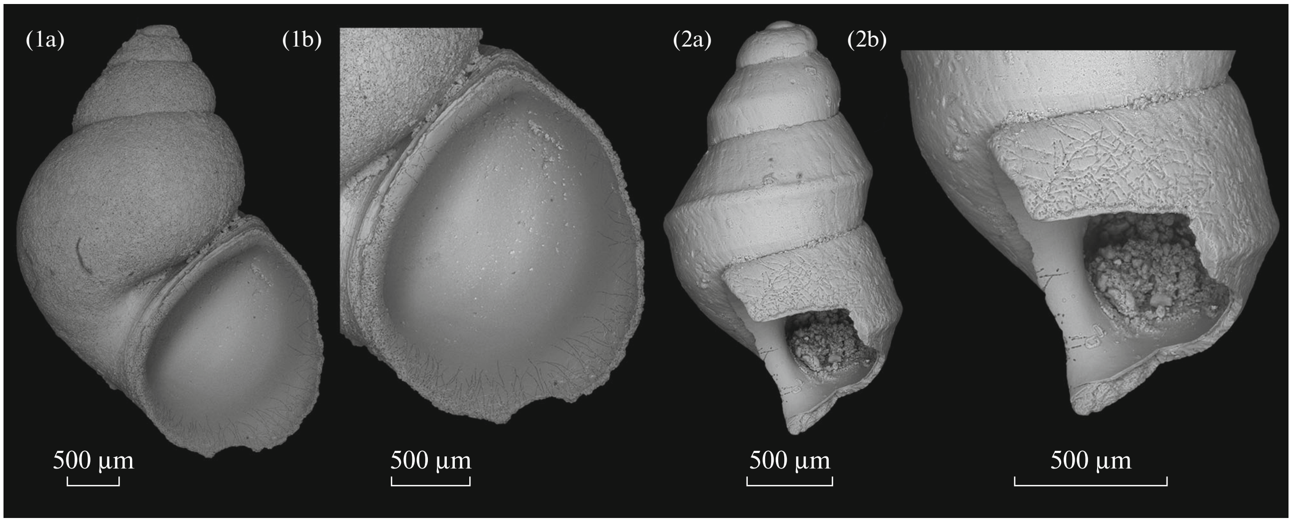

Fig. 15. Bio-erosion on shells of *Pseudamnicola* (1a, 1b) and Pyrgulidae (2a, 2b), sample F3. Section Paşayurdu, Eastern Turkiye, Late Pliocene.

forms that can stand brackish conditions (Table 1). We consider *Dreissena* bivalves as a separate group, because though they can bear brackish-water conditions, the lack of bioerosion manifestations precludes lumping them with *Pseudamnicola* and Pyrgulidae, potentially brackish-water and showing obviuos bioerosion signs.

Taxonomic differences between the samples are low and mainly expressed in the presence/absence of some species, likely related to local taphonomy. Variations in shares of different environmental types of molluscs likely reflect changes in deltaic sedimentation.

The list of terrestrial molluscs contains *Vallonia* sp. (n = 40), *Pupilla* sp. (n = 19), two different species of the family Enidae (only fragments with aperture are present ($n1$ = 29; $n2$ = 1)), cf. *Multidentula pupoides* (Krynicki, 1833) (n = 61), Succineidae indet. (fragments and juveniles (n = 45)) and shell fragments of the Geomitridae family (n = 12) were determined.

The freshwater molluscs include *Bithynia* sp. (fragments) (n = 3), *Lymnaea* ex. gr. *stagnalis* (Linnaeus, 1758) (fragments of spire) (n = 2), *Radix lessonae* (Issel, 1865) (n = 57), Lymnaeidae indet. (n = 61), *Anisus* sp. (n = 95), *Gyraulus* sp. (n = 39), *Armiger crista* (Linnaeus, 1758) (n = 5), *Bathyomphalus* sp. (n = 1), *Planorbarius* sp. (n = 2), *Dreissena* sp. (n = 1027), and Pisidioidea gen. spp. (n = 55).

Water molluscs that can also live in brackish-water conditions include *Pseudamnicola* sp. (n = 750) and Pyrgulidae indet. (fragments) (n = 4).

Among terrestrial molluscs, the species resembling *Multidentula pupoides* (Krynicki, 1833) prevails. By the shell shape and character of the apertural denticles, this species is close to *Multidentula pupoides* (Krynicki, 1833) and *Multidentula lamellifera* (Rossmässler, 1858). These species conchologically are very similar, but deviate in the structure of genitals. *M. lamellifera* differs from *M. pupoides* in the presence of a diverticle at the receptaculum seminis. Our shell is slightly larger with slightly less developed apertural

Table 2. Shares of environmental types of molluscs in samples from Late Pliocene delta deposits (Paşayurdu site)

Samples	Land	Fresh-water	Can stand brackish water	*Dreissena*
F1		1		
F2	96 (39%)	65 (26%)	29 (12%)	58 (23%)
F3	246 (17%)	192 (14%)	111 (8%)	865 (61%)
F4	26 (4%)	37 (5%)	561 (77%)	100 (14%)
F5	7 (14%)	7 (14%)	35 (68%)	2 (4%)
F6	6 (20%)	2 (7%)	22 (73%)	–
F7	–	1	–	–
F8	–	1	–	–

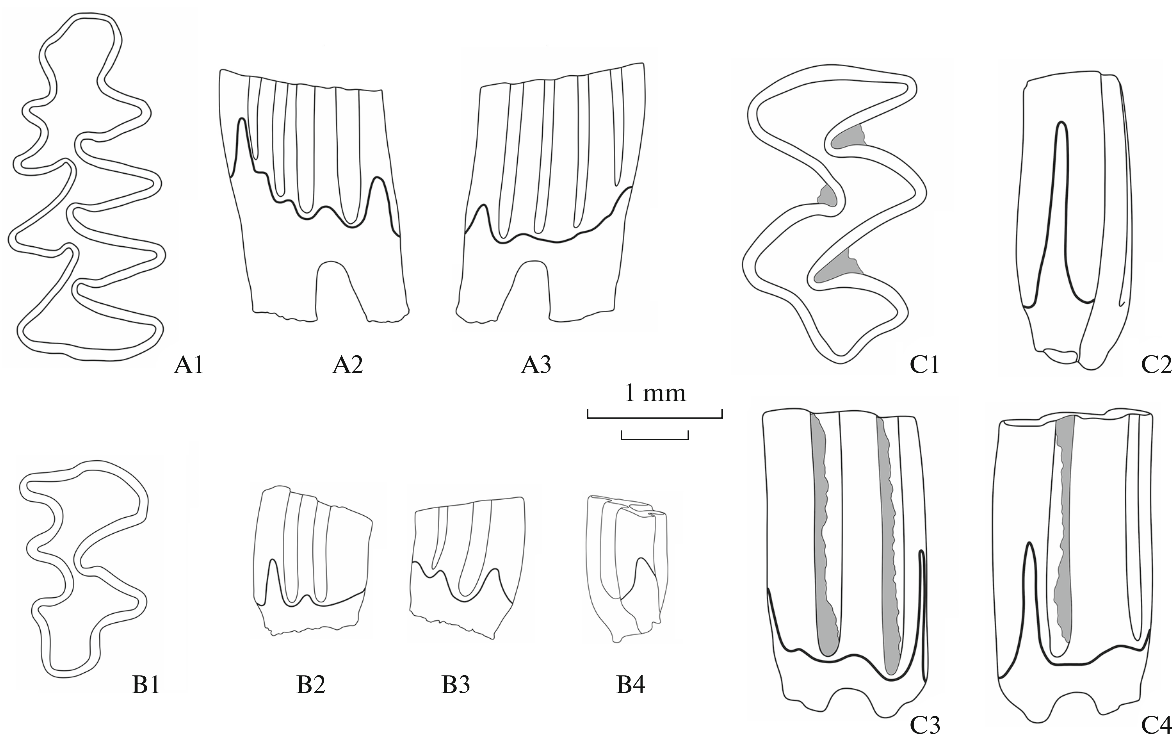

Fig. 16. Fossil remains of small mammals from sections of Late Pliocene deltaic deposits in the Erzurum Basin, Eastern Turkiye. 1. A, B: *Borsodia* sp., Paşayurdu; A, m1, sin., T7/18: A1, occlusal; A2, labial; A3, lingual vew. B, M3, dex., T29/19: B1, occlusal; B2, labial; B3, lingual; B4, posteror vew. C: *Mimomys* cf. *polonicus*, Çiğdemli; M2, sin., T4/18: C1, occlusal; C2, labial; C3, lingual vew. Scale bars are for occlusal (upper) and lateral views (lower).

denticles. *M. pupoides* is common in the Greater Caucasus, Georgia, and Armenia. It inhabits scree habitats of mountain slopes in the Artvin, Kars, and Erzurum Provinces of Turkiye. In Armenia, it is characteristic of the mountain-steppe conditions. *M. lamellifera* occurs in Çanakkele, Manisa, Amasya, Tokat, Sivas, and Mardin Provinces. They prevail in North Anatolia, being common in Amasya and Tokat Provinces and more rare in others, inhabiting wooded habitats (Akramovski, 1976; Schütt, 2005; Welter-Schultes, 2012). We assume that our shells are closer to *M. pupoides*. Many representatives of the Enidae and Geomitridae families also prefer steppe settings. *Vallonia* usually prefers wet habitats and Succineidae occupy moist habitats. In our case, they apparently lived along the water basin shore.

Few of our shells are identical to *Radix lessonae* (Issel, 1865) described and illustrated by Schütt (1991) from the sand pit east of Horasan, Turkiye (Pliocene Horasan Beds). The researchers noted their small size of 5–6 mm, although some fragments belong to larger shells (Issel, 1865; Andrusov, 1923; Kolesnikov, 1950). Schütt (1991) reported variable shell size from small to larger forms.

The second (after *Dreissena*) most abundant mollusc is *Pseudamnicola*. All SEM inspected shells of *Pseudamnicola* show microscopic traces of drilling (bioerosion). The same traces were also found on a shell of Pyrgulidae (Fig. 15). This may indicate that these molluscs lived in different conditions relative to the rest members of this taphocoenosis. Because species of these groups tolerate both fresh and brackish water conditions, and this type of bioerosion is more typical for saline waters and is rare in fresh waters, it can be assumed that the stream that formed the studied delta flowed into a brackish water body. No borings were found on the shells of other mollusc species, which excludes post-sedimentary alterations.

From an ecological point of view, most freshwater species, such as members of the Lymnaeidae and Planorbidae, prefer conditions with slow current and abundant vegetation. Summing up the above given considerations we can assume that the studied association inhabited steppe-like areas on the land and aquatic habitats along the shores of Late Pliocene fluviatile-lacustrine water basin, mostly fresh-water in the delta zone and conceivably brackish-water off-shore.

Small mammals. Several teeth of small mammals were found in samples taken from the layers of phases I (samples T1/18, T30/19, T33/19), III (T31/19), phase VII (samples T7/18, T29/19), and VIII (T29A/19) of the axial part of the delta (58/17) and from layer 1.6 of the section in a quarry located northwest of the Çigdemli village (59/17) and representing

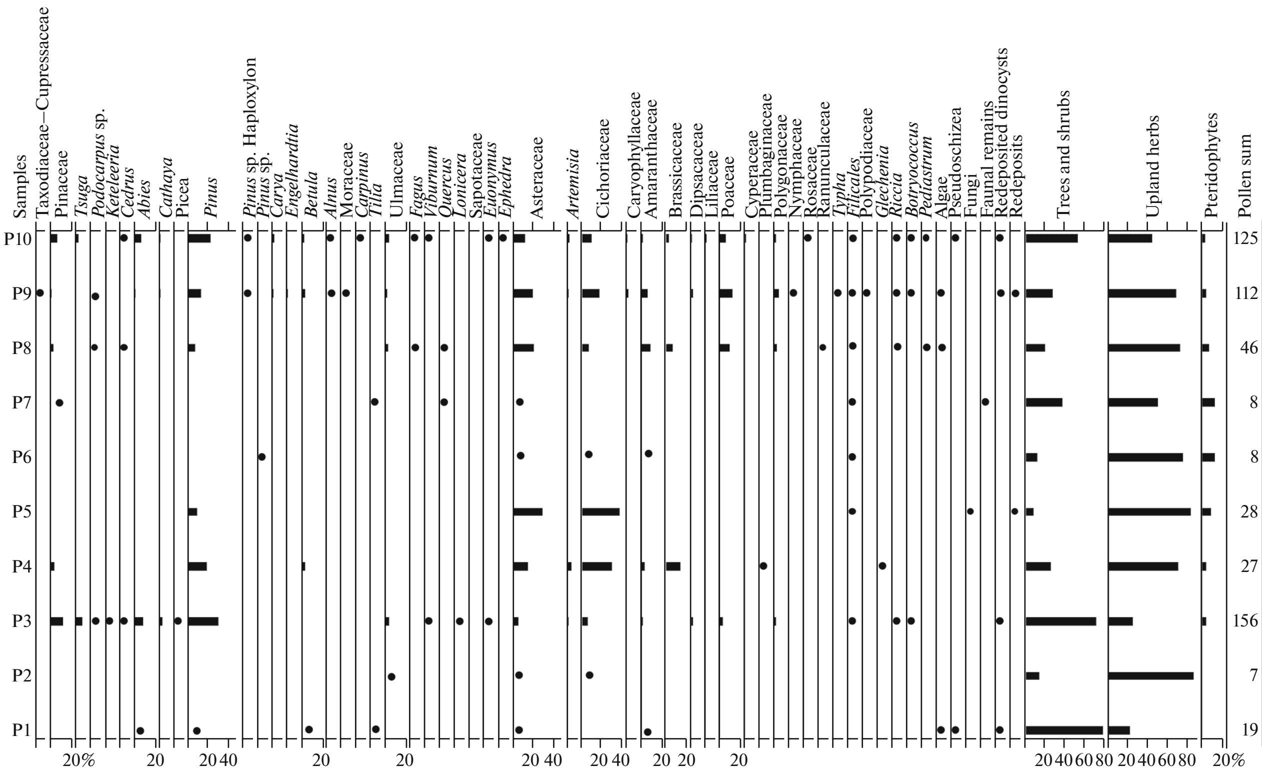

Fig. 17. Pollen diagram for the delta deposits. ●—single pollen grains. Position of samples is shown in Fig. 8.

the southern periphery of the delta (T4/18). The fossil material is referred to *Mimomys* cf. *polonicus* Kowalski, 1960 (T1/18, T29/19, T30/19, T33/19, T4/18) and *Borsodia* sp. (T7/18, T29/19, T30/19) (Fig. 16). All finds belong to the MN16 unit of the European biochronological scale and determine the age of the host sediments as the Late Pliocene (Piacenzian). In the regional aspect the small mammal fauna of the Paşayurdu-Çiğdemli deltaic deposits is immediately evolutionary preceding to the fauna of Pekecik located in the neighbouring Horasan basin (Ünay, de Bruijn, 1998; Simakova et al., 2021). The Pekecik fauna includes fossil arvicolines *Mimomys praepliocaenicus* Rabeder, 1981, *Mimomys reidi* Hinton, 1910, *Borsodia* cf. *praehungarica* (Schevtschenko, 1965), *Pitymimomys stranzendorfensis* Rabeder, 1981, and *Clethrionomys primitivus* Popov, 2000. This fauna belongs to the unit MN17 and Early Villanyian and based on paleomagnetic data dates to the terminal Gauss Chron, ca. 2.6 Ma (Simakova et al., 2021). This time level provides an upper age control for the Paşayurdu-Çigdemli fauna. The latter fauna is thus bracketed between 2.6 Ma and ca. 3.0 Ma. The lower time limit is controlled by the lower limit of the MN16b biochronological unit, which is estimated to be close to 3.0 Ma (Fejfar et al., 1998).

The paleoenviromental signature of the sparse small mammal association indicates the presence of riparian (*Mimomys*) and steppe-like (*Borsodia*) habitats.

Palynological Data

Ten palynological samples have been taken from delta phases I to X. Sampling points of samples P2-P10 in the main exposure are indicated in Fig. 8. The sample P1 was taken at the base of the delta sequence in the rear quarry (Fig. 12) immediately to the N from the main section.

The lower sample P1 was collected from the brown clays of the lacustrine type with fragments of molluscan fauna. The pollen of the arboreal group slightly dominates (55%) in the total composition. *Pinus* and *Abies* are abundant in the pollen spectra (Fig. 17). The arboreal group also includes *Tsuga canadensis* type and *Tsuga diversifolia* type, *Cedrus*, *Carya*, *Fagus, Betula, Alnus, Carpinus,* and *Ulmus*. The herbaceous group is represented by the pollen of Asteraceae, Poaceae and more rare *Ephedra*, Chenopodiaceae, and Plumbaginaceae. The sample contains the spores of green algae *Botryococcus braunii* and *Pediastrum* sp. The spectrum also contains redeposited palynomorphs of the Mesozoic and Paleogene age (Pinaceae sp., *Chiropteridium* sp., *Meiorugonyaula*x sp., and *Callialasporites* cf. *trilobatus*).

These data show that coniferous forests with *Cedrus, Tsuga*, and *Abies* grew at higher elevations. Mixed forests with *Pinus, Fagus, Carpinus*, and *Ulmus* occurred below. Low hypsometric levels were covered with meadow-steppe vegetation. A similar palynolog-

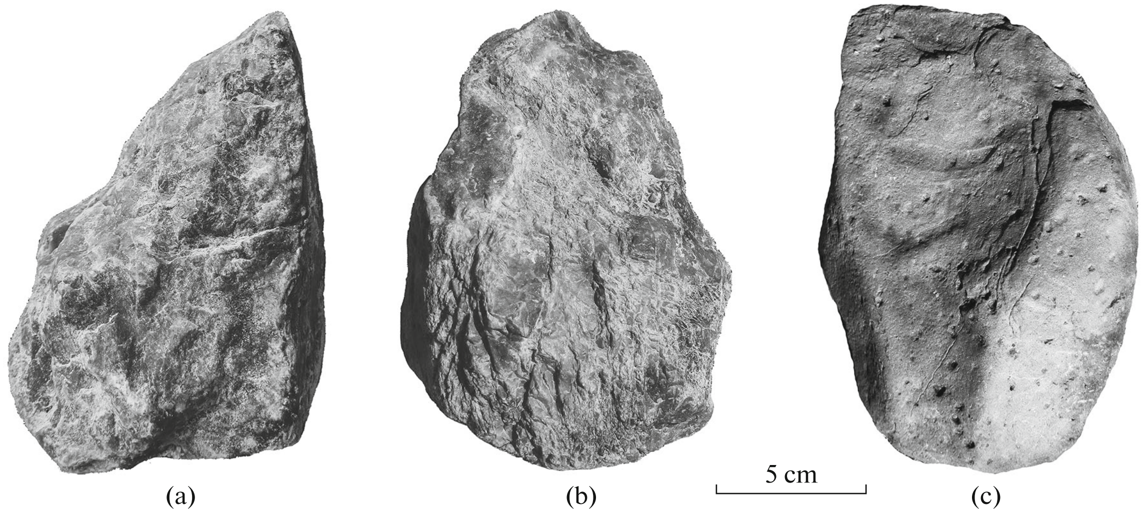

Fig. 18. Early Paleolithic stone tools (site 58/17) from the surface ((a, b) cores) and in deposits of the Early Pleistocene terrace ((c) pick).

ical picture is characteristic for the lacustrine clays of the sample P8 at the top of the phase VIII.

In other samples taken from the sediments of the delta (except samples P1, P2, P8), the concentration of palynomorphs is poor. However, all samples show a high content of herbaceous pollen grains in the total composition of the pollen spectra (70–80%). They represent Asteraceae, Chenopodiaceae, Brassicaceae, and Poaceae. It is conceivable that formation of delta sediments took place under climatic aridization and expansion of meadow coenoses.

The dominance of coniferous (pine) forests in the mountain areas of the North-Eastern Mediterranean, Turkiye, south of the Russian Plain, North Caucasus, and Georgia is noted in the Late Pliocene (Ananova, 1974, Shatilova, 1974; Jiménez-Moreno et al., 2007, 2015; Yavuz-Işık et al., 2010; Işik et al., 2011; Shatilova et al., 2011; Naidina and Richards, 2016). All authors noted the arid climate at the end of the Pliocene. Thus, the obtained palynological material supports the Late Pliocene age of the delta sediments. The delta was formed at the time of a climatic aridization.

Archaeological Data

Several weathered and slightly rounded Paleolithic pieces have been collected on the surface of the terrace formed by gravels of the phase 12 covering cross-bedded deposits of the delta axis (site 58/17). These are two cores, three flakes and a pointed tool made of andesite or dacite. The cores 11–14 cm-long have large uni-directional scars on the knapping surface (Figs. 18a, 18b) and unprepared striking platforms. The flakes are also quite large (length, 9–10 cm) with unprepared butts. Two flakes are semi-cortical, i.e., there are single scars and cobble cortex on the dorsal face. A dorsal face of the third flake shows previous sub-radial or fan-like detachments. A single tool (length, 7.3 cm) was fashioned on a flake. Initially its ventral side was worked with thinned flat detachments and then terminal flaking formed both edges and pointed tip. The technological and morphological features of the artifacts suggest their Acheulian age. They are not sufficiently indicative to be placed definitely into a particular period of the Acheulian, though more likely, they belong to the earlier stages of the epoch. Since these pieces were found at the top of the terrace, the latter cannot be younger than the early Middle Pleistocene.

Two other Paleolithic pieces made of siliceous rock were found in the gravel talus below a section with exposed layer 12 in the large quarry neighboring in the north-west to the delta section of the site 58/17. The first is a small semi-cortical flake that might belong to any period. In contrast, the second artifact enables to specify age limits of the layer 12. This is a very large and massive tool (15.2 × 10.6 × 9.8 cm) with a narrow end fashioned as an oblique and slightly concave cutting edge. For the given features, this tool should be identified as chisel-ended pick (Fig. 18C). The pick was made of a bar-like piece and its butt, plain ventral face and one edge are natural faces with several flattening removals. Another lateral edge, dorsal face and working edge were formed by intensive, but rather rough flaking. This tool type is very characteristic for the Early Acheulian, gets rare in middle Acheulian industries of early Middle Pleistocene, and disappears hereafter. Hence, the find of a pick in gravels allows to date the phase 12 to Early Pleistocene.

Magnetostratigraphy

Altogether 41 palaeomagnetic samples were collected from the main section of the central part of the delta (to the SW of the village of Paşayurdu). 39 samples showed normal remanent magnetic polarity and two samples from the upper phases gave uncertain results. 15 palaeomagnetic samples were collected from the southern periphery of the delta (the quarry to the NW of the village of Çigdemli). 13 samples showed normal magnetic polarity and two samples from the middle part of the section gave uncertain results. Taking into account the Late Pliocene biotic signal from the section and archaeological data, the paleomagnetic data likely indicate its correlation with the Gauss paleomagnetic chron (C2An).

Summing up the obtained results it is possible to date the delta deposits (phases I to XI) and their analogs to the Late Pliocene (Piacenzian) and the covering terrace alluvium (bed 12) to the Early Pleistocene.

DISCUSSION

The described Upper Pliocene delta represents an excellent example of the Gilbert-type delta. The obtained data can be used for interpretation of similar sedimentological formations that are controversial because of worse exposition or preservation. This is especially important for understanding the structure of large deltas that are promising for hydrocarbon exploration. The studied delta belongs to the river that fell into the Erzurum Basin from the west. The fine-grained clastic composition of the delta deposits indicates that the longitudinal river slope was weak and the uplift of clastic material sources was insignificant.

The Upper Pliocene sediments of the axial part of the delta (site 58/17) form the base of the terrace covered by the Lower Pleistocene alluvium. The western continuation of this alluvium composes the 2-meter thick upper layer of the site 1/19 outcrop, where the lower 3.5 m thick sequence of silts with two paleo-soil horizons can be correlated to the upper part of the site 59/17 section. Farther to the west, the thicker analogs of the same gravels are exposed in sites 2/19 to 4/19 and compose the upper part of the site 5/19 section, covering with unconformity the dipping in the eastern directions upper Miocene–Pliocene soft siltstones, marls, and marly clays on the northern side of the Karasu River valley. These gravels mark the channel of the Early Pleistocene river that flowed to the ENE and, perhaps, inherited from the Upper Pliocene river delta.

The recent Karasu River (upper reaches of the Euphrates River) drains the Erzurum Basin and flows southwards of the mentioned Early Pleistocene valley to the WSW, i.e., in the opposite direction (Fig. 2). The Karasu River terraces are lower than the outcrops marking the Early Pleistocene valley. Therefore, the Karasu River valley is younger and was formed not earlier than the late Early Pleistocene or early Middle Pleistocene. The drainage system of the Erzurum Basin was thus considerably restructured.

The Erzurum Basin is now a western member of a row of intermontane depressions. The Pasinler, Horasan, and Agri (Middle Araxes) Basins are situated to the east of it. All three basins are drained by the Araxes River and/or its tributaries. The Agridag Ridge with the Late Quaternary active Ararat (= Agri) volcano in the east is situated to the south of the Horasan and Agri basins. To the south of the ridge, the Agri Basin is situated. It is drained by the Murat River, the largest tributary of the Euphrates, flowing down from the slope of Ararat Mountain.

The Erzurum, Pasinler, and Horasan basins are now separated by the NE-trending weakly uplifted sawnecks ruptured by longitudinal active faults with a leading left-lateral component of movements. All three basins feature the similar type of infill of fine-grained clastic and less common carbonate deposits of Upper Miocene–Pliocene. The same deposits compose the NE-trending sawnecks, where they are combined with the Late Miocene–Pliocene subaerial volcanic rocks. These volcanic rocks are exposed in the sawnecks between the Erzurum and Pasinler Basins and, to a lesser extent, between the Pasinler and Horasan Basins. The volcanic formations are intermittent and allow water communication between the basins. We consider that the paleo-Araxes valley extended to the Erzurum Basin and further to the west in the Late Pliocene–Early Pleistocene. The valley has a cellular form and consists of wide basins with lacustrine-lagoon and alluvial sedimentation and narrowed river valleys in sawnecks between them.

The Upper Miocene–Pliocene thin-bedded silts and marls of sites 61/17 and 5/19 are exposed westward of the Upper Pliocene delta. This shows that the Erzurum water reservoir decreased in the Late Pliocene because of uplift of the western margins of the basin. In the Early Pleistocene, the tectonic uplift increased and also involved the sawneck between the Erzurum and Pasinler Basins. The Erzurum Basin was isolated and the upper reaches of the paleo-Araxes were captured by the upper reaches of the Euphrates River in the late Early Pleistocene or early Middle Pleistocene.

The rebuilding of the drainage system of the Erzurum Basin is of particular importance in connection with the problem of the penetration of oceanic waters into the Akchagylian basin of the Caspian region. In the 22–25 m thick fine-grained uppermost Pliocene part of the lacustrine-alluvial Pekecik section of the Horasan Basin, the marine dinocysts of the Akchagylian aspect were found (Simakova et al., 2021). The similarity of the sections of the Horasan and Erzurum Basins and the possibility of water communication between them in the Late Pliocene allow us to assume the presence of the Upper Pliocene marine Akchagylian in the Erzurum Basin. We did not find a direct evidence of such a connection, but the presence of mollusc species that can tolerate brackish-water conditions does not contradict it.

It has been suggested that the waters of the Mediterranean Sea or the Persian Gulf could enter the Akchagylian basin through the upper reaches of the Euphrates River and the Erzurum Basin. However, the results presented in this paper contradict this assumption. First, the Late Pliocene water reservoir of the Erzurum Basin was limited in the west by the river delta, which flowed into the basin from the west. Secondly, the upper reaches of the Euphrates penetrated into the Erzurum Basin not earlier than the end of the Early Pleistocene, i.e., after the Akchagylian events, when the Erzurum Basin was isolated from the Araxes River valley. This makes the inflow of the oceanic waters into the Akchagylian basin through the upper reaches of the Euphrates and the Erzurum depression very unlikely.

CONCLUSIONS

The intermontane Erzurum Basin arose in NE Turkiye no later than the late Miocene between two Late Mesozoic ophiolite zones, continuing the Izmir–Ankara–Erzincan suture to the east. In the Late Miocene–Pliocene, the basin was filled with sediments of the lacustrine-lagoon type. The Gilbert type delta formed in the western part of the basin in the Late Pliocene. The age of the delta is substantiated by the findings of the fauna of mollusks and small mammals, the results of palynological and magnetostratigraphic analysis. The exposed part of the delta consists of 11 wedge-shaped bodies of mainly fine-grained deposits that represent different phases of the delta development. Toplap division of some of these phases was eroded by subsequent currents due to water level changes. The bottomsets are buried. Foresets are dipping to the east with a variety of angles ranging from 5° to 35°. Most of them have soft sediment deformation structure (SSDs) especially at the high angle parts of the foreset beds. The eroded surface of the delta is overlain by the Lower Pleistocene alluvial pebbles and sands with records of river flow to the east.

The delta structure and location show that some river flowed into the Erzurum Basin water reservoir from the west in the Late Pliocene. The fine-grained clastic composition of the delta deposits indicates that the longitudinal slope of this river was weak. The presence of upper Miocene–Pliocene silts and marls of the lacustrine-lagoon type to the west of the delta, near the western borders of the basin testifies that the Erzurum water reservoir was reduced at the time of the delta formation due to the rise of the western part of the Erzurum Basin. Its reduction continued in the Early Pleistocene.

The Erzurum Basin is a western member of a row of intermontane basins extending eastward by the Pasinler and Horasan ones. All three basins are composed of the similar upper Miocene–Pliocene sediments. They formed in a single basin of sedimentation of that time. The basin had a cellular structure and consisted of wide depressions with lacustrine-lagoon and alluvial sedimentation that corresponded to the resent basins, and narrow river segment between the depressions. The Pasinler and Horasan Basins are drained now by the Araxes River and its tributaries. It is likely that the paleo-Araxes spread to the Erzurum Basin in the Late Pliocene and Early Pleistocene, and the described delta was formed by the paleo-Araxes upper reaches that flowed into the basin from the west. The Erzurum Basin was isolated from the Araxes river system in the late Early Pleistocene by tectonic uplift of the sawneck between the Erzurum and Pasinler Basins. As a result, the upper reaches of the paleo-Araxes were captured by the spreading into the Erzurum Basin upper riches of the Euphrates River (Karasu River), which drain the Erzurum Basin now.

The Akchagylian marine dinocysts were found in the layers of the Horasan Basin, which are attributed to the uppermost Pliocene. The waters of the Akchagylian reservoir could reach the Erzurum Basin. However, the assumption that the upper reaches of the Euphrates River and the Erzurum Basin were the channel, through which waters and biota of oceanic origin (from the Mediterranean Sea or the Persian Gulf) entered the Akchagylian sea, seems very unlikely for two reasons. First, the Erzurum Bain was limited in the Late Pliocene by the river delta, which flowed into the reservoir from the west. Secondly, the upper reaches of the Euphrates penetrated into the Erzurum Basin and captured its drainage network already after the basin of the Akchagylian time (Late Pliocene–Gelasian) ceased to exist.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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