



Pliocene – Early Pleistocene history of the Euphrates valley applied to Late Cenozoic environment of the northern Arabian Plate and its surrounding, eastern Turkey

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ABSTRACT

The Pliocene–Quaternary paleogeography of the Euphrates River valley changed due to sinistral movements on the East-Anatolian Fault Zone (EAFZ) and the Taurus Ridge rise by movements on the South-Taurus Thrust. Evidence of these changes is based on studies of the Pliocene–Quaternary deposits of the Euphrates River basin to the north and to the south of the Taurus Ridge and the Late Cenozoic deformation including offsets on the EAFZ. Combination of methods was used to date the Pliocene–Quaternary deposits. It includes geological and geomorphic analysis and correlation of sections, determination of remanent magnetization, paleontological and archaeological finds, pollen analysis, and K–Ar dating of volcanic rocks. To the north of the Taurus Ridge, the Late Miocene tectonic depressions were filled by lakes connected by braided streams. In the Early Pliocene, the Euphrates and Murat river valleys formed and the Euphrates flew to the south westwards of its recent position, via the graben-like trough of the Sultan-Suyu River valley and farther to the Erikdere that are recent Euphrates tributaries. The flow was interrupted later because of some desiccation and rise of the Taurus Ridge. The flow recommenced in the end Gelasian – early Calabrian via the Göksu-Çayı and Erikdere valleys consecutively and was interrupted again. At the end of Calabrian (~0.8–0.9 Ma), the Euphrates waters found the recent way via the Taurus Ridge and the former upstream bottoms of the Euphrates and its tributaries valleys became a vast upper terrace. After this, the Taurus Ridge rose by more than 330 m. Lower terraces were formed because of the tectonic uplift that was more intense to the north of the Taurus Ridge (0.13–0.16 mm/year), than to the south of it (0.1 mm/year). The new-formed segment of the Euphrates valley was offset on the EAFZ at 12 km that gives the slip rate of 13–15 mm/year.

1. Introduction

The aim of the present paper is to determine the roles of the Taurus Ridge rise due to movements on the South-Taurus (Bitlis) Thrust Zone, and left-lateral slip on the East Anatolian Fault Zone (EAFZ) during the Pliocene–Quaternary evolution of the Euphrates River valley. Pliocene–Quaternary sections north and south of the Taurus Ridge, offsets of the Euphrates and its major tributaries on the EAFZ, and other

deformation are studied, and the Euphrates river basin evolution is reconstructed. The study region occupies the lower Murat River valley, the right bank of the Euphrates River downstream of the Murat mouth around the city of Malatya, and the Euphrates western tributaries to the south of the Taurus Ridge (Figs. 1–3). The valleys are surrounded by mountains of low and middle height. The highest mountain is the Taurus Ridge with some peaks up to 2500 m.

Studies of the Lower Pleistocene deposits and their paleontological

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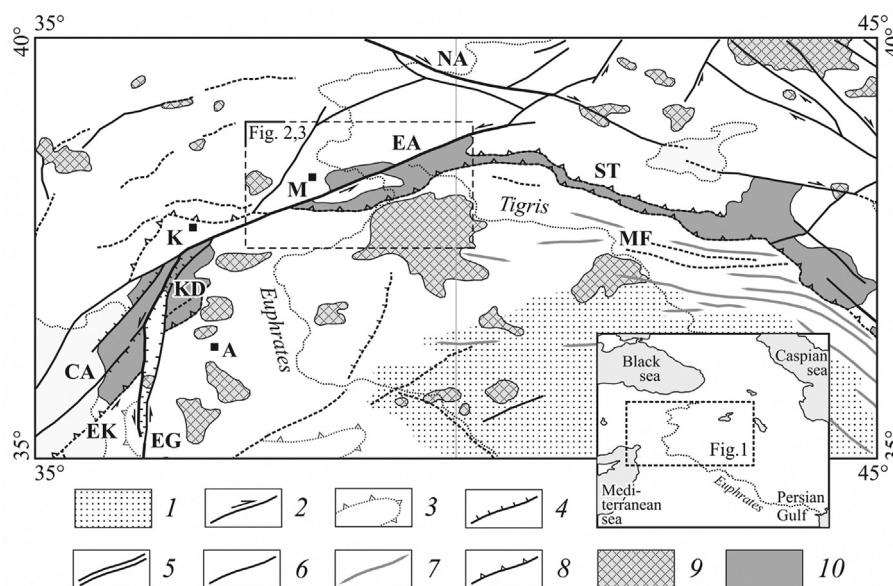


Fig. 1. Tectonic scheme of the foreland and northern surrounding of the Arabian Plate. The region of studies is shown. (A) the city of Aleppo, (K) the city of Kahramanmaraş, (M) the city of Malatya.

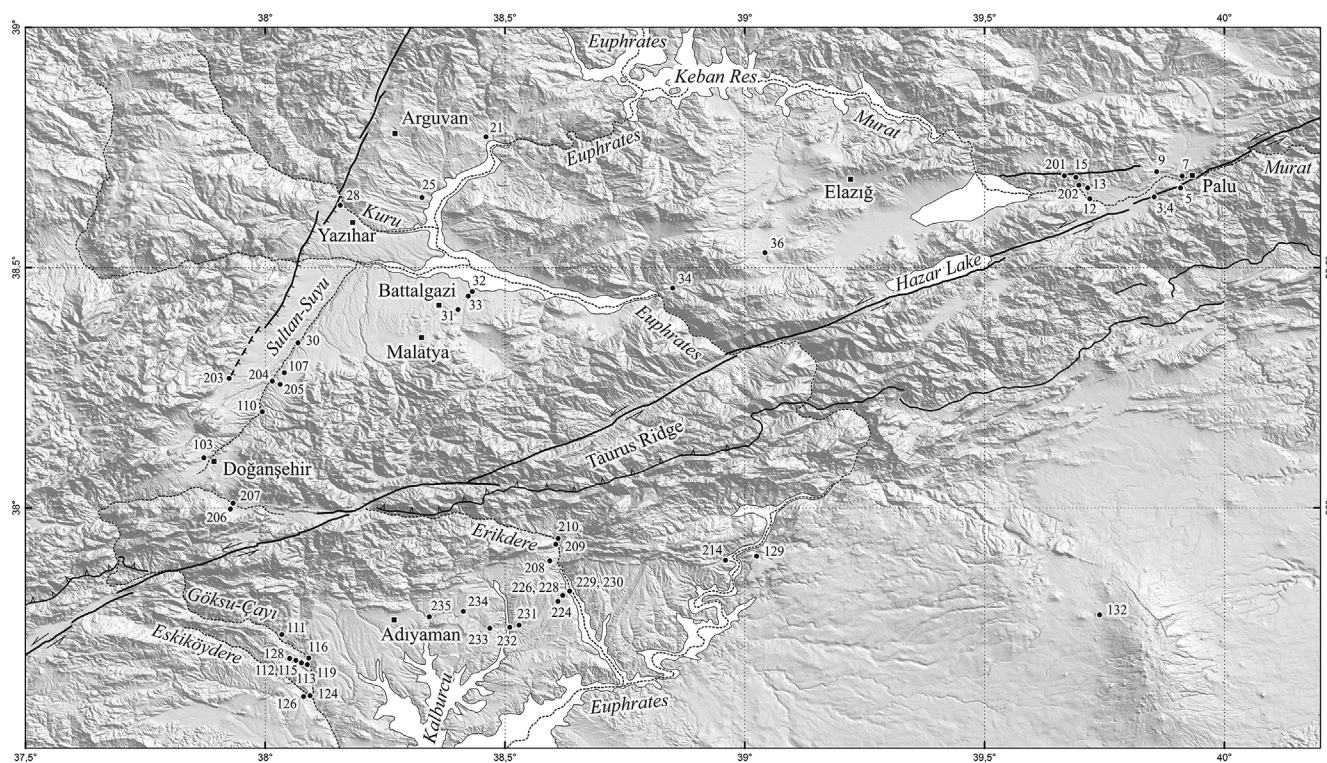


Fig. 2. The map of topography and drainage system of the region of studies with major Late Cenozoic faults and sites of observation mentioned in the text.

dating, as well as finding of the *Homo erectus* cranium fragments were the most successful in Western Turkey (Alçiçek et al., 2013; Lebatard et al., 2014). At the same time, Eastern Turkey and particularly the Euphrates and Murat valleys are situated on the migration pathway of the earliest human ancestors, whose archaeological remains were found in Syria, South-Eastern Turkey, Armenia, Georgia and on slopes of the Greater Caucasus (Besançon et al., 1978; Copeland, 2004; Demir et al., 2008; Shchelinsky et al., 2010; Ferring et al., 2011; Belyaeva and Lyubin, 2013; Amirkhanov et al., 2014). This impelled us to pay particular attention to the Lower Pleistocene deposits and their geomorphological position to get an insight into the paleoenvironment of the

oldest hominine migration.

In our stratigraphic studies of the Lower Pleistocene and Pliocene, we used combination of methods described in details in our previous investigations in Syria (Trifonov et al., 2012, 2014) and Armenia (Trifonov et al., 2016). The applied methods consisted in geomorphic correlation of terraces, detailed description and correlation of sections based on age determination by examination of remanent magnetic polarity of deposits, K-Ar dating of volcanic rocks, pollen analysis, and interpretation of faunal and archaeological finds. Each of these methods alone cannot give a certain explanation if used separately, but the integration of methods can lead to new and significant results. We note

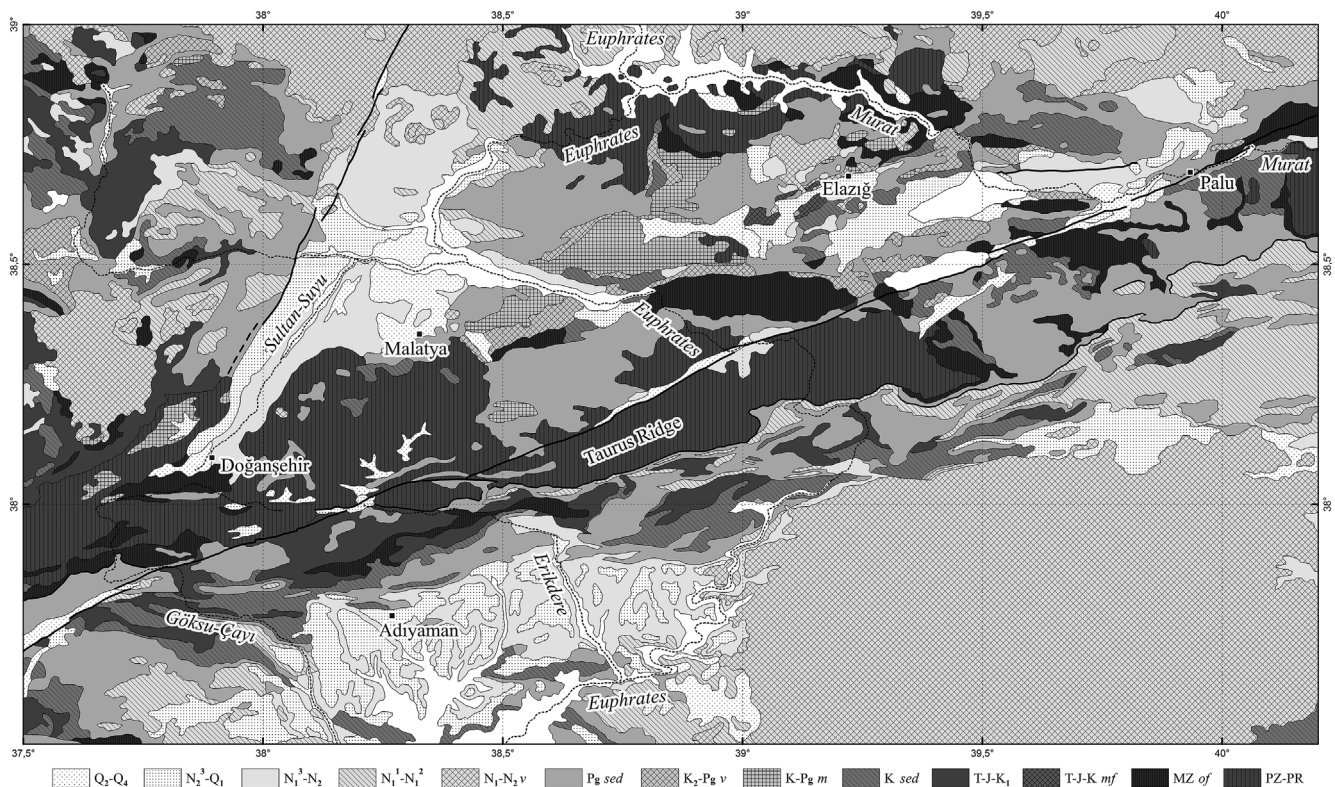


Fig. 3. Simplified geological map of the region of studies, after (Geological Map of Turkey, 2002a,b) with changes. (Q₂-Q₄) Middle Pleistocene to Holocene; (N₂³-Q₁) Lower Pleistocene (Palu Formation and its analogs); (N₁³-N₂) Pliocene and probably Upper Miocene (Çaybağı Formation and its analogs); (N₁¹-N₁²) Lower and Middle Miocene; (N₁-N₂ v) Miocene and Pliocene, volcanic; (Pg sed) Paleogene sedimentary; (K₂-Pg v) Upper Cretaceous and Paleogene, volcanic; (K-Pg m) Cretaceous and Paleogene intrusions; (K sed) Cretaceous sedimentary; (T-J-K₁) Triassic, Jurassic, and Lower Cretaceous; (T-J-K mf) Triassic, Jurassic, and Cretaceous metamorphosed; (MZ of) Mesozoic ophiolite; (PZ-PR) Paleozoic and Proterozoic metamorphic.

particularly our new technique of paleomagnetic sampling collected in loose deposits. Its application was sometimes the only source of information for “dumb” parts of the sections.

Magnitudes of strike-slip fault displacement were estimated by measurement of offsets of drainage system elements including large valleys, like the Euphrates and Murat Rivers. Magnitudes of vertical uplift were determined by comparison of heights of correlated terraces. The terraces corresponding to an epoch of existence of lake in a valley, give the most correct result of the comparison. If we try to estimate the uplift by comparison of fluvial terraces, we must take a longitudinal river profile into account. For example, the altitudes of Early Pleistocene terraces of the Sultan-Suyu River decrease from its upper reaches that are situated in the Taurus Ridge, downstream. The Sultan-Suyu River is the right tributary of the Euphrates and currently flow to the NNE. But the Sultan-Suyu valley was a segment of the Euphrates valley in the Early Pleistocene. Its water flew to the SSW through the Taurus Ridge and the Sultan-Suyu recent upper reaches were lower, than its lower reaches at that time. Thus, the difference of altitudes between the Sultan-Suyu upper and lower reaches corresponds only to the minimum rise of the Taurus Ridge from the end of Early Pleistocene.

The present paper contains results of studies of Joint Turkish-Russian Group that worked in the described region in 2014–2016 according to the agreement between the Furat University in the city of Elazığ and the Geological Institute of the Russian Academy of Science in Moscow for studies of Pliocene-Quaternary stratigraphy and tectonics. The Russian participants of the Joint Group were invited for field works in Turkey by the Furat University that has permission to carry out this kind of studies. During field works in Turkey, the Joint Group did not produced any excavations of paleontological and archaeological sites, but collected different samples from natural outcrops and land surface, including fragments of fossil mammal bones and Paleolithic specimens.

In every season, we informed the Furat University administration about our finds and placed them to the Furat University after field works for the further on presentation to the Elazığ University Museum. The University collection of our finds contains now the well preserved skull of *Parabos cf. savelisi* from Kahta, several fragments of other large mammal bones, and Paleolithic artefacts from different sites. Our finds of fragments of *Hipparion cf. crassum*, *Arvernoceros sp.*, and *Gazella cf. desperdita* from the Sultan-Suyu valley were lost after their documentation because of bad preservation. The small mammal material listed in the paper was retrieved from sediments during the sample sorting in the laboratory in Moscow and will be transported to Furat University after morphological description in a separate publication.

In this paper, we use the stratigraphic division of the Neogene and Quaternary, adopted at the 33rd IGC (www.stratigraphy.org), and the following abbreviations: K₂Pn – Upper Cretaceous and Paleocene, E – Eocene, N₁³ – Upper Miocene, N₂¹ – Lower Pliocene (Zanclean), N₂¹ – Upper Pliocene (Piacenzian), Q₁¹ – Gelasian, Q₁ol – Olduvai subchron, Q₁² – Calabrian, Q₁²j – Jaramillo subchron, Q₂¹ – lower Middle Pleistocene (≥0.5 Ma), Q₂ – Middle Pleistocene, Q₃ – Upper Pleistocene, Q₄ – Holocene, H – altitude above sea level (a.s.l.), h – height above local river channel, s – site of observation, and N – normal and R – reverse magnetic polarity. Coordinates of sites were measured at the top of sections. All sections are described from top downwards.

2. Geological background

The South-Taurus (Bitlis) Thrust Zone (STTZ) combined with the Neotethys suture forms a structural axis of the region (Fig. 1). Robertson et al. (2004) reported that the relic Neotethys basin deepened in the Paleocene – Middle Eocene after the diastrophism of the end Cretaceous – Early Paleogene producing obduction of ophiolites

(Knipper et al., 1988). Subduction of the Late Eocene – Oligocene formed the accretion prism composed of fragments of the Mesozoic oceanic crust and its Early Paleogene cover. Subsequent collision of the Taurides and the Arabian Plate led to the covering of the STTZ prism by the Lower Miocene deposits.

More detailed data on the evolution of subduction into collision and further tectonic history were obtained for the STTZ and its southern surrounding westward of the EAFZ near the town of Çağlayancerit between cities of Kahramanmaraş and Malatya (Akinci et al., 2016). The STTZ is formed by series of nappes with coarse deposits including ophiolite debris at the base. The ophiolite mélange covers them, and the same ophiolites are affected eastward by the Late Cretaceous granites. The Bulgurkaya sedimentary mélange overthrusts the ophiolites. It consists of blocks of the Malatya Formation rocks, Upper Cretaceous and Eocene shallow-water carbonates and sandstones that are cemented by the pelagic material. The upper nappe consists of the metamorphic Malatya Formation that represents the Taurides basement (Fig. 3). The Arabian Foreland is composed of the Eocene and Lower Miocene carbonates that were replaced in the Early Miocene to the north by deep-water turbidites composed of the Taurides debris. According to the Akinci et al. (2016) interpretation, the ophiolites represent the basement of the subducted Neotethys crust and the Bulgurkaya mélange matrix represents its cover. The Bulgurkaya mélange constitutes the accretion lens in the Taurides side of the basin. As the ophiolites are Cretaceous, the later oceanic crust was not formed within the basin. Collision began in the Oligocene – Early Miocene, and the Lower Miocene turbidites deposited in the basin that was formed by thrusting of the Taurides into the Arabian Plate margin. Thrusting continued later on and produced the uplift of the Taurus Ridge that increased erosion and accumulation of the Upper Miocene – Quaternary alluvium in the Arabian Foreland. The sinistral shift on the EAFZ occurred in the Pliocene and Quaternary (Şaroğlu et al., 1992).

Oligocene deposits of Northern Syria represent the regressive part of the Early Paleogene sedimentary cycle (Krashenninikov, 2005). The regression increased in the Early Miocene. The Middle Miocene marine transgression spread over the whole northern Arabian plate (Ponikarov et al., 1967; Hüsing et al., 2009). Our studies show that relic bay of the Mediterranean existed in Southern Turkey till the Late Miocene. In the Ceyhan River valley to the NW of the city of Kahramanmaraş (s 120; N 37.62328°; E 36.80498°; H = 508 m), the shallow-water marls contain nannoplankton and benthic foraminifers. According to the M.E. Bylinskaya's examination, the benthic forms include genera *Heterolepa* sp., *Elphidium* sp., and *Ammonia* sp. of the Late Miocene (N-16, ~9 Ma). According to the L.A. Golovina's estimates, the nannoplankton is represented by the Neogene cosmopolitan species *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Helicosphaera carteri*, *Sphenolithus moriformis*,

and *Discoaster variabilis*. Their combination gives a possibility to suppose the Late Miocene age not earlier than zone NN 10 (9.53 Ma). The deposits contain rare grains of *Abies*, *Keteleeria*, *Momipites*, *Pinus* sp., *Moraceae*, *Ostrya*, *Carpinus*, *Ilex*, *Artemisia*, *Chenopodiaceae*, *Poly-podiaceae*. They justify that mixed forests grew in the Late Miocene, and the conifers occupied highlands. This bay was isolated by the Aleppo platform block from the Mesopotamian Foredeep, where fine-grained sediments, marls and gypsum accumulated in the lagoon conditions (Neotectonics, 2012).

Particular coastal Middle Miocene facies, that show cross-bedding sandstones and poorly sorted conglomerates of marine and fluvial origin, are formed in front of the STTZ. Derman (1999) described them northwards of Kahramanmaraş city and interpreted as delta deposits. Demir et al. (2008) assumed that they belonged to the Paleo-Euphrates. But similar deposits extend eastward along the STTZ and probably represent destructed products of thrusting and corresponding uplift of the Taurides margin (Robertson et al., 2016). Our pollen analysis of these conglomerates did not show any evidence of their marine sedimentation in the western bank of the Euphrates River (s 214 in Fig. 2; N 37.89096°; E 38.96053°; H = 620 m).

To the north of the Taurus Ridge, the oldest units are gneisses and slates of the Precambrian–Paleozoic Malatya Formation and the Upper Paleozoic – Lower Mesozoic marbles (Fig. 3). The Late Mesozoic–Cenozoic section starts with the Senonian calc-alkaline volcanic rocks of island-arc type. They are covered with the Maastrichtian–Paleogene carbonates and fine-grained deposits. They are mostly shallow-water marine formations, but the more deep-water deposits are present in the Middle Eocene – Lower Oligocene (Cronin et al., 2000, 2005; Çelik, 2012). The accumulated formations were deformed in the Oligocene and Early Miocene. This formed weakly contrasted topography with low highlands that is expressed by fine-grained composition of the Middle Miocene to Pliocene lacustrine and fluvial deposits. The coarse composition of the Pleistocene alluvium indicates quick uplift of the region.

These processes were accompanied by sub-areal basaltic volcanism. The Early and Middle Miocene basalts with 21–17 Ma K–Ar dates form a wide belt that extends along the western margin of the Arabian Plate in Syria (Trifonov et al., 2011). The belt continues to the north, where the basalts are characterized by 19–17 Ma K–Ar dates to the SE of the Kahramanmaraş city (Arger et al., 2000; Tatar et al., 2004). Similar basalts are found to the north of the South Taurus suture. In the right slope of the Euphrates valley eastwards of the town of Arguvan (s 24; N 38.82717°; E 38.40542°; H = 1366 m), the Middle Miocene carbonates and clay slates contain three layers of basalts. Two upper layers are characterized by K–Ar dates of 15.0 ± 0.9 and 18.5 ± 0.9 Ma; the date of the lower layer is not representative because of too big portion

Table 1

New K–Ar dates and chemical composition of volcanic rocks in Eastern Turkey.

No	Sample Year- No	Location	Coordinates WGS84	Name of the rock	Material	K, % $\pm$ σ	$^{40}\text{Ar}_{\text{rad}}$ (ng/g) $\pm$ σ	$^{40}\text{Ar}_{\text{atm}}$ % (in sample)	Age, Ma $\pm$ 2σ
1	2014-10/1	Elazığ City, s 10	N 38°38.545' E 39°13.554'	Basalt Q ₁ ²	Ground-mass	2.08 ± 0.03	0.210 ± 0.003	35.0	1.45 ± 0.06
2	2014-24/2	Right side of the Euphrates valley, s 24	N 38°49.630' E 38°24.325' H = 1366 m	Basalt N ₁ ²	"	0.384 ± 0.010	0.400 ± 0.007	84.6	15.0 ± 0.9
3	2014-24/5	Right side of the Euphrates valley, s 24	N 38°49.630' E 38°24.325' H = 1366 m	Basalt N ₁ ²	"	0.458 ± 0.010	0.592 ± 0.006	50.6	18.5 ± 0.9
4	2014-24/7	Right side of the Euphrates valley, s 24	N 38°49.630' E 38°24.325' H = 1366 m	Basalt N ₁ ²	"	0.830 ± 0.017	0.96 ± 0.03	91.4	16.6 ± 1.1
5	2015-129	Left side of the Euphrates valley, s129	N 37°53.923' E 39°01.529' H = 709 m	Basalt N ₁ ³	"	1.33 ± 0.02	0.806 ± 0.003	46,6	8.70 ± 0.25
6	2015-131	Left side of the Euphrates valley, s131	N 37°53.235' E 39°03.393' H = 850 m	Basalt N ₁ ³	"	0.840 ± 0.015	0.484 ± 0.003	65,4	8.3 ± 0.3
7	2015-132	Left side of the Euphrates valley, s132	N 37°46.632' E 39°44.404' H = 1227 m	Basalt Q ₁ ²	"	1.42 ± 0.02	0.1048 ± 0.001	46,9	1.06 ± 0.05

Table 2
Chemical composition of volcanic ricks dated by the K-Ar method, Eastern Turkey.

Main oxides, %													
No.	Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	K ₂ O	Na ₂ O	P ₂ O ₅	Lost	Sum
1	2014-10/1	44.83	2.85	19.71	10.15	0.19	2.56	9.31	3.00	6.00	0.80	0.30	99.71
2	2014-24/2	46.57	1.23	16.46	10.87	0.15	8.31	8.02	0.34	3.31	0.16	4.34	99.77
3	2014-24/5	47.40	1.44	19.07	10.03	0.14	4.83	9.66	0.51	4.62	0.25	1.83	99.78
4	2014-24/7	49.72	1.45	17.50	9.33	0.13	1.65	10.66	0.75	4.73	0.17	3.39	99.50
5	2015-129	48.18	2.66	15.78	10.81	0.15	5.37	8.44	1.68	3.40	0.37	2.63	99.37
6	2015-131	49.07	1.95	16.52	11.65	0.16	4.68	9.88	0.86	3.65	0.21	0.52	99.15
7	2015-132	45.22	3.59	14.50	14.21	0.18	5.86	8.72	1.68	4.35	0.56	1.10	99.96

Minor elements (ppm)																			
No.	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	As	Rb	Sr	Y	Zr	Nb	Mo	Ba	Pb	Th	U
1	29	150	76	51	25	50	73	19	< 3	44	930	27	270	97	< 1	560	15	14	7
2	27	120	230	56	160	40	73	15	5	13	250	24	98	8	< 1	160	6.3	< 2	< 2
3	27	140	140	40	55	51	77	18	3	16	320	27	130	8	< 1	120	8.2	3	< 2
4	28	130	110	32	93	69	69	18	7	25	420	28	160	13	< 1	240	9.5	3	< 2
5	17	233	198	40	60	37	104	22	< 5	23	484	23	194	29	< 3	262	5.4	3	< 2
6	19	210	309	51	168	81	102	22	< 5	17	378	21	137	14	< 3	155	4.2	< 2	< 2
7	20	251	288	58	227	98	134	24	< 5	14	893	21	272	39	4.3	182	4.1	2.9	< 2

of atmospheric argon in the probes (Tables 1 and 2).

The large Karacadağ field of basic lavas covers the northern Arabian Plate SE of the studied region (Keskin et al., 2012b; Ekici et al., 2012, 2014). Keskin et al. (2012a) divided volcanism of the lava field into three stages. Using K-Ar dates, they attribute the late part of the first stage to 6.5–7.0 Ma, the early part of the second stage to 4.0–2.6 Ma, its late part to 1.8–1.0 Ma, and the third stage to ~0.4 Ma and younger. Our studies allowed to date the early part of the first stage to 9.0–8.0 Ma (samples 129 and 131 in Table 1) and the end of the second stage to 1.06 ± 0.05 Ma (sample 132).

To the north of the South-Taurus suture, volcanic formations dated to Pleistocene are rare. The only proved Pleistocene basaltic flow with K-Ar date 1.45 ± 0.06 Ma is situated near the Elazığ city (s 10; N 38.64242°; E 39.22591°; Fig. 4 and Table 1). The basalt has the R magnetic polarity and covers the 2.5-meter thick loam. Its upper part has the N polarity and the lower part has the R polarity. The palynological analysis of the paleosoil interbed within the loam shows domination of pollen of Pinus, Betula, Asteraceae, and Chenopodiaceae (Fig. 5). Pollen of Podocarpus, Cathaya, Abies, Cedrus, Picea, Ulmus, Quercus and Engelhardia are present in the forest group. A portion of

grasses ranges from 28 to 35%. Composition of the spectra indicates forest-steppe landscapes and is characteristic for the Pliocene–Early Pleistocene deposits.

3. Results of studies of the Pliocene and Quaternary deposits

3.1. The Pliocene–Quaternary sections to the north of the South-Taurus Thrust

3.1.1. The Kovancılar, Karangıbaşı and Örenköy sections of the Pliocene and early Quaternary

Three terraces are distinguished within the lower Murat River. Terraces I and II (the latter is subdivided into two sublevels in some areas) spread locally. The upper terrace III is traceable over vast territories in different parts of the valley. A cover of terrace III is composed of Lower Pleistocene deposits named as the Palu Formation. It covers the Eocene volcanic rocks near the town of Palu (s 7 in Fig. 2) and the Mesozoic gabbroids in the left bank of the Euphrates River (s 34). More often, the Palu Formation overlies the Çaybağı Formation that is considered to be Upper Miocene to Pliocene in age (s 9, 13, 15, 19, 21,

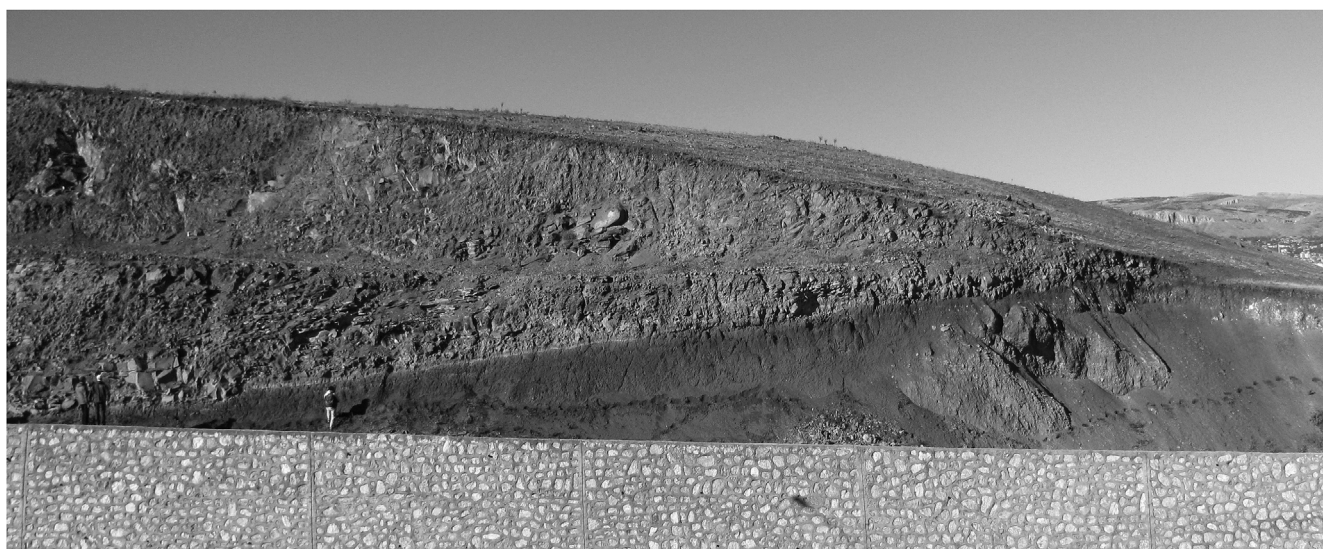


Fig. 4. The Lower Pleistocene basaltic flow with the K-Ar date 1.45 ± 0.06 Ma and underlying loam to the SE of the Elazığ city (10 in Fig. 2); photo by V.G. Trifonov.

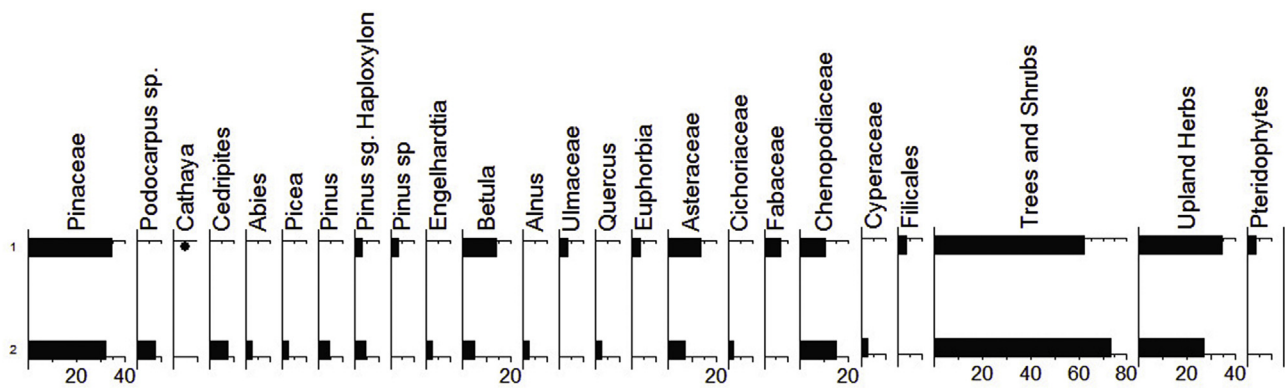


Fig. 5. Pollen diagram for the loam underlaying the basaltic flow to the SE of the city of Elazığ

25, and 202). The Kovancılar section (s 9; N 38.6992°; E 39.86158°; H = 981 m; Fig. 6) exposes both formations. Because the Early Paleolithic artefacts were found in layer 17, the layers 1–17 are attributed to the Pleistocene (Palu Formation). Their total thickness is ~115 m, while the thickness of the lower part of the section (Çaybağı Formation) is ~85 m.

A large section of the Çaybağı Formation is exposed south of Karangıbaşı village (s 202; N 38.66438°; E 39.71867°; H = 837 m; Fig. 7). The total thickness is about 160 m and layers 1–5 (45 m thick) belong to the Lower Pleistocene that covers the Pliocene layers 6–23 with subtle unconformity. Farther to the SE (s 13), the Palu Formation pebbles up to 4 m thick compose the terrace III cover and overlie the fine-grained sandstones, silts and clays of the up to 5 m thick (apparent thickness) Çaybağı Formation with unconformity. Fresh-water mollusks as well as fragments of a tubular bone of a small deer or an equid (hipparion) size were found in the latter.

The Örenköy section is exposed on the right (eastern) side of the Sultan-Suyu River valley and forms the Pliocene basement of terrace III (s 110; N 38.20025°; E 37.99458°; H = 1099 m; Fig. 8). Its pebble cover appears sporadically, is not thicker than 10 m, and overlies the basement with unconformity. Total thickness of the section is about 100 m.

3.1.2. The Quaternary sections

The pebbles composing the upper layer of section s 13 extend to the south, where the Pleistocene deposits are exposed in the quarry (s 12; N 38.66105°; E 39.71807°; H = 933 m; Fig. 9). Their upper layer 1 consists of loam and fine-grained sands with three horizons of paleosol. Fragments of mollusk shells (mainly sub-areal gastropods of the Pleistocene aspect) and bones were found in the lower part of the layer. The lower layer 2 is composed of pebbles, gravel and cross-bedding sands. Total thickness of the section is 38–39 m.

In the western part of the town of Palu (s 7; N 38.6872°; E 39.91263°; H = 1012 m; h = ~160 m), the 38-meter thick Palu Formation overlies the Eocene deposits with unconformity and is characterized by variable sand-gravel-pebble composition. In the south-eastern bank of the Murat River, the terrace III deposits also overlie the Eocene and consist mostly of pebbles and gravel. Their thicknesses are not more than 20 m. Thus, the high thickness of the Palu Formation and abundance of fine-grained deposits are characteristic only for the Kovancılar (s 9) and Karangıbaşı (s 202) sections. The section Hacımekke (s 15) has the intermediate characteristics. It is ~90 m thick and the fine-grained deposits are more abundant than the coarse ones. However, this section corresponds partly to the alluvium fan overlying the terrace III surface, and its total thickness is larger than that of the Palu Formation.

The Palu Formation is represented sporadically and covers the Çaybağı Formation with subtle unconformity visible southwards of the Arguvan town in the right bank of the Euphrates River downstream the Murat River mouth. To the south of the Kuru River and the town of

Yazihan, the Palu Formation is continuously exposed and extends to the south along the right bank of the Euphrates River and the Sultan-Suyu River valley up to the town of Doğanşehir near the axial part of the Taurus Ridge. Several terraces are identified here and the Palu Formation composes the upper terrace. It is absent in the eastern bank of the Euphrates.

In the Bahçeli section (s 21; N 38.77148°; E 38.4609°; H = 820 m; Fig. 9), sands and pebbles compose the 30 m thick analogs of the Palu Formation, covering the Çaybağı silts and clays. The 105 m thick Tah-talı section is situated on the south-western bank of the Kuru River (s 28; N 38.63265°; E 38.15277°; H ~ 875 m; h ~ 125 m; Fig. 9). The upper 75–80 m of the section are composed of silt and loam with thick pebble lenses that cover the 25–35 m thick well-rounded conglomerates that represent the channel facies of alluvium. Pebbles vary in size and consist of volcanic rocks including young basalts, silts of the Çaybağı Formation, carbonates, and diorites with rare flint and jasper. A bottom of the section corresponds to the top of the 20 m high lower terrace.

The 130 m thick section is exposed in terrace III scarp located 1 km north of the Sultan-Suyu Reservoir in the eastern bank of the same river (s 30; N 38.34263°; E 38.06963°; H = 960 m; h ~ 130 m; Fig. 9). The section (see the Supplement) is composed of sandstones, silt and loam with conglomerate lenses of different thickness. All pebbles of the section are well-rounded and represent channel alluvium. In the middle part of the section, the surfaces of the fine-grained layers under conglomerates are eroded and covered with caliche.

To the south of the Sultan-Suyu Reservoir, the 96-meter thick Sahiköy section of terrace III is exposed in the eastern bank of the Sultan-Suyu River (s 205; N 38.27126°; E 38.02579°; H = 995 m; h = 105 m; Fig. 9; see the Supplement). Analogs of the upper part of this section are exposed in the western slope of the Sultan-Suyu valley, being uplifted by the boundary normal fault (the Altınlı section, s 203 in Fig. 9). Outcrops of the same deposits extend within the fault scarp to the south and a thick sequence of well-rounded conglomerates and sandstones is exposed in s 102. The thickness of terrace III cover decreases in the right bank of the Sultan-Suyu River, where the exposed basement of the terrace is described in the Örenköy section (s 110). Further south, the 11–12 m thick cover of terrace III is exposed in the upper reaches of the Sultan-Suyu River (s 103; N 38.10466°; E 37.87357°; H = 1285–1290 m, Fig. 9). The upper 3 m of the section s 103 are composed of rounded pebbles that represent a major river alluvium. The pebbles overlie the 7–8 m thick lens-type intercalation of coarse-grained sandstones, gravel and pebbles, where the pick-like Early Paleolithic artefact was found. In the adjacent outcrop s 108 (N 38.09893°; E 37.86757°), local clastic material composes the pebbles of this layer.

The 14 m thick section of terrace II of the Sultan-Suyu valley is exposed in s 107 (N 38.27895°; E 38.03241°; H = 966 m; Fig. 9). This is lens-type intercalation of sandstones (and loam in the lower part) and conglomerates with pebbles of small and middle size and abundant

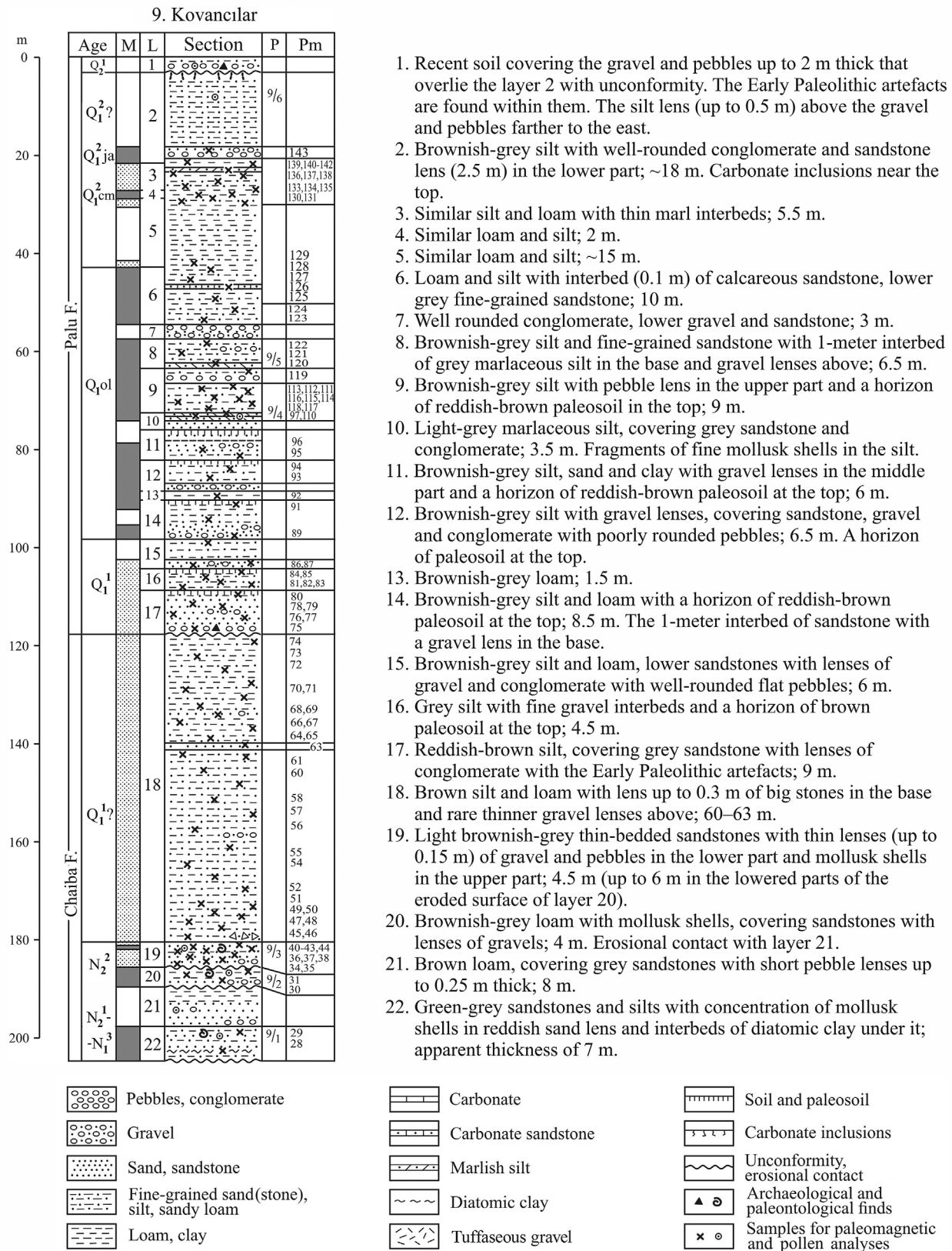


Fig. 6. The Kovancilar section of the Pliocene and Lower Pleistocene deposits in the right bank of the Murat River (9 in Fig. 2). M – magnetic polarity, L – layer, P – palynological samples, Pm – paleomagnetic samples.

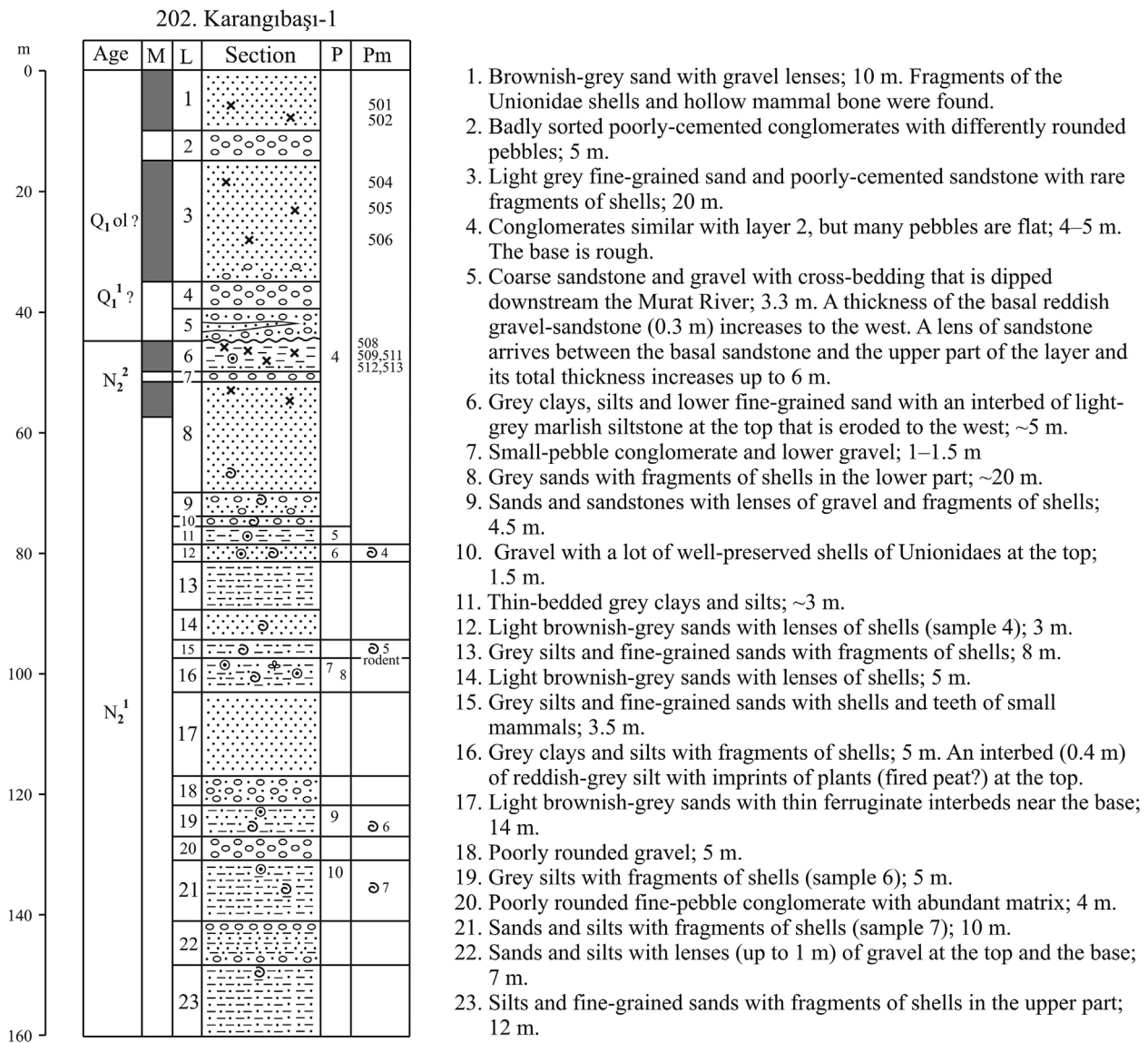


Fig. 7. The Karangibaşı section of the Pliocene and Lower Pleistocene deposits in the right bank of the Murat River (202 in Fig. 2).

sand matrix. Pebbles are mostly well-rounded, but some lenses contain a lot of poorly-rounded pebbles of local diorites. Orientation of pebbles reveals the NW water flow direction.

Vast area of Pleistocene deposits is situated on the Euphrates right bank to the east of the described area, between the Malatya city and the town of Battalgazi (Fig. 2). 17 m thick conglomerates with sandstone lenses are exposed in the quarry dug in terrace III eastwards of Eskimalatya village (s 31; N 38.06963°; E 38.40235°; H = 849 m; Fig. 11). Pebbles are poorly sorted and are well to poorly rounded. Rounded Early Paleolithic artefacts were found in the lower and middle parts of the section. It is covered by 2 m thick silt with carbonate inclusions and carbonate travertine (0.3 m) at the base.

Two sections of the same terrace were described near the village of Çolakoğlu to the east of the town of Battalgazi. In the upper part of the 14 m thick section Çolakoğlu-I (s 32; N 38.44938°; E 38.43112°; H = 706 m; Fig. 10), the upper 4 m are composed of sand and silt with lenses of pebbles and gravel. The pebbles and gravel dominate in the lower 10 m of the section. They contain lenses of silt and cross-bedding sand. The lower part of the 18 m thick section Çolakoğlu-II (s 33; N 38.4423°; E 38.42332°; H = 715 m; Fig. 10) is composed of sand and silt. Pebbles cover and partly replace these deposits.

3.2. The Pliocene–Quaternary sections to the south of the South-Taurus Thrust

Five terraces were determined in the valley of Erikdere (Erik River) that is the right tributary of the Euphrates River (Figs. 2 and 3). A section of terrace V is exposed to the NE of the town of Kahta (s 224; N 37.80553°; E 38.61171°; H = 765 m; h = 240–245 m; Fig. 11; see the Supplement). The layers 1–7 represent the 16-m thick terrace cover that overlies the slightly deformed layers 8–22 of the Pliocene – Upper Miocene terrace basement with an unconformity. The cranium of *Parabos cf. savelsi* was found about 15 m below the basement top within coarse sandstone of the lowest part of layer 10 that is deepened into the lower deposits of layer 11.

Section of terrace IV (s 226; N 37.81671°; E 38.62351°; H = 710 m; h = 185–190 m; Fig. 11; see the Supplement) consists of the about 75-meter thick cover (layers 1–19) and the Pliocene – Upper Miocene basement (layers 20 and 21) of apparent thickness 10 m. The layer 21 is overlaid by the terrace III gravel. The terrace IV cover is composed mainly of conglomerates with layers of sandstones, silts and sandy loam. Six 0.2–0.3 m thick paleosol horizons are identified in the top of fine-grained layers.

Up to 1 m thick terrace III cover (s 227; N 37.81886°; E 38.62045°;

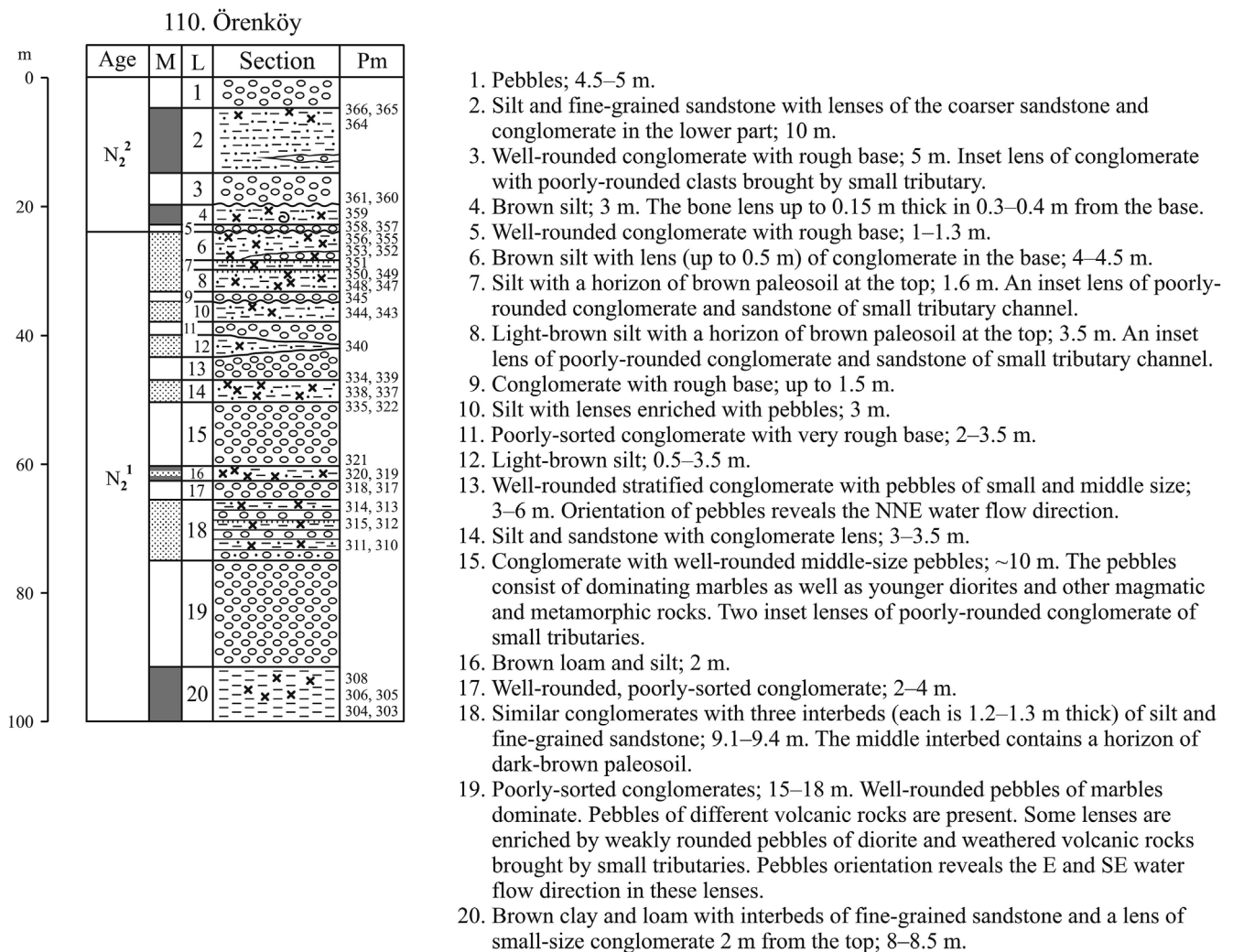


Fig. 8. The Örenköy section of the Pliocene deposits in the eastern side of the Sultan-Suyu River valley (110 in Fig. 2).

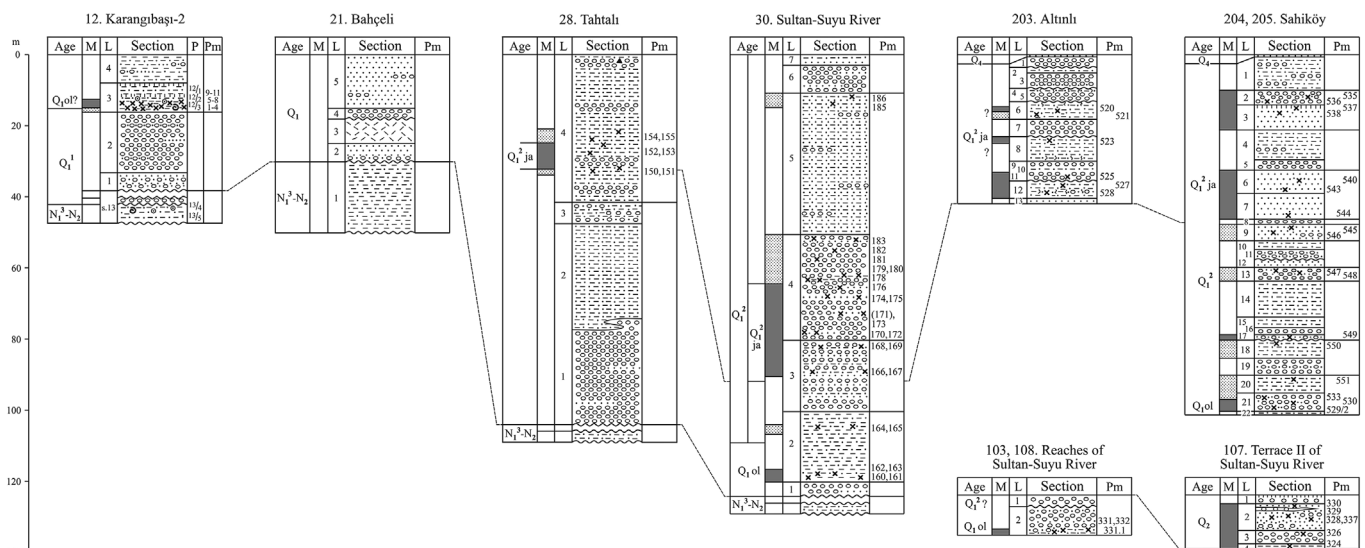


Fig. 9. Sections of the Lower Pleistocene deposits in the Murat River valley, the right bank area of the Euphrates River to the west of the city of Malatya and in the Sultan-Suyu River valley (12, 21, 28, 30, 203, 205, 103, and 107 in Fig. 2).

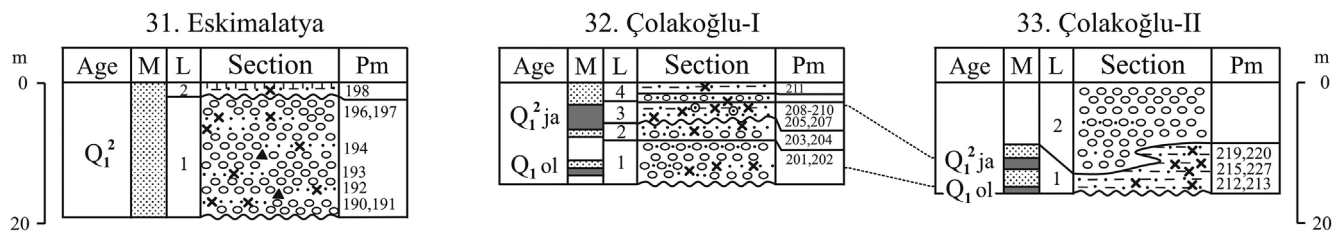


Fig. 10. Sections of the Lower Pleistocene deposits in the right bank area of the Euphrates River to the east of the city of Malatya (31, 32, and 33 in Fig. 2).

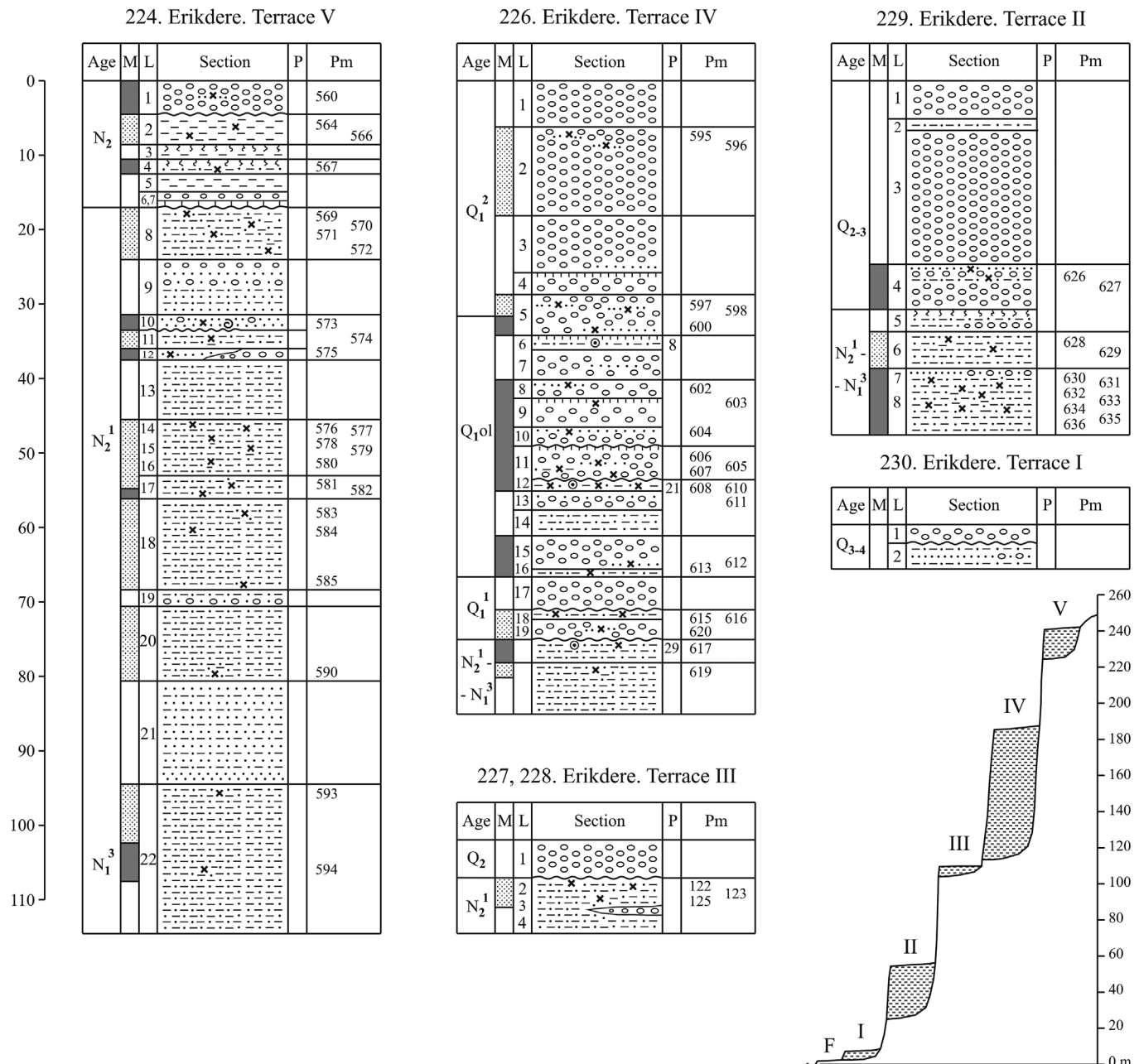


Fig. 11. Sections of the Pliocene and Pleistocene deposits in the Erikdere valley to the NE of the town of Kahta (224, 226, 227, 229, and 230 in Fig. 2).

H = 633 m; h = ~110 m; Fig. 11) is composed of well-rounded pebbles. Their thickness increases up to 5 m in the adjacent s 228. The pebbles are underlain by brownish-grey silts up to 10 m thick similar to those of layers 20 and 21 of s 226. The silts contain a lens of pebbles with silt matrix in 4–4.7 m from the top.

The terrace II section is exposed in s 229 (N 37.82571°; E 38.63434°;

H = 577 m; h = ~55 m; Fig. 11; see the Supplement). Layers 1–4 of the section form the terrace cover and the lower deposits correspond to the same terrace basement as in terraces III, IV and probably V.

A relic of terrace I remained in the northern slope of terrace II (s 230). The relic rises at 6 m above the flood plain and at 8 m above the water level of the Erikdere (N 37.82828°; E 38.63561°; H = 522 m). The

Table 3

Correlation of river terraces in the northern margin of the Arabian Plate near the South-Taurus Thrust Zone.

Valley	Water level, m	Flood-plane, m	I terrace, m	II terrace, m	III terrace, m	IV terrace, m	V terrace, m
Age	Recent	Q ₄	Q ₃ ²	Q ₂ ² -Q ₃	Q ₁ ² -Q ₂ ¹	Q ₁ ol-Q ₁ ²	N ₂
Magnetic polarity		N	N	N	N (mainly) R (lowest)	R (upper) N (lower)	N (upper) R (lower)
Göksu-Çayı	480 s 117	482 (2) s 119	485 (5) s 119	521 (39) s 116	546 (66) s 113	IV = 632 (150) s 112	645 (164) re-duced, s128
Eskiköy-dere	453 s 124			476 23), re-duced, s 124		588 (135) s 125, 126	
Kalburcu	556 s 233			576 (20) s 232	610 (54) s231 636 (67) s235	673 (117) s 233	712 (156) s 234
Erikdere, Kahta	522 s 230	524 (2) s 230	530 (8) s 230	577 (55) s 229	632 (110) s 227, 228	710 (185–190) s 226	765 (240–245) s 224
Erikdere, Teğmenli	570 s 209			645 (75) s 209		760 (190) s 208	

P.S. Height above sea level is shown without brackets; height above recent channel is shown in brackets.

relic is composed of (1) the pebbles with very rough base, (2) intercalation of sand, gravel and silt, and (3) the same silt as at the base of terrace II (s 229, layer 8). About 0.5 km upstream Erikdere, terrace I is composed of pebbles, gravel and sand. The flood-plain consists of thin-bedded silts near s 230.

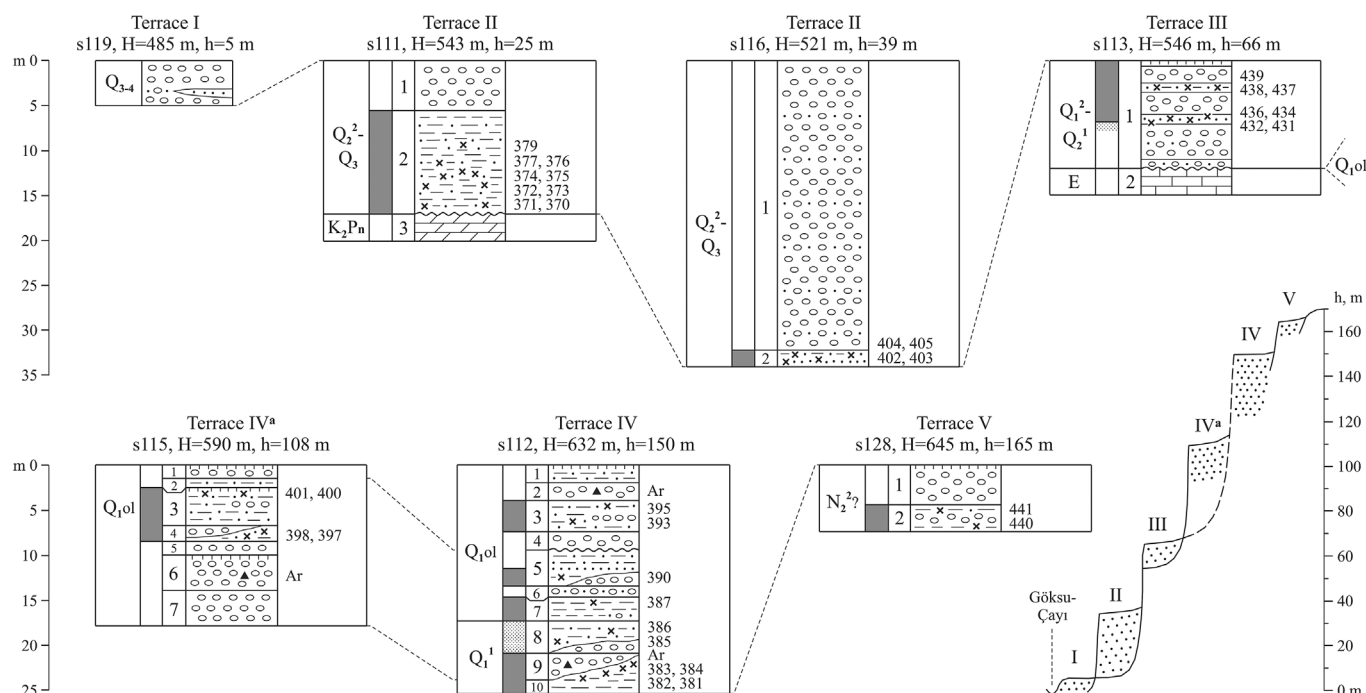
Therefore, the relative succession and height of the Erikdere terraces are as following: flood-plain – 2 m; terrace I – 8 m; terrace II – 55 m; terrace III – 110 m; terrace IV – 185–190 m and terrace V – 240–245 m.

Upstream of the described area, the Erikdere crosses an anticline that is composed of the Paleogene limestone. Further north, the Erikdere valley widens crossing a syncline in the Paleogene deposits. Two terraces are identified in this area near the village of Teğmenli (Table 3). The upper terrace (s 208; N 37.88876°; E 38.59483°; H = 760 m; h = 190 m) corresponds to terrace IV of s 226 and is composed mostly of well rounded conglomerates with sandstone interbeds. They are about 55 m thick and cover the Paleogene terrace basement. The lower terrace (s 209; N 37.92394°; E 38.60826°; H = 645 m; h = 75 m) corresponds probably to terrace II of s 229 and is composed mainly of stratified pebbles. Their thickness decreases out of the recent river channel from 30 – 40 m to 10–15 m, where they overlie

the thin-bedded sandstones of Eocene or Middle Miocene that gently dip to the south.

Five terraces were identified in the valley of Göksu-Çayı (Göksu River) that is another right tributary of the Euphrates River (Figs. 2 and 3). The upper terrace V is the lowered part of wide watershed between valleys. The section of this terrace cover is exposed near the village of Şambayat (s 128; N 37.68463°; E 38.05266°; H = 645 m; h = 163–165 m; Fig. 12). The upper part of the section is composed of weakly rounded conglomerates with lenses of more fine-grained deposits and rough base; 4–4.5 m. Brown silts and clays with conglomerate lens up to 1.5 m thick underlie the upper conglomerates. The total thickness of the section is 7 m.

The exposed cover of terrace IV (s 112; N 37.67928°; E 38.06823°; H = 632 m; h = 150 m) is of 26 m thick and the thickness of the lower terrace IV^a cover (s 115; N 37.67851°; E 38.07084°; H = 590 m; h = 108 m) is about 15 m. Terrace IV^a represents the local formation that limits terrace IV (s 112) to the river side. Near their contact, terrace IV^a layers dip 5–10° NW and they become horizontal outwards the contact. The section s 115 is similar in general with layers 4–9 of s 112 (Fig. 12; see the Supplement). Their similarity is expressed by the same magnetic polarity, the presence of two similar horizons of paleosol, and

**Fig. 12.** Sections of the Pliocene and Pleistocene deposits in the Göksu-Çayı valley (111, 112, 113, 115, 116, 119, and 128 in Fig. 2).

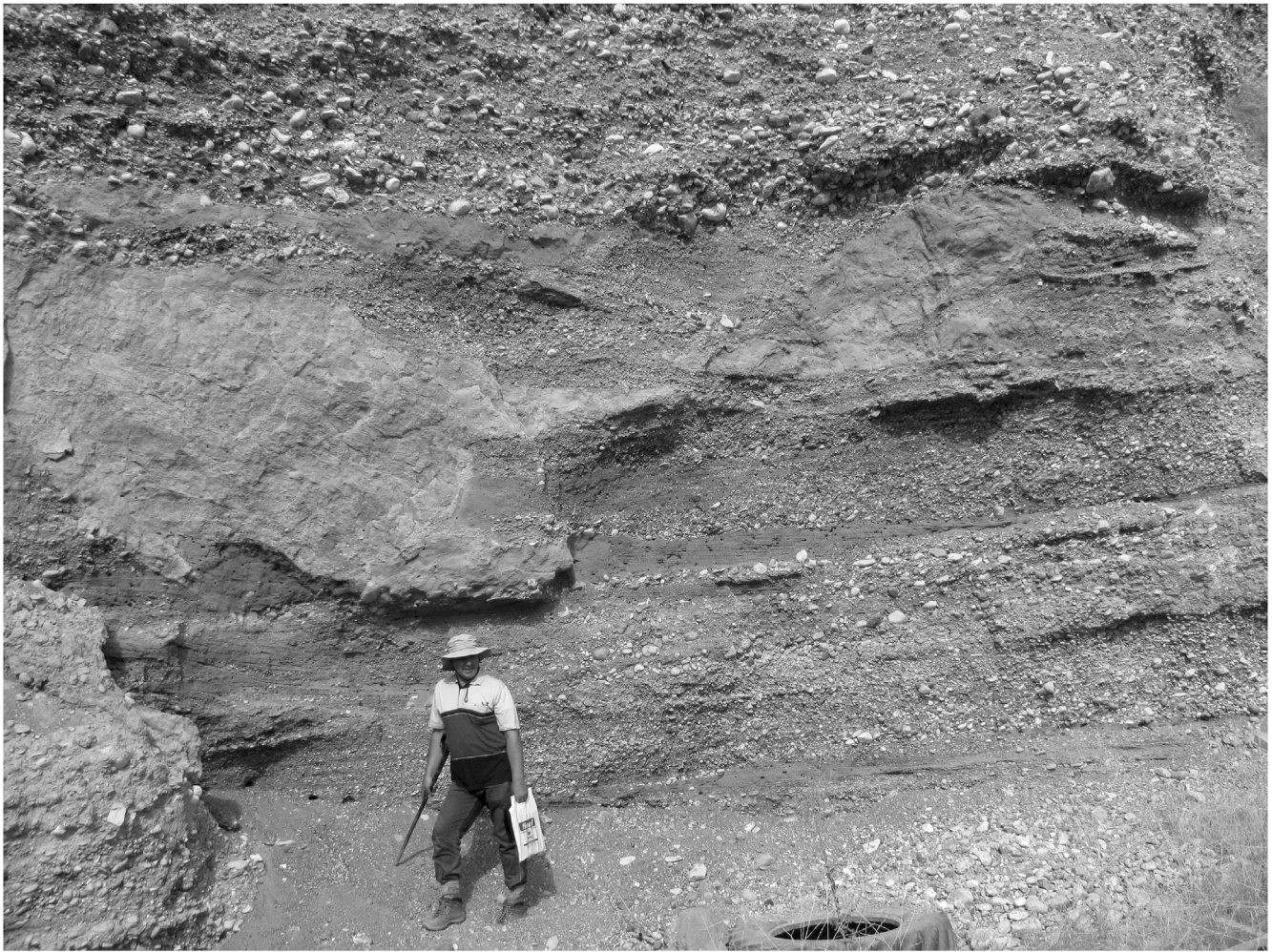


Fig. 13. Seismites in the lower part of the terrace II section of the Göksu-Çayı (s 116); photo by V.G. Trifonov.

a general change from conglomerates near the base to fine-grained deposits near the top. In consequence, we consider that terrace IV^a is a fragment of terrace IV with eroded upper layers (10–12 m) that slipped down as a landslide onto the terrace III surface. The vertical magnitude of the slipping is about 40 m. The Early Paleolithic artefacts were found in layers 2 and 9 of s 112 and in layer 6 of s 115. The two latter localities represent probably the same archaeological horizon.

Terrace III (s 113; N 37.67609°; E 38.08305°; H = 546 m; h = 65–66 m) is characterized by thick basement of Eocene carbonates and relatively thin veneer (10–11 m). The latter is composed primarily of well-rounded pebbles with interbeds of silt in the upper part and sandstone at the very bottom. Orientation of pebbles indicates the water flow down the Göksu-Çayı valley. The small fragments of carbonates compose up to 0.8 m thick lens between the veneer and the basement of the terrace.

In the opposite left bank of the Göksu-Çayı (s 116; N 37.68098°; E 38.08961°; H = 521 m; h = 39 m), terrace II is composed of 20 m thick layer of well-rounded pebbles with cross-bedding in some lenses. Up to 3 m thick layer of intercalation of gravel, sandstones and silts is exposed in the base of the section. This layer contains big deformed blocks of sedimentary rocks, probably, of paleoseismic origin (Fig. 13). Upstream the Göksu-Çayı (s 111; N 37.73756°; E 38.02938°; H = 543 m; h = ~25 m), the 5 m thick well-rounded pebble layer composes the upper part of terrace II veneer. The pebbles consist of the Eocene limestone ($\leq 10\%$), ophiolite rocks (gabbro, diorite, jasper; $\geq 20\%$), marbles and other metamorphic rocks of the Malatya Formation (60–70%). The pebbles overlie the interlaminated clays, silts and fine-

grained sands of lacustrine origin; > 11 m. The Cretaceous–Paleocene marls are exposed below.

Terrace I is composed of pebbles with lenses of carbonated conglomerate and fine-grained sandstone (s 119; N 37°40'24.09"; E 38°05'25.15"; H = 485 m; h = 5 m). Terraces I and II are located within a relatively narrow valley that is limited by the Eocene carbonates that compose the basement of terrace III. Terraces IV and V spread far beyond the valley.

Three terraces are identified in the adjacent Eskiköydere (Eskiköy River) valley. Terrace III was described near the Bostancık village (s 126; N 37.60675°; E 38.08144°; H = 583 m; h = 130–140 m; Fig. 14). Its 35–40 m thick veneer overlies the Miocene siltstones and marls with unconformity. The cover is composed of silts with lenses (0.1–0.5 m) of conglomerate. A 7–10 m thick layer of well-rounded and poorly-sorted conglomerates with sandstone lenses lies along the cover base that is very uneven. The Early Paleolithic artefacts were found within the layer.

Terrace II section is exposed near the river mouth (s 124; N 37.60906°; E 38.09511°; H = 476 m; h = 23 m). The 6.5 m thick silt lies at the top. Its upper and middle parts represent the cultural layer of an old settlement and contain the Neolithic flint tools and ceramics. The silt covers the lower 5.5 m thick layer of well-rounded pebbles with unconformity. A thin lens of pebbles with the abundant Middle Paleolithic artefacts was found within the layer. The upper interbed of pebbles covers and the lower pebble layers replace downstream the 5–6 m thick layer of thin-bedded silt of lacustrine origin. These are probably the bayou deposits.

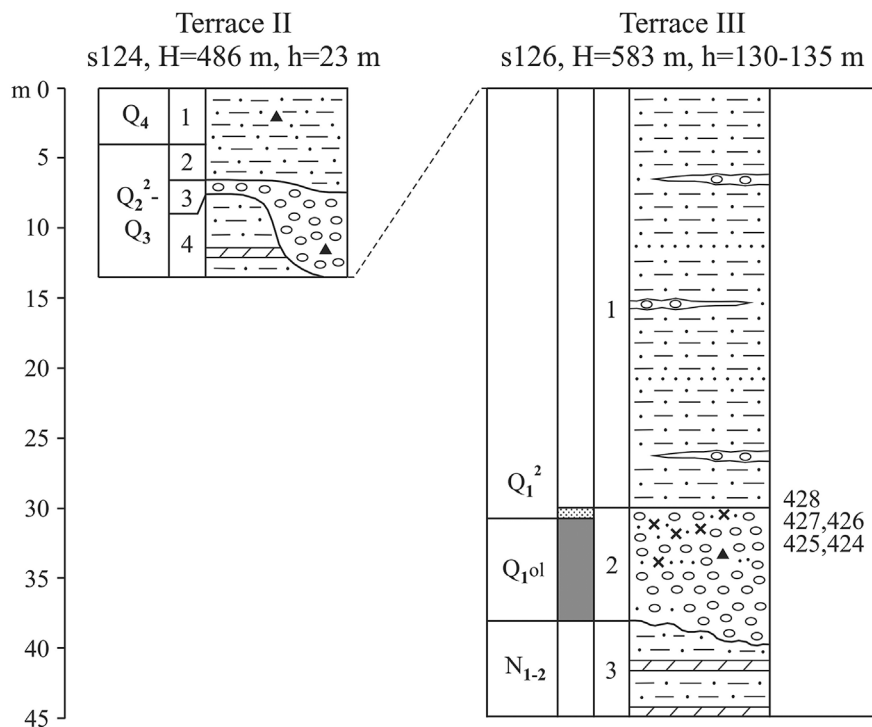


Fig. 14. Sections of the Pleistocene deposits in the Eskiköydere valley (124 and 126 in Fig. 2).

The Eskiköydere is the tributary of the Göksu-Çayı. Terrace III corresponds to the Göksu-Çayı terrace IV. The both terraces contain the Early Paleolithic artefacts. The Eskiköydere terrace II is lower than the Göksu-Çayı terrace II, probably, because the human activity destroys a part of the terrace cover.

Analogs of the same terraces were identified between the Erikdere and Göksu-Çayı valleys in the Kalburcu River basin to the east of the city of Adıyaman (Table 3). The most interesting results were obtained on a fragment of terrace III (s 231; N 37.75501°; E 38.52990°; H = 610 m; h = 54 m; the height can be reduced) that is composed of the 0.5 m thick pebbles covering the Upper Miocene siltstones. Five hand-axes of the middle-late Acheulian aspect were found on the terrace surface. Terrace II section is exposed in s 232 (N 37.75124°; E 38.51145°; H = 576 m; h = 20 m). The section consists of pebbles with sand lenses that are characterized by the N magnetic polarity and overlay the Upper Miocene – Pliocene siltstones. Several flakes and nucleus of the middle Paleolithic type were found on the terrace surface.

3.3. Dating of the Pliocene–Quaternary deposits

3.3.1. Paleontological data

Malacofauna. All mollusks were found in the Çaybağı Formation. The most representative collection was extracted from the Karangibaşı section (s 202). Mollusks were collected also in the lower part of the Kovancılar section (s 9) and in the right bank of the Euphrates River (s 25; N 38°38,696'; E 38°19,704'; H = 741 m).

The bivalve mollusk of the Dreissenidae family and the fresh-water mollusk of genus of *Planorbis* were found in layer 22 of the Kovancılar section (s 9). The preservation of two valves of the Dreissenidae justifies its local burial. *Planorbis* prefers stagnant waters and rivers with slow flow. That indicates the lacustrine sedimentation. Fragments of Unionidae gen. were found in the same layer. The mollusk *Theodoxus* aff. *licherdopoli* described from the Pliocene Levantine strata (Stefanescu, 1896) was found in layer 19 of s 9 (Fig. 15, N 1–5). *Theodoxus* sp., *Bithynia* sp. (operculum), *Parafossarulus* sp. (operculum), Hydrobiidae gen., *Valvata* spp., *Lymnaea* sp., *Galba* sp.,

Planorbidae gen., *Segmentina* sp., Unionida gen., and Pisidiidae gen. were also found in the same layer. This faunal association can be attributed to the Pliocene. All finds belong to freshwater forms, some of which (*Lymnaeidae* and *Planorbidae*) prefer the stagnant waters and rivers with slow flow, but the mollusks of *Theodoxus* genus are characteristic for rivers with quick flow and surf zones of large lakes with stone bottom. Based on these species, it is likely that the environment was a river with varying hydrodynamic conditions and sedimentation.

More certain data on the malacofauna age were obtained in the Karangibaşı section (s 202) by studies of shells of the Unionidae family (Fig. 16). General appearance of shells allows us to attribute them to the *Psilunio* and *Cuneopsisidea* genera. According to the shape of the shell and the morphology of the hinge plate, they resemble *Psilunio* aff. *sibirinensis* (Penecke, 1883), *P.* aff. *stolitzkai* (Neumayr, 1875), and *Cuneopsisidea* aff. *recurvus* (Stefanescu, 1896). One of the shells is similar to *Cuneopsisidea* aff. *beyrichi* (Neumayr, 1875) in the sculpture pattern. These forms were described from the Pliocene of Romania (Neumayr, 1875; Stefanescu, 1896), and they are also known from the middle of Paludina beds of Slavonia, the Lower Pliocene deposits of Moldova (Chepalyga, 1967; Stratigraphy of the USSR, 1986; Gojick, 2006; Gojick and Datsenko, 2007), and the Lower Pliocene of Turkey – Çaybağı Formation (Koç Taşgin et al., 2012). In our collection of fossils, there are some shells defined as *Psilunio* sp. and representatives of this genus dominate. Ghenea (2004) notes that the appearance of *Psilunio sibirinensis* and the wide-spread occurrence of smooth Unionidae are characteristic for the Lower Romanian, while the genus *Cuneopsisidea* characterizes the Middle Romanian (the Romanian corresponds to the uppermost Lower Pliocene and Upper Pliocene). According to the Andreescu et al. (2013) data, assemblages of mollusks with *Psilunio sibirinensis* are attributed to the uppermost Dacian (late Early Pliocene), and they correlate the latter with the MN 15 zone of the European continental scale and suggest that it corresponds most likely to its upper part (MN 15b). In addition, there are forms showing some features of the genus *Ebersininaia*, which appears in the Middle Romanian and is most developed in the Upper Romanian. Based on the data of Ghenea (2004) and Andreescu et al. (2013), these deposits can be correlated to upper Dacian – lower Romanian age. Thus, according to the general association of Unionidae,

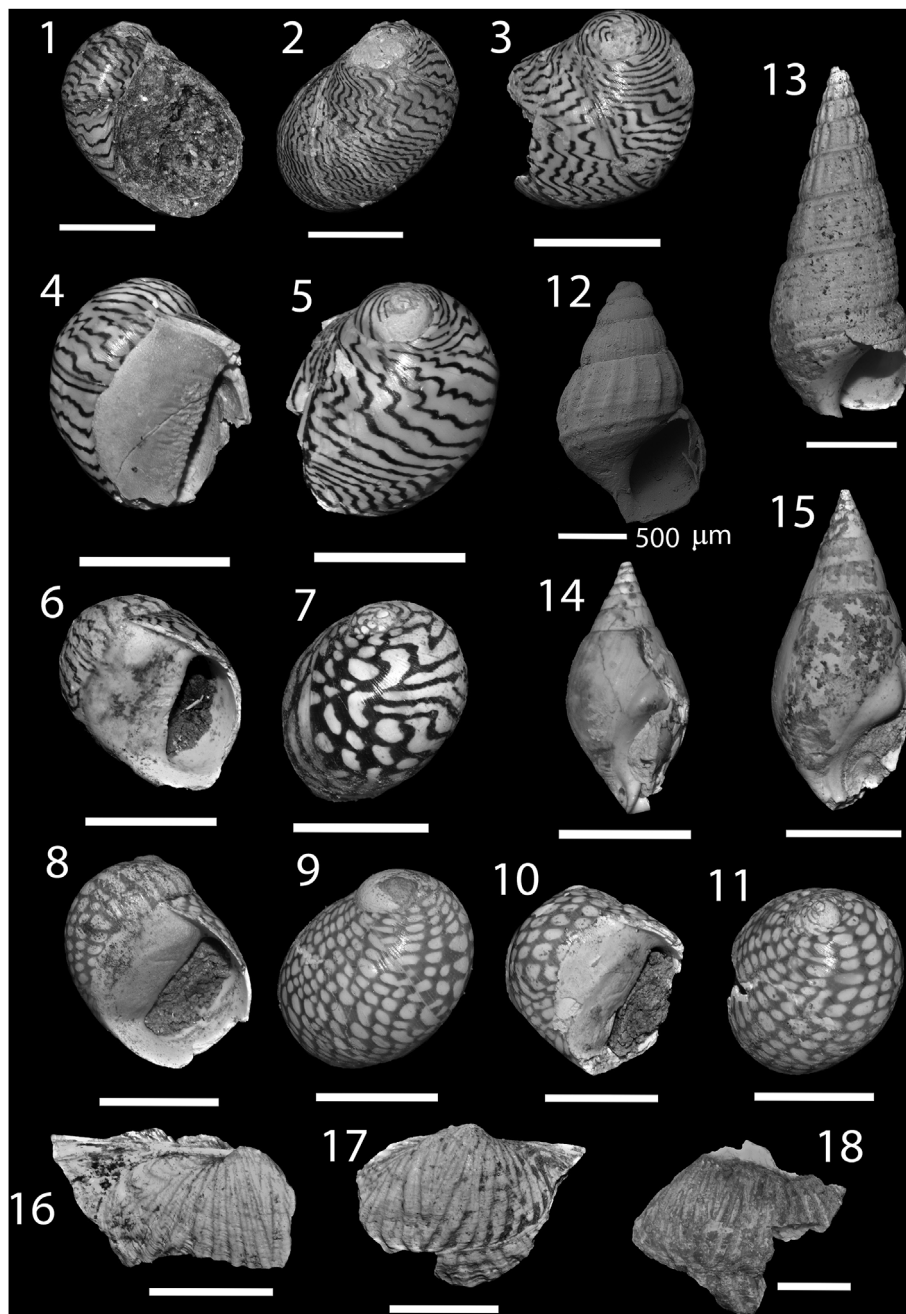


Fig. 15. *Theodoxus* and other mollusks from the Kovancılar (s 9), Karangibaşı (s 202) and s 25 sections: (1–5) *Theodoxus* aff. *licherdopoli* (Stefanescu, 1896) – s 9, layer 19; (6, 7) *Theodoxus* sp. 1 – s 202, layer 21; (8–11) *Theodoxus* sp. 2 – s 202, layer 21; (12, 13) *Melanoides curvicastra* (Deshayes, 1832) – s 202, layer 21; (14, 15) *Melanopsis* sp. – s 25; (16–18) Unionidae gen. – s 202, layer 21. Scale bar is 5 mm. Photos by P.D. Frolov.

we assume the Early Pliocene age for the deposits. Some shells are preserved with double valves that indicates their autochthon burial.

Six samples of other mollusks were extracted from different layers of the Karangibaşı section (Table 4 and Fig. 17): sample 4 – from layer 12, sample 6 – from layer 19, and sample 7 – from layer 21. Samples 1 to 3 (downwards) were collected in s 201 (N 38.66521°; E 39.71482°) to the NW of s 202. Perhaps, these deposits correspond to layers 16 and 17 of s 202. *Theodoxus* spp., Bellamyinae gen., *Melanoides curvicastra* (Deshayes), *Bithynia* sp. (operculum), *Parafossarulus* sp. (operculum), Hydrobiidae indet., *Pyrgula* sp., *Valvata* spp., *Lymnaea* sp., *Radix* sp., *Planorbarius* sp., *Gyraulus* sp., *Armiger* sp., Planorbidae gen., *Limax* sp., Pisidiidae gen., and *Dreissena* sp. were determined in the samples 1 to 7. Fragments of claws of freshwater crabs were also found in the sample 7.

Melanoides curvicastra is known from the Middle-Upper Miocene till

the upper Calabrian. However, flat whorls and weak axial ribs are characteristic of the Miocene and Lower Pliocene forms (Esu, 1980; Esu and Girotti, 1974). *Melanoides curvicastra* was found in Turkey in the Dacian (Lower Pliocene) deposits of the Karaburun Peninsula (Akartuna, 1962). Presence of the families Lymnaeidae and Planorbidae testifies to the lacustrine conditions, and presence of representatives of the genus *Theodoxus* testifies to the rheophilic conditions. Most of this association are representatives of freshwater genera, widespread in the fossil and modern fauna of Europe. However, Bellamyinae and *Melanoides* are palaeotropical elements (Heller, 2007). The characteristic sculpture of fragments of Unionidae from sample 7 (Fig. 17, N 16–18) indicates the same conditions. In general, the found mollusks testify to the subtropical climate.

The Çaybağı Formation mollusks were spread in river, delta and

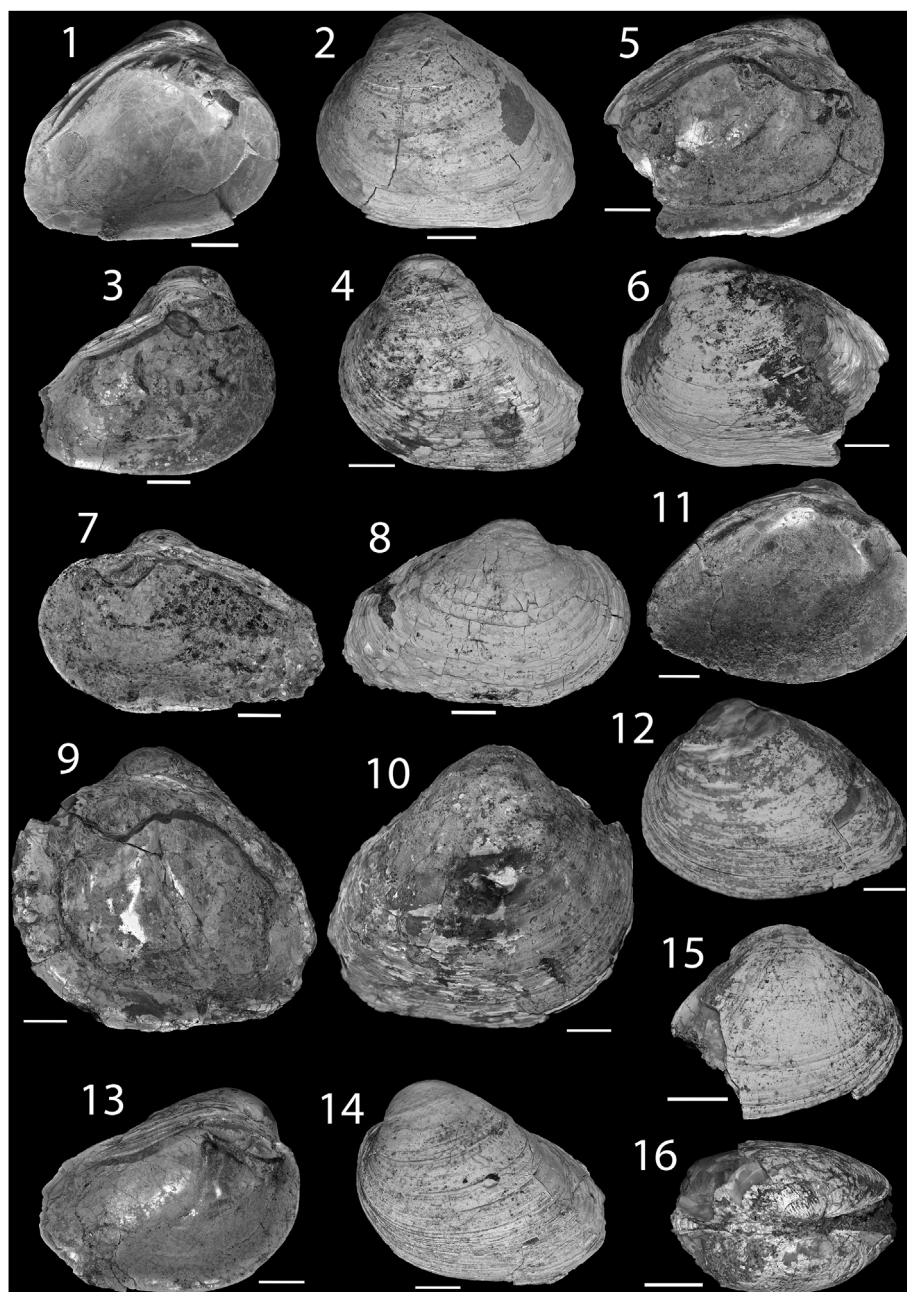


Fig. 16. Unionidae from the Karangibaşı (s 202) section: (1, 2) *Psilunio* aff. *sibinensis* (Penecke); (3, 4) *Psilunio* aff. *stolitzkai* (Neumayr, 1875); (5, 6) *Psilunio* sp. 1; (7, 8) *Psilunio* sp. 2; (9, 10) *Psilunio* sp. 3; (11, 12) aff. *Ebersinia* sp.; (13, 14) *Cuneopsidea* aff. *recurvus* (Stefanescu, 1896); (15, 16) *Cuneopsidea* sp. Scale bar is 10 mm. Photos by P.D. Frolov.

lacustrine conditions that are expressed in lithology of sediments. Finds of fish tooth, ostracods and fresh-water gastropods of Hydrobiidae gen. and *Melanopsis* sp. (Bandel, 2000) in the right bank of the Euphrates River (s 25) corroborate this environmental conclusion.

Small mammals. The layers 15–17 of s 202 with Unionidae also yielded scattered and severely damaged fragment of costal plate of a land turtle (?Testudinidae indet.), abundant fish bones, and few teeth and bones of small mammals: *Amblycoptus* sp., Desmaninae gen., *Ochotona* sp., Leporidae gen., Arvicolidae gen. cf. *Propliomya*, Rodentia gen. The most important chronological markers of this small fauna are several dental fossils of rhizodont voles (Arvicolidae). The material includes a nearly complete specimen (left m2), two fragmentary m2, and a fragment of m3. All of them belong to a medium size vole (m2: 1.57×0.95), with low dentin tracts not higher than 0.15–0.3 mm, broadly fused T1 and T2, undifferentiated enamel, and acrorhiz

structure of the posterior root. The molars characterize a primitive vole of the Pliocene appearance. Although these specimens cannot be reliably determined to the genus level, the closest match is late Early Pliocene *Pliomys/Propliomya* group. In Turkey, several localities with Pliocene *Propliomya* are dated to MN15. The Anatolian material is assigned to *Pliomys* sp. from locality Ortalica, MN15, and *P. graecus* from locality Yenice I, MN16 (Unay and de Bruijn, 1998). The type material of *P. graecus* comes from the Greek locality Tourkobounia 1, MN16 (de Bruijn and van der Meulen, 1975). A similar *Propliomya* species *P. hungaricus* is known from late Early Pliocene of Hungary (type locality Csarnota 2, MN15) and Greece (Notio 1, MN15) (de Bruijn and Hordijk, 2009). In Northern Black Sea region, the group is represented by an apparent phyletic lineage of geologically succeeding forms from *P. kowalskii* and *P. destinatus*, MN15 (Tesakov, 2005) to *P. jalpugensis*, MN16 (Nesin, 1983), and to *P. ucrainicus* (MN16–MN17) (Topachevsky and

Table 4
Mollusks from the Karangibaşı section (s 202).

Mollusks	4 (L12)	1 (L16?)	2 (L16?)	3 (L17?)	6 (L19)	7 (L21)
<i>Theodoxus</i> sp. 1						+
<i>Theodoxus</i> sp. 2					+	
Bellamyinae gen.		+		+	+	
<i>Melanoides</i>					+	+
<i>curvicosta</i> (Deshayes)						
<i>Bithynia</i> sp.			+			
<i>Bithynia</i> sp. (operculum)	+	+	+	+	+	+
<i>Parafossarulus</i> sp. (operculum)					+	
Hydrobiidae gen.	+	+	+	+	+	+
<i>Pyrgula</i> sp.					+	+
<i>Valvata</i> sp. 1		+	+		+	+
<i>Valvata</i> sp. 2	+				+	
<i>Lymnaea</i> sp.		+	+	+		
<i>Radix</i> sp.					+	
Planorbidae gen.				+		
<i>Planorbarius</i> sp.	+	+		+		
<i>Gyraulus</i> sp.						
<i>Armiger</i> sp.						
<i>Limax</i> sp.	+		+			
Unionidae gen. (palaeotropical elements)						+
Pisidiidae gen.					+	
<i>Dreissena</i> sp.						+

L – layer number.

Nesin, 1989). The Anatolian material closely resembles the most basal forms of *Propiomys* of late Ruscinian, MN15, biochronological units: *P. hungaricus* and *P. destinatus*. We, therefore, provisionally date the enclosing deposits to late Early Pliocene, late Zanclean, the mammal zone MN15.

Another small mammal yielding a chronological reference is the large anourosoricid shrew, *Amblycoptes* sp. represented by the upper molarised unicuspid A1. The degree of molarisation in this tooth is close to that described for *Amblycoptes* sp. from the late Ruscinian (MN15) fauna of Osztramos 7 in Hungary (Reumer, 1984).

The Kovancilar section (layer 19) yielded an undeterminable fragment of a turtle (*Testudines* indet.) and scarce remains of small mammals including Ochotonidae gen., Arvicolidae 1 and 2. The only indirect chronological character is apparently two different size vole species that may refer to Late Pliocene time, the time of strong differentiation of this group of rodents.

Large mammals. The incomplete skull of relatively large Bovidae was found in the layer 10 of the basement of Erikdere terrace V near the town of Kahta (Fig. 18). Its width at the posterior sides of orbits is 161 mm. The postcornual braincase is well developed. The bending of the skull's axis is slight. The frontal part is slightly concave. An anterior part of the horn base is situated above a mid-point of the orbit. A front of the latter is above the posterior side of M3. The bases of horn-cores are 39 × 52 mm. The distance between the horn-cores bases is 1.6 times more than their diameter. Long and relatively straight keelless horn-cores have an elliptical cross-section (compression index 75) and significantly incline backwards. The angle of their divergence is ~25°. The antero-posterior diameter is 49 mm. The upper teeth are relatively brachydont with well-developed parastyles and mesostyles. A length of the molar row M1–M3 is 72.5 mm.

Morphological and morphometric parameters allow to identify the specimen as *Parabos* cf. *savelisi* (Crégut-Bonnoure and Tsoukala, 2017). Representatives of the genus *Parabos* are known from the Early Pliocene (Ruscinian) of Greece, France, Spain, and possibly Italy (Gromolard and Guerin, 1980; Crégut-Bonnoure and Tsoukala, 2017). Although some authors range the distribution of this genus from the Late Miocene (mammal zone MN 12) till the Late Pliocene (MN 16) (Solounias, 1982;

Fejfar et al., 2012), the phylogenetic relationships and taxonomy of the genus continue to be under discussion (Fejfar et al., 2012; Kostopoulos, 2006). The species of *Parabos savelisi* was described in the single locality Gephyra (northern Macedonia, Greece) with the age estimated as Early Villafranchian (Late Pliocene, MN 16a) (Crégut-Bonnoure and Tsoukala, 2017). This age estimate can be, though, questioned, with Early Pliocene (Ruscinian) as a suggested alternative. Taking into account the separate character of our find, we broadly estimate its age as Pliocene.

In the described region, the Middle Turolian (Upper Miocene) fauna is reported from alluvial deposits of Kahta Member of the Selmo Formation. This association from the Erikdere village surroundings includes *Amphiorhycteropus gaudryi*, *Hipparion* sp. (middle-size form), *Hipparion* sp. (small form), *Ancylotherium pentelicum*, *Gazella* sp., *Pachytragus* sp., *Prostrepsiceros* sp. and Giraffidae gen. indet. (Kaya et al., 2012).

The lower teeth of gazelle and the upper teeth of hipparion as well as fragments of limb bones were found in the bone lens within layer 4 of the Örenköy (s 110) section (Fig. 19). The following taxa are identified: large equid *Hipparion* cf. *crassum*, deer *Arvernoceros* sp., gazelle *Gazella* cf. *deperdita*. This association is typical for the Pliocene of Europe, Mediterranean, and the Black Sea region. The fossils can be dated to the Ruscinian – early Villafranchian (MN 15–16). The age seems to be closer to the early Villafranchian (Piacenzian). The well-known Turkish fauna site Gülyazı corresponds to this level and is correlated with the zone MN 16b.

3.3.2. Palynological data

The pollen spectra from layers 16, 19 and 21 of the Karangibaşı (s 202) section represent the lower and middle parts of the Çaybağı Formation (Fig. 20). The conifers dominate in the spectra (80%). They are represented mainly by *Pinus* – *Pinus* section *Diploxylon*, *Pinus* section *Haploxylon* (cf. *Pityosporites microalatus*, *Pituspollenites labdacus*, *Pityosporites cedrisacciformis*). There is pollen of *Abies* (*Abiespollenites maxima*, *A. latisaccatus*), *Podocarpus* sp., and single grains of *Tsuga*, *Cedrus*, *Picea*, and *Keteleeria*. Angiospermea are represented by grains of *Juglans*, *Engelhardia*, *Comptonia*, *Acer*, *Alnus*, *Ulmus*, and *Moraceae*. The grass pollen occupies 20–30%. Asteraceae, Apiaceae, Caryophyllaceae, Chenopodiaceae are identified among the pollen of grasses and shrubs. Therefore, the role of Angiospermea and meadow vegetation was relatively significant.

Three samples were collected in s 201 from layers of the Çaybağı Formation that possibly correspond to layers 16 and 17 of the Karangibaşı section. The conifers *Pinus*, *Podocarpus*, *Cedrus*, and *Taxodiaceae* also dominate in the spectra. The pollen of *Tsuga*, *Abies*, and *Picea* are rare. There are single grains of *Juglans*, *Castanea*, *Carpinus*, and *Alnus*. The grasses are represented by pollen of Asteraceae, Apiaceae, Chenopodiaceae, Brassicaceae, Nymphaeaceae, and Dipsacaceae. The spores of Polypodiaceae, *Gleichenia*, *Riccia*, Sphagnales, and *Foveotrilletes* were identified. The spectra show that uplands were covered by the pine-cedar forests with the presence of *Podocarpus*, *Picea*, and *Abies* and areas of meadow vegetation. Presence of the algae *Botryococcus*, *Spirogyra*, *Pediastrum*, and *Pseudoschizaea* justifies the fresh-water lacustrine sedimentation of the section.

The pollen spectra from layers 11 and 12 of s 202 represent the upper part of the Çaybağı Formation. They are characterized by increase of a portion of pollen of grasses and shrubs. These are Asteraceae, Chenopodiaceae, Plumbaginaceae. The pollen of *Ephedra* arrives. A portion of the *Pinus* pollen reduces. The forest-steppe landscapes with possible elements of vertical zonation began to dominate. *Sciadopites*, *Podocarpus*, *Cedrus*, *Tsuga*, *Picea*, and *Abies* could grow in highlands. The mixed forests with *Pinus*, *Acer*, Juglandaceae, *Quercus*, *Carpinus*, and *Ulmus* grew lower. Lowlands were occupied by meadow-steppe vegetation.

The pollen spectra from the Kovancilar (s 9) section demonstrate successive changes also. The conifers dominate (80%) in the spectrum

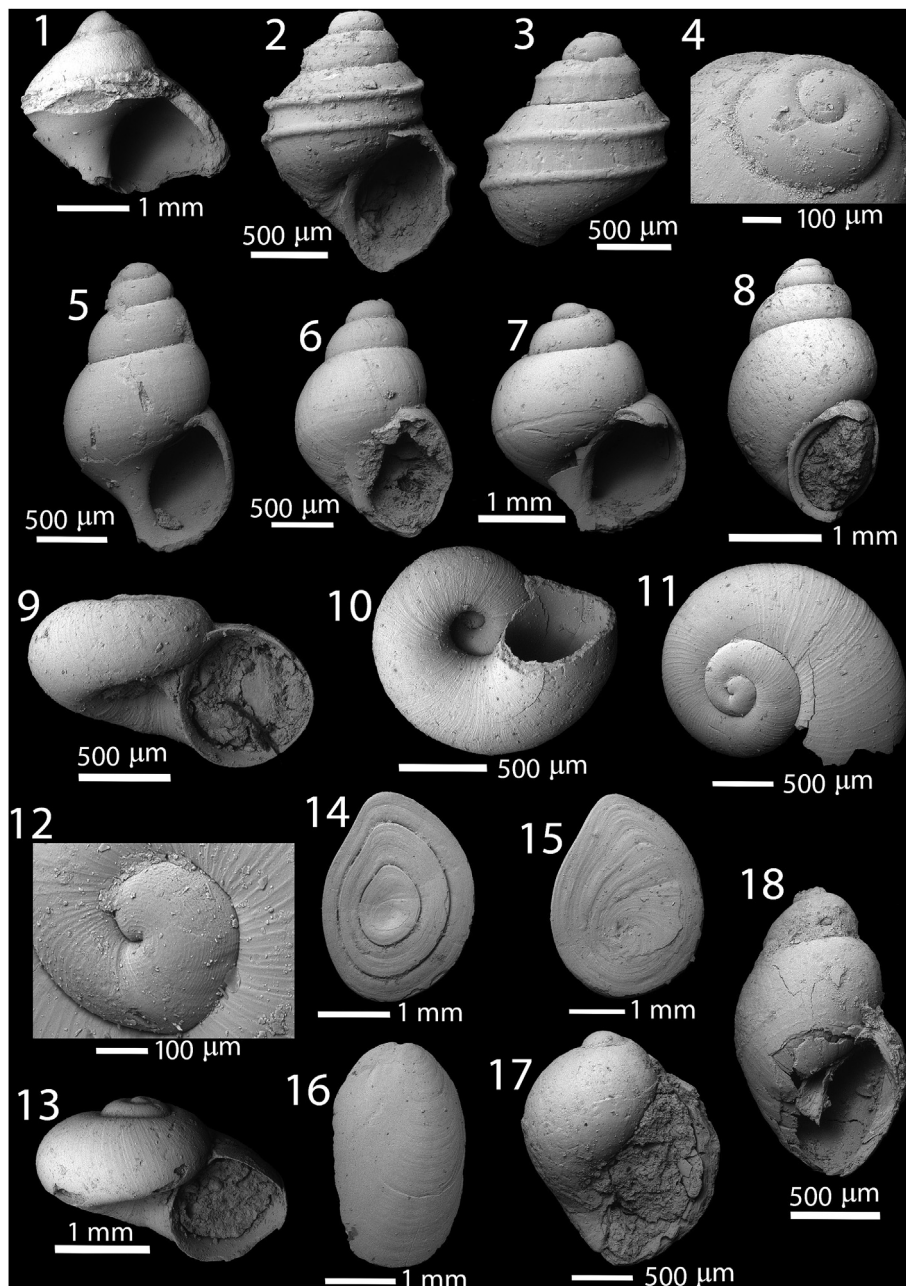


Fig. 17. Mollusks from the Karangibaşı (s 202) section: (1) Bellamyinae gen. – layer 16, upper part (?); (2–4) Pyrgula sp. – layer 21; (5) Hydrobiidae gen. – layer 12; (6) Hydrobiidae gen. – layer 12; (7) Hydrobiidae gen. – layer 17 (?); (8) Hydrobiidae gen. – layer 16 (?); (9, 11, 12) Valvata sp. 1 – layer 21; (10) Valvata sp. 1 – layer 16 (?); (13) Valvata sp. 2. – layer 21; (14) Bithynia sp. (operculum) – layer 16 (?); (15) Parafossarulus sp. (operculum) – layer 19; (16) Limax sp. – layer 16 (?); (17) Radix sp. – layer 19; (18) Lymnaea sp. – layer 17 (?). Photos by P.D. Frolov.

from layer 22 (Fig. 21). They are mostly *Pinus* sp., cf. *Pinus ruthenica*, *Pityosporites minutus*, *P. pristipollinatus*, *P. alatus*, *P. cedrisacciformis*, *Pinuspollenites labdacus*. Other conifers are represented by pollen of *Abies* (*Abies cristata*, *Abiespollenites maxima*, *A. latisaccatus*), *Podocarpites nageiaformis*, and rarely *Tsuga ignicula*, *Sciadopites*, *Cedrus*, and *Picea*. The Angiospermea are represented by single grains of *Betula*, *Alnus*, *Quercus*, *Nyssa*, *Sapotaceae*, and *Asteraceae*. There are also the spores of fresh-water Algae: *Botryococcus*, *Ovoidites*, and *Spirogyra*. This spectrum is similar to the spectra from layers 16, 19, and 21 of s 202. Its composition indicates the domination of coniferous forests in the time of relatively cool and dry climate.

In the pollen spectrum from the upper part of layer 20 of s 9, content of grass (*Asteraceae*, *Chenopodiaceae*, *Poaceae*, *Ephedra*) increases up to 40%. Content of *Cedrus* and *Abies* decreases. The Angiospermea are

represented by the pollen of mesophyte forests: *Juglans*, *Carya*, *Engelhardia*, *Alnus*, *Acer*, *Ulmus*, and *Quercus*. The forest-steppe landscapes began to dominate because of some aridization. The redeposited Paleogene dinocysts *Impagidinium* cf. *patulum*, *Cleistosphaeridium placacantum*, *Impagidinium sphaericum*, and *Deflandrea phosphoritica* were also found in the spectrum. Trees are represented by the pollen of pine, fir and birch in the poor pollen spectrum from the upper part of layer 19 (the horizon with shells). There are signs of continuing cooling and the forest-steppe landscapes continue to dominate. The spectra from layers 19 and 20 of s 9 are similar to spectra from layers 11 and 12 of s 202.

The domination of coniferous (*Pinaceae*) forests in highlands is reported for the NE Mediterranean in the end Late Miocene and the Late Pliocene (Jimenez-Moreno et al., 2007), Turkey in the Pliocene (Yavuz Işık et al., 2011), and south of the Russian Plain and Georgia in the end

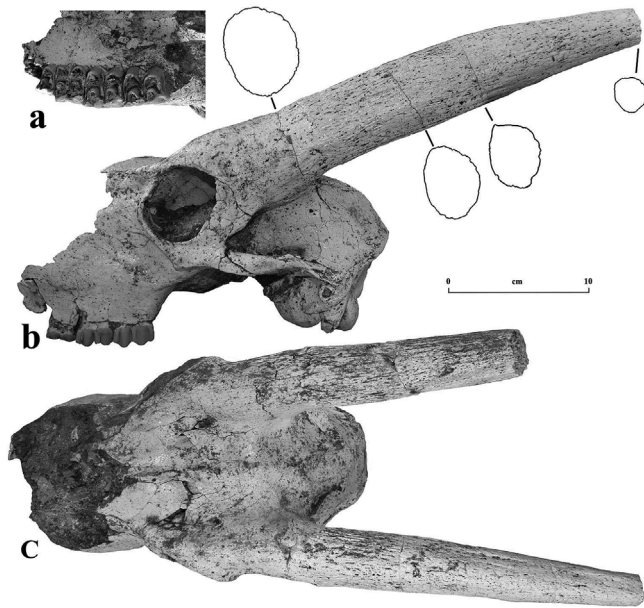


Fig. 18. Cranium of the Pliocene *Parabos* cf. *savelisi* (Crégut-Bonnoure and Tsoukala, 2017), layer 10 of the Erikdere terrace V section (s 224) near the town of Kahta: a – occlusal view of left teeth row, b – lateral view, c – dorsal view; photos by V.V. Titov.

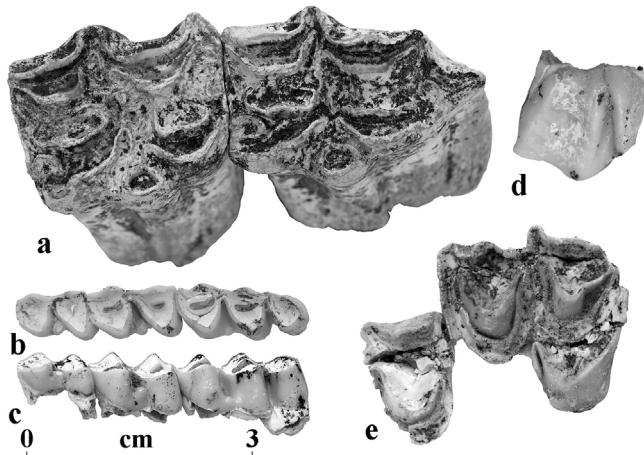


Fig. 19. Bone remains from layer 4 of the Örenköy (s 110) section, Early Villafranchian (Piacenzian): a – upper teeth M2-M3 of *Hipparion* cf. *crassum*, occlusal view; b, c – left teeth row with m1-m3 of *Gazella* cf. *deperdita*, b – occlusal view, c – buccal view; d, e – upper teeth of *Arvernoceros* sp., d – right P3, buccal view, e – left M2-M1 (fragmental), occlusal view. Photos by V.V. Titov.

Miocene – Pliocene (Ananova, 1974; Shatilova, 1974; Shatilova et al., 2011; Naidina and Richards, 2015). The quoted authors note also aridization at the end Pliocene–Gelasian. So, the obtained data give a possibility to date the examined parts of the Karangibaşı (s 202) and Kovancılar (s 9) sections to the Pliocene. Layers 16 to 21 of the Karangibaşı section, their analogs in s 201 and layer 22 of the Kovancılar section can belong to the Lower Pliocene.

Correlation of the spectra shows changes of sedimentation conditions. Presence of the algae spores of *Spirogyra*, and *Botryococcus* and the stagnicolous fresh-water mollusk *Planorbarius* as well as good preservation of Unionidae and Dreissenidae (two joint valves) testify to the sedimentation of layer 22 of s 9 in stagnant water setting. Arrival of the redeposited dinocysts in layer 20 and *Theodoxus* cf. *licherdopoli* in layer 19 of s 9 indicates local increase of the rate of water flow.

The poor pollen spectra obtained from layers 2, 8, and 10 of the Kovancılar (s 9) section have similar features. The single grains of *Engelhardia*, *Betula*, Apiaceae, Liliaceae, and *Botrychium* were found in the marlaceous silt of layer 10. In spectra of the marlaceous silt from layer 8 and the silt from layer 2, the pollen of leaf-bearing trees *Betula*, *Alnus*, *Ostrya*, and *Engelhardia* dominates. The pollen of *Picea*, *Pinus*, *Corylus*, *Ulmus*, and *Quercus* is present. The grass is represented by grains of Asteraceae, Chenopodiaceae, Brassicaceae, and Poaceae. There are redeposited spores and dinocysts of the Late Cretaceous (*Circulodinium distinctum*). The spectra demonstrate the mosaic character of vegetation and the wide distribution of forest-steppe landscapes. The mesophilic elements dominate. Contribution of *Betula*, *Picea*, *Ostrya*, and *Engelhardia* increases in comparison with the lower deposits.

Three samples were extracted from the two lower paleosol horizons of layer 1 of the Karangibaşı-2 (s 12) section (Fig. 22). The pollen of *Pinus*, *Betula*, and Asteraceae dominates in the spectra. The contribution of *Cedrus*, *Picea*, *Ostrya*, *Engelhardia*, and Chenopodiaceae is significant, although variety of conifers is not wide. The broad-leaved are represented by the pollen of *Juglans*, *Tilia*, *Ulmus*, *Olea*, and *Quercus*. There are the redeposited Cretaceous spores and dinocysts. The spectra demonstrate predominance of the forest-steppe landscapes and similarity to the spectra from layers 2, 8, and 10 of the Kovancılar. Significant amount of the pollen of *Betula*, *Ostrya*, Asteraceae, and Chenopodiaceae is characteristic for the spectra of the both sections. Variety of conifers decreases. The broad-leaved are represented mainly by mesothermal elements: *Juglans*, *Tilia*, *Ulmus*, *Olea*, and *Quercus*, with the exception of more thermophilic *Engelhardia*. The redeposited Cretaceous dinocysts were found also in the both sections. Taking into account the data on aridization and cooling in the end Pliocene–Gelasian (Jimenez-Moreno et al., 2007; Yavuz Isik et al., 2011; Biltekin et al., 2015), we date layers 2, 8, and 10 of s 9 and layer 1 of s 12 to the final Pliocene–Early Pleistocene.

The pollen spectrum from the silt lens in layer 1 of the Kovancılar section is characterized by the predominance of Chenopodiaceae, *Betula*, and *Pinus*. The pollen of *Salix*, *Tilia*, and Asteraceae is present. The single redeposited Cretaceous spores (*Stereisporites*) were found. The spectrum shows predominance of the open landscapes and the dry and cool climate and is certainly attributed to the Pleistocene.

Thus, according to the palynological data, the Karangibaşı (s 202) and Kovancılar (s 9) sections demonstrate progressing aridization and cooling from Pliocene to Early Pleistocene. The lower and middle parts of the Çaybaşı Formation section (Pliocene) were deposited mainly in stagnant water, probably lacustrine conditions with presence of fresh-water algae. A rate of water flow increased in the Late Pliocene and Early Pleistocene. The algae spores were not found in fluvial sediments of the Lower Pleistocene Palu Formation.

3.3.3. Archaeological data

All the finds to the south of the Taurus Ridge were made of flint. The most representative collection was obtained from the Şambayat and Bostancık localities (layer 6 of s 115, layers 2 and 9 of 112, and the lowest Quaternary layer of s 126). Domination of choppers and absence of hand-axes justify that the collection belongs to the Mode 1 (Ozherelyev et al., 2018). In the Olduvai gorge sites, picks were found mainly in the middle and upper parts of the Bed II (sites BK, EF-HR that were qualified as the developed Oldowan and Early Acheulian) (Leakey, 1971, pp. 132–135, 209–210). Some finds from the upper part of Bed I (FLK North – typical Oldowan) that were identified as proto-bifaces by M. Leakey (pp.78–79), are similar to our pick-like tools. Another important characteristic of our sites is presence of big flake fragments including the secondary ones, and retouched flakes and fragments of tools (heavy-duty scrapers, side scraper, notched tool). Typological variability of retouched tools is characteristic for both the Oldowan (Eastern and Northern Africa and Caucasus) and the Early Acheulian (Africa and Near East). Taking into account the above

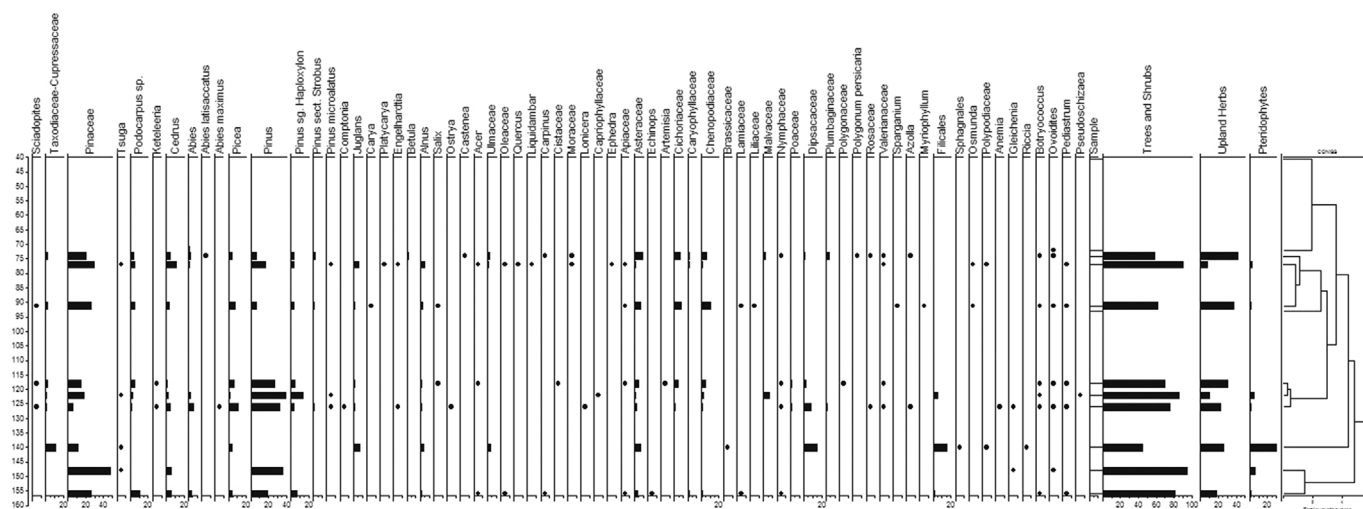


Fig. 20. Pollen diagram for the layers 16, 19, and 21 of Karangıbası-1 section (202 in Fig. 2 and 6).

observations, we attribute the described industries to the Oldowan culture (Mode 1) with elements and features of the Early Acheulian (the big flakes, pick-like tool on big flake, and blanks for bifacial tools) (Ozherelyev et al., 2018).

The early Paleolithic stone artefacts collected from the stratigraphic sections to the north of the Taurus Ridge, are similar to the mentioned industries, but were produced from the metamorphosed rocks. They were found in the lower part of layer 17 of s 9 and the lower and middle parts of the Eskimalatya (s 31) section. The finds from layers 1 of s 9 can be attributed as the earliest Acheulian ([Ozheryev et al., 2018](#)). They are very rounded and probably reworked from the lower layers.

Middle-late Acheulian hand-axes characteristic for the Middle Pleistocene were found on the surface of terrace III of the Kalburcu River (s 231). They can be dated to the Middle Pleistocene. The only stratified Middle Paleolithic site was found in the terrace II section s 124 near the mouth of the Eskiköy River. All the artefacts are concentrated in the 10 cm thick interbed within the pebble layer and represent the single cultural-chronological complex. It has analogs in the Middle Paleolithic sites of the Levant and can be attributed to the final part of Middle Pleistocene or the early Late Pleistocene (Ozherelyev et al., 2018).

3.4. Tectonics of the Pliocene-Quaternary sedimentation areas and their surroundings

Quaternary deformation is represented in the region by fault offsets,

folding, and different rates of uplift of the land surface.

The NE-trending sinistral East Anatolian Fault Zone (EAFZ) is the important element of the Late Cenozoic structure (Şaroğlu et al., 1992; Duman and Emre, 2013). The majority of researchers consider that the EAFZ formed in the Pliocene-Quaternary (Yürür and Chorowicz, 1998), although, according to Westaway (2004), it could develop since the end of Miocene. Barka and Kadinsky-Cade (1988) estimated 5 mm/year for the Late Cenozoic left-lateral slip rate. Westaway (2004) estimated the sum of slip rates on the EAFZ strands in its south-western termination at 6–8 mm/year. According to the GPS data, the slip rate on the EAFZ itself is 4–8 mm/year and reaches ~9 mm/year in the 50 km band near the fault zone (McClusky et al., 2000). The slip rate reaches 10 ± 0.3 mm/year in the balanced GPS model of the zone and decreases in its south-western termination, where the lateral slip is supplemented by the component of transverse lengthening (Reilinger et al., 2006).

In the studied region (Figs. 2 and 3), the EAFZ is formed by several strands that are often situated en echelon relative to each other (Duman and Emre, 2013). The fault zone is expressed by narrow tectonic depression, which falls into elongated pull-apart basins and relative uplifts cut by fault scarps and canyons. These scarps separate tectonic terraces (Fig. 23, a). The sinistral offsets and sharp bends of small streams and ravines reach several tens of meters along some strands (Fig. 23, b). The valleys of the Murat, Euphrates and Göksu-Çayı are sinistrally displaced by 12–15 km along the EAFZ (Fig. 2).

Lesser faults and fault-flexure zones accompany the EAFZ. The W-

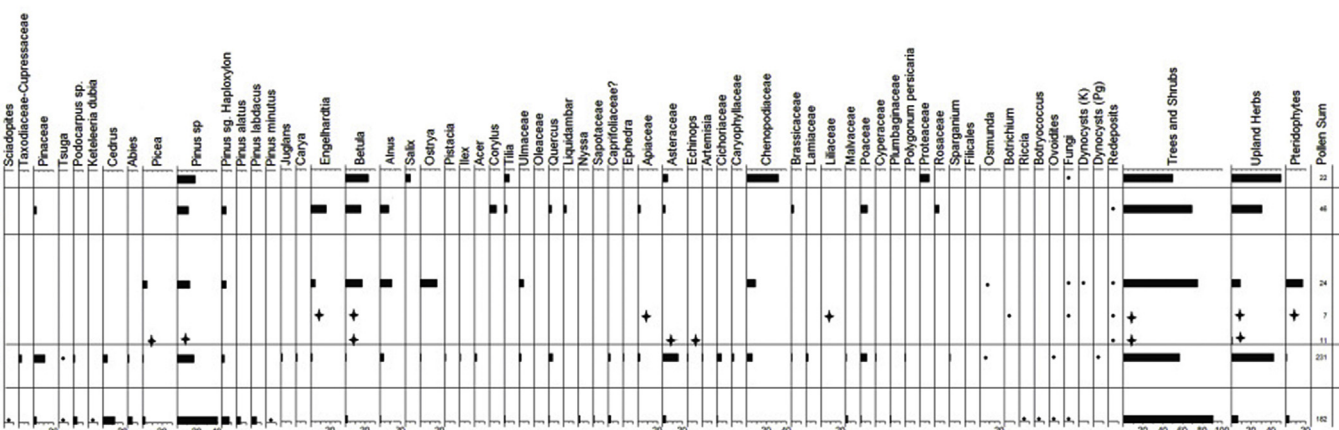


Fig. 21. Pollen diagram for the layer 22 of the Kovancilar section (9 in Fig. 2 and 6).

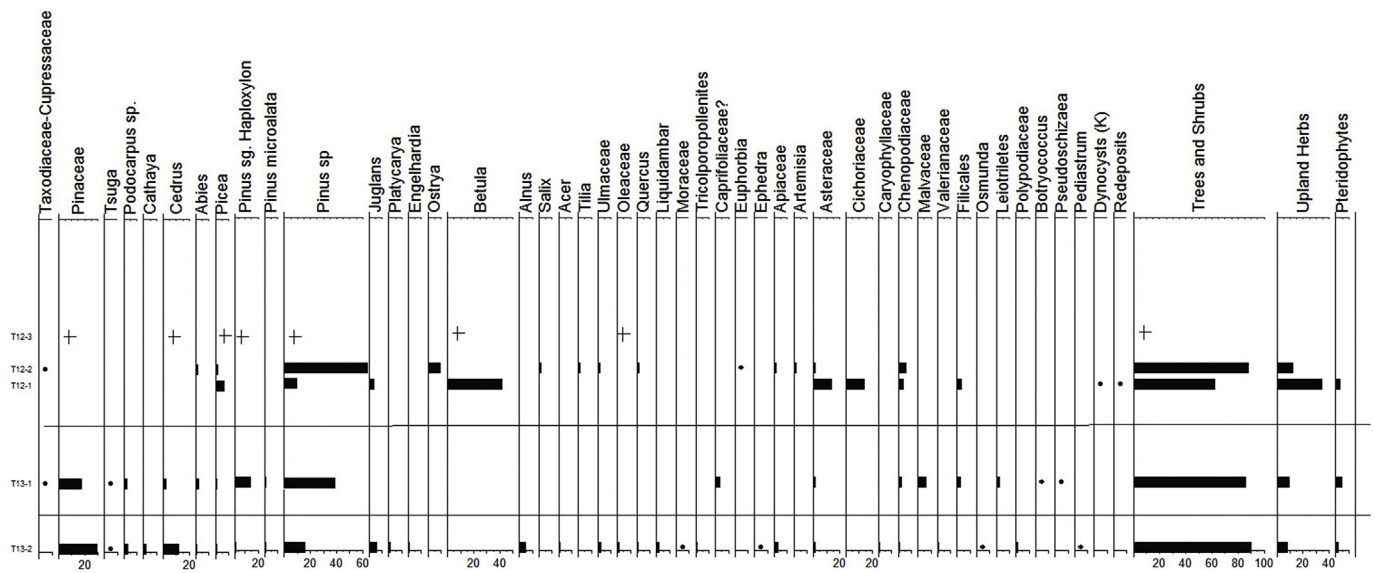


Fig. 22. Pollen diagram for the layers 1 of the Karangibaşı-2 section (12 in Fig. 2 and 7).

trending fault zone bounds to the north the area with thick Lower Pleistocene deposits in the northern bank of the Murat River. These deposits are represented in the Kovancılar (s 9) and Karangibaşı (s 202) sections. In s 201, the fault zone is expressed in topography by a scarp with uplifted northern side and separates the Lower Pliocene marls, sandstones and clay slates with peat interbeds of the northern side from the Pliocene and Lower Pleistocene deposits of s 202 that are tilted 40–50° to the north. Thickness of the Lower Pleistocene sequence is noticeably reduced in the other sections of the northern Murat bank (s 7 and s 12) as well as in its southern bank. Being offset now on the EAFZ, the thin sections of the southern bank (s 3–5) were situated primary near the thin section s 12. So, the elongated W–E-trending depression accompanied the north-western side of the EAFZ. A portion of the Lower Pleistocene fine-grained lacustrine deposits increases within the depression (s 9, 15, and 202). In its southern side, the dipped contact of the Palu and Çaybaşı Formations is offset by a thrust (s 13; Fig. 24).

The N–S-trending band of the Palu and Çaybaşı deposits, occupying the western bank of the Euphrates River downstream the Murat mouth, is restricted to the west by a fault expressed through several scarps with uplifted western sides. The Pliocene and Lower Pleistocene deposits are mineralized and deformed within the fault zone to the west of Tahtalı (s 28) section. Thickness of the Lower Pleistocene deposits is reduced to the east (compare section s 28 and s 30 in the band with sections 31–33 eastwards of the Malatya city). Similar Lower Pleistocene deposits are absent in the eastern bank of the Euphrates River. Therefore, the old Euphrates valley used the NS-trending tectonic depression that formed in the Pliocene. The depression extends to the SSW as the Sultan-Suyu River valley and reaches the northern slopes of the Taurus Ridge. The above mentioned fault strikes along the steep western side of the valley. En echelon row of smaller normal faults ruptures the eastern side of the valley (Figs. 25 and 26).

Local folding deformation of the Lower Quaternary deposits was described on the northern bank of the Keban Reservoir (Çelik, 2012). The Lower Quaternary deposits are tilted at the angles of 15–20° in s 5, 10° in s 36 and 15° in s 103. The Palu Formation of the Kovancılar (s 9) section is dipped to the north and NNW. This monocline extends to the west (angles 40–50° in s 202) and to the east, where the same layers dip to the north at the angle ~ 35° in the north-western margin of the town of Palu (Fig. 27). The lowest layers of the Kovancılar section (the Çaybaşı Formation) dip at the angle ~ 35°. The angles increase to 40–45°, then 55–60° and upper decrease to 50–55° in layer 18. The angles decrease in the Palu Formation upwards from 45° in layer 17 to

40° in layer 15, 35° in layer 12, 30° in layers 11, 10 and 2, and 25° in the upper layer 2. Layer 1 is almost horizontal (parallel to the terrace surface) and covers layer 2 with angular unconformity. But the latter sharply decreases in 150–200 m to the east.

These changes have different origin. The increase of dip in layer 18 can be related to local flexure. The overall larger dip in the Çaybaşı Formation relative to the Palu Formation can be a result of unconformity between them. The successive decrease of the Palu Formation tilting upwards can be due both to the approach to the central part of syncline and/or the contemporaneous development of the deformation. When interpreting the unconformity between layers 1 and 2, we take into account that the Kovancılar section is situated in the transitional area between the northern limb of the partly eroded anticline composed by the Çaybaşı Formation and the Eocene deposits and the axial part of syncline filled by the Palu Formation. The anticline grew during the Palu Formation accumulation and its rise came to an end in the late Calabrian – early Middle Pleistocene. In the upper and, correspondingly, northern part of the section, inclination of the Palu layers decreases near base of the syncline, where they form the terrace III cover. According to this interpretation, the unconformity between layers 1 and 2 is local and is caused by erosion in the margin of the syncline base.

The EAFZ, the W–E-trending reverse faults and compressed folds in the right side of the lower Murat valley, and the N–S-trending zone of extension in the right side of the Euphrates valley (Fig. 2) could be formed in the single stress field with the N–S-trending direction of the compression. This stress field is derived from the collision between Arabian Plate and the Anatolia-Tauride platform, and the related consequent compression, which is the reason of the present day compression and the Late Cenozoic activity in the area.

4. Discussion

4.1. Age of the Çaybaşı and Palu Formations and their stratigraphic analogs

According to the data on malacofauna and small mammals, the lower and middle parts of the Çaybaşı Formation that is exposed in the Karangibaşı (s 202) section and in s 201 belong to the Lower Pliocene. The upper part of the Çaybaşı Formation of s 202 that is characterized by N magnetic polarity can correspond to the Upper Pliocene, which is confirmed by the palynological data. The lower part of the Kovancılar (s 9) section contains two erosional contacts corresponding probably to

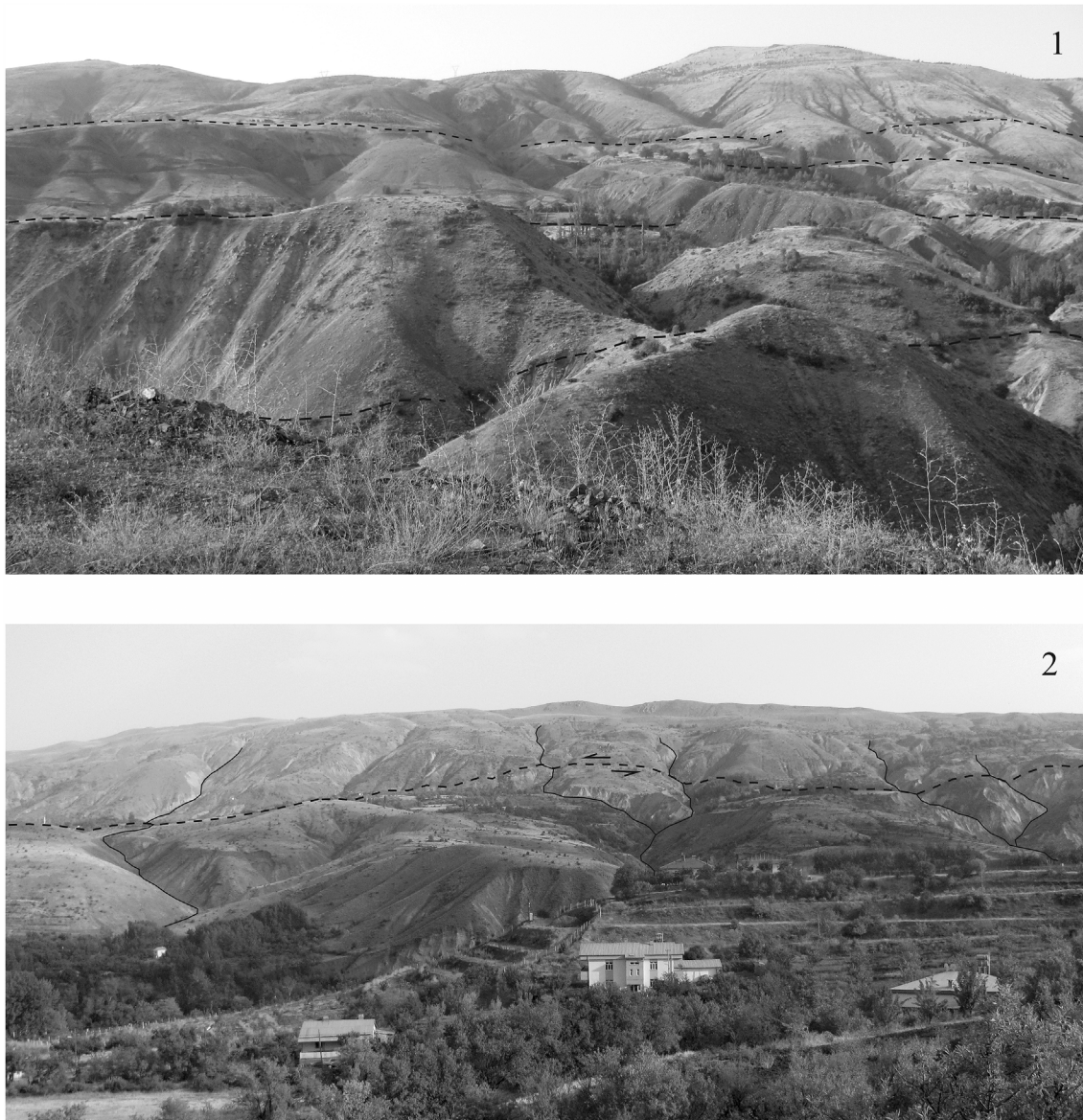


Fig. 23. Tectonic terraces (1) and sinistral offsets of small streams (2) on the East Anatolian Fault Zone; photos by V.G. Trifonov.

nonsequences and making difficult dating of the formation. The data on palynology and malacofauna confirm the Lower Pliocene or, taking into account the N magnetic polarity, even the Upper Miocene age for the lower part of the exposed section (layer 22). The overlying layer 20 has also the N magnetic polarity and the lower part of the layer 19 has the R polarity. The upper part of layer 19 has the N polarity again and contains the Pliocene mollusks and Upper Pliocene teeth of rodents. Thick layer 18 of the s 9 section covers the layer 19 without discontinuity, has the R polarity and is overlain by pebbles of the layer 17 with the Oldowan lithics. This gives a possibility to assume the Late Pliocene age of the upper part of layer 19 and the Gelasian age of layer 18. Thus, the Karangbaşı and Kovancılar sections contain both the Lower and Upper Pliocene layers of the Çaybaşı Formation. The lowermost part of the formation can belong to the Upper Miocene and the uppermost part – to Gelasian.

The bone fossils of *Hipparion* cf. *crissum* and *Gazella* cf. *deperdita* from layer 4 of the Örenköy (s 110) section are dated to the Ruscinian – early Villafranchian (MN 15–16) and are closer to the early Villafranchian (Piacenzian), which is confirmed by the paleomagnetic data. The bone bed is located near the bottom of the upper part of the section that is characterized by the N magnetic polarity. The lower

deposits have mainly R magnetic polarity and probably correspond to the Early Pliocene (Zanclean).

The relationships of the Palu Formation and its stratigraphic analogs with the underlying deposits, the results of analysis of the pollen and archaeological data justify the Early Pleistocene age of the formation. This conclusion can be detailed by the analysis of remanent magnetic polarity data (Fig. 28). This is related, first of all, to the dating of the Early Paleolithic artefacts. Stratified sites with the earliest Paleolithic stone industries were found in Israel (Bar-Yosef et al., 1993; Ronen, 2006; Zaidner et al., 2010), the Orontes River valley (Besançon et al., 1978), the middle Euphrates valley (Copeland, 2004) and El-Kowm region in Syria (Le Tensorer et al., 2015), the Birecik area in SE Turkey (Demir et al., 2008), NW Armenia (Belyaeva and Lyubin, 2013), the southern Georgia (Lordkipanidze et al., 2007; Ferring et al., 2011), the north-western (Shchelinsky et al., 2010) and eastern (Amirkhanov et al., 2014, 2016) slopes of the Greater Caucasus. The artefacts in the Euphrates River valley in Syria are ~2.0–1.5 Ma (Demir et al., 2007; Trifonov et al., 2012, 2014). The Georgian and Armenian finds are ~1.85–1.75 Ma and are attributed to the Oldovai subchron and the earliest Upper Matuyama chron, i.e., the lowermost Calabrian (de Lumney et al., 2002; Lordkipanidze et al., 2007; Presnyakov et al.,

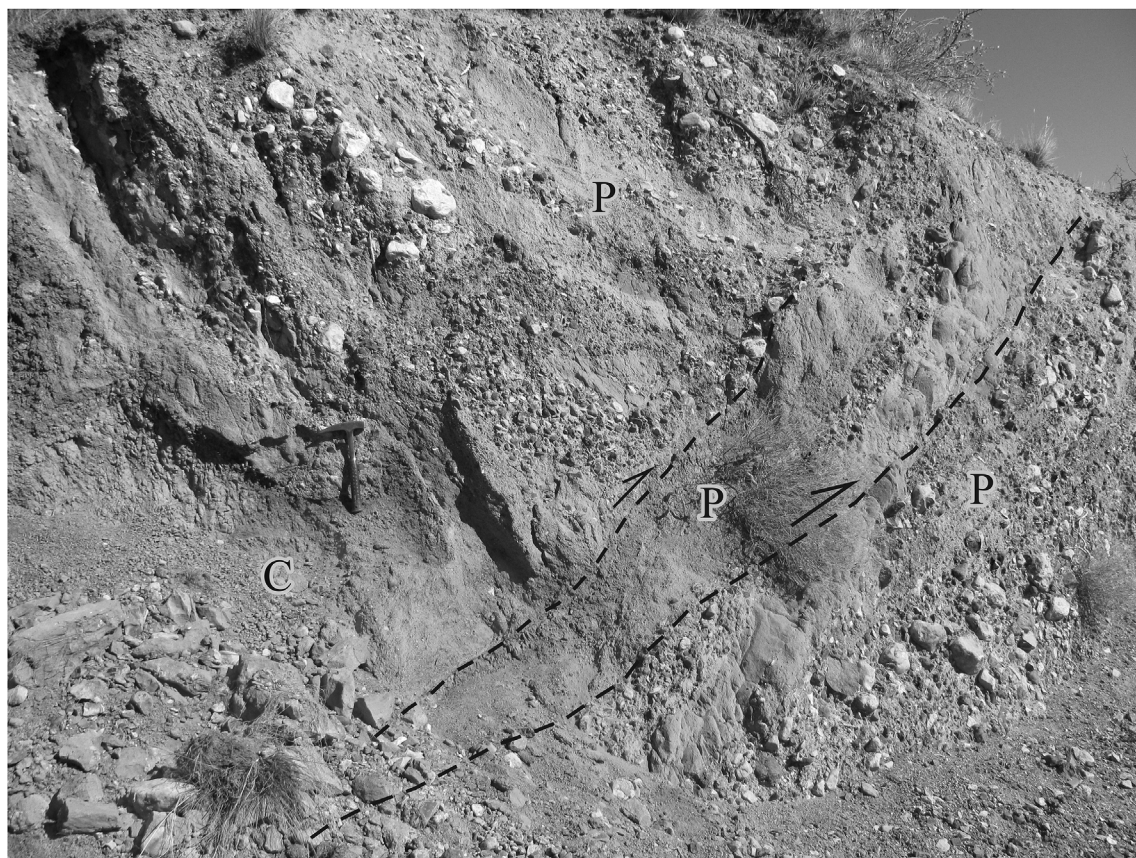


Fig. 24. Reverse fault and near-fault deformation on the boundary of the Palu (P) and Çaybağı (C) Formations in the Karangıbaşı-2 section (13 in Fig. 2); photo by V.G. Trifonov.



Fig. 25. Normal fault in the Örenköy section (110 in Fig. 2); photo by V.G. Trifonov.

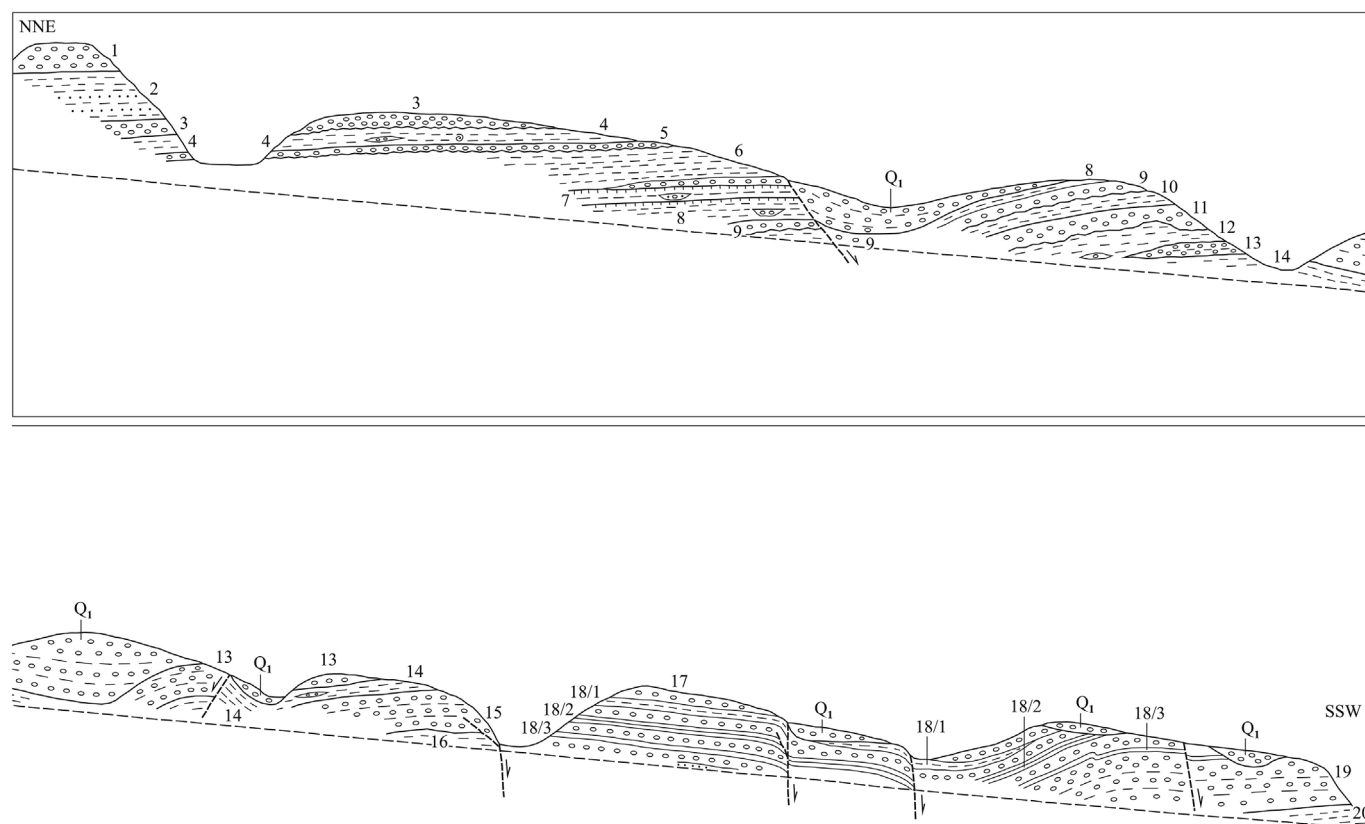


Fig. 26. Drawing of the Örenköy section (110 in Fig. 2 and 6). Numbers of the layers are shown.



Fig. 27. Dip of layers of the Palu Formation in the north-western margin of the town of Palu; photo by V.G. Trifonov.

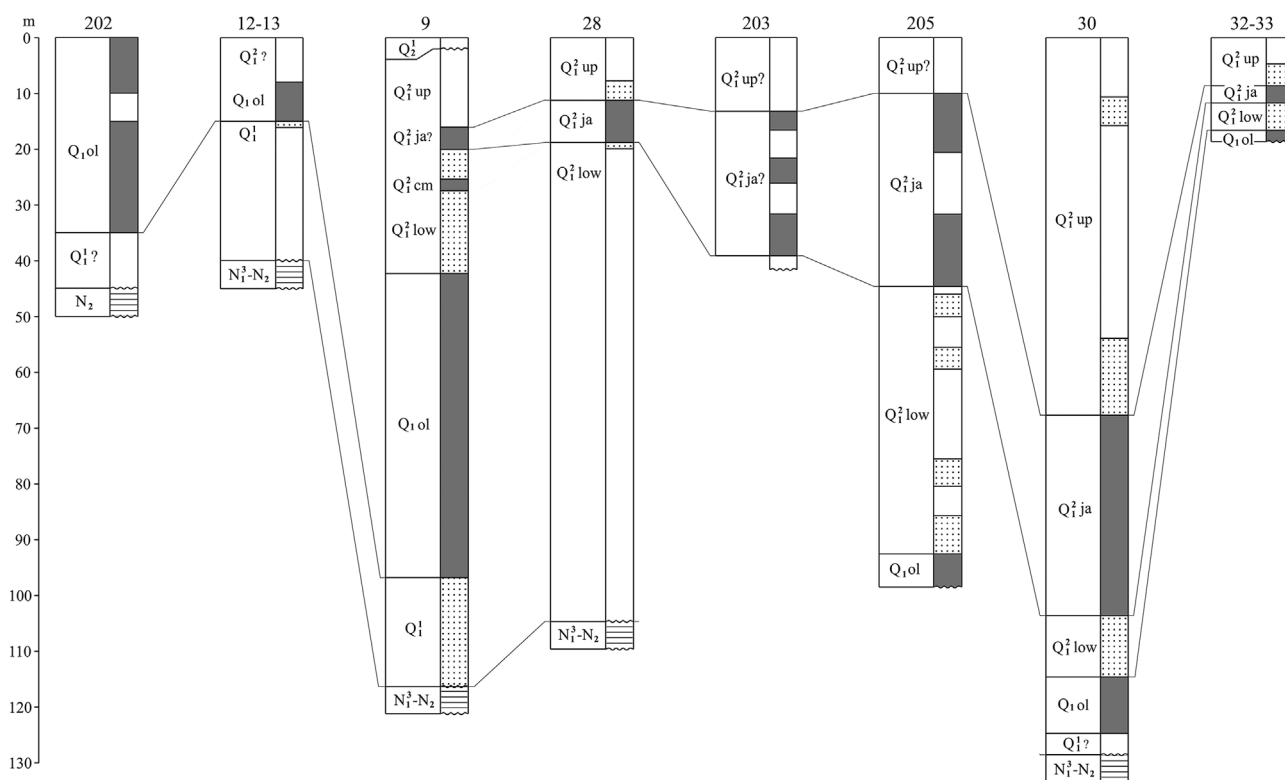


Fig. 28. Correlation of remanent magnetic polarity in the Lower Pleistocene sections to the north of the Taurus Ridge.

2012; Trifonov et al., 2016). The archaeological site Muhkai-II in Dagestan (the eastern Greater Caucasus) corresponds to the late Gelasian and Calabrian. The lowest layers with the Oldowan industries have the R magnetic polarity, underlie the layers correlated to the Olduvai subchron and are dated to ~ 2.0 Ma, according to the paleontological and paleomagnetic data (Amirkhanov et al., 2014, 2016). This allows us to date the Oldowan industry of layer 17 of the Kovancilar (s 9) section to the same age, since layer 17 also has the R magnetic polarity and underlies layers 6–14 with N polarity, which may probably correspond to the Olduvai subchron. In the Şambayat locality of the Oldowan industries, the correlated layer 9 of s 112 and layer 6 of s 115 underlie also the layers corresponding to the Olduvai subchron. But the layer 2 of s 112 and the Bostancık (s 126) deposits with the Oldowan artefacts correlate probably to the Olduvai subchron or the lowermost Calabrian.

Two interpretations of paleomagnetic characteristics of the Kovancılar (s 9) section are possible. According to the first interpretation, layers 3–5 of s 9 correspond to the Upper Matuyama chron, i.e., Calabrian, layer 4 correlates to the Jaramillo subchron, and layers 2 and 1 can relate to the lowermost Middle Pleistocene. According to the second interpretation, layers 2–5 correspond to the Upper Matuyama chron and only layer 1, covering them with unconformity, was formed during the Brunhes Chron and correlates to the lowermost Middle Pleistocene. Layers 2 and 4 that are characterized by the normal polarity can be correlated correspondingly to the Jaramillo and Cobb Mountain subchrons. Taking into account the relative thickness of layers with normal polarity, the second interpretation seems to be preferable.

The base of the Palu Formation is not exposed in the Sultan-Suyu (s 30) section, but the adjacent outcrops show that the base of s 30 is close to the contact of the Palu and Çaybağı Formations. Two intervals of N magnetic polarity are identified among the deposits with R polarity in the Sultan-Suyu (s 30) and Çolakoğlu (s 32 and s 33) sections. Basing on this similarity, we attribute the lower interval to the Olduvai subchron and the upper interval to the Jaramillo subchron as a part of the Upper Matuyama (Calabrian) deposits. Comparing the Sultan-Suyu section to

the Sahiköy one (s 205), we correlate the upper interval with N polarity of s 205 (layers 2–7) to the Jaramillo subchron, and the lower part of the Sahiköy section to the lower Upper Matuyama, except the lowest layer 21 that can represent the Olduvai subchron. The interval with N polarity, correlated with the Jaramillo subchron, is identified in the Tahtalı (s 28) and Altınlı (s 203) sections. The Eskimalatya (s 31) section with the R polarity corresponds, possibly, to the Upper Matuyama (Calabrian).

The represented correlations lead to two conclusions. First, the thicknesses of the correlated layers vary to the north of the Taurus Ridge. They are essentially higher in the N-S-trending band to the west of the Malatya city than to the east of it. Second, the accumulation of the Palu Formation was completed and terrace III formed in its surface at the Calabrian (0.9–0.8 Ma). The silts of layer 1 of the s 9 could be deposited at the surface of terrace III after its formation. Further incision of the Euphrates River and its tributaries into the terrace III surface led to the formation of two or three lower terraces in the Middle and Late Pleistocene. This dating is confirmed by the N magnetic polarity of the lower terrace deposits (s 107) in the Sultan-Suyu valley. Thus, the Palu Formation completed the wide-spread sedimentation in the Euphrates River basin. Younger alluvium accumulated locally along the river channels.

To the south of the Taurus Ridge, the Pliocene–Quaternary sedimentation developed differently. The archaeological finds and magnetic polarity in the deposits of terrace IV of the Göksu-Çayı (s 112 and s 115) and terrace III of the Eskiköydere (s 126) allows to date them to the Olduvai subchron and, possibly, the latest Gelasian and earliest Calabrian. It is correlated with terrace IV of the Erikdere (s 226). The higher terrace V of the Göksu-Çayı and Erikdere is older. The skull of *Parabos* cf. *savelisi* from the upper part of the Erikdere terrace V basement section is dated at the Pliocene (Lower Pliocene?). The dominated R magnetic polarity of the section confirms this conclusion, although the lower part of the section can belong to the Upper Miocene. Accordingly, the terrace V cover is younger. Taking into account prevailing N magnetic polarity of its deposits, we assume terrace V to be of

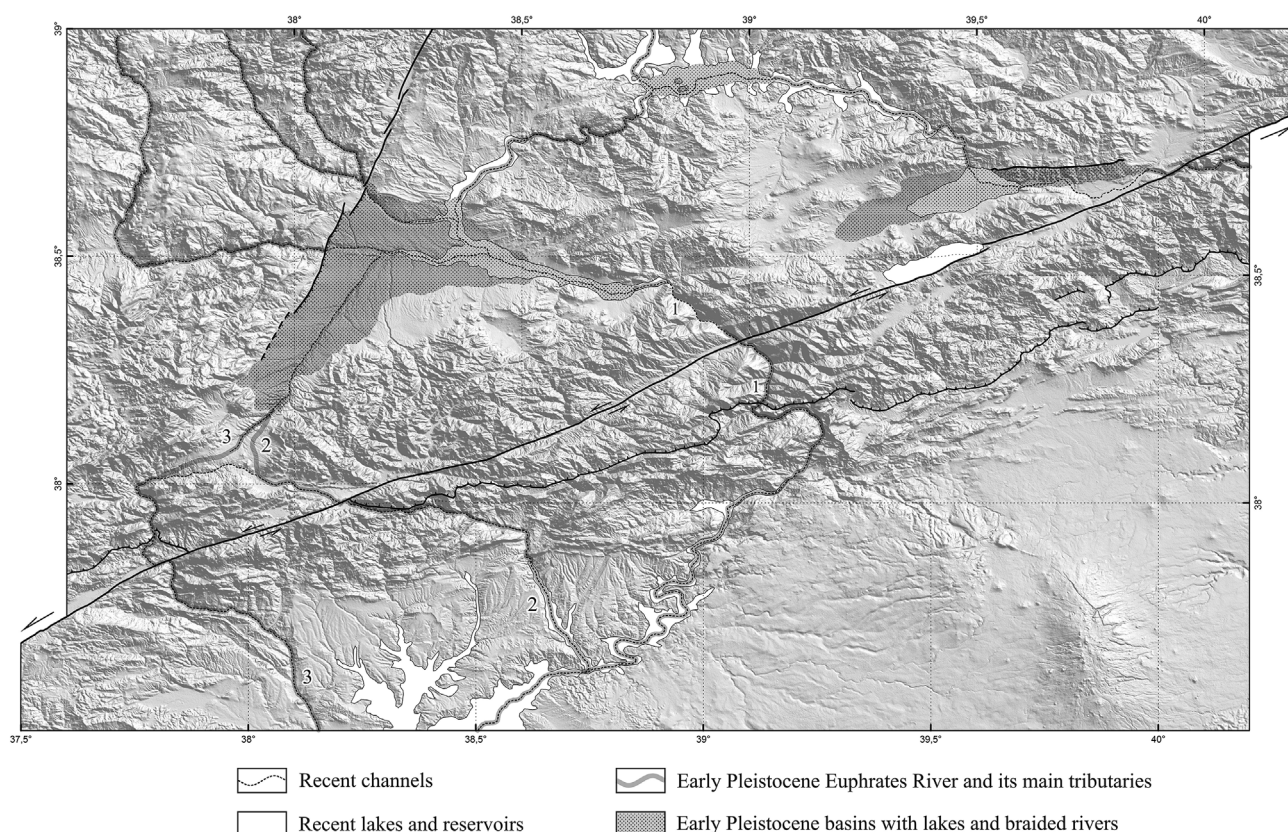


Fig. 29. Reconstruction of the Early Pleistocene Euphrates river basin drainage system without its 12-km offset on the East Anatolian Fault Zone since the late Calabrian.

the Late Pliocene age. Thus, the terrace formation began in the Euphrates river basin to the south of the Taurus Ridge earlier than to the north of the ridge. R polarity of the lowermost layers and N polarity of the upper layers of terrace III of the Göksu-Çayı justify that the terrace cover belongs to the final Calabrian and the early Middle Pleistocene. The terrace II deposits have N polarity and contain the Middle Paleolithic artefacts in the Eskiköydere. This gives a possibility to date the terrace at the late Middle and Late Pleistocene. Correspondingly, terrace I belongs to the end of Pleistocene – early Holocene.

4.2. Paleogeographic and paleotectonic reconstructions

River valleys formed in the Pliocene to the south of the Taurus Ridge. Altitudes of incision and thickness of alluvium depended essentially on local tectonics (development of growing anticlines and depressions). Nevertheless, some general trends can be specified. The difference between altitudes of terraces V and IV reaches 55 m in the Erikdere valley to the NE of the town of Kahta, where the river crosses the pericline of growing anticline (s 224 and s 226 in Fig. 2). In the Göksu-Çayı valley, the difference between altitudes of the same terraces does not exceed 15 m. The valleys were wide and slightly incised. Intensity of incision and accumulation of terrigenous material increased before and during formation of the IV terrace cover, i.e. in the latest Gelasian and earliest Calabrian. 75 m of sediments were deposited in the Erikdere valley (s 226) and they were mostly well-rounded alluvial pebbles. The rocks of the uplifted northern side of the South-Taurus Thrust (metamorphic rocks of the Malatya Formation, ophiolites and intrusive rocks) as well as deposits of local uplifts and the Neogene basalts are present in the terrace debris. Incision increased after formation of the terrace IV alluvium. The difference between altitudes of terrace IV and III reaches ~80 m in the Erikdere and Göksu-Çayı

valleys (Table 3). The sedimentary cover of terrace III (the final Calabrian and early Middle Pleistocene) is 11 m in the Göksu-Çayı valleys and is not more than 5 m in the Erikdere and Kalburcu valleys. Perhaps, this depended on the decrease of water volume that could be partly due to aridization. The intense incision continued in the Middle Pleistocene after the terrace III formation. The difference between altitudes of terraces III and II is 55 m in the Erikdere valley and ~30–40 m in the Göksu-Çayı and Kalburcu valleys. The valleys became narrower and thickness of the terrace II alluvium reaches about 30 m that indicates intense erosion and abundance of water.

To the north of the Taurus Ridge, the fine-grained composition of the Çaybağı Formation (Pliocene and, possibly, from the end of Miocene to early Gelasian) indicates the low contrast of topography and absence of high uplifts in the region. The sedimentation occurred at the end of Miocene – Early Pliocene in stagnant water conditions, partly lacustrine and partly produced by braided slow streams. The poor water flow is justified also by the presence of spores of Algae *Spirogura*, *Botryococcus* and stegonicolous fresh-water mollusk of genus *Planorbarius* as well as good preservation of Unionidae and Dreissenidae (two fasten valves) in layer 22 of the s 9 and in layers 16 to 21 of s 202. Finds of the re-deposited Paleogene dinocysts in layer 20 and Theodorus cf. licherdopoli in layer 19 (s 9) indicate local increase of the flow velocity in the Late Pliocene. Perhaps, the Euphrates and Murat river channels formed at the Pliocene.

Three components are identified within the Pliocene deposits of the Sultan-Suyu valley. They are: (1) fine-grained deposits (mainly silts) of the stagnant waters; (2) coarse debris of small tributaries that are identified because of peculiarities of composition, poor rounding and orientation of pebbles; (3) conglomerates with well-rounded pebbles belonging to the channel facies of big river. In overall a portion of pebbles decreases upstairs, where silts dominate. Attempts to estimate direction of flow in the main stream by pebble orientation did not give

the certain result, although the NNE direction downstream the recent valley determined more often than other directions in the middle and upper parts of the s 110 section. Transition from the conifer forests at the end of Miocene – earliest Pliocene to the forest-steppe landscapes at the Late Pliocene can be due to some aridization.

Considerable amount of well-rounded pebbles in the Lower Pleistocene terrace III cover indicate a long distance alluvial transport from uplifted and eroded areas. Poorly rounded coarse debris points to the growth of local uplifts. At the same time, the fine-grained deposits of the stagnant waters continue to play a significant role, especially in the upper parts of the section, where carbonation of terrigenous deposits indicates some aridization. Increased thickness and fine material portion in the Kovancılar (s 9) section demonstrate development of the local depression inherited from the Pliocene. The other area of tectonic subsidence that was inherited from the Pliocene developed in the western bank of the Euphrates River to the west of the Malatya city and along the Sultan-Suyu River and reached the Taurus Ridge near the town of Doğanşehir.

Terrace III is absent in the recent Euphrates valley near its intersection with the Taurus Ridge (1 in Fig. 29). Only the lower terraces are present there. This means that the Euphrates River flew in other way during the terrace III cover accumulation. The Sultan-Suyu trough-like valley could be the ancient Euphrates channel at that time. The abundant well-rounded fluvial pebbles up to boulder size compose the Sultan-Suyu terrace III up to the river source near the Taurus Ridge. The Sultan-Suyu River is too small to produce wide valley and transport these pebbles. The farther flow of the ancient Euphrates could occur along the Erikdere or Göksu-Çayı valleys, where formation of the river terraces began in the Pliocene. Just to the south of the Sultan-Suyu source, the Doğanşehir tectonic depression strikes from the village of Küçükülü in the west up to the village of Mestan in the east. The recent Göksu-Çayı upper reaches flow along the depression and the Erikdere source is located in its eastern margin. The only 30-m high strath terrace without any relics of alluvium was found in the Göksu-Çayı part of the depression (s 206; N 38.00277°; E 37.93168°; H = 1330 m). This argues rather against than for the Euphrates transit, but the absence of gravel is possible in the river segment with quick water flow, like in a riffle.

The Euphrates transit via the Sultan-Suyu to the Erikdere could exist in the Early Pliocene that is justified by presence of the fluvial conglomerates in both valleys. It was interrupted in the Late Pliocene and the Gelasian because of the Taurus Ridge rise and some aridization. This is expressed by abundance of the fine-grained deposits accumulated in the stagnant waters and signs of northern flow in the pebble orientation of the Sultan-Suyu Pliocene conglomerates. At the end of Gelasian and the early Calabrian, the southern flow recommenced that is justified by presence of the fluvial conglomerates in the Sultan-Suyu, Erikdere and Göksu-Çayı valleys. Perhaps, two latter valleys successively gave way to the Euphrates flow (2 and 3 in Fig. 29). Later the flow was interrupted again. Large portion of the Calabrian was deposited by stagnant waters and formed several horizons of carbonated paleosol. The recent Euphrates segment crossing the Taurus Ridge formed at the end Calabrian. This led to the sharp increase of incision and transformation of the former bottoms of the Euphrates and its tributaries upstream the new-formed segment into terrace III. The Sultan-Suyu depression rose relative to the valley part near the new-formed segment by ~250 m (compare the terrace III altitudes in s 30 and s 32–33).

The EAFZ developed simultaneously to the drainage system, causing and rebuilding the latter. The Kovancılar depression developed as the syncline complementary to the EAFZ and the Sultan-Suyu valley was formed as the trough of extension auxiliary the EAFZ. The sinistral offset on the EAFZ could dam the upper reaches of the Erikdere and Göksu-Çayı and hamper the Euphrates flow on these valleys. The reconstruction of the ancient Euphrates drainage gives a possibility to estimate the rate of the Quaternary sinistral movements on the EAFZ.

The new-formed Euphrates segment is displaced on the EAFZ by 12 km. The segment formed at the end of the Calabrian (0.9–0.8 Ma). Therefore, the average rate of the subsequent lateral slip of the Euphrates is 13–15 mm/year. This estimate can be overstated, because the new-formed Euphrates segment could inherit some local drainage elements that were displaced earlier. The Murat and Göksu-Çayı valleys are offset on the EAFZ by 13–15 and 13.5 km, correspondingly. These valleys existed in the Pliocene and their offsets mean that the slip on the EAFZ began at least in the Pliocene, but its rate was smaller than the rate during the last 0.9–0.8 Ma.

The other important estimate is related to the Quaternary uplift of the Taurus Ridge. The evidence of the Euphrates flow on the Sultan-Suyu valley shows that the source of the recent Sultan-Suyu River was situated lower than its recent downstream part. In the latter (s 30), terrace III has the altitude of 960 m. The altitude reaches 1099 m to the north of the Örenköy stream mouth (s 110) and 1290 m near the Sultan-Suyu River source (s 103). This means that the Sultan-Suyu River source area rose by more than 330 m relative to the lower part of the valley. The 190-m uplift is concentrated near and on the northern slope of the Taurus Ridge. Probably, its axial part rose more intensively. The South-Taurus Thrust Zone (STTZ) is expressed by scarps with the subsided southern sides. The uplift decreased with moving to the south off the STTZ. The terrace IV height is 760 m (h = 190 m) in the Erikdere valley near the STTZ (s 208) and only 632 m (h = 150 m) in the Göksu-Çayı valley, situated 20 km southwards of the STTZ (s 112). The latter altitude is 650–660 m lower than the Sultan-Suyu source (s 103).

The total uplift of the studied region supplemented differentiated rates of vertical movements. Its minimum magnitude is estimated by the value of recent incision into the terrace III surface (the late Calabrian) and reaches 115–135 m to the north of the Taurus Ridge. This corresponds to the average uplift rate of 0.13–0.16 mm/year. The incision was smaller during the commensurable time in the northern Arabian Plate. The recent incision to the Calabrian terrace IV is 190–120 m in different valleys. If the terrace age is about 1.5 Ma, the average rate of the incision is 0.12–0.08 mm/year. The recent incision to the Göksu-Çayı and Kalburcu terrace III (h = 54–67 m; the early Middle Pleistocene) gives similar rates. The larger elevation of the Erikdere terrace III to the NE of the Kahta town is caused by rise of the local anticline. The average estimates of the incision are commensurable with the incision values of the same age downstream the Euphrates: 56–80 m in the Birecik segment, Southern Turkey (Demir et al., 2008), and 45–70 m in the Jرابلس segment, Northern Syria (Trifonov et al., 2014). We defined this area as the Aleppo mobile block of the Arabian Plate. Downstream, in the south-western side of the Mesopotamian Foredeep, the incision to the simultaneous terraces decreases to 20–40 m (Trifonov et al., 2012).

The described tectonic movements occurred unevenly. Westaway et al. (2006) reported the phase of tectonic activation at 0.5–0.7 Ma. The deformation of the Kovancılar (s 9) section and tectonic tilting of the Lower Pleistocene deposits in the other sites (s 5, 36, 103) took place probably just at that time.

5. Conclusions

The paper represents data on Pliocene and Lower Pleistocene sequences and their deformation in the Euphrates river basin for comparison its areas to the north and to the south of the Taurus Ridge that is bordered to the south by the South-Taurus Thrust. The thrust serves the boundary of the Arabia-Caucasus part of the Alpine-Himalayan Belt and the Arabian Plate Foreland. Lithological and geomorphological correlations, palynological analysis, determination of the paleontological and archaeological finds and remanent magnetic polarity of deposits, and K-Ar analysis of volcanic rocks were used to date the deposits.

Tectonic depressions that are situated to the north of the Taurus Ridge and joined by braided streams, were developed in the Pliocene and Gelasian. Fine-grained deposits of stagnant waters were

accompanied by some portion of the sand-pebble alluvium. The portion of coarse alluvium increased at the end of the Gelasian and the Calabrian because of the erosion of the developing uplifts. Sharp incision of river channels to the former vast area of accumulation occurred at the end of Calabrian and led to formation of terrace III. The further uneven incision due to the tectonic uplift of the region produced the local lower terraces.

To the south of the Taurus Ridge, i.e., in the Arabian Plate Foreland, formation of the river terraces started in the Early Pliocene. The terraces were wide and the rates of incision were small in the beginning. From the Middle Pleistocene, the incision accelerated and the lower terraces localized near the recent channels. Development of this process was studied in the Erikdere and Göksu-Çayı valleys, where the rates of incision and, correspondingly, tectonic uplift were lower than to the north of the Taurus Ridge and increased only in local anticlines.

The Kovancılar and Sultan-Suyu tectonic depressions developed to the north of the Taurus Ridge, being linked with the East Anatolian zone of the sinistral faults (EAFZ). The Kovancılar depression was the W–E-trending syncline complementary to the EAFZ and the NNE–SSW-trending Sultan-Suyu valley was the trough of extension auxiliary the EAFZ. The recent Euphrates River segment does not have terrace III near the intersection with the Taurus Ridge and formed later. The Euphrates flew earlier along the Sultan-Suyu depression and farther the Erikdere and partly Göksu-Çayı valleys to the basin that is occupied by the Atatürk Reservoir now. This water transit could exist in the Early Pliocene. It was interrupted in the Late Pliocene because of the uplift of the Taurus Ridge and some aridization. The transit resumed at the end of Gelasian – early Calabrian and was interrupted again. The flow across the Taurus Ridge along the recent Euphrates segment formed in the late Calabrian. The existence of the formed water transit is justified by presence of the thick pebble alluvium of the corresponding age in the above mentioned valleys. The terrace III pebbles are traced along the Sultan-Suyu River up to its source, although the recent river is too small to form this wide valley and thick pebble alluvium.

The newly-formed in the late Calabrian the Euphrates River segment is displaced on the EAFZ to the left by 12 km. This gives the possible average slip rate of 13–15 mm/year. The source of the Sultan-Suyu River was uplifted relative to its lower part since the end Calabrian by 330 m. The axial part of the ridge was uplifted higher and increased the magnitude of vertical offset on the South-Taurus Thrust zone in the Arabian Plate boundary.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.quaint.2018.06.009>.

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