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The Upper Pliocene – Quaternary geological history of the Shirak Basin (NE Turkey and NW Armenia) and estimation of the Quaternary uplift of Lesser Caucasus

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A B S T R A C T

Stratigraphy, structure, and tectonics of the Turkish part of the intermontane Shirak Basin and the adjacent Susuz Basin were studied based on methods of structural geology, geological and geomorphological correlation, paleontology, paleomagnetism, and archaeology. For the first time, the Pliocene-Quaternary stratigraphy and tectonics of the western Turkish and eastern Armenian parts of the Shirak Basin were correlated. Sedimentary cover of the western part of the basin consists of four units: the Lower Akchagylian (Piacenzian) marine deposits, Karakhach, Ani, and Arapi lacustrine-alluvial units. The Upper Pliocene age of the former formation in the Demirkent section is evidenced by normal palaeomagnetic signature and dinocysts of the Akchagylian aspect with some forms known to have a highest stratigraphic datum near the Pliocene–Quaternary boundary. The age of the Karakhach unit is estimated at 1.9–1.7 Ma based on similar geomorphological position and composition with corresponding deposits in Armenia, normal polarity, and a record of the Early Palaeolithic artefact. The dating of the Ani unit to the Calabrian, and the Arapi unit to the lower Middle Pleistocene is evidenced by assemblages of molluscs and small mammals, Acheulian artefacts, palaeomagnetic data, and geomorphological position similar to the correlated sedimentary sequences in the Armenian part of the basin.

The level of the Akchagylian brackish water basin at the Neogene–Quaternary boundary (2.58 Ma) was close to the recent oceanic level. The recent altitude of the top of the Lower Akchagylian deposits in the Demirkent section is 1565 m. This defines the average rate of the Quaternary uplift in this part of Lesser Caucasus at 0.6 mm/year. The Shirak Basin is bounded and ruptured by fault and flexure-fault zones. Because of offsets on the Çamuşlu and Akhuryan zones, the central part of the northern Shirak Basin is subsided relative to the Demirkent section at 130–165 m. The movements in the Çarçioğlu zone caused a 100–120 m rise of the Ani unit surface in the Susuz Basin relative to the adjacent part of the Shirak Basin. The north-western border of the Susuz Basin is uplifted on the Sarikamiş fault zone. Thus, the Quaternary uplift ranges near 0.6 ± 0.1 mm/year. To the north of the Shirak Basin, in the Upper Akhuryan and Lori Basins and the Debed River valley, the rate of uplift during 0.65–0.6 Ma is estimated at about 1 mm/year and the adjacent Bazum and Javakheti Ridges rose more intensively. Therefore, the uplift could accelerate during the time interval of 0.65–0.6 Ma.

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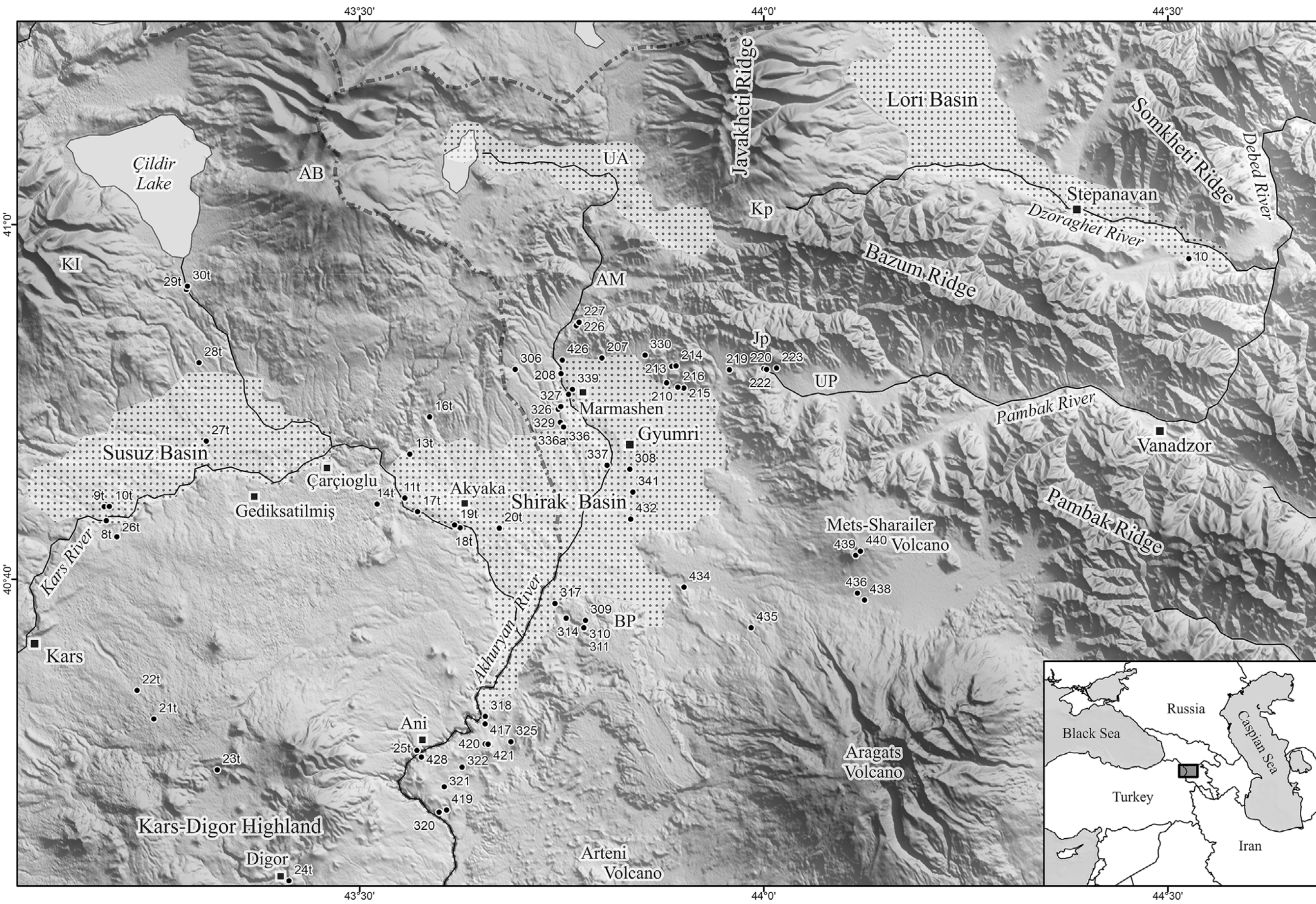

Fig. 1. Topography and drainage system in the NE Turkey and NW Armenia with sites of observation mentioned in the text.
(AB) Akbaba Highland, (AM) Amasia Basin, (BP) Bartsrashen Plateau, (Jp) Jajur Pass, (KI) Kisir Highland, (Kp) Karakhach Pass, (UA) Upper Akhurian Basin, (UP) Upper Pambak Basin.

1. Introduction

The present paper is devoted to the Pliocene-Quaternary geology of the Shirak Basin and its surrounding in NE Turkey and NW Armenia. Two stages of the basin evolution differentiated during this time interval. The first stage was characterized by uneven subsidence of different parts of the basin. Our goal is to define spatial and temporal distribution of this process and try to identify its sources. During the second stage, the basin underwent uneven tectonic uplift and became a part of mountain system of Lesser Caucasus. Our goal is to analyse and calculate mountain-producing vertical movements in the region and to estimate their total (characteristic for the whole region) and local (depending on relative movements of structural elements) components.

We studied the eastern Armenian part of the region in 2014–2016 and published the results (Trifonov et al., 2016, 2017; Shalaeva et al., 2019). In this paper, we represent new data on the western Turkish part of the basin obtained in 2017 and 2019 and results of comparative analysis of both its parts and adjacent territories.

2. Methods

In the study of the Turkish part of the Shirak Basin, we used the same combination of geomorphological, lithological, paleontological (including palynology), palaeomagnetic, radio-isotopic, and archaeological methods that was used in the Armenian part of the basin (Trifonov et al., 2017; Shalaeva et al., 2019; Tesakov et al., 2019). Description of sections, studies of lithological variations, contacts between the units, and tectonic deformation were carried out during field works. Because the tops of different sedimentary units form terrace-like geomorphological levels, they were correlated, their altitudes were measured by the GPS receivers, and altitudinal profiles were constructed across the basin and the adjacent territory to determine relative position of the levels and their tectonic deformation. Using the GPS data and the 3 arc-seconds DEM on the base of SRTM provided the accuracy of the altitudinal estimates not worse than 5 m.

Molluscs were collected and examined by P.D. Frolov and the found small mammals were identified by A.S. Tesakov in the Geological Institute of the RAS. The palinological samples were collected and examined by A.N. Simakova with consulting of G.N. Aleksandrova for identification of found Pliocene dinocysts. Probe maceration was performed by the method adopted in Geological Institute of the RAS, which is a modification of the Grischuk's separation method (Grichuk and Zaklinskaya, 1948), namely, the samples were additionally treated by sodium pyrophosphate and hydrofluoric acid. Pollen diagrams were constructed in Tilia 1.5.12 program, which allows to calculate the general spectrum (arborescent pollen + nonarborescent pollen + spores = 100%) and individual components as a portion of the total amount of grains. The archaeological finds were studied in the Instute of Archaeology of the RAS by D.V. Ozherelyev and in the Institute for the History of Material Culture of the RAS by E.V. Belyaeva.

Palaeomagnetic samples were taken as hand blocks and oriented using a magnetic compass. The local magnetic declination was calculated using the IGRF model. The palaeomagnetic procedures were performed in the Palaeomagnetic laboratory of the Institute of Physics of the Earth of the RAS by A.V. Latyshev. All the samples were subjected to the stepwise alternating fields (AF) demagnetization up to 130 mT with the AF-demagnetizer inbuilt in the 2G Enterprises cryogenic magnetometer. The remanent magnetization of samples was measured using the 2G Enterprises cryogenic magnetometer “Khramov”. The isolation of the natural remanent magnetization (NRM) components was performed with Enkin's (Enkin, 1994) palaeomagnetic software package using principal component analysis (Kirschvink, 1980). The quality of palaeomagnetic signal varies from sample to sample. Nevertheless, more than 80% of the studied samples were suitable to define the palaeomagnetic directions. The $^{40}Ar/^{39}Ar$ dating of andesite from site 29t was carried out under leadership of Dr. A.V. Travin in the Sobolev Institute of Geology and Mineralogy, the Siberian branch of the RAS, the city of Novosibirsk.

All sections are described in the paper from the top downwards. H is the height a.s.l., T is thickness of the layer, N is normal remanent magnetic polarity, and R is reverse one.

3. Geological setting of the Shirak Basin and general features of its Armenian part

The Shirak Basin is the largest intermontane depression in the western Lesser Caucasus. The basin is situated at altitudes between 1500 and 1700 m a.s.l. and contrasts with its mountain surrounding that is uplifted up to 2000–2500 m with higher (up to 3000–4000 m) Quaternary volcanoes (Figs. 1 and 2). The Akhuryan River crosses the basin from north to south and incises into the basin flat surface up to several tens of meters.

The basin is bounded to the north by the western spurs of the Bazum Ridge that are composed of Paleogene, Cretaceous, and Jurassic rocks with fragments of the Meso-Tethys (the northern branch of Neo-Tethys) suture, which is considered to be a western part of the Sevan-Hakari ophiolite zone (Knipper, 1975; Khain, 2001; Adamia et al., 2011, 2017). Formation of the oceanic crust composing the ophiolites began in the Late Triassic and its subduction lasted from the Middle Jurassic up to Turonian or possibly Campanian, according to the data on island type volcanism and other records (Knipper et al., 1997; Bagdasaryan and Gukasyan, 1985; Danelian et al., 2007, 2010; Galoyan et al., 2007, 2018; Rolland et al., 2010; Sosson et al., 2010). The south-western continuation of the suture is exposed to the west of the city of Kars and probably farther to the south near the town of Horasan (Geological Map of Turkey, Kars, 2002), where it joins with the Izmir–Ankara–Erzincan suture (Sengör, Yilmaz, 1981). Another branch of the latter suture extends to the east of the town of Horasan up to the town of Kağizman, where it turns to the south-east, follows along the south-western coast of the Urmia Lake, and farther joins with the southern Neotethys suture (Geological Map of Iran, 1978). Avagyan et al. (2017) consider that ophiolites of this southern branch are allochthonous and are obducted from the Sevan–Hakari suture zone. However, structural position of the southern branch between the Taurides and Iranian microplates attributes it rather to the independent branch of the suture zone.

The Pambak Ridge bounds the Shirak Basin to the east and separates it from the Sevan Basin. The ridge is composed mainly of the Eocene volcanic and clastic rocks (Gabrielyan, 1964; Djrbashyan, 1990; Sahakyan et al., 2017) as well as the Cretaceous rocks in southern Tethys facies (Aslanyan, 1958) and the Upper Miocene lavas (Karapetian et al., 2001). The same Eocene rocks are exposed to the west of the Shirak Basin, westward of the city of Kars.

The Aragats volcano that was active in the time range from 1.0 to 0.45 Ma (Chernyshev et al., 2002) forms the eastern part of the southern border of the Shirak Basin. Relics of the smaller 1.28 ± 0.06 Ma old Arteni volcano are identified in the Aragats western slope (Lebedev et al., 2011). The western foot of the Aragats volcano is composed of volcanic-terrigenous breccia (sites 310 and 311 in Fig. 1) that consists of andesitic fragments including big angular blocks in tuffaceous and hydrothermally reworked matrix. Three K/Ar dates of andesitic fragments range from 24.4 ± 0.6 Ma to 24.8 ± 0.7 Ma; the obtained age 1.6 ± 0.7 Ma of the matrix should be used with caution because of a large portion of atmospheric ^{40}Ar in the sample (Shalaeva et al., 2019). Sayadyan (2009) reported the same breccia of several hundred meters thick in the boreholes below the sedimentary cover of the Shirak Basin and correlated the breccia to the Voghchaberd Unit with a probable Messinian age near the city of Yerevan.

To the west of the Aragats volcano, the southernmost part of the basin sedimentary cover is found near the village of Haykadzor (site 318). The sedimentary deposits are underlain by volcanic rocks that border the basin near the ruins of the medieval city of Ani. The volcanic complex consists of two main units. The K/Ar dates of the lower unit of basaltic andesites and andesites are ranged from 5.8 ± 0.2 Ma to 4.26 ± 0.12 Ma and the dates of the upper unit of rhyolitic lithic tuffs and ignimbrites are 3.14 ± 0.10 Ma to 2.8 ± 0.15 Ma (Trifonov et al., 2017; Shalaeva et al., 2019). The upper unit is covered in the Ani city by a layer of basaltic andesite K/Ar dated by V.A. Lebedev to 2.64 ± 0.10 Ma (Shalaeva et al., 2019). The Pliocene volcanic units extend to the west up to the Kars city, forming the Digor Highland that borders the Shirak Basin to the south-west. The Pliocene volcanic rocks are covered in some areas by the Quaternary lavas.

A small band of the Pliocene and Quaternary volcanic rocks between the villages of Gediksatilmiş and Çarçioğlu separates the Shirak and more western Susuz Basins, but a narrow corridor of sedimentary rocks crossing the band shows that the basins communicated during the sedimentation. The Kisir Daği and Akbaba Daği highlands composed of the Pliocene and Quaternary volcanic rocks border the Susuz and the north-western Shirak Basins to the north.

Several smaller intermontane depressions accompany the Shirak Basin. Those are the Selim Basin to the SW of the city of Kars, the Upper Akhuryan Basin between the Bazum Ridge and the volcanic Javakheti Highland, the Lori Basin between the Javakheti, Somkheti and Bazum Ridges, and a chain of small depressions between the Bazum and Pambak Ridges.

Sayadyan (2009) divided the sedimentary cover of the Armenian part of the Shirak Basin into four formations. They are: (1) the Akchagylian deposits corresponding to the Piacenzian and Gelasian and known only in boreholes; (2) the Eopleistocene deposits corresponding to the Calabrian and identified only in the northern side of the basin; (3) the Ani unit dated to the lower Middle Pleistocene; and (4) the Arapi unit dated to the upper Middle Pleistocene.

Our studies in the Armenian part of the Shirak Basin that are founded on the lithological, paleontological, palaeomagnetic, geomorphological, and radio-isotopic researches refined the age of the formations and the history of the basin (Trifonov et al., 2017; Shalaeva et al., 2019; Tesakov et al., 2019). We identify the Eopleistocene deposits (2) with the Karakhach unit of the Lori Basin that was dated to the time interval about 1.9–1.7 Ma using the SIMS $^{238}U/^{206}Pb$ dating of tuffs, K/Ar dating of volcanic rocks, and examination of remanent magnetic polarity (Presnyakov et al., 2012; Trifonov et al., 2016). The Ani unit is identified with the upper Calabrian, although the uppermost part of the sections can belong to the lowermost Middle Pleistocene. The Arapi unit was deposited at about 0.75 to 0.65 Ma (Agajanyan and Melik-Adamyan, 1985; Melik-Adamyan, 1994; Tesakov et al., 2019) and is covered by dacitic ignimbrite with the K/Ar dates about 0.7–0.65 Ma (Trifonov et al., 2017; Shalaeva et al., 2019). The Kurtan unit is the stratigraphic analog of the Ani and Arapi units in the Upper Akhuryan and Lori Basins (Trifonov et al., 2016). In the northern Shirak Basin, the Karakhach and Ani units are underlain by a basaltic andesite with the $^{40}Ar/^{39}Ar$ date of 2.09 ± 0.05 Ma (Ritz et al., 2016) and K/Ar dates of 2.1 ± 0.2 and 2.25 ± 0.10 Ma (Shalaeva et al., 2019).

The Karakhach, Ani and Arapi units correspond to three cycles of sedimentation that started with lacustrine accumulation and ended with alluvium accumulation. The lacustrine part is relatively poor in the Karakhach unit and dominates in the Ani and Arapi units. In the northern Shirak Basin, the Arapi unit is incised into the Ani unit, and the Ani unit is incised into the Karakhach unit. Southward, the units

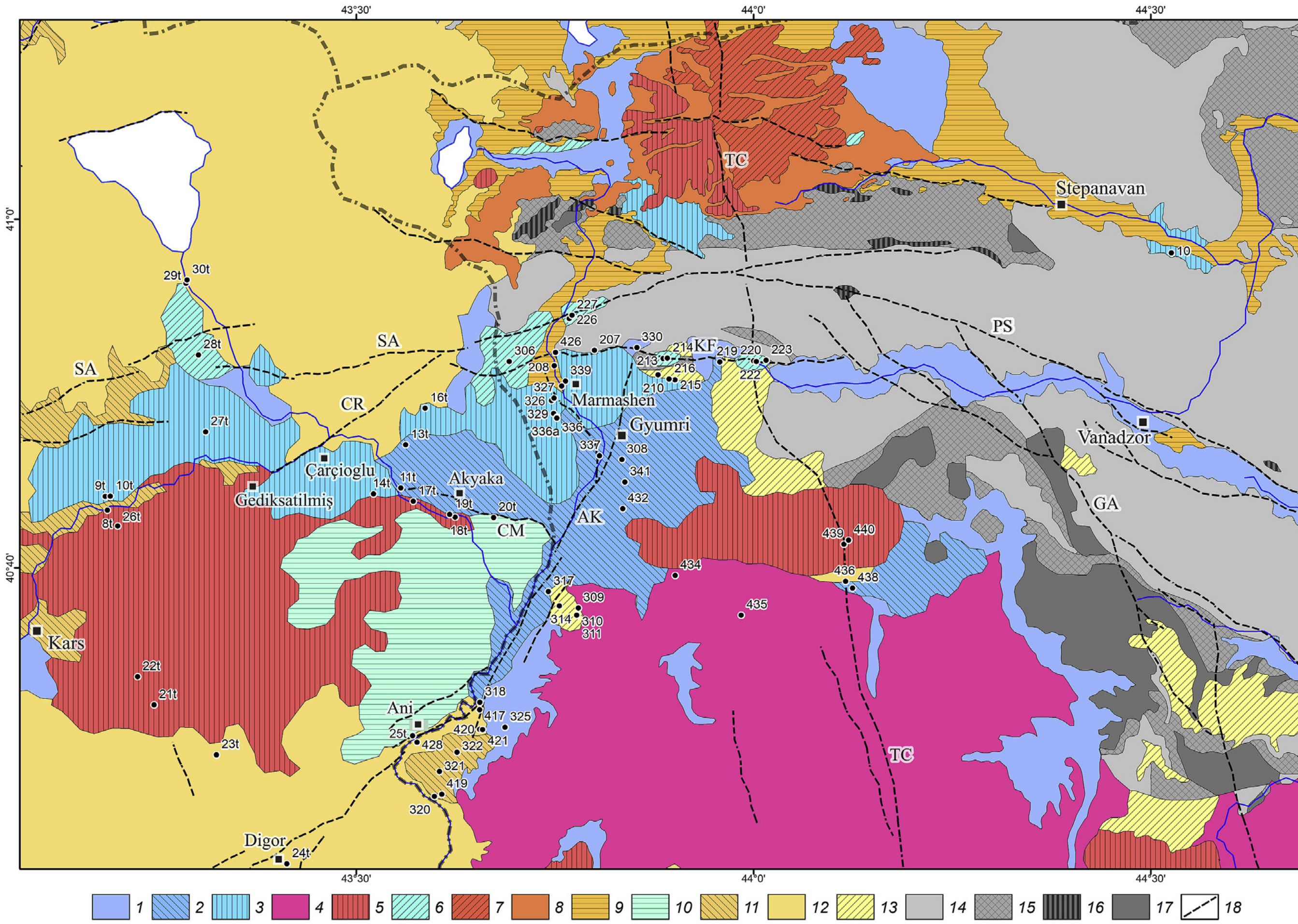

Fig. 2. Geological map of the Shirak Basin and its surrounding with main sites of observation, after (Nalivkin, 1976; Geological Map of Turkey, Kars, 2002; Shalaeva et al., 2019) with additions.
Nalivkin, 1976 (1) The upper Middle Pleistocene to Holocene deposits; (2) Arapi unit, the lower Middle Pleistocene; (3) Ani unit in the Shirak and Susuz Basins, the Calabrian, and Kurtan unit in the Lori and Upper Akhurian Basins, the Calabrian and lower Middle Pleistocene; (4) volcanic rocks of the Aragats center (1.0–0.4Ma); (5) the Lower and lower Middle Pleistocene volcanics, including rocks of Mets-Sharailer Volcano (~0.9–0.5Ma), Arailer and Arteni Volcanoes (~1.35–1.0Ma), and the V trachiandesite unit of the Javakheti Ridge (~1.7Ma); (6) Karakhach unit (1.9–1.7Ma); (7) the IV dacite unit of the Javakheti Highland (~1.8–2.0Ma); (8) the III trachiandesite unit of the Javakheti Highland (~1.8–2.0Ma); (9) the II basic lava unit of the Javakheti Highland (~2.0–2.5Ma); (10) the Upper Pliocene deposits; (11) the Pliocene acid tuffs; (12) the Pliocene and possibly Messinian basic to acid lavas that can include the Lower Pleistocene lavas in the Akbaba and Kisir Highlands; (13) the Upper (?) Miocene volcanics; (14) Paleogene (mainly Eocene); (15) Cretaceous and Jurassic; (16) Mesozoic ophiolitic and ultrabasic rocks; (17) Paleozoic and Precambrian; (18) faults and flexure-fault zones. (AK) Akhurian fault, (CM) Çamuşlu flexure fault zone, (CR) Çarçioğlu flexure-fault zone, (GA) Garni fault, (KF) Kaps flexure-fault zone), (PS) Pambak-Sevan-Syunik fault zone, (SA) Sarikamiş fault zone, (TC) Trans-Caucasus flexure-fault zone.

cover each other and each younger unit extends farther to the south than the older one. These relationships show that the northern part of the Shirak Basin uplifted and the basin migrated to the south during the Early and early Middle Pleistocene (Shalaeva et al., 2019).

4. Results

4.1. Geological composition of the western Shirak Basin

4.1.1. Arapi unit

The most complete section of the Arapi unit is exposed near the village of Çamuşlu (N40°44.600′; E43°33.351′; site 11t). The Arapi deposits are incised into an escarp of the Pliocene-Lower Pleistocene sequence that consists of three 10–12-m thick layers of andesite with about 30-m thick layer of conglomerates and finer-grained clastic sediments between the lower and middle andesite layers. The Arapi unit is composed of (Fig. 3):

1. Silt with lenses of sands and gravels; T is about 10 m (it seems to reach 25–30 m because of tilting and offset of the unit on a flexure-fault zone that strikes along the escarp). Fauna of molluscs was found in the upper part. N magnetic polarity in the lower part.
2. Well rounded pebbles of small and middle size with lenses of sand and silt; T is up to 1.5 m. The Acheulian artefacts are found. The top of bed 2 (H = 1511 m) is a part of spacious terrace.
3. Fine-grained sandstone and silt; T is 4 m. N magnetic polarity in the lower part.
4. Thin-bedded fine-grained sandstone and silt with diatomaceous silt in the base (1 m), interbeds of diatomites and lenses of gravel; T is 8 m. Fauna of molluscs. Bones in the basal diatomaceous silt. N magnetic polarity with two 1-m thick intervals of R polarity.

The other Arapi outcrops (sites 13t, 17t, and 18t) represent only fragments of the unit section. Tops of all of them have a height of 1510–1514 m. The Arapi sediments are overlain by lavas in sites 13t and 17t. Site 19t is situated in the Arapi basin margin. The section consists of:

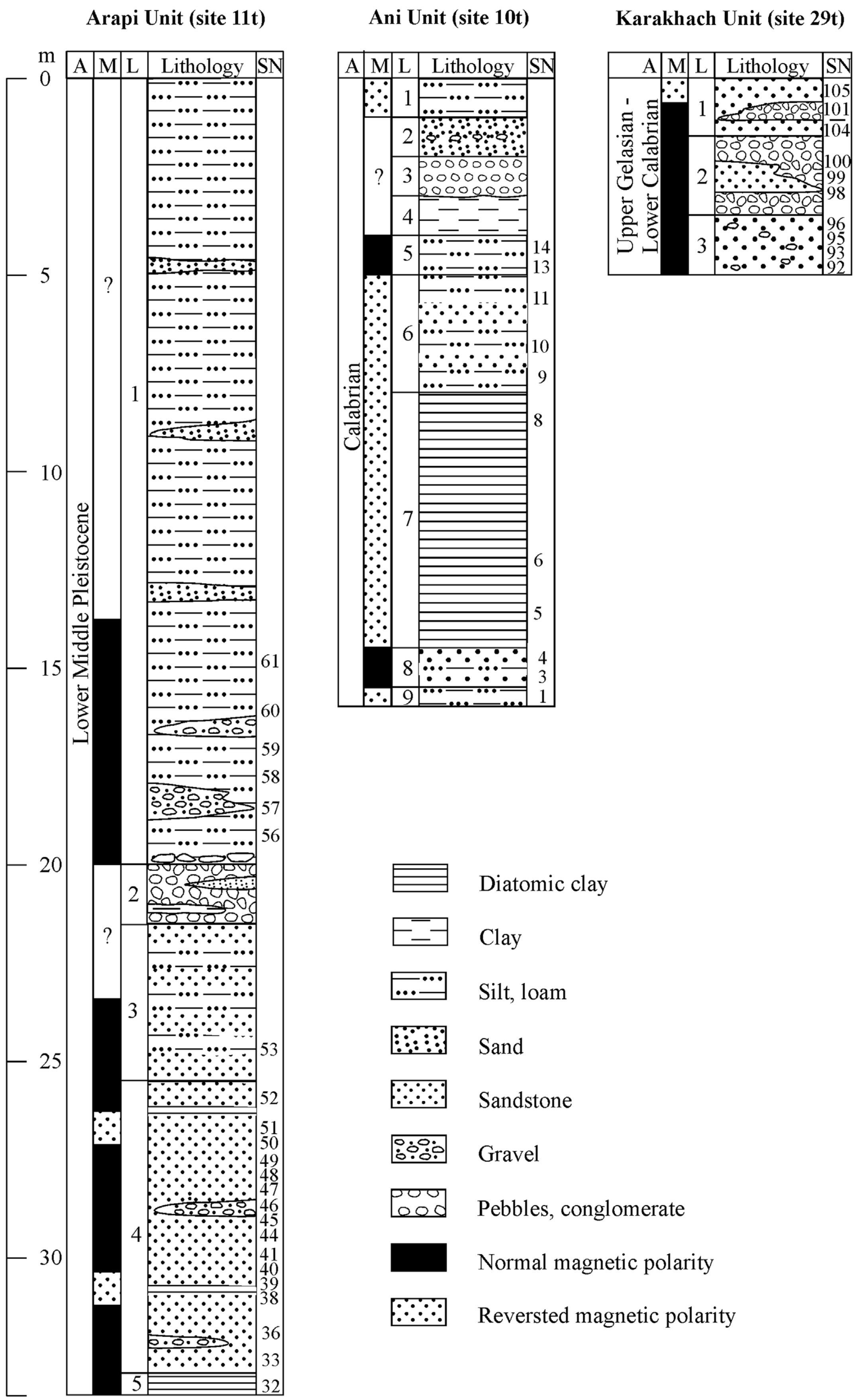

Fig. 3. Stratigraphic sections of the Arapi (Çamuşlu,11t), Ani (Çamçavuş, 10t), and Karakhach (29t) units in the Susuz and western Shirak Basins. Position of the sections is shown in Figs. 1 and 2. (A) stratigraphic position, (M) magnetic polarity, (L) numbers of layers or beds, (SN) numbers of palaeomagnetic samples.

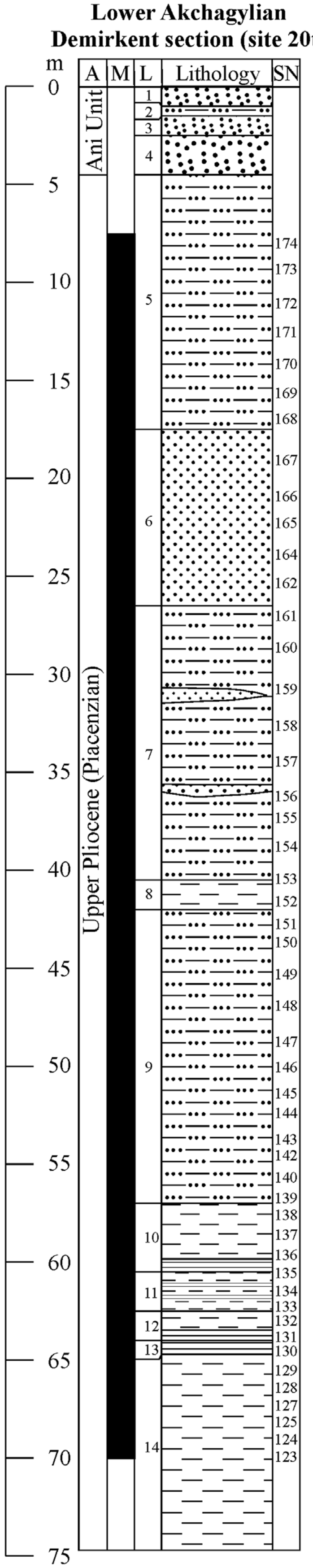

Fig. 4. Stratigraphic section of the Upper Pliocene – Early Pleistocene deposits at Demirkent (site 20t). See Fig. 3 for the legend.

1. Several andesitic layers.
2. Red argillite burnt by lava; T is 0.5 m.
3. Lapilli; T is 4 m.
4. Bedded sandstone; T is 2 m.
5. Sandstone consisting of andesitic grains and tuffaceous matrix; T is 11 m.

Beds 4 and 5 show N magnetic polarity.

4.1.2. Ani Unit

In the western Shirak Basin, the Ani unit is exposed only near its margins and outcrops fragmentally. In site 16t (NW of the basin), the Ani section underlies the andesitic layers and is composed of: (1) Tuffaceous sand; 1.6 m; (2) Greenish-grey clay with two interbeds (0.7–0.9 m each) of diatomaceous silt; up to 4 m. All deposits (possibly, except the basal clay) show R magnetic polarity. Site 14t is particularly interesting, because it demonstrates evident covering of the Ani unit by a lava flow. This section is the following: (1) Basaltic andesite, red in the base; 2 m; (2) Black loam, reddish and condensed in the uppermost part; 0.2–0.4 m; (3) Diatomaceous silt; 0.5 m; (4) Grey clay; 0.3 m. The beds (2) and (3) show N magnetic polarity.

The more complete Çamçavuş section of the Ani unit is exposed in the southern Susuz Basin (site 10; Fig. 3):

1. Loam, carbonated along fractures and in the top; T is 1 m. R magnetic polarity.
2. Sand with gravel; T is 1 m.
3. Poorly consolidated well rounded conglomerate with pebbles of small and middle size; T is up to 1 m. The rough erosional lower surface. The Early Palaeolithic artefacts.
4. Greenish clay with abundant shells of molluscs; T is up to 1 m.
5. Thin-bedded silt and fine-grained sandstone; T is 1 m. N magnetic polarity.
6. Thin-bedded silt and fine-grained sandstone with 10–15 cm thick interbeds of ferruginate sandstone; T is 2.5–3 m. Shells of molluscs concentrate in several lenses. R magnetic polarity.
7. Diatomaceous clay and silt with shells of molluscs; T is 6–6.5 m. R magnetic polarity.
8. Thin-bedded fine-grained sandstone and silt; T is 1 m. N magnetic polarity.
9. Silt; T is 0.5 m. R magnetic polarity.

The lower lacustrine (beds 4–9) and upper alluvial (beds 1–3) parts of the Ani unit are identified in the site 10t. Bed 3 thickens up to 1.5 m and contains boulders in the adjacent site 9t, where the Acheulian tools were found. The more complete section of the upper alluvial part is exposed in a quarry of site 27. This section consists of: (1) Grey sand with stones; 1 m; (2) Brownish sandy loam with stones and pebbles; 2 m; (3) Sandstones with conglomerate lenses; 1.5 m; (4) Clay and silt with shells of molluscs that belong to the lower lacustrine part of the unit. Remain of the elephant leg were found in the quarry bottom. Probably, they belong to the bed (3).

4.1.3. Karakhach unit

The deposits that can be identified with the Karakhach unit are exposed in the northern border of the Susuz Basin (sites 28t and 29t). In site 28, the 25–30 m thick clastic sequence covers andesite in H = 1785 m. In site 29 the Karakhach deposits are incised into the basaltic andesite with the $^{40}Ar/^{39}Ar$ date 3.65 ± 0.08 Ma and are composed of (Fig. 3):

1. Coarse sandstone with conglomerate lens; T is 1.5 m.
2. Conglomerate with sandstone lens; T is 1.5–2 m.
3. Intercalation of sandstones with different size of grains; T is 1.6 m.

The sequence shows N magnetic polarity, except the upper (0.4 m) part of bed 3 that can have R polarity. A big chopper of the Early Palaeolithic aspect was found in bed 2.

4.1.4. Lower Akchagylian (Upper Pliocene)

The late Pliocene deposits were found to the south of the town of Akyaka in the Demirkent section (site 20t; N40°42.897′; E43°40.367′; H = 1570 m) called after a neighbouring village. The section (Fig. 4) is composed of:

1. Cross-bedded sand and gravel with inclusion of pebbles 2–3 cm and rarely up to 20 cm; T is 2 m.
2. Horizontally bedded silt with abundant shells of molluscs; T is 0.5 m.
3. Sand and gravel with graded layering and abundant shells of molluscs; T is 1 m.
4. Coarse cross-bedded sand with fragments of mollusc shells; T is 2 m.
5. Silt with horizontal bedding; T is 13 m.
6. Thin-bedded fine-grained sandstone; T is 9 m.
7. Thin-bedded silt and rarer fine-grained sandstone; T is 14 m.
8. Dark-grey clay; T is 1.5 m.
9. Thin-bedded silt; T is 15 m.
10. Dark-grey clay with diatomaceous clay (0.3 m) in the base; T is 3.5 m.
11. Silt with clay interbed; T is 2 m
12. Dark-grey clay with diatomaceous clay (0.3 m) in the base; T is 1.5 m.
13. Diatomaceous silt; T is 0.7 m.
14. Dark-grey clay; T is 9–10 m.

The upper 5–6 m thick beds 1–4 are composed of deltaic and alluvial sediments of Early Pleistocene (Calabrian) dated by molluscs and small mammals. The layer 1 yielded two small tools of the Early Paleolithic aspect. The lower, about 70 m thick deposits (beds 5–14) show N magnetic polarity. They were deposited in the brackish-water basin characterised by the Caspian type dinocysts of the Lower Akchagylian aspect in beds 10–14.

4.2. Dating of deposits of the Turkish part of the Shirak Basin

4.2.1. Faunal data (molluscs and rodents)

Molluscs. Shells of molluscs were found in the sections Demirkent (20t), Çamçavuş (10t), and Çamuşlu (11t).

In Demirkent, molluscs were collected from the upper (alluvial) part of the section (layers 2–4). The assemblage contains freshwater gastropods and bivalves of the families Hydrobiidae, Valvatidae, Planorbidae, Pisidiidae, and genus *Dreissena*. *Falsipyrgula* cf. *sieversi* (Boettger, 1881) and *Falsipyrgula* cf. *bakhtarana* (Schütt et Mansoorian, 1999) were determined among Hydrobiidae. The former species is known from Calabrian sites Yayladag (Vasilyan et al., 2014) and Voghji (Tesakov et al., 2019) referred to Ani Unit, the latter form was found in the Voghji site. A molluscan assemblage of the layer 5 (at the top of the lower part of the section) includes Hydrobiidae, Valvatidae, Bithyniidae, Lymnaeidae, Planorbidae, *Vallonia* sp., Pisidiidae, Euglesidae, and *Dreissena* sp. This assemblage shows an earlier and more lacustrine stage of the basin development after the retreat of the sea. The lower (clayey) part of the Demirkent section contains abundant shells of *Dreissena* sp. concentrated in several shell beds. *Dreissena* from the lower part of the section differs from those found in the upper, fluvial part of the section.

The section near Çamçavuş, bed 6, yielded a molluscan assemblage including Hydrobiidae, Valvatidae, *Acroloxus* sp., *Radix* sp., Planorbidae, Pisidiidae, and *Dreissena* cf. *diluvii* (Abich, 1859). Hydrobiids include *Falsipyrgula* cf. *shadini* (Akramowski, 1956) and *Falsipyrgula* cf. *sieversi*. Based on this occurrence we correlate this fauna with Calabrian sites Yayladag (Schütt, 1997; Vasilyan et al., 2014) and Voghji (Tesakov et al., 2019), and refer it to the Ani unit. A fragment of a last whorl of *Falsipyrgula* cf. *bakhtarana* was found here too. It is very close to the record in the upper part of Demirkent section.

The bed 1 of Çamuşlu section produced the following mollucan assemblage: *Falsipyrgula* cf. *sieversi*, cf. *Pseudamnicola* sp., *Valvata* spp., *Radix* sp., *Planorbis* sp., *Gyraulus* sp., *Armiger* sp., *Pupilla* sp., Pisidiidae, Euglesidae, and *Dreissena* cf. *diluvii*. In comparison with Demirkent and Çamçavuş sites here we found more diverse limnofilic forms, e.g. Planorbidae, and abundant small bivalves of the families Pisidiidae and Euglesidae. *Falsipyrgula* cf. *sieversi* is a common element in these assemblages. A lack of diverse species of Pyrgulinae may indicate a younger age of this assemblage or a different type of freshwater basin and sedimentation.

Small mammals. The paleontological record of small mammals in the region of the study is scarce. Nevertheless, the published data enable reliable age models for late Early Pleistocene (Vasilyan et al., 2014) and early Middle Pleistocene (Agadjanyan and Melik-Adamyan, 1985; Tesakov et al., 2019). In this study, scanty remains of small mammals were found in the sections Demirkent (20t), Çamçavuş (10t), and Çamuşlu (11t).

In Demirkent, the material comes from beds 3 and 4. The assemblage (n = 6) contains Microtini cf. *Allophaiomys* sp. (fragments of M1), *Prolagurus* cf. *pannonicus* (Kormos, 1930) (fragmentary m1, m2, and M3), and ?*Ellobius* sp. (a fragment of M2) indicating the age of late Early Pleistocene, mid-late Calabrian.

The section near Çamçavuş produced two fragments of vole molars, M1 or M2, from bed 6. They belong to a rootless form of Microtini. Judging from the undifferentiated enamel it can be tentatively attributed to the Early Pleistocene radiation of *Allophaiomys*-like forms. This determination implies a broad time interval within the Calabrian.

The section Çamuşlu yielded a single molar fragment from bed 1. This molar belongs to a small rhizodont vole with thin undifferentiated enamel. This morphology excludes *Mimomys* and *Ellobius* and tentatively indicates a form of rooted Lagurini. The lagurines lost molar roots at the Gelasian-Calabrian transition. Having in mind an extremely poor preservation of this fossil we do not make any conclusions on the age of the enclosing deposits prior to more ample material.

4.2.2. Palynological data

The most important result was obtained in beds 8–14 of the fine-grained part of the Demirkent section (site 20t). In four horizons, cysts of marine dinoflagellates that are characteristic for the Upper Pliocene deposits were found. They are *Caspidinium rugosum* Marret, 2004 type, *Spiniferites ramosum* (Ehrenberg, 1838) Mantell, 1854, cf. *Impagidinium inaequalis* (Wall et Dale in Wall et al., 1973) Londeix et al., 2009, cf. Pontiadinium, and *Ataxodinium* cf. *confusum* Versteegh and Zevenboom in Versteegh, 1995 (Fig. 5). Spores of fresh-water and brackish-water algae *Pediastrum, Botryococcus, Spirogyra,* and *Planctonites* were found in the same samples (Fig. 5). Amount of marine dinocysts decreases and amount of algae spores increases up the section that indicates a gradual freshening of the basin. The consistent presence of dinocysts and spores of algae in several beds excludes their accidental occurrence in the deposits.

The upper stratigraphic limit of dinocysts *Ataxodinium* cf. *confusum* and *Pontiadinium* and spores of *Planctonites* is the Upper Pliocene – Early Pleistocene (Head, 1992; Williams et al., 1998; Lenz, 2000). It is thus likely that the fine-grained and normally magnetised sediments of the Demirkent section containing the dinocysts and algae were deposited in shallow waters of the brackish Early Akchagylian (Upper Pliocene) transgression of the Caspian Sea. The Akchagylian marine deposits are widespread in Azerbaijan. In Eastern Georgia, they are known mainly in the Lori Highland and the south-eastern Kakhetia and are represented by shallow water facies with molluscs (Uznadze, 1965; Shatilova et al., 2011). In the Armenian part of the Shirak Basin, the Akchagylian marine molluscs were found in the core of borehole 12 near the Marmashen Monastery (site 340) (Zaikina et al., 1969; Sayadyan, 2009).

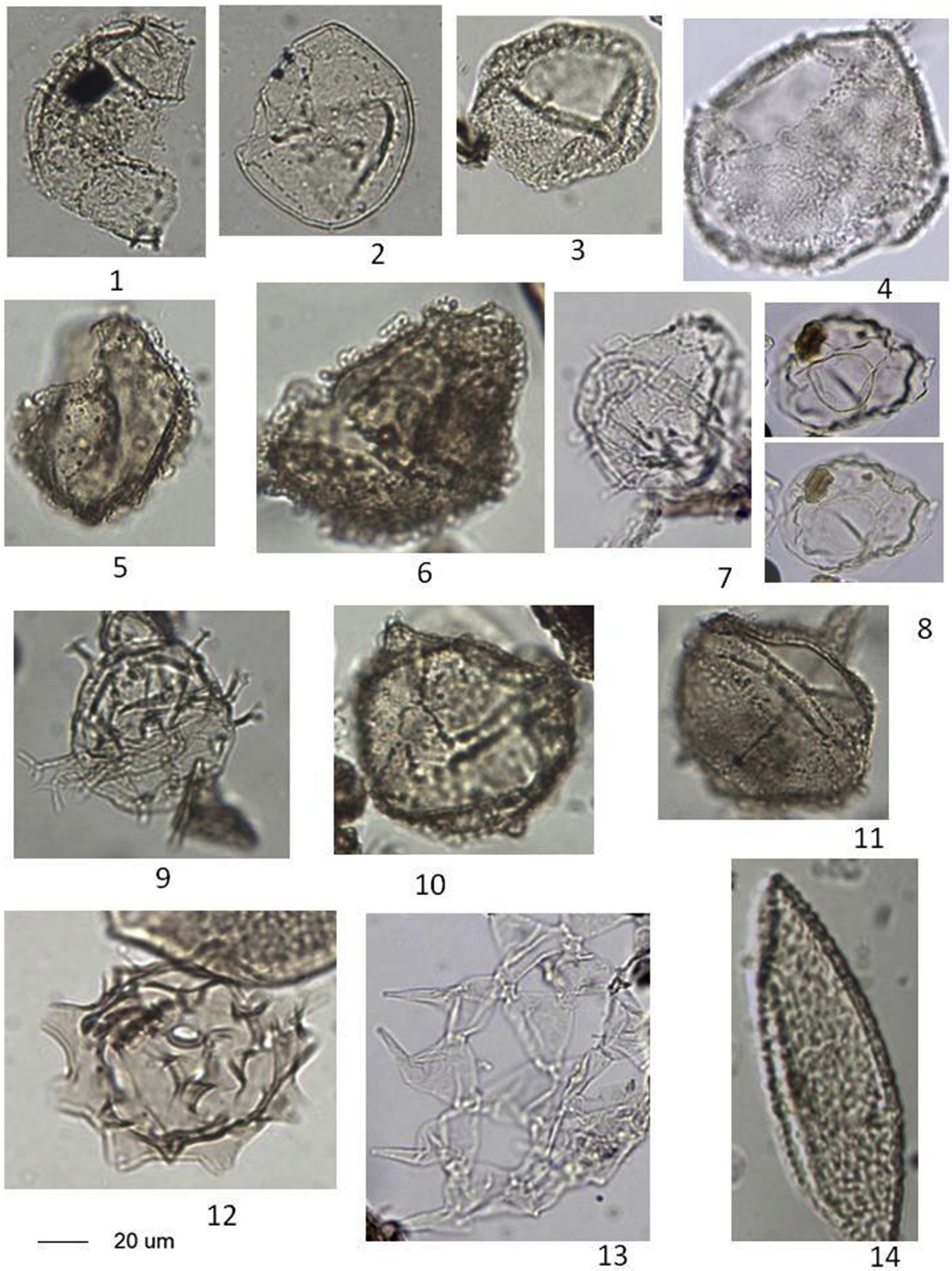

Fig. 5. The late Pliocene brackish-water cysts of dinoflagellates (1–11) and spores of algae (12–14) collected from beds 10–14 of the Demirkent section (site 20t), the western Shirak Basin, NE Turkey: (1–4) *Caspidinium* type 1; (5, 6) *Caspidinium* type 2; (7) cf. *Impagidinium inaequalis*; (8) *Ataxodinium* cf. *confusum*; (9) *Spiniferites ramosum*; (10, 11) cf. *Pontiadinium*; (12) *Planctonites*; (13) *Pediastrum simplex* Meyen 1829, (14) *Spirogyra*.

The nonarboreal pollen with Asteraceae and Chenopodiaceae dominates in pollen spectra of the studied samples (Figs. 6 and 7). The pollen of *Ephedr*a, Apiaceae, Fabaceae, and *Artemisia* is present. Pines dominate in the arboreal group. The conifers also include *Tsuga (T.* canadensis (L.) Carrière, 1855, T. sieboldiformi Carrière, 1855, T. diversifolia (Maxim.) Masters, 1881, *Podocarpus, Cathaya, Picea, Cedrus, Abies*, and Taxodiaceae. The leaved trees are represented by pollen of Juglandaceae (*Carya, Juglans*, *Engelhardtia*), *Betula, Alnus*, *Fagus, Quercus,* and *Carpinus*. The pollen assemblage likely indicates an altitudinal zonation with coniferous forests occupying the highlands, and the mixed forests with *Pinus,* Juglandaceae, *Quercus,* and *Carpinus* occurring at lower elevations. Lowlands were covered by meadow-steppe vegetation. The climate was arid.

4.2.3. Archaeological data

The most interesting artefacts were found in five sites: 11t (Çamuşlu), 20t (Demirkent), 9t (Çamçavuş), and 29t (near Çildir Lake).

In the site 11t a heavy-duty scraper and a flake were extracted from the layer 2 within about 40 m thick escarp of the lower Middle Pleistocene sequence (Arapi unit). The scraper (12.1 × 8.9 × 3.8 cm) was fashioned on the sub-quadrangular fragment of dacite-andesite boulder. The convex working edge is shaped by unifacial single-raw

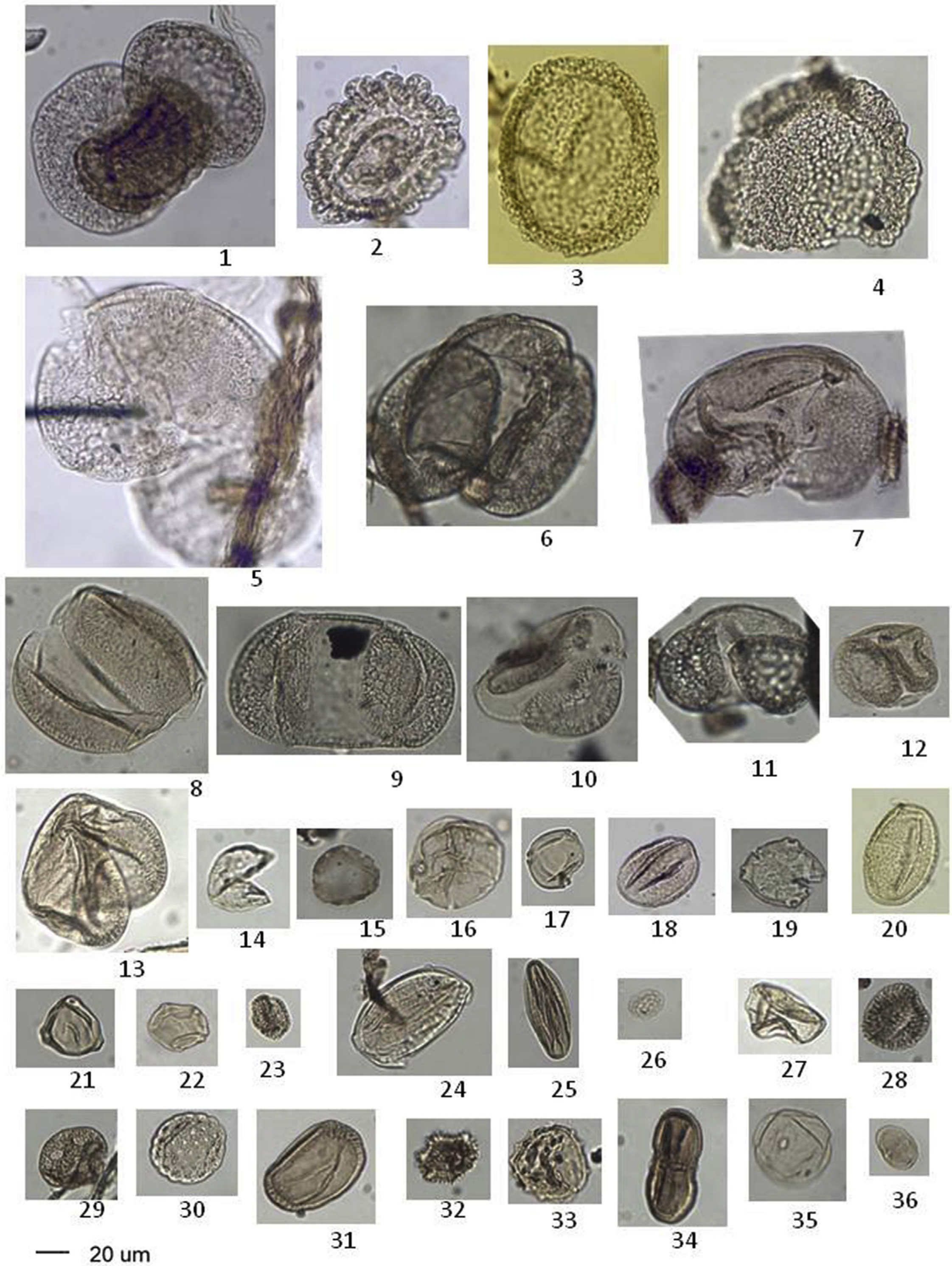

Fig. 6. Pollen collected from beds 10–14 of the Demirkent section (site 20t), the western Shirak Basin, NE Turkey: (1) *Podocarpus*; (2) *Tsuga sieboldiformis*; (3) *Tsuga diversifolia*; (4) *Tsuga canadensis*; (5, 6) *Abies*; (7) *Picea*; (8) *Cedrus*; (9) *Cathaya*; (10–12) *Pinus* sg. *Diploxylon*; (13) *Pinus* sg. *Haploxylon*; (14) Taxodiaceae; (15, 16) *Juglans*; (18) *Quercus*; (19) *Carpinus*; (20) aff. Fagaceae; (21) *Betula*; (22) *Alnus*; (23) *Salix*; (24, 25) *Ephedra*; (26) Chenopodiaceae; (27) Cyperaceae; (28) Brassicaceae; (29) Caryophyllaceae; (30) *Polemonium*; (31) Polygonaceae; (32, 33) Asteraceae; (34) Apiaceae; (35) Poaceae; (36) Boraginaceae.

retouch consisting of large-sized flake scars. The flake (7 × 5.7 × 2.2 cm) made of grey flint and covered by ochre-coloured patina has a large bulb of percussion. Both artefacts are rounded. Three more dacite-andesite tools were found in the exposure of the same layer that lies on a terrace adjoining to the main escarp. They are large side scraper (8.2 × 11.3 × 2.5 cm), crude handaxe (13.3 × 9.9 × 4.4) and chisel-ended pic (12.0 × 10.0 × 6.9 cm). The side scraper with straight cutting edge is made from tabulated piece of sub-rectangular form. The handaxe (Fig. 8) shaped by series of large removals may be defined as sub-cordiform type. The pic of sub-triangular shape has also triangular cross-section (trihedral type). All three faces are formed by large removals.

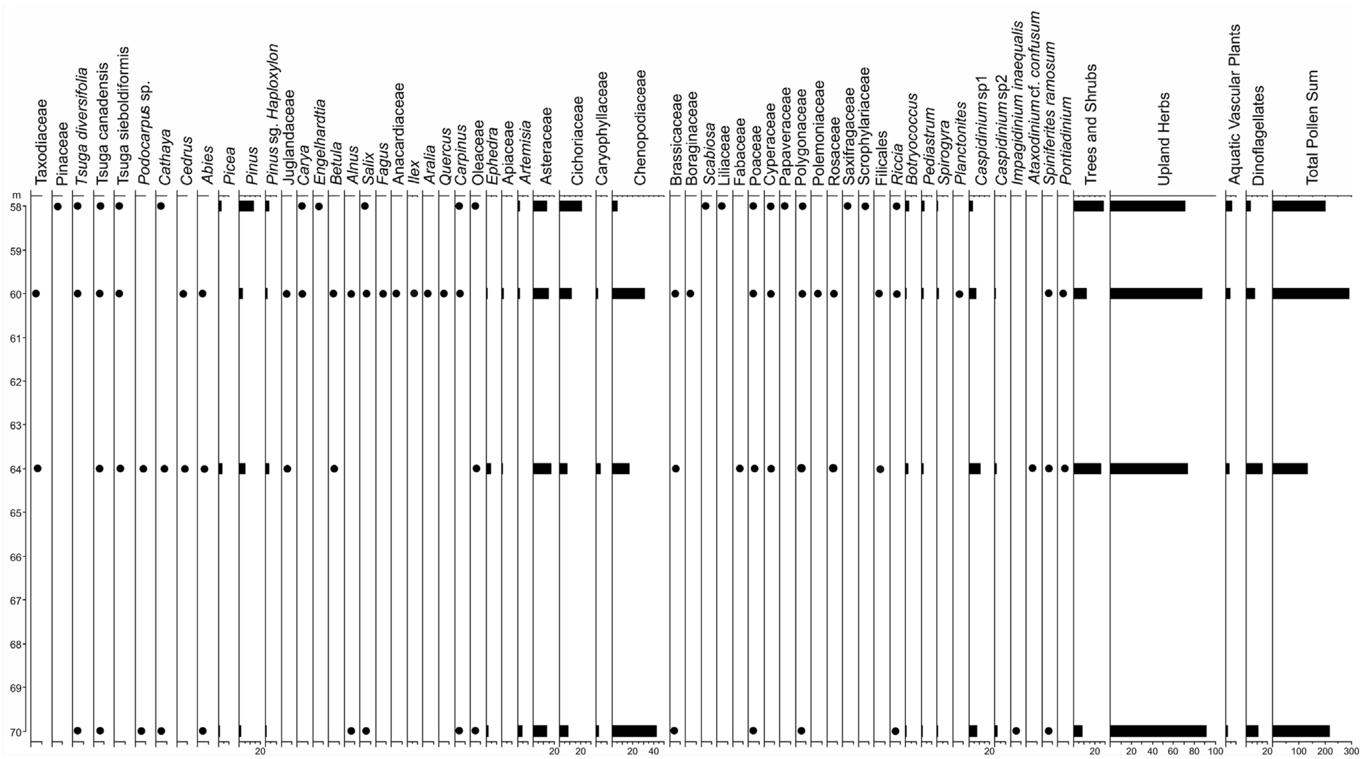

Fig. 7. Pollen diagram for beds 10–14 of the Demirkent section (site 20t), the western Shirak Basin, NE Turkey. Total pollen sum is given in number of grains. All other characteristics are given in percents of the total sum. Dots are single grains.

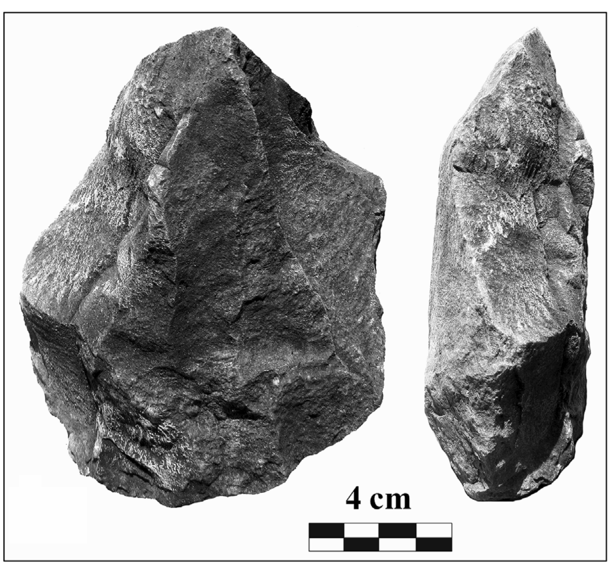

Fig. 8. Handaxe found in the Arapi unit near the Çamuşlu village (layer 2 of the site 11t).

In the site 20t two small, but massive tools (4.2 × 1.9 × 1.5 cm and 3.2 × 2.1 × 2.0 cm) have been extracted from the layer 1 (Ani unit). They are side scraper with convex working edge fashioned by three removals and chisel-ended tool. Both are made of massive pieces of flint and slightly rounded.

Of special interest is a large elongated tool of near-triangular form (21 × 10.4 × 4.5 cm) found in site 9t (Ani unit). Although this basalt tool is very rounded, it clearly has an asymmetric sharp edge shaped by bifacial flaking and opposite backed side as well as a handle formed by series of removals. The tool is similar to macro-knives of "tsaldi" type known in the Acheulian localities of Armenia and Georgia (sites Kudaro I, Tsona, Dashtadem, Muradovo, and Karakhach). This tool type is considered as characteristic form of the regional Acheulian (Lyubin, Belyaeva, 2014). A flat almond-form pebble (17 × 9.9 × 3.2 cm) with scars of bifacial flaking was found as well in the surface of basaltic andesite covering the Ani section of site 14t. It resembles a crude handaxe.

A remarkable chopper with bifacially flaked edge (Fig. 9) was found in the bed 2 of the site 29t (Karakhach unit). The chopper of near-oval form (19.2 × 13.0 × 9.7 cm) was made from a boulder of local basaltic andesite. The cutting edge carefully fashioned by large-scaled removals is located on the narrow end. The rest of the tool surface was not processed. The chopper is rounded and its working edge is somewhat blunted.

Judging by technological and morphological features all the collected tools belong to the Early Palaeolithic. Because at present the finds are too scarce and scattered it is too early to make any extended description of local lithic industries. However, one may clarify their type and chronological range by analyzing the most indicative large tools. Choppers occur in both Oldovan and Acheulian industries, but handaxes, picks, and peculiar tool type as "tsaldi" certainly indicate Acheulian. Furthermore, pics together with crude handaxes are known to exist during Early-Middle Acheulian (Early Pleistocene-beginning of Middle Pleistocene) and not later. Their presence in the Arapi and Ani units confirms ages of these deposits estimated on the basis of other data.

4.3. *Tectonics of the Shirak Basin*

4.3.1. *Inner structure of the Shirak and Susuz Basins*

The Pliocene-Quaternary deposits usually occur almost horizontally within the Shirak Basin. It is difficult to estimate their deformation by change of thickness of the deposits, because the base of majority of sections is not exposed and their upper layers are often eroded. So, the main instrument of tectonic analysis is a relative position of terrace-like topographic levels on the surface of the deposits.

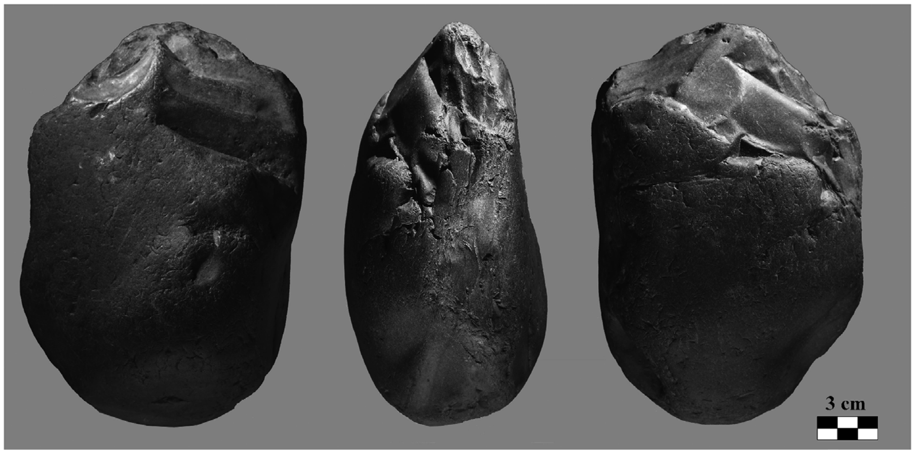

Fig. 9. Chopper found in the Karakhach unit near the Çildir Lake (layer 2 of site 29t).

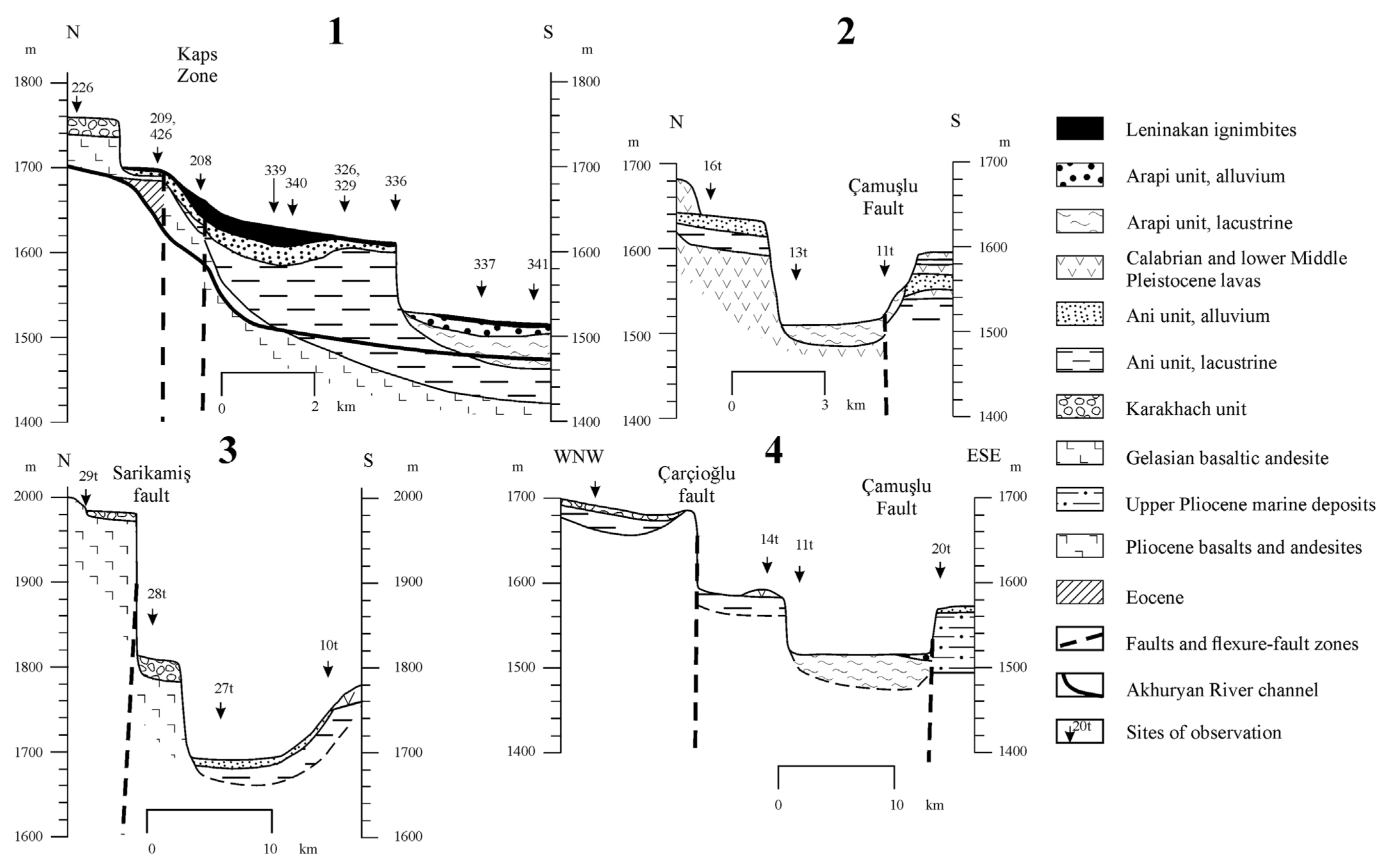

Fig. 10. Geological-geomorphological profiles across the northern Shirak Basin and Susuz Basin. (1) The NNE-trending profile across the northern Shirak Basin along the eastern bank of the Akhuryan River, NW Armenia. (2) The N-trending profile across the north-western Shirak Basin, NE Turkey. (3) The approximately N-trending profile across the Susuz Basin, NE Turkey. (4) The WNW-trending profile across the Susuz and north-western Shirak Basins, NE Turkey. Location of major faults and fault-flexure zones and sites of observation is shown.

In the Armenian part of the basin, the Akchagylian (Piacenzian–Gelasian) deposits are known only from boreholes in the north of the basin (Sayadyan, 2009). The younger units are sequentially incised into each other (Fig. 10.1). For example, the Karakhach unit surface (Karakhach terrace) is situated in the northern border of the basin at the elevations of 1750 m (site 306) and 1770 m (site 226), whereas the altitudes of the Ani terrace are 1690–1700 m (sites 209 and 426). In the northern part of the basin, the Ani terrace gently dips to the south from 1610 to 1615 m (sites 326, 329, and 339) to ~1600 m (site 336), and the Arapi terrace occurs at 1500–1516 m (sites 308, 341, and 432).

The similar relationships are observed in the western Shirak and Susuz Basins. The Karakhach terrace is situated at the height of 1814 m in the northern Susuz Basin (site 28t), whereas the altitude of the Ani terrace is 1695 m in the basin center (site 27t), and is at 1750 m in its southern margin (sites 9t and 10t) (Fig. 10.3). In the western Shirak Basin, the altitude of the Ani terrace decreases from 1636 m in the northern margin (site 16t) to 1590 m in the center (site 14t), and the heights of the Arapi terrace are 1510–1515 m (sites 11t, 13t, 17t, and 18t) (Fig. 10.2). Thus, the altitudes of the Ani terrace as well as the Arapi one are similar in the Armenian and Turkish parts of the northern Shirak Basin.

The top of the Arapi lacustrine deposits is situated at heights of 1525–1530 m in two outcrops of the northern part of the basin. They are the site 327 (Agajanyan and Melik-Adamyan, 1985) and site 11t. This is partly due to the fault offsets (Fig. 2), but not entirely. In site 11t, the Arapi terrace (1511 m) partly erodes the primary top of the unit. This proves that the terrace was formed after the accumulation of the unit, but before its eroded surface was covered by the ignimbrite with the K-Ar dates 0.7–0.65 Ma.

The Arapi terrace very gently lowers to the south down to 1495–1500 m in the south-east of the basin (sites 314 and 316), and to 1490 m in its southern termination (site 318). Whereas the total southward lowering of the Arapi terrace in the Shirak Basin amounts to 20–25 m, the Akhuryan River channel lowers to the south from 1520 m to 1400 m (Shalaeva et al., 2019).

The sedimentary units have dissimilar ranges and occurence. The Karakhach unit is present only in the northern borders and at the margins of the Shirak and Susuz Basins, but the unit is absent southward, where the Ani unit covers the older lavas (site 339). The Ani unit thickness is maximal in the northern Shirak Basin. The Ani deposits occur on the land surface due to tectonic deformation in the center of the basin (site 317), where they underlie the Arapi unit, but the latter covers the older rocks farther to the east (site 314) and to the south (site 318).

The described relationships show that the northern Shirak Basin uplifted and the area of sedimentation gradually shifted to the south during the last 2 Ma.

4.3.2. Faults and flexures

Flexure-fault zones extend along the borders of the Shirak Basin. They are expressed by changes of altitudes of terraces on the unit surfaces and occasionally also by changes of thickness of the units and offsets in the pre-Quaternary rocks.

The N-trending zone of deformation that was interpreted by Milanovsky (1968) as a part of the Trans-Caucasus transverse uplift, limits the Shirak Basin to the east. The zone forms a horst in the transverse profile. The magnitude of vertical offset is higher on the eastern side of the horst than on the western one. The Karakhach terrace is uplifted at ~180 m in the horst (Jajur Pass, sites 220 and 222) relative to the northern border of the Shirak Basin (sites 306, 226 and 213) (Trifonov et al., 2017; Shalaeva et al., 2019). Farther to the north, the analogous changes of altitudes of the Karakhach unit and underlying lava flows take place from the Upper Akhurian Basin to the east via the Karakhach Pass to the Lori Basin (Trifonov et al., 2016). The Javakheti volcanic Ridge, the Sharailer and Aragats volcanos are situated along the uplifted zone.

The Kaps flexure-fault zone forms the northern boundary of the Shirak Basin. The pre-Quaternary faults that were activated in the Late Quaternary are exposed in some parts of the zone. The flexural bend is expressed by sharp dipping of the Ani terrace to the south from 1695 to 1700 m (sites 209 and 426) to 1665–1670 m (sites 208, 215, and 216) and 1610–1615 m (sites 326, 329, and 339) (Fig. 10.1). The thickness of the Ani unit increases at the same direction from 5 to 6 m (sites 209 and 426) to 15–20 m (site 208), 55 m (site 326) (Shalaeva et al., 2019), and probably 140 m in the bore-hole 6 near the Marmashen village (Zaikina et al., 1969). The same tendency is expressed by lowering of the Ani terrace from 1636 m (site 16t) to 1590 m (site 14t). The total offset of the Karakhach unit can reach 260 m (Shalaeva et al., 2019).

The Çarçioğlu flexure-fault zone forms the north-western boundary of the Shirak Basin. The zone is expressed by an escarp with the uplifted north-western side as well as faults in the north-eastern termination (Geological Map of Turkey, Kars, 2002). The displacement on this zone causes some 100–120 m higher altitudes of the Ani terrace in the Susuz Basin (1693–1753 m in sites 9t, 10t, and 27t), than in the western Shirak Basin (1590–1635 m in sites 14 and 16), although they were primary parts of the same lacustrine basin (Fig. 10.4).

The Sarikamiş fault extends along the north-western border of the Susuz Basin. We consider that this fault is a part of the active East Anatolian Fault Zone (EAFZ) north-eastward of its intersection of the North Anatolian Fault Zone (Trifonov et al., 1994). The EAFZ is characterized by dominant sinistral offsets with minor reverse uplift of the north-western side in the north-eastern part. The difference between altitudes of the Karakhach terrace in sites 29t (1985 m) and 28t (1814 m) expresses vertical offset on the north-eastern termination of the Sarikamiş fault (Fig. 10.3). To the north of the Gumri city, the Sarikamiş fault joins with the active dextral Pambak-Sevan-Syunik Fault and the active dextral Garni Fault with minor reverse uplift of the north-eastern side (Karakhanian et al., 2004). All these faults were activated during the Spitak 1988 strong earthquake (Trifonov et al., 1994).

The NNE-trending Akhurian Fault cuts the Shirak Basin (Gabrielyan et al., 1981). The fault is expressed by a straight segment of the Akhurian River valley between the Arapi village (site 337) and the Ani town ruins (sites 25t and 428) and is traced to the south-west, where the sinistral bends of rivers and ravines were found on the fault (Trifonov et al., 1994). Vertical offsets were not found in the straight segment of the Akhurian valley, but the ENE-trending auxiliary thrusts were found near the Lusaghbyur village (site 217) (Baghdasaryan, Karakhanyan, 2016; Shalaeva et al., 2019). Because of it, the Arapi terrace is locally uplifted to 15 m. The Akhurian Fault divides into two branches near the Arapi village. The western branch diverges to the NW and acquires vertical component of motion that is expressed by elevation of the Arapi terrace at ~10 m to the west.

The WNW-trending Çamuşlu Fault extends between the Akhurian Fault and the Çarçioğlu flexure-fault zone and is expressed by the escarp with uplifted southern side. The magnitudes of vertical offsets increase to the east, i.e., to the Akhurian Fault. The rise of the Arapi unit top is about 20 m near the Çamuşlu village (site 11t). In site 19t situated in the southern fault side, the height of the Arapi unit top reaches 1527 m and deposits dip with angle 10° to the NE. The Ani unit top reaches 1570 m in site 20t, where the unit is represented only by its upper alluvial part. It directly covers the Upper Pliocene fine-grained deposits (Fig. 10.4). Their top is situated in 1565 m. The bore-hole 12 near the Marmashen Monastery (site 340) demonstrates that the top of the Akchagylian deposits is situated at the depth 72 m (1443 m a.s.l.) and the depth of these deposits in the borehole breast reaches 198 m (1317 m a.s.l.) (Zaikina et al., 1969). The molluscs similar to the Upper Akchagylian (Gelasian) of the Caspian Sea were found at the depths 76–80 m, and the Lower Akchagylian (Piacenzian) molluscs were obtained from the depths 115–198 m (Sayadyan, 2009). Therefore, the top of Pliocene in the borehole 12 that is correlated to the top of Pliocene in the Demirkent section (site 20t) is situated at the depths between 1435 m and 1400 m. The difference of the Pliocene top in these localities indicates that the total vertical offset on the Çamuşlu and Akhurian Faults reaches 130–165 m. The Ani unit terrace in site 20t (1570 m) is not higher than in adjacent part of the Shirak Basin. This proves that the offset formed before accumulation of the Ani unit.

5. Discussion

5.1. Correlation of the data, a general stratigraphic column, and sedimentary evolution of the Shirak Basin in the Upper Pliocene and Quaternary

The lower part of fine-grained deposits of the Demirkent section contains dinocysts of the Akchagylian aspect, i.e., belongs to the Piacenzian or Gelasian. Some of the discovered dinocysts and spores of algae are characteristic for the Pliocene and disappear at the Pliocene–Quaternary boundary. The entire fine-grained part of the section is characterised by normal magnetic polarity and can be correlated to the Gauss palaeomagnetic chron. These data testify to the Late Pliocene (Piacenzian) age of the section. The new "short model" of the onset of the main marine Akchagylian transgression dated to late

Gauss time interval (Krijgsman et al., 2019; Van Baak et al., 2019) further restricts the age of the Demirkend brackish-water deposits.

The deposits that are described in 4.1.3 as the Karakhach unit are similar to it in the Lori Basin (Trifonov et al., 2016) by composition and location in the northern border of the Shirak and Susuz Basins. The coarse deposits of site 29t are incised into basaltic andesite with the $^{40}Ar/^{39}Ar$ date 3.65 ± 0.08 Ma and show normal magnetic polarity. The large chopper of the Early Palaeolithic aspect was found here. Using these data, we identified the described deposits with the Karakhach unit of the Lory Basin and date them to 1.9–1.7 Ma.

The Ani and Arapi unit molluscs belong to Pleistocene. The assemblage of molluscs from the Ani unit is older than the Arapi one. The Acheulian artefacts were found in the Arapi section (site 11t), on the surface of basaltic andesite covering the Ani unit (site 14t), and within the upper alluvial part of the Ani unit (sites 9t, 10t and 20t). The Ani unit shows the reverse magnetic polarity with two intervals of normal polarity and the whole Arapi unit shows normal polarity. Based on these data and the correlation with the Armenian part of the Shirak Basin (Shalaeva et al., 2019; Tesakov et al., 2019), the Ani unit is attributed to the Calabrian, and the Arapi unit is attributed to the lower Middle Pleistocene. The find of a rootless vole Microtini gen. in the Çamçavuş section (site 10t) of the Ani unit does not contradict to its upper Calabrian age.

The general stratigraphic column of sedimentary deposits in the western Shirak Basin and the Susuz Basin is shown in Fig. 11.

The represented data show that the brackish Caspian Basin waters penetrated to the Shirak Basin in the Late Pliocene. The residual basin probably remained here in the early Gelasian (Sayadyan, 2009) and disappeared later. Position of the channel that joined the Shirak Basin and the Caspian in the Late Pliocene is questionable. The southern channel is doubtful, because the southern surrounding of the Shirak Basin is covered by the Upper Pliocene subaerial tuffs and ignimbrites and no sign of marine sedimentation of that time has been found in the Araks and Upper Murat River valleys. Perhaps, the junction of the basins occurred via the Lower Kura depression, where the Akchagylian marine deposits are present, but these deposits are unknown between the Lower Kura and Shirak Basins.

In the upper Gelasian, the northern Shirak Basin was covered by subaerial lavas. The fluvial sedimentation of the latest Gelasian and the earliest Calabrian (about 1.9–1.7 Ma) was concentrated in the northern border and the northern part of the basin, where a big valley drained the basin and flew to the east via the Jajur Pass to the recent Pambak and Agstev river valleys (Milanovsky, 1968; Trifonov et al., 2017). The Calabrian lacustrine sedimentation occurred in the joint Shirak and Susuz Basins and finished by the alluvium accumulation and drainage of waters to the lower Akhuryan valley. The same cycle of the lacustrine and later alluvial sedimentation took place in the lower Middle Pleistocene and finished at ~0.6 Ma. The later alluvium accumulation concentrated along the recent Akhuryan River and its tributaries.

During the Calabrian and earlier Middle Pleiscocene, faults and flexure-fault zones developed, bounding the Shirak Basin. The northern part of the basin relatively rose and area of sedimentation migrated to the south.

The Shirak Basin is surrounded by volcanic formations that were erupted during the basin subsidence. The southern migration of the basin coincided in time with increase of activity of the Aragats volcanic center. This gives a possibility to suppose that the subsidence was caused by motion and transformation of the lithospheric mantle material manifested by the volcanism (Shalaeva et al., 2019).

5.2. Estimation of the Quaternary uplift of Lesser Caucasus

The discovery of the Late Pliocene dinocysts of Caspian type in section 20t gives a possibility to estimate most correctly the Quaternary tectonic uplift of this part of Lesser Caucasus. The discovery conforms to the earlier records of the Akchagylian molluscs in the borehole 12

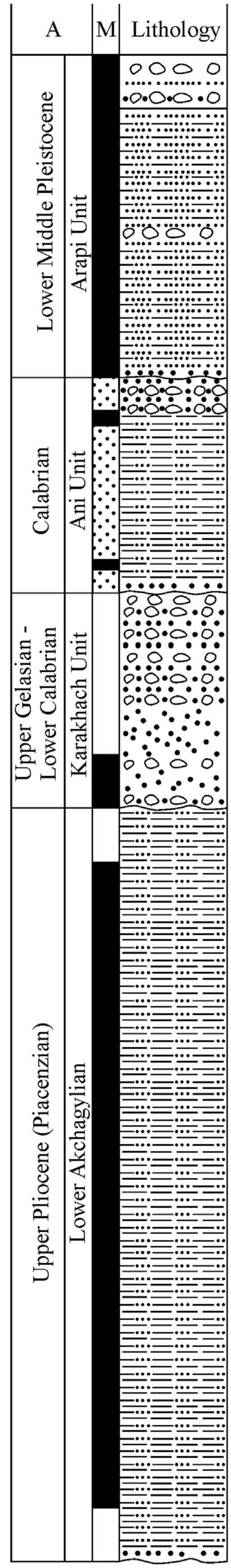

Fig. 11. General stratigraphic column of the Pliocene-Quaternary sedimentary deposits of the western Shirak Basin, NE Turkey. See Fig. 3 for the legend.

(Sayadyan, 2009) and testifies to the penetration of the Akchagylian transgression of the Caspian Sea into the Shirak Basin. The maximal Early Akchagylian transgression level was probably about 100 m higher than the present world sea level and decreased down to 0 a.s.l. by the onset of the Quaternary (2.58 Ma) (Popov et al., 2010). The lower part of the Upper Akchagylian (Gelasian) is present in the borehole 12. In section 20t, the Upper Akchagylian deposits are absent. They could be not accumulated or be eroded later. Anyway, the uplift of section 29t started at the beginning of the Quaternary. It has reached 1565 m by now. This gives the minimal average rate of the uplift about 0.6 mm/year.

The subsidence of the Shirak Basin decreases the total Quaternary uplift within the basin to about 150 m. On the other hand, the vertical component of the Late Cenozoic motion on major faults increases a rise of uplifted fault sides. For example, the northern side of the Sarikamiş fault is uplifted relative to the northern Susuz Basin that is expressed by higher altitude of the Karakhach unit in site 29t (H = 1985 m) in comparison with site 28t (H = 1814 m). Because of these variations, the average uplift rate for the Quaternary can be estimated at 0.6 ± 0.1 mm/year.

Thus, the Quaternary tectonic uplift of the region contains the dominant general component (about 0.6 mm/year) that locally increases or decreases because of relative tectonic movements, mainly on faults and flexure-fault zones, or influence of the lithosphere processes expressed in volcanism. This intense total tectonic uplift is characteristic for the Pliocene-Quaternary development of the whole Alpine-Himalayan belt and other mountain regions. In many of them, the collisional compression was not enough to produce real recent mountain systems. They were partly and somewhere mainly caused by decrease of density of the Lower Crust and the Uppermost Mantle in a process of transformation of the lithosphere under influence of the sub-lithosphere mantle flows (Artyushkov, 1993, 2003; 2012; Trifonov et al., 2008, 2012; Trifonov and Sokolov, 2014; Trifonov, 2016).

The data on Kurtan unit in the Lori Basin and Debed River valley give a possibility to estimate the uplift during the shorter time interval of 0.65–0.6 Ma. The typical facies of the Kurtan unit consist of fine-grained sand, silt, and loam that were deposited by stagnant waters in lake or braided streams with a very slow flow. This means that the gradient of topography was small or absent within the area of sedimentation. Now the height of the Kurtan unit top decreases from 1300 m in the south-eastern Lory Basin (site 10) downstream of the Dzoraghet and Debed Rivers up to 610 m to the NE of the town of Alaverdi (site 63; N41°11.148′; E44°52.060′). The Kurtan unit accumulation finished by 0.65–0.6 Ma (Trifonov et al., 2016). Therefore, the site 10 rose relative to the site 63 up to 690 m or a little less during the last 0.65–0.6 million years and the average rate of relative uplift could exceed 1 mm/year. The western Lori Basin rose 200 m higher than its eastern part and the Upper Akhuryan Basin rose about 200 m higher than the western Lori Basin; the uplift of the adjacent Bazum and Javakheti Ridges was somewhat more intense (Trifonov et al., 2016). Thus, the uplift of this part of Lesser Caucasus could accelerate up to 1–2 mm/year during 0.65–0.6 Ma.

Analysis of rates of uplift of the region during the Quaternary shows that the topography of the early Paleolithic epoch was much lower and gentler than the recent one. This stimulated migration of early hominines to the region (Trifonov et al., 2019).

6. Conclusions

Stratigraphy, composition and tectonics of sedimentary cover of the western Turkish part of the intermontane Shirak Basin and the adjacent Susuz Basin were studied and correlated to the eastern Armenian parts of the Shirak Basin. The sedimentary cover of western Shirak and Susuz Basins is composed of the Upper Pliocene formation and Karakhach, Ani, and Arapi Pleistocene units. The discovery of the Upper Pliocene dinocysts within the former formation and its normal magnetic polarity testify to its Lower Akchagylian (Piacenzian) age. The age of the Karakhach unit is estimated at about 1.9–1.7 Ma on the grounds of similarity of its geomorphological position and composition with the Karakhach deposits in the Armenian part and normal polarity of the deposits. The dating of the Ani unit to the Calabrian, and the Arapi unit to the lower Middle Pleistocene is based on assemblages of molluscs and rodents, the finds of Acheulian hand-axes and pics within the deposits, and by their magnetic polarity (reverse with two intervals of normal polarity in the Ani deposits and normal in the Arapi deposits), as well as support from a correlation of their geomorphological position to corresponding units in the Armenian part of the Shirak Basin.

The discovery of brackish-water dinocysts of the Caspian type in the Upper Pliocene deposits gives a possibility to estimate the rate of the Quaternary uplift of this part of Lesser Caucasus. The level of the early Akchagylian (Upper Pliocene) brackish water basin was higher than the world oceanic level and lowered to 0 a.s.l. at the Pliocene–Quaternary boundary (2.58 Ma). The recent altitude of the top of the lower Akchagylian deposits is 1565 m in the Demirkent section (site 20t). This defines the average rate of the Quaternary uplift at 0.6 mm/year. The Shirak Basin is bounded and ruptured by faults and flexure-fault zones. Because of offsets on the Çamuşlu and Akhuryan zones, the central part of the northern Shirak Basin is subsided relative to the Demirkent section at 130–165 m. The movements on the Çarçioğlu zone caused a rise of the Ani unit surface in the Susuz Basin relative to its altitudes in the adjacent part of the Shirak Basin at 100–120 m. The north-western border of the Susuz Basin is uplifted on the Sarikamiş fault zone. Thus, the Quaternary uplift varies at 0.6 ± 0.1 mm/year. To the NE of the Shirak Basin, in the Lori Basin and the Debed River valley, the rate of uplift during 0.65–0.6 Ma is estimated at about 1 mm/year by comparison of recent altitudes of the Kurtan unit that was deposited by stagnant waters in the same sedimentary basin. The adjacent Bazum and Javakheti Ridges rose more intensively. Therefore, the uplift could accelerate at 0.65–0.6 Ma up to 1–2 mm/year.

Declaration of competing interest

We declare that during the manuscript titled “Brackish-water Caspian-type Upper Pliocene – Lower Pleistocene deposits in the western Shirak Basin (NE Turkey and NW Armenia) and estimation of the Quaternary uplift of Lesser Caucasus” submitted for the Quaternary International (the issue, SEQS 2018) involves no conflicts of interests.

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References

Adamia, S.A., Chkhotia, T.G., Gavtadze, T.T., Lebanidze, Z.A., Lursmanashvili, N.D., Sadradze, N.G., Zakaraia, D.P., Zakariadze, G.S., 2017. Tectonic setting of Georgia – eastern Black sea: a review. In: In: Sosson, M., Stephenson, R.A., Adamia, S.A. (Eds.), Tectonic Evolution of the Eastern Black Sea and Caucasus, vol. 428. Geological Society, London, Special Publications, pp. 11–40.

Adamia, S.A., Zakariadze, G., Chkhotua, T., Sadradze, N., Tsereteli, N., Chabukiani, A., Gventsadze, S., 2011. Geology of the Caucasus: a review. Turk. J. Earth Sci. 20, 489–544.

Agadjanyan, A.K., Melik-Adamyan, G.U., 1985. Melkiye mlekopitayushchiye rannego pleistotsena Shirakskoi kotloviny Armenii (Early Pleistocene small mammals in the Shirak basin of Armenia). Bull. Comm. Study Quat. 54, 91–100 (in Russian).

Artyushkov, E.V., 1993. Fizicheskaya Tectonika (Physical Tectonics). Nauka, Moscow, pp.

456 (in Russian).
Artyushkov, E.V., 2003. Abrupt continental lithosphere weakening as a precondition for fast and large-scale tectonic movements. Geotectonics 37, 107–123.
Artyushkov, E.V., 2012. Neotectonic crustal uplifts as a consequence of mantle fluid infiltration into the lithosphere. Russ. Geol. Geophys. 53, 738–760. https://doi.org/10.1016/j.rgg.2012.04.005.
Aslanyan, A.T., 1958. Regionalnaya Geologiya Armenii (Regional Geology of Armenia). Aipetrat, Yerevan (in Russian).
Avagyan, A., Shahidi, A., Sosson, M., Sahakyan, L., Galoyan, G., Muller, C., Vardanyan, S., Bahar Firouzi, Kh, Bosch, D., Danelian, T., Asatryan, G., Mkrtchyan, M., Ali Shokri, M., 2017. New Data on the Tectonic Evolution of the Khoy Region, NW Iran. vol. 428. Geological Society, London, Special Publication, pp. 99–116. https://doi.org/10.1144/SP428.13.
Bagdasaryan, G.P., Gukasyan, R.Kh, 1985. Geokhronologiya Magmaticheskikh, Metamorficheskikh I Rudnykh Formatsii Armyanskoi SSR (Geochronology of Magmatic, Metamorphic and Ore Formations of the Armenian S.S.R.). Print office of the Academy of Sciences of the Armenian SSR, Yerevan, pp. 294 p. (in Russian).
Baghdasaryan, H.R., Karakhanyan, A.S., 2016. New data about movement's kinematics in Akhuryan fault zone (Republic of Armenia). Proc. NASRA: Earth Sci. 69 (1), 3–11.
Chernyshev, I.V., Lebedev, V.A., Arakelyants, M.M., Jrbashyan, R.T., Gukasyan, YuG., 2002. Quaternary geochronology of the Aragats volcanic center, Armenia: evidence from K–Ar dating. Dokl. Earth Sci. 384 (4), 393–398.
Danelian, T., Asatryan, G., Sahakyan, L., Galoyan, G.H., Sosson, M., Avagyan, A., 2010. New and revised Radiolarian biochronology for the sedimentary cover of ophiolites in the Lesser Caucasus (Armenia). In: In: Sosson, M., Kaymakci, N., Stephenson, R.A., Bergerat, F., Starostenko, V. (Eds.), Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform, vol. 340. Geological Society, London, Special Publications, pp. 383–391.
Danelian, T., Galoyan, G., Rolland, Y., Sosson, M., 2007. Palaeontological (Radiolarian) late Jurassic age constraint for the Stepanovan ophiolite (Lesser Caucasus, Armenia). In: Proceedings of the 11th International Congress, vol. 40. pp. 31–38 Athens, May 2007. Bulletin of the Geological Society of Greece.
Djrbashyan, R.T., 1990. Paleogenovye Vulkanicheskiye Poyasa Zony Zakrytiya Okeana Tetis (Malyi Kavkaz) (Paleogene Volcanic Belts of the Zone of Closing Tethys Ocean (Lesser Caucasus)). Doctoral thesis. Caucasian Institute of Mineral Resources, Tbilisi (in Russian).
Enkin, R.J., 1994. A Computer Program Package for Analysis and Presentation of Paleomagnetic Data. Pacific Geoscience Centre. Geological Survey of Canada, pp. 16.
Gabrielyan, A.A., 1964. Paleogen I Neogen Armyanskoi SSR (Paleogene and Neogene of the Armenian S.S.R.) Print. office of the Academy of Sciences of the Armenian S.S.R., Yerevan (in Russian).
Gabrielyan, A.A., Sarkisyan, O.A., Simonyan, G.P., 1981. Seismotektonika Armyanskoi SSR (Seismotectonics of the Armenian S.S.R). Yerevan State University, Yerevan, pp. 284 (in Russian).
Galoyan, G., Melkonyan, R.L., Atayan, L.S., Chung, S.-L., Khorenyan, R.H., Lee, Y.-H., Amiraghyan, S.V., 2018. On the petrology and geochemistry of Jurassic magmatics of the Somkheti segment of Somkheto-Karabagh tectonic zone (northern Armenia)// Izvestiya (Proceedings) of the National Academy of Sciences of Armenia. Earth Sci. 71 (1), 3–27.
Galoyan, G., Rolland, Y., Sosson, M., Corsini, M., Melkonian, R., 2007. Evidence for superposed MORB, oceanic plateau and volcanic arc series in the Lesser Caucasus (Stepanavan, Armenia). Compt. Rendus Geosci. 339, 482–492.
Geological Map of Iran, 1978. Sheet No. 1. Scale 1:1000000. National Iranian Oil Company, Tehran.
Geological Map of Turkey, Kars, 2002. Scale 1:500,000. Compiled by N. Akdeniz. General Directorate of Mineral Researxh and Exploration, Ankara.
Grichuk, V.P., Zaklinskaya, E.D., 1948. Analiz Iskopaemykh Pyltsy I Spor I Ego Primeneniye V Paleogeografii (The Analysis of Fossil Pollen and Spore and Using These Data in the Paleogeography). Geographis Publishing House, Moscow, pp. 224 (in Russian).
Head, M.J., 1992. Zygospores of the zygnemataceae (Division chlorophyta) and other freshwater algal spores from the uppermost Pliocene st. Erth beds of cornwall, southwestern England. Micropaleontology 38, 237–260.
Karakhanian, A.S., Trifonov, V.G., Philip, H., Avagyan, A., Hessami, Kh, Jamali, F., Bayraktutan, M.S., Bagdassarian, H., Arakelian, S., Davtian, V., Adilkhanyan, A., 2004. Active faulting and natural hazards in Armenia, eastern Turkey and northwestern Iran. Tectonophysics 380, 189–219.
Karapetian, S.G., Jrbashian, R.T., Mnatsakanian, A.K., 2001. Late collision rhyolitic volcanism in the north-eastern part of the Armenian highland. J. Volcanol. Geotherm. Res. 112 (1–4), 189–220.
Khain, V.E., 2001. Tektonika Kontinentov I Okeanov (2000) (Tectonics of Continents and Oceans (2000)). Nauchnyi Mir, Moscow, pp. 606 (in Russian).
Kirschvink, J.L., 1980. The least-square line and plane and the analysis of paleomagnetic data. Geophys. J. R. Astron. Soc. 62, 699–718.
Knipper, A.L., 1975. Okeanicheskaya Kora V Strukture Alpiiskoi Skladchatoi Oblasti (Oceanic Crust in Structure of the Alpine Folded Region). Nauka, Moscow, pp. 208 (in Russian).
Knipper, A.L., Satian, M.A., Bragin, N.Y., 1997. The upper Triassic – lower Jurassic volcanogenic and sedimentary deposits of the Old Zod Pass (Transcaucasia). Stratigr. Geol. Correl. 5 (3), 257–264.
Krijgsman, W., Tesakov, A., Yanina, T., Lazarev, S., Danukalova, G., Van Baak, C.G.C., Agustí, J., Alçiçek, M.C., Aliyeva, E., Bista, D., Bruch, A., Büyükmeriç, Y., Bukhsianidze, M., Flecker, R., Frolov, P., Hoyle, T.M., Jorissen, E.L., Kirscher, U., Koriche, S.A., Kroonenberg, S.B., Lordkipanidze, D., Oms, O., Rausch, L., Singarayer, J., Stoica, M., van de Velde, S., Titov, V.V., Wesselingh, F.P., 2019. Quaternary time scales for the Pontocaspian domain: interbasinal connectivity and faunal evolution. Earth Sci. Rev. 188, 1–40. https://doi.org/10.1016/j.earscirev.2018.10.013.
Lebedev, V.A., Chernyshev, I.V., Yakushev, A.I., 2011. Initial time and duration of Quaternary magmatism in the Aragats neovolcanic area (Lesser Caucasus, Armenia). Dokl. Earth Sci. 437 (2), 532–536.
Lenz, O.K., 2000. Paläoökologieeines Küstenmooresaus dem Eozän Mitteleuropas am Beispiel der Wulfersdorfer Flöze und deren Begleitschichten (Helmstedter Oberflözgruppe, Tagebau Helmstedt). Dissertation zur Erlangung des Doktorgrades der Mathematisch-Naturwissenschaftlichen Fakultäten der Georg-August-Universität zu Göttingen. Göttingen, pp. 229.
Lyubin, V.P., Belyaeva, E.V., 2014. Makro-nozhi v ashele kavkaza (Macro-knifes in the Caucasus Acheulian). Short Commun. Inst. Archaeol. 235, 44–59 (in Russian).
Melik-Adamyan, G.U., 1994. K voprosu o verkhnei biostratigraficheckoi granitse ignimbritov Kasakh-Pambakskogo tipa Armenii (On the upper biostratigraphic boundary of ignimbrites of the Kasakh-Pambak type in Armenia). Izvestiya of the Nat. Acad. Sci. Republic of Armenia, Earth Sci. Ser, Yerevan 47 (3), 9–12 (in Russian).
Milanovsky, E.E., 1968. Noveishaya Struktura Kavkaza (Neotectonics of Caucasus). Nedra, Moscow, pp. 483 (in Russian).
Nalivkin, D.V. (Ed.), 1976. 1. VSEGEI, Leningrad, pp. 500000.
Popov, S.V., Antipov, M.P., Zastrozhnov, A.S., Kurina, E.E., Pinchuk, T.N., 2010. Sea-level fluctuations on the northern shelf of the Eastern Paratethys in the Oligocene–Neogene. Stratigr. Geol. Correl. 18 (2), 200–224.
Ritz, J.-F., Avagyan, A., Mkrtchyan, M., Nazari, H., Blard, P.-H., Karakhanian, A., Philip, H., Balescu, S., Mahan, S., Huot, S., Münch, P., Lamothe, M., 2016. Active tectonics within the NW and SE extensions of the Pambak-Sevan-Syunik fault: implications for the present geodynamics of Armenia. Quat. Int. 395, 61–78.
Rolland, Y., Galoyan, G., Sosson, M., Melkonyan, R., Avagyan, A., 2010. The Armenian ophiolite: insights for Jurassic back-arc formation, lower Cretaceous hot spot magmatism, and upper cretaceous obduction over the south Armenian block. In: In: Sosson, M., Kaymakci, N., Stephenson, R.A., Bergerat, F., Starostenko, V. (Eds.), Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform 340. Geological Society, London, Special Publications, pp. 353–382.
Sahakyan, L., Bosch, D., Sosson, M., Avagyan, A., Galoyan, Gh, Rolland, Y., Bruguier, O., Stepanyan, Zh, Galland, B., Vardanyan, S., 2017. Geochemistry of the Eocene magmatic rocks from the Lesser Caucasus area (Armenia): evidence of a subduction geodynamic environment. In: In: Sosson, M., Stephenson, R.A., Adamia, S.A. (Eds.), Tectonic Evolution of the Eastern Black Sea and Caucasus, vol. 428. Geological Society, London, Special Publications, pp. 73–98.
Sayadyan, YuV., 2009. Noveishaya Geologicheskaya Istoriya Armenii (The Newest Geological History of Armenia). Ghitutyun, Yerevan (in Russian).
Schütt, H., 1997. Altpleistozane Mollusken im Becken von Pasinler bei Erzurum, Turkei. Geol. Palaeontol. 31, 275–284.
Sengör, A.M.C., Yilmaz, Y., 1981. Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75, 181–241.
Shalaeva, E.A., Trifonov, V.G., Lebedev, V.A., Simakova, A.N., Avagyan, A.V., Sahakyan, L.H., Arakelyan, D.G., Sokolov, S.A., Bachmanov, D.M., Kolesnichenko, A.A., Latyshev, A.V., Belyaeva, E.V., Lyubin, V.P., Frolov, P.D., Tesakov, A.S., Sychevskaya, E.K., Kovalyova, G.V., Martirosyan, M., Khisamutdinova, A.I., 2019. Quaternary geology and origin of the Shirak Basin, NW Armenia. Quat. Int. 509, 41–61.
Shatilova, I., Mchedlishvili, N., Rukhadze, L., Kvavadze, E., 2011. The History of the Flora and Vegetation of Georgia (South Caucasus). Georgian National Museum, Institute of Paleobiology, Tbilisi, pp. 200.
Sosson, M., Rolland, Y., Muller, C., Danelian, T., Melkonyan, R., Kekelia, S., Adamia, Sh, Babazadeh, V., Kangarli, T., Avagyan, A., Galoyan, Gh, Mosar, J., 2010. Subductions, obduction and collision in the Lesser Caucasus (Armenia, Azerbaijan, Georgia), new insights. In: In: Sosson, M., Kaymakci, N., Stephenson, R., Bergerat, F., Starostenko, V. (Eds.), Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform, vol. 340. Geological Society, London, Special Publications, pp. 329–352.
Tesakov, A.S., Simakova, A.N., Frolov, P.D., Sytchevskaya, E.K., Syromyatnikova, E.V., Foronova, I.V., Shalaeva, E.A., Trifonov, V.G., 2019. Early-Middle Pleistocene environmental and biotic transition in NW Armenia, southern Caucasus. Palaeontol. Electron. 22 (2). https://doi.org/10.26879/916. 25A 1-39. 41.
Trifonov, V.G., 2016. Collision and mountain building. Geotectonics 50 (1), 3–24. https://doi.org/10.1134/S0016852116010052.
Trifonov, V.G., Artyushkov, E.V., Dodonov, A.E., Bachmanov, D.M., Mikolaichuk, A.V., Vishnyakov, F.A., 2008. Pliocene-Quaternary orogeny in the central Tien Shan. Russ. Geol. Geophys. 49, 98–112. https://doi.org/10.1016/j.rgg.2007.06.012.
Trifonov, V.G., Ivanova, T.P., Bachmanov, D.M., 2012. Recent mountain building in geodynamic evolution of the central Alpine-Himalayan Belt. Geotectonics 46, 315–332. https://doi.org/10.1134/S0016852112050068.
Trifonov, V.G., Karakhanian, A.S., Kozhurin, A.I., 1994. Major active faults of the collision area between the Arabian and the Eurasian plates. In: Continental Collision Zone Earthquakes and Seismic Hazard Reduction. Proceedings of International Conference. IASPEI/IDNDR, Yerevan, pp. 56–78.
Trifonov, V.G., Lyubin, V.P., Belyaeva, E.V., Lebedev, V.A., Trikhunkov, Y.I., Tesakov, A.S., Simakova, A.N., Veselovsky, R.V., Latyshev, A.V., Presnyakov, S.L., Ivanova, T.P., Ozhereliev, D.V., Bachmanov, D.M., Lyapunov, S.M., 2016. Stratigraphic and tectonic settings of Early Palaeolithic of north-west Armenia. Quat. Int. 420, 178–198. https://doi.org/10.1016/j.quaint.2015.08.019.
Trifonov, V.G., Shalaeva, E.A., Sahakyan, L.Kh, Bachmanov, D.M., Lebedev, V.A., Trikhunkov, YaI., Simakova, A.N., Avagyan, A.V., Tesakov, A.S., Frolov, P.D., Lyubin, V.P., Belyaeva, E.V., Latyshev, A.V., Ozherelyev, D.V., Kolesnichenko, A.A., 2017. Quaternary tectonics of recent basins in NW Armenia. Geotectonics 51 (5), 499–519.
Trifonov, V.G., Tesakov, A.S., Simakova, A.N., Bachmanov, D.M., 2019. Environmental and geodynamic settings of the earliest hominin migration to the Arabian-Caucasus region: a review. Quat. Int. https://doi.org/10.1016/j.quaint.2019.03.008.
Trifonov, V.G., Sokolov, S.Yu, 2014. Late Cenozoic tectonic uplift producing mountain

building in comparison with mantle structure in the Alpine-Himalayan Belt. Int. J. Geosci. 5, 497–518. https://doi.org/10.4236/ijg.2014.55047.
Uznadze, M.D., 1965. Neogenovaya Flora Gruzii (Neogene Flora of Georgia). Academy of Sciences of the Georgian S.S.R., Tbilisi 193 p. (in Russian).
Vasilyan, D., Schneider, S., Bayraktutan, M.S., Şen, Ş., 2014. Early Pleistocene freshwater communities and rodents from the Pasinler Basin (Erzurum province, north-eastern Turkey). Turk. J. Earth Sci. 23, 293–307. https://doi.org/10.3906/yer-1307-16.
Van Baak, C.G.C., Grothe, A., Richards, K., Stoica, M., Aliyeva, E., Davies, G.R., Kuiper, K.F., Krijgsman, W., 2019. Flooding of the Caspian Sea at the intensification of northern hemisphere glaciations. Glob. Planet. Chang. 174, 153–163. https://doi.org/10.1016/j.gloplacha.2019.01.007.
Williams, G.L., Lentin, J.K., Fensome, R.A., 1998. The Lentin and Williams Index of Fossil Dinoflagellates, 1998 Edition. vol. 34. American Association of Stratigraphic Palynologists, pp. 1–817 Contributions Series.
Zaikina, N.G., Sayadyan, YuV., Sokolova, N.S., 1969. K istorii rastitelnosti Shirakskoi ravniny (On history of vegetation in the Shirak plain). Biol. J. Acad. Sci. Armen. SSR 22 (4), 67–74 (in Russian).