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Quaternary volcano-lacustrine patterns and palaeobotanical data in southern Armenia

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ABSTRACT

The morphogenetic evolution of the Lesser Caucasus has been strongly influenced by Plio-Quaternary volcanic and tectonic events and Pleistocene glaciations. Fluvio-lacustrine environments, indicated by diatomaceous deposits, prevailed in the Syunik region of southern Armenia during the Pliocene and Pleistocene. The Pleistocene diatomaceous deposits studied contain leaf impressions and pollen, allowing local palaeoclimatic reconstructions. The chronology of morphogenetic events has been determined by 17 radiometric dates (K/Ar, Ar/Ar, U/Th), palaeomagnetic investigations and is placed in a spatial context by a detailed geomorphological map and a 24-km geological transect of the Vorotan valley, the main area studied. Before 1.21 Ma, tectonic movements (antecedents of the lower part of the Vorotan valley) generated extensive lake formations with diatomaceous deposits. From 993 ka, volcanic eruptions produced lava flows that covered the fluvio-lacustrine accumulations. During Marine Isotopic Stages 12, 6 and 4, glaciers and fluvio-glacial deposits were probably present overall the principal uplands and valleys of southern Armenia. At 53.68 ka (MIS 3), 12.6 ka, 10.78 ka and 4.14 ka (MIS 1), the development of travertines on some slopes and in some valleys highlights temperate and humid climatic phases. Palaeobotanical studies of leaf and pollen floras show that the vegetation changed several times from forested to steppic phases in response to the climate oscillations of the Lower Pleistocene. This work proposes a first morphogenic and palaeoclimatic reconstruction from the lower Pleistocene to the Postglacial period, when the first settlements of the population in the Lesser Caucasus were influenced by tectono-volcanic events, lake level changes and glacial–interglacial oscillations forced by the obliquity orbital parameter (41 ky cycles).

1. Introduction

Multidisciplinary studies of Plio-Quaternary geomorphologic and palaeoclimatic evolution have rarely been attempted in Eurasia. In the Syunik region (southern Armenia, Fig. 1) several geomorphological units provide rich sources of information about Quaternary landscape evolution and palaeoclimate. In the main valleys, diatomaceous fluvio-lacustrine deposits with palaeontological content (leaf imprints, pollen, insects and mammal bones) are related to major volcanic activity, basaltic flows and tectono-orogenic movements that occurred during the Quaternary period.

The recent discovery of indicators of early prehistoric human occupation in Georgia (Dmanisi) around 1.81 Ma (Gabunia et al.,

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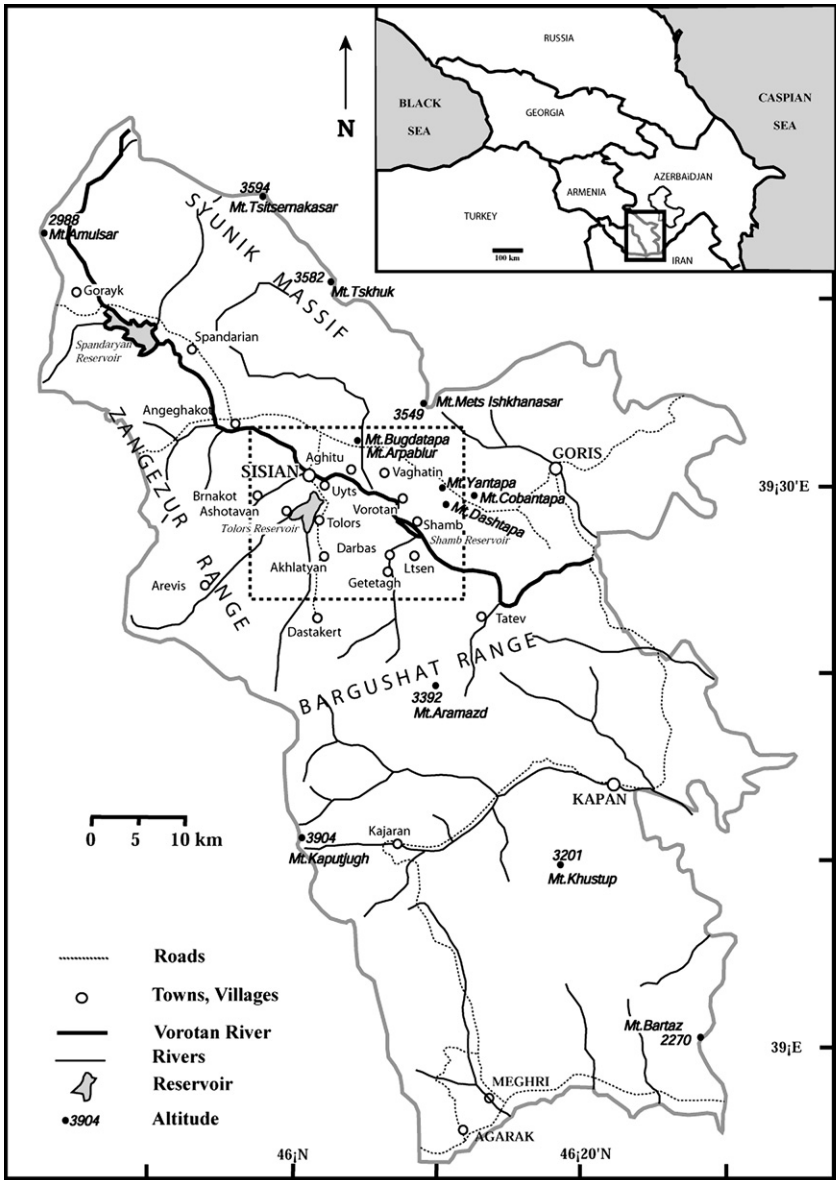


Fig. 1. Geographical map of south-eastern Armenia showing the study area.

2000, 2002) and the numerous Palaeolithic (middle to upper) sites studied by the French Caucase Mission (French Foreign Ministry, CNRS and the UMR 5133 from the Maison de l'Orient of University of Lyon, France) in Armenia, underline the necessity of understanding the climate, the palaeoenvironmental context and the landscape in which the first human populations began to settle the Caucasus and Eurasia during the Quaternary.

Several Russian collectors deposited the first palaeobotanical specimens of these diatomaceous lacustrine deposits from Syunik in the Department of Paleobotany of the Komarov Botanical Institute of Saint Petersburg prior to 1937. The first studies on the fossil flora of this area were published by Kryshtofovich (1939). The Armenian researchers A.L. Takhtajan and N.G. Gokhtuni collected plant fossils from the Sisian region after 1940 and deposited them in the Botanical Institute of Yerevan (Takhtajan and Gabrielyan, 1948; Gokhtuni, 1987, 1988, 1989). Since 1990, I. G. Gabrielyan has collected and studied fossil plants from various localities including those from the area of Sisian (Vorotan group floras).

A synthesizing work on these floras remains to be undertaken, as does a detailed chronostratigraphic study in order to define the relative positions of all the layers and to correlate the lake deposits with the Quaternary volcanic episodes. A study of climate quantification from fossil floras was carried out recently (Bruch and Gabrielyan, 2002).

In the mountains and secondary valleys, glacial landforms such as moraines, erratic blocks and fluvio-glacial deposits provide a basis for palaeogeographical and palaeo-climatological reconstruction up until the Late Quaternary period. In some valleys, postglacial deposits including travertines and alluvial terraces give some insights into evolution linked to the complex global environmental history since the lower Pleistocene.

The study is focused on the Vorotan valley area (Syunik) which contains a suite of interesting geomorphological units with great palaeoenvironmental analysis potential. The goal of the research is to better understand Quaternary vegetation and climate fluctuations, in the context of volcanic and tectonic activity, extensive lake development, glacial systems, and general morphogenic variability. A detailed picture of the vegetation in connection with all these parameters allows construction of a preliminary overall pattern of Quaternary paleoenvironmental evolution.

This paper presents a first Quaternary landscape reconstruction for southern Armenia with the objectives of (a) identifying precisely periods of large lake development related to the volcanic activity which represent attractive environment to the earliest human occupations presumed in the region; (b) defining the morphoclimatic components, the rhythms and the chronology of the major Quaternary morphogenic events in southern Armenia; (c) establishing the basis of a preliminary Quaternary environmental reference pattern, from local to general importance, useful to the archaeological research in Lesser Caucasus.

2. General environmental context

2.1. Present climate and vegetation of the area

The region under study ranges from 1200 to 2200 m in elevation. In the 1300–1500 m zonel, the climate is cool temperate. Above, it is a cool mountain climate. In the central area (near the town of Sisian) the mean annual temperature is 6.6 °C, and in the north-western area from 2000 m to 2200–2300 m it is 2.7 °C (near Spandaryan Lake). The mean annual precipitation varies according to altitude: from 1300 to 1500 m in altitude, 350–400 mm; from 1500 to 2000 m, 400–500 mm; higher than 2000 m, 500–600 mm and above (Baghdasaryan, 1958). Precipitation is mainly concentrated in spring and autumn (Baghdasaryan, 1958).

This territory is mostly covered with steppic vegetation. The lower mountain zones are covered by *Festuca* and *Stipa* steppes with *Festuca ovina*, *Festuca chalcophaea*, *Stipa capillata*, *Dactylis glomerata*, *Koeleria cristata*, *Alopecurus aequalis*, *Bromus squarrosus*, etc. On upper zones, dominant steppic species are *Astragalus aureus* and *Astragalus microcephalus*, while *Poa alpina* is prevalent in the subalpine and alpine grasslands (Maghakyan, 1948). Deciduous forests remain locally on northern slopes in the south-eastern part of the Sisian region near the villages of Arevis and Dastakert (Fig. 1), and in the southern part of the region near the villages of Darbas and Ltsen (Fig. 1). The main tree and shrub species in these forests are *Quercus macranthera*, *Carpinus betulus*, *Acer campestre*, *Acer ibericum*, *Pyrus caucasica*, *Ulmus minor* (*foliacea*), *Salix caprea*, *Juniperus polycarpos*, *Juniperus oblonga*, *Crataegus caucasica*, *Cotoneaster integerrima*, *Viburnum lantana*, and *Lonicera caucasica* (Maghakyan, 1948).

2.2. Geological and geomorphological setting of the Sisian region

The Syunik volcanic massif, which occupies all the left bank of the Vorotan River from the north-west to the south-east, is almost entirely covered with Neogene and Quaternary volcanic rocks, as well as volcanic detrital rocks and lacustrine sediments. It corresponds to the south-eastern part of the Pambak-Sevan-Syunik fault zone, one of the main active structures of the region (Philip et al., 2001). This massif is characterized by great variations in absolute and relative altitudes. Some volcanic mountains exceed 3500 m (Tsitsernakasar: 3594 m; Tskhuk: 3582 m; Mets Ishkhanasar: 3549 m; Aramazd: 3392 m) rising to between 1000 and 1500 m above the surrounding peripheral lava plateaux (in the main study area), the altitude of which is 1400–2000 m. The Vorotan valley (Fig. 1), with canyons that reach a depth of 500 to 800 m close to the village of Vaghatin, forms a border between the volcanic massif of Syunik and the northern part of the folded and fractured chain of Zangezur, which is a recently uplifted Alpine chain.

According to most geologists, a significant uplift of the Amulsar Mountain separated the Vorotan and Arpa valleys during the Miocene. Some authors think that the Vorotan River was disconnected from the Arpa River in the area of Spandarian and Gorayk even before the uplift of Amulsar Mountain and that they were joined together upstream (Balyan, 1969; Gevorgyan, 1986; Gaginyan, 1989) at the same period. The transformation of the Vorotan palaeo-valley into a system of lacustrine basins probably occurred during the Pliocene. The Quaternary Sisian basin, according to an uplift rate of around 3 mm/year during the last million years in the Lesser Caucasus (Mitchell and Westaway, 1999), was probably around 300 m lower than today.

The present-day Vorotan valley is closely related to the Plio-Pleistocene palaeo-valley and appears as a synclinal-graben system of connected canyons and valleys. The entire valley has an irregular transverse profile. The left bank consists of structural terraces in thick volcanic flows of the Syunik massif, whereas the right bank, steep and heavily dissected by lateral ravines, is composed of sedimentary and volcanogenic rocks of the Zangezur chain (Jurassic and Cretaceous deposits, Palaeogene intrusive granitic rocks).

After the Shaghap basin, located in the upstream part of the area studied (Fig. 1), the river flows into a deep canyon, which is formed by the contact between the lava and the volcanic Eocene rocks. Then the valley widens out gradually and emerges in the Sisian basin, where the Vorotan River receives an important tributary from the right bank, the Sisian River. In this valley and the Sisian depression diatomaceous fluvio-lacustrine units and alluvial deposits are the main components of the landscape, with basaltic flows and metamorphic rock on the surrounding hills.

The diatomaceous deposits reach thicknesses of 100–450 m. This sediment preserves many plant fossils (primarily leaves and pollen) and some animal remains, generally well preserved. The K/Ar and Ar/Ar dates on the associated basaltic flows and pumices, as well as the palaeomagnetic results, suggest that these lacustrine formations developed from the Lower to Middle Pleistocene.

Downstream from the Sisian basin, the Vorotan River continues in a canyon which descends gradually and reaches a depth of more than 700 m in the area of Tatev village (Fig. 1). After the confluence with the Goris River, the valley becomes embanked and connects with the Hagaru valley.

3. Methodology

3.1. Geomorphology, radiometric chronology and magnetostratigraphy

Field observations were used to draw a geomorphological map of the area that includes the lacustrine diatomaceous basins as well as the basaltic flows, glacial landforms and alluvial deposits (Fig. 2). The various outcrops with fossil flora are indicated.

A geological transect, 24-km in length and oriented from W–E to NE–SW (Figs. 3–5) indicates the relationship between morphology and the organisation of the stratigraphical units. Many natural sections in the palaeo-valley deposits and a borehole on the right bank of the Vorotan River (Matevosov, 1984–1985) expose the succession of geological events. The most complete fluvio-lacustrine stratigraphical sequence (Shamb section, Figs. 6 and 7) was sampled and investigated for its sedimentological characteristics and its potential for chronological, palaeontological and geophysical analysis.

Ten basalt samples, one scoria and two pumices, were taken for K/Ar and Ar/Ar analyses. The basalt samples come from the Uyts–Aghitu–Shamb zone: the scoria was removed from the

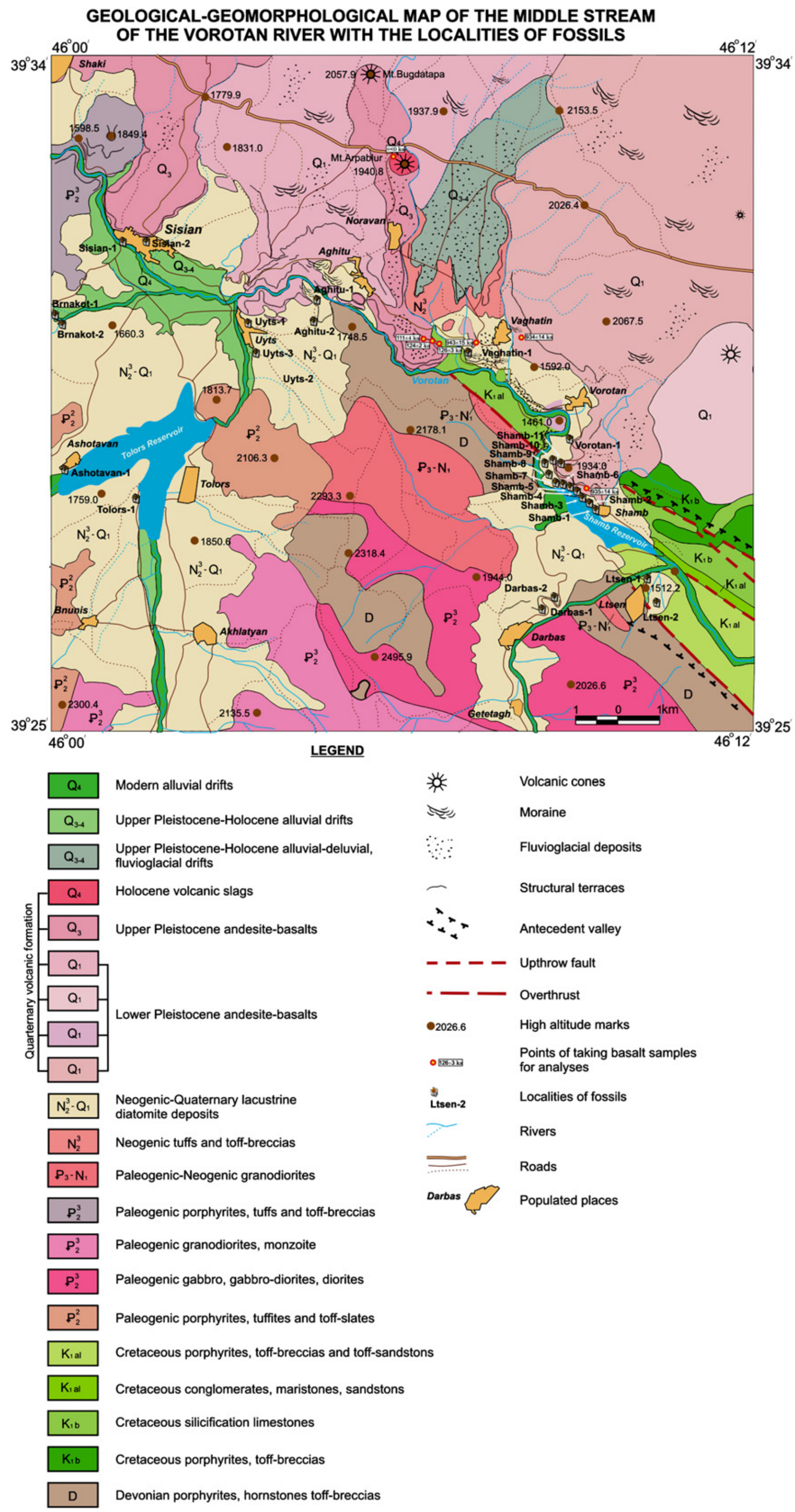


Fig. 2. Geomorphological map of the middle reaches of the Vorotan River.

slopes of the Arpablur volcanic cone (Fig. 2) and the pumice samples were collected in the Shamb section (Fig. 2).

Standard methodology for K/Ar dating was utilised (Guillou et al., 2010; Dalrymple and Lanphere, 1969; Chernyshev et al., 2006). Age determinations were performed in the CEA laboratory at Gif-sur-Yvette (France). The fraction size of the materiel analysed is between 0.250 and 0.125 mm, ultrasonically washed in $HC_2H_3O_2$.

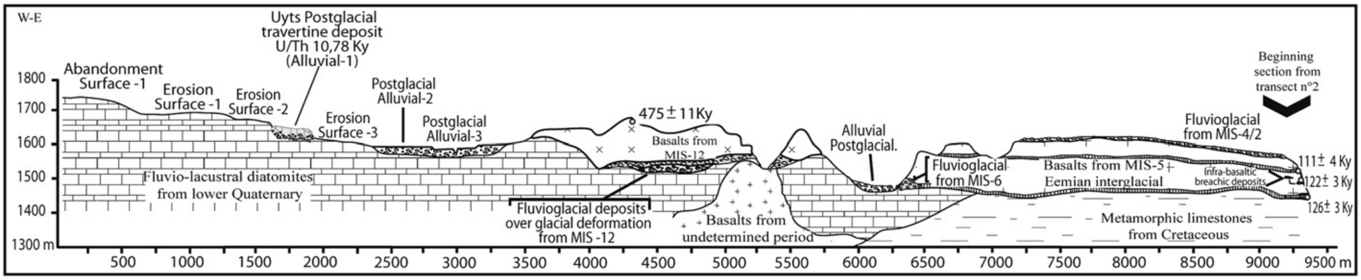


Fig. 3. Uyts–Aghitu geomorphological transect.

The constants used are:

$\lambda_\beta = 4.962 \times 10^{-10}/a$
$\lambda_\varepsilon = 0.572 \times 10^{-10}/a$
$\lambda_{\varepsilon'} = 0.0088 \times 10^{-10}/a$

$$\text{AGE} = \frac{1}{\lambda_\beta + (\lambda_\varepsilon + \lambda'_\varepsilon)} \ln\left[\frac{\lambda_\beta + (\lambda_\varepsilon + \lambda'_\varepsilon)}{(\lambda_\varepsilon + \lambda'_\varepsilon)} \times \frac{^{40}\text{Ar}}{^{40}\text{K}} + 1\right]$$

$^{40}\text{K/K} = 1.167 \times 10^{-4}$ g/g

Error on the age is at 2σ.

The Ar/Ar samples (pumices) were irradiated in the nuclear reactor at the McMaster University in Hamilton (Canada). Age determinations were performed in the Geosciences Azur laboratory at Nice (France). The detailed Ar/Ar results and methodology are given in the paper by Joannin et al. (2010).

In addition, four travertine formations were sampled for U/Th dating the freshwater travertine of Uyts in the upstream part of the Vorotan valley, freshwater travertines of Shamb in the middle part of the Vorotan valley and the hydrothermal travertine of Tatev in the downstream part of the Vorotan valley (Figs. 1, 2 and 8).

U/Th age determinations were performed in the IFM-GEOMAR laboratory at Kiel (Germany). U/Th dating was based on $^{230}\text{Th}/^{234}\text{U}$ measurements of the travertine facies. It is important to make sure that samples have not been previously contaminated by thorium of different ages (Eikenberg et al., 2001). Consequently, it is necessary to measure the $^{230}\text{Th}/^{232}\text{Th}$ ratio so that the results can be trusted. High ratios, up to 17 (Bischoff et al., 1988) or 20 (Ivanovich and Harmon, 1992), indicate that detrital contamination by Th is negligible and allow acceptance of dates. Nevertheless, low values of this ratio do not systematically invalidate the dates. In several cases, reliable dates have been obtained even when the $^{230}\text{Th}/^{232}\text{Th}$ ratio was very low (Quinif, 1989; Ambert et al., 1995; Mlakar et al., 1999). Dates based on U/Th measurements can be compared to the calendar chronology without calibration.

The magnetostratigraphy of the Shamb section (Joannin et al., 2010) was established from eighteen oriented samples. These samples were treated in the Fort Hoofddijk laboratory of Utrecht University using compressed air. The natural remanent magnetization (NRM) was measured on a horizontal cryogenic magnetometer. The direction of the NRM component was calculated by principal-component analysis. The thermal demagnetization diagrams are characterized by linear decay of NRM to a temperature of 360 °C.

3.2. Palaeoecological in situ sampling and laboratory analysis

More than 8000 leaf imprints samples were collected from the Shamb section and several other nearby localities (Brnakot, Tolors, Uyts). The best preserved samples were photographed or drawn and identified with reference to botanical material held in the herbarium of the Botanical institute of National Academy of Sciences of Yerevan. One hundred palynologic samples of the Shamb section were analysed and correlated with the macrobotanical data (Joannin, 2007). Samples were processed using a standard method adapted from Cour (1974). HCl and HF attacks were followed by residue sieving between 160 μm and 10 μm and enrichment process (using $ZnCl_2$ at density 2). They were treated and analysed in the PEPS laboratory (University of Lyon 1, France).

4. Results

4.1. Geochronology

Seventeen dates were obtained on various materials such as pumices interbedded in the diatomaceous deposits, basalt flows,

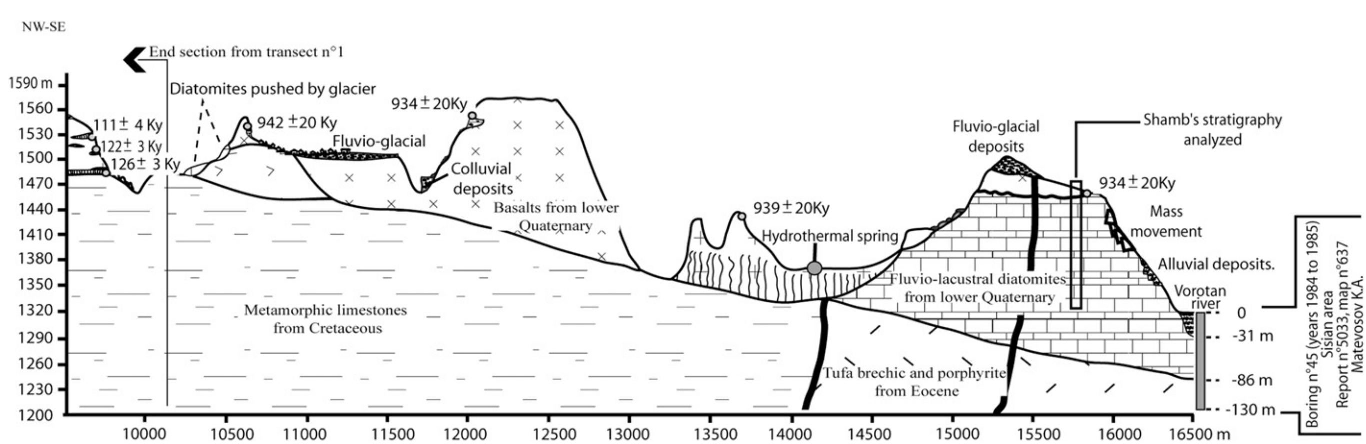


Fig. 4. Aghitu–Shamb geomorphological transect.

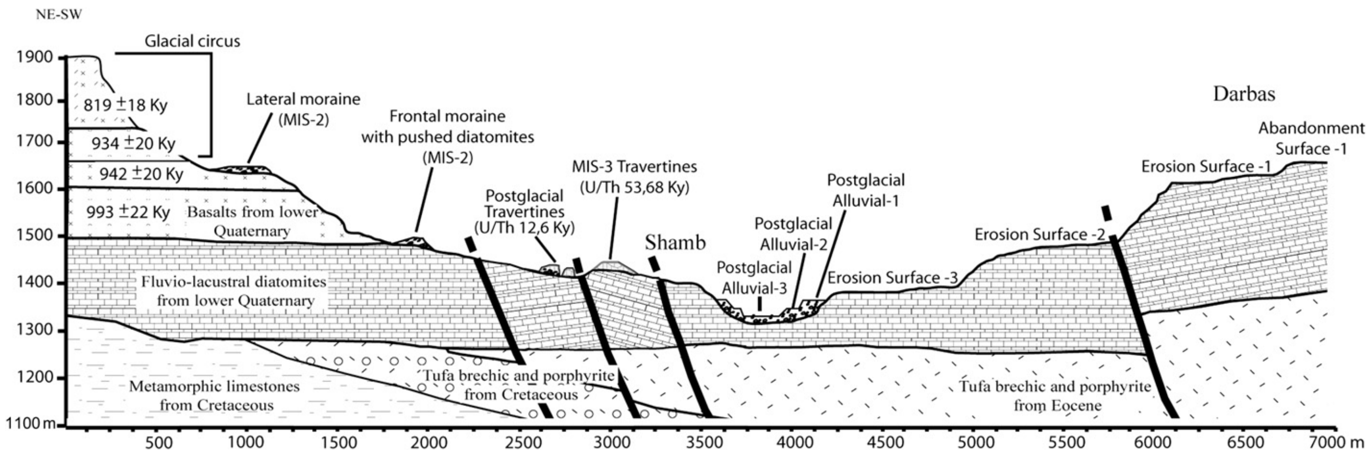


Fig. 5. Shamb–Darbas geomorphological transect.

scoria (volcanic cone) and travertine (hydrothermal carbonates) in order to have a complete event chronology based on a comparison of various formations. The K/Ar and U/Th data are given in Tables 1 and 2. The Ar/Ar results (Joannin, 2007; Joannin et al., 2010) are given in the Shamb stratigraphy description. Obtained ages range between the Lower Pleistocene and the Holocene and provide an interesting Quaternary event chronology of southern Armenia.

4.2. Geomorphology

The diatomaceous units of the studied area are well known to the geologists and palynologists of the former Soviet Union (e.g. Sayadian et al., 1983). New palaeoenvironmental studies (Gabrielyan, 1994, 1996; Bruch and Gabrielyan, 2002; Gabrielyan and Gasparyan, 2003, 2004, 2005) provide a better indication of the chronological implications of these particular lacustrine deposits.

The local palaeogeography during the Plio-Quaternary was characterized by the presence of large lakes which were probably formed by tectonic (antecedent valleys) and volcanic activity (dams generated by basaltic flows). Three major volcanic phases occurred in Armenia between the Miocene and the Quaternary (Karapetyan et al., 2001): during the Middle Miocene, the Upper Miocene–Lower Pliocene and the Pleistocene-postglacial period. The many volcanoes of the area (Fig. 2) are regarded as Quaternary.

Volcanic activity in the Sisian/Shamb area corresponds to the Quaternary phase. The numerical dates on basalt rocks, pumices and scoria need to be more numerous to give a complete geochronological understanding of the whole complex (Midyan et al., 1976; Sayadian et al., 1983; Karapetyan et al., 2001). Nevertheless, the numerical geochronology of the different volcanic units studied allows division of this Quaternary phase into six local stages (Figs. 2–5, Table 1):

- (1) between 1.2 Ma and 990 ka
- (2) 940 ka and 930 ka
- (3) around 820 ka
- (4) around 475 ka
- (5) between 126 and 111 ka
- (6) during the Holocene

Expression of this Quaternary volcanic activity evolved from pumice deposition and basaltic lava flows to the development of scoria cones during the last million years. This kind of evolution is probably indicative of a decrease in the activity of magmatic chambers from the lower Pleistocene to the Holocene. Today, intensive seismicity (dramatically represented in 1988 by the destructive Spitak earthquake that devastated the northern part of Armenia, Cisternas et al., 1989) is the most recent evidence of an active regional geodynamic.

Many field-trips in the Sisian-Shamb area (between 2003 and 2006) enabled precise definition of the borders of palaeo-lakes generated by this regional geodynamic activity (Fig. 2). On the western edges, alluvial deposits fed by the hydrographic system of the Vorotan basin are mixed with lacustrine sediments. The alluvial sediment content decreases with the depth increase of the palaeo-lake in the middle part of the basin. The western mountain river systems were certainly the main water supply for the palaeo-lakes (Fig. 2).

In the upper zone of the Vorotan valley, in the Sisian–Aghitu area, the age of the lacustrine formations needs to be refined. Future Ar/Ar results on some pumice levels sampled in these

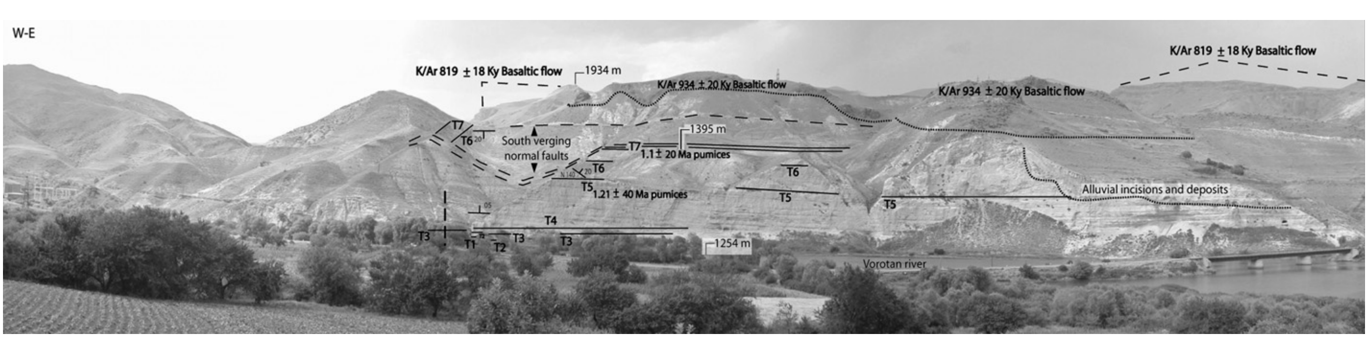


Fig. 6. Analytical overview of the Shamb sequence.

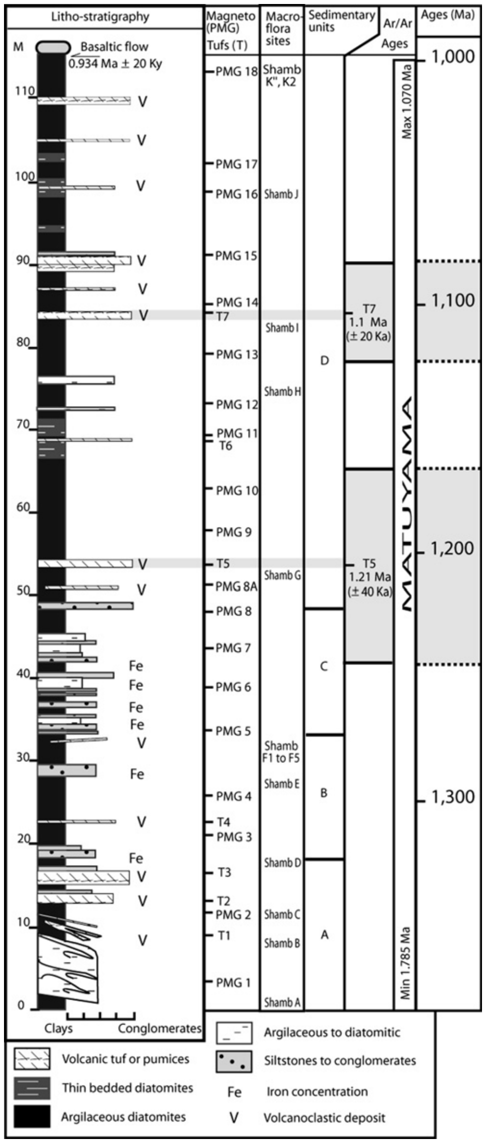


Fig. 7. Stratigraphic section of Shamb.

formations and a K/Ar basalt sample collected in a flow under the paleo-lake deposits will further support the numerical chronology (Ollivier et al., 2007). In the middle zone of the Vorotan valley, the geomorphological and geochronological data extracted from the Aghitu–Vaghatin–Shamb area place the entire local complex in the lower Quaternary period. The dating results of the basaltic flows covering these diatomaceous lacustrine formations (with burned contact) fall between 993 ± 22 ka and 934 ± 20 ka; (Figs. 4 and 5, Table 1).

The south-east system at the highest altitude between Dastakert and Darbas localities is the oldest in the area, and it is probably linked to upper Pliocene tecto-orogenic activity. Sedimentary facies in these deposits show numerous preliminary silicifications (nodules and interstratified levels, Fig. 8). This important diagenetic evolution and the higher topographical position (testifying to tectonic activity) of the deposits indicate a pre-Quaternary origin for the Dastakert and Darbas formations (Figs. 2 and 5).

According to the dating of a basalt flow at 475 ± 11 ka over fluvio-glacial formations and glacial deformations of the paleo-lake deposits, most of the Quaternary basaltic flows on the left bank of the Vorotan River were glaciated not later than at least MIS 12 (Figs. 2 and 3 and Table 1). Glacial and periglacial remnants are represented as moraines, erratic blocks, fluvio-glacial deposits, roches moutonnées, striated rocks and periglacial slope formations (Fig. 8). Frequently, the older diatomaceous lacustrine deposits, well stratified, were pushed by the glacier advance and represent a unique form of moraine. During the last deglaciation, fluvio-glacial discharge frequently impacted the lacustrine deposits in the valley and resulted in a warped stratigraphy with interpenetration between pebbles and diatomaceous layers (Fig. 8). The evidence of several glaciations described at relatively modest altitudes (bottom of the Vorotan valley around 1500 m) underline the important role of the Quaternary cold episodes in the Pleistocene morphodynamics of southern Armenia, which represents a new major element in the understanding of the southern Caucasus and its Quaternary paleoclimates.

Most of the major valleys (Sisian, Vaghatin and Shamb basins) contain upper Pleistocene or postglacial alluvial formations (Fig. 2) affected by fitting or terracing and sometimes associated with travertine deposits (Uyts and Shamb, notably). The geomorphological organisation of these formations depends on the palaeoclimatic and/or orogenic conditions that occurred between the last glacial periods and the present-day.

The 24-km transect undertaken (Figs. 3–5) shows the various geomorphological units that illustrate the diachronic phases of Quaternary geomorphic evolution proposed:

- Diatomaceous lacustrine deposits, lower Pleistocene;
- Basaltic flows, lower to upper Pleistocene;
- Glacial remnants, middle to upper Pleistocene;
- Alluvial deposits (detrital and/or travertine); upper Pleistocene and/or postglacial times.

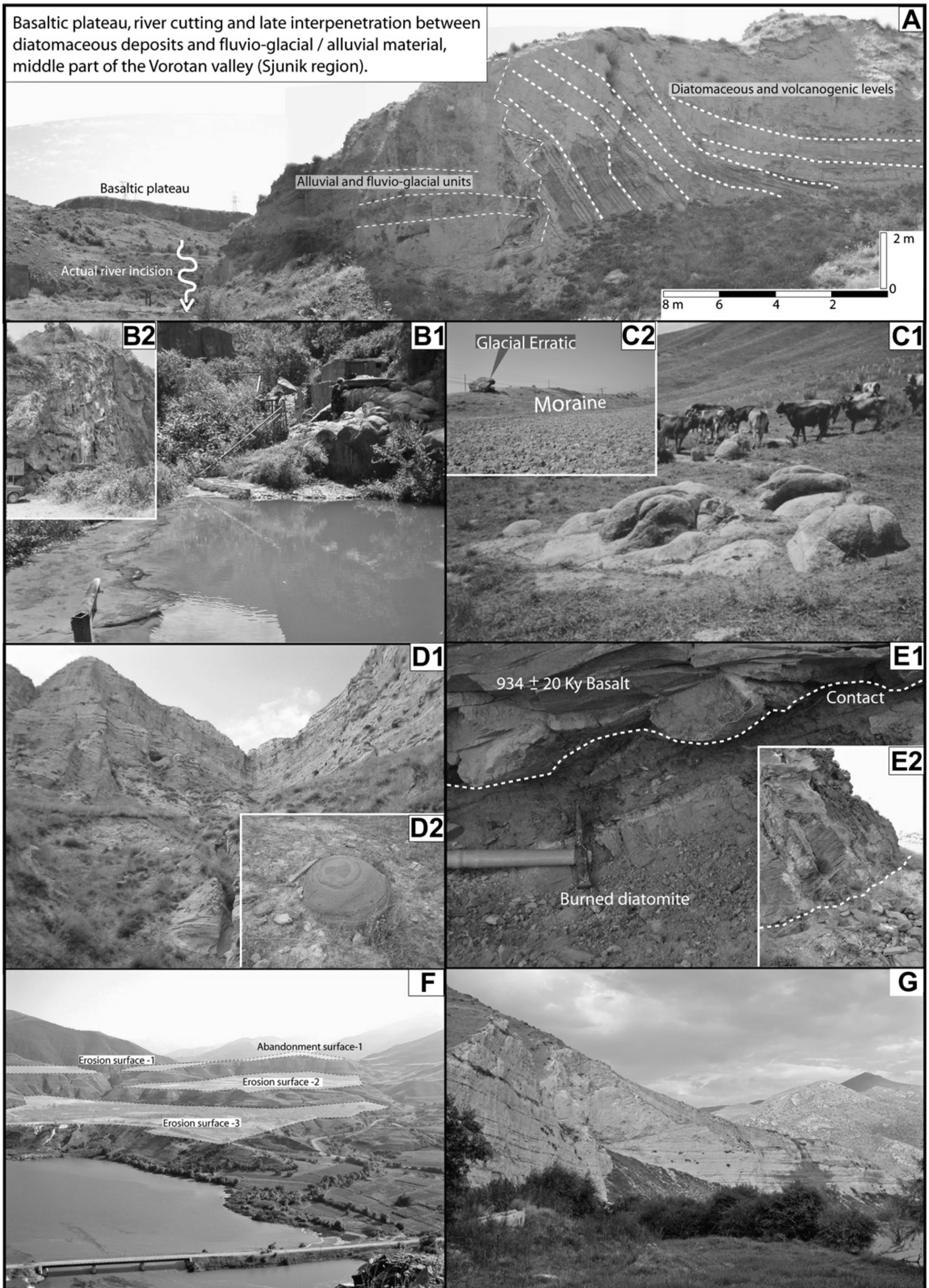
In the area, the different Quaternary morphosedimentary units are successively intercalated or interstratified. Abandonment, erosion surface morphology, geometry of the formations and radiometric dating give clues to understanding the event chronology of a composite Quaternary morphogenesis.

4.3. *Palaeoecology*

4.3.1. *Stratigraphy of the main leaf flora locality: Shamb*

Many fossil outcrops of the Sisian region (Vorotan Group fossils, Fig. 10) have already been sampled previously by Gabrielyan (1994, 1996). To supplement the lists of flora and clarify the stratigraphic sections in a correct chronostratigraphic scale, study was undertaken of the diatomaceous formations of Aghitu (N 39°51′13″, E 046°06′13″, altitude 1522 m, Fig. 2), Uyts-2 (N 39°34′12″, E 46°05′10″, altitude 1605 m, Fig. 2), Brnakot-2 (N 39°30′34″, E 46°00′02″, altitude 1671 m, Fig. 2) and Tolors (N 39°28′04″, E 046°01′11″, altitude 1680 m, Fig. 2).

Each of the site stratigraphies shows diatomaceous layers interstratified with pebbles or grey sandy fluviatile units that are covered by lower to middle Pleistocene basaltic flows (993 ± 22 ka to 475 ± 11 ka, Table 1, Figs. 2–5). Many fossils were collected in each locality and represent various and outstanding palaeontological specimens: leaf imprints, seeds, insects and a vertebrate skeleton in Uyts-2 site (*Lepus* species, Fig. 10, Gabrielyan et al., 2005). In some places such as the Brnakot-2 locality, leaf imprints give an idea of the palaeogeographical and spatial organisation of the lakes, with sandy layers richer in water plants (*Potamogeton*) that indicate the proximity of lake banks in shallow-water environments. By far the richest and most beautiful section of lacustrine diatomites was that of Shamb (Figs. 6 and 8), an abrupt cliff in the left bank of the Vorotan River that contains a long sediment profile



A : View of quaternary geomorphological units in the Vorotan valley ; B1 : Tatev actual hydrothermal spring ; B2 : Tatev hydrothermal holocene travertine ; C1 : Roche Moutonnee (Pokr Sevkar, altitude 2800 m) ; C2 : Moraine and glacial erratic near Aghitu (Vorotan valley, altitude1500 m) ; D1: Darbas diatomaceous formation (upper pliocene) ; D2 : Nodule silicification (Darbas area) ; E1: Contact between basalt flow and diatomite (Shamb) ; E2 : General view of the contact ; F : Erosion or abandonment surfaces in the downstream part of the Vorotan valley ; G : Shamb diatomaceous formation.

Fig. 8. A review of geomorphological units of the area studied.

Table 1
K/Ar dates (LSCE–CEA–CNRS, France).

Sample ID / Experience no.	Weight molten (g)	K* (wt.%)	^{40}Ar* (%)	^{40}Ar* (10^{-12} mol/g)	^{40}Ar* mean weight (±1σ)	^{40}Ar*/^{40}K (10^{-5})	Age ± 2σ, ka
V0-02							
7282	1.07058	2.656 ± 0.027	4.080	4.718			
7298	0.91141	2.656 ± 0.027	4.105	4.451	4.574 ± 0.019	5.769	993 ± 22
PR-5							
6780	1.01989	2.665 ± 0.027	6.863	4.310			
6796	1.06928	2.665 ± 0.027	7.099	4.403	4.356 ± 0.017	5.476	942 ± 20
V0-01							
7281	1.05224	3.072 ± 0.037	5.582	4.951			
7297	1.15649	3.072 ± 0.037	6.059	5.055	5.002 ± 0.020	5.455	939 ± 20
PR-7							
6801	2.46800	3.072 ± 0.037	25.800	4.991			
6817	2.15518	3.072 ± 0.037	42.584	4.965	4.978 ± 0.018	5.429	934 ± 20
PR-4							
6625	1.60022	3.528 ± 0.035	19.913	5.738			
6641	1.02721	3.528 ± 0.035	4.969	5.688	5.715 ± 0.022	5.428	934 ± 20
SHAMB-22							
7104	1.49254	3.412 ± 0.034	8.757	4.880			
7120	1.53515	3.412 ± 0.034	7.771	4.816	4.849 ± 0.018	4.761	819 ± 18
UY-04							
7232	1.02020	2.499 ± 0.025	5.040	1.992			
7250	0.99227	2.499 ± 0.025	5.114	2.131	2.057 ± 0.011	2.758	475 ± 11
PR-6							
6781	1.08420	2.490 ± 0.025	6.212	5.305			
6797	2.60782	2.490 ± 0.025	4.592	5.506	5.459 ± 0.048	7.345	126 ± 3
PR-2							
6604	1.49025	2.457 ± 0.025	6.759	5.044			
6620	2.67667	2.457 ± 0.025	14.346	5.264	5.214 ± 0.034	7.110	122 ± 3
PR-1							
6603	1.41035	2.383 ± 0.024	1.304	4.851			
6619	1.42617	2.383 ± 0.024	0.920	4.314	4.568 ± 0.055	6.422	111 ± 4
PR-3							
6612	0.59541	2308	−0.291	≤0	–	0.10	0 (Holocene)
6634	0.49728	2308	0.012	2.9	–	–	

(N 39°28′11″, E 046°08′33″, altitude at the level of the Vorotan River: 1340 m).

The Shamb formation (Fig. 6) is cut by normal east–west faults, with strong dip and collapse of the southern compartments. These faults affect the summit basalt dated to 934 ka, and they induce repetitions of the diatomite succession. In addition, important landslides towards the south affect the higher part of the outcrop, covering the layers *in situ*. Nevertheless, two well-preserved continuous sections established a 115-m composite succession (Fig. 7). A detailed stratigraphic analysis was carried out (Fig. 7) and samples were taken for palaeomagnetic and Ar/Ar dating. Macroflora and pollen samples (from the whole succession) also were taken.

The palaeomagnetic results reveal reversed polarity for the entire Shamb section (Fig. 7). Taking into account the age of the different basalts covering the local upper diatomites (between 993 ± 22 ka and 934 ± 20 ka, Figs. 4–8, Table 1), and those of the two volcanic pumices levels (T5: 1, 21 Ma and T7: 1, 10 Ma, Fig. 7), the fluvio-lacustrine deposits of Shamb appear to belong to the reversed Matuyama chron, between the normal Olduvai and Jaramillo subchrons. The complete results of the Ar/Ar dating are given by Joannin et al. (2010).

In the basal part of the section (sedimentary unit A, Fig. 7), zones disturbed by many undulations between two non-deformed levels could correspond to seismites formed at the interface between water and sediment. These facies appear as visco-plastic deformations with sloping pleats, stretched layers and diapiric injections leading to the formation of pillow and ball structures, and sometimes to a blending of various facies (sandstone-tuff-diatomites).

The next part of the section (sedimentary unit B, C and D, Fig. 7) contains rhythmic sedimentary sequences, each a few decimeters or more thick, with altering coarse and fine facies. Several upper horizontal grey pumice zones of variable thickness (2–4 m) alternate with the diatomite levels, themselves crossed by fine

Table 2
U/Th dates (IFM-GEOMAR, Kiel, Germany).

Sample	Age	±	min-Age, Ky	max-Age, Ky	^{238}U, ppm	±, ppm	^{232}Th, ppb	±, ppb	^{230}Th, ppt	±, ppt
Tat1	4.14	0.36	3.78	4.50	0.1277	0.0018	6.91	0.02	0.197	0.010
Uyts 6	10.78	1.79	9.01	12.58	0.609	0.000	161.298	0.546	1.62	0.01
Sha2	12.6	3.81	8.40	16.03	0.698	0.000	546.449	1.283	3.72	0.01
Sha1	53.68	1.96	51.74	55.66	1.99472	0.00211	197.22	1.56	20.307	0.467

Sample	^{230}Th/^{232}Th, dpm/dpm	±, dpm/dpm	^{238}U/^{232}Th, dpm/dpm	±, dpm/dpm	^{230}Th/^{238}U, dpm/dpm	±, dpm/dpm	^{230}Th excess/^{238}U, dpm/dpm	±, dpm/dpm	^{234}U/^{238}U, dpm/dpm	±, dpm/dpm
Tat1	5.31	0.27	57.2	0.8	0.09283	0.00483	0.08234	0.00581	2.2064	0.0341
Uyts 6	1.874	0.012	11.682	0.040	0.16044	0.00092	0.10908	0.01715	1.1579	0.0007
Sha2	1.272	0.005	3.953	0.009	0.32171	0.00094	0.16994	0.05060	1.6030	0.0008
Sha1	19.22	0.47	31.31	0.25	0.61405	0.01414	0.5949	0.0162	1.4956	0.0025

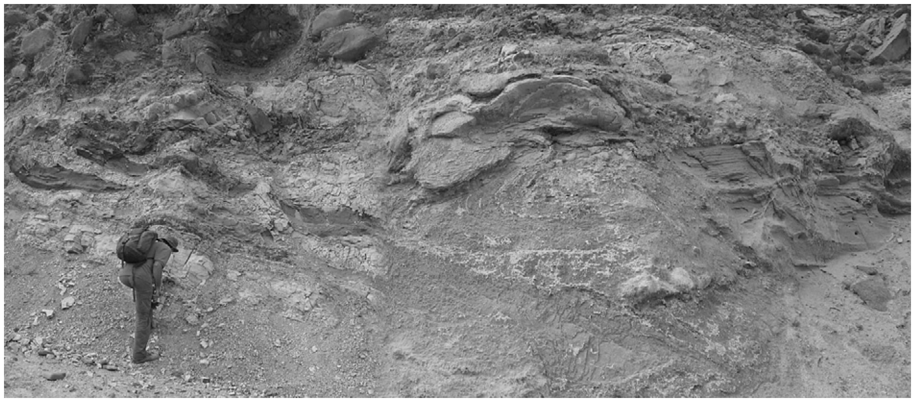


Fig. 9. Glacial deformation from MIS 12.

(centimetric-scale) sandy oxidized beds. Some remains of basaltic flows appear on the hills which dominate the section (Figs. 4–7). A geodesic reference mark (1520 m) is at the top of one. At the basal part of this volcanic flow is the contact between basalt and diatomites, which have a dark, then reddish aspect over approximately 30 cm, indicating that they were burned by the lava in fusion (Fig. 8). In this zone, the greater age of the lake deposits compared to this lava flow is reinforced by the K/Ar analysis (sample 6625: 934 ± 20 ka).

The sedimentary sequences defined in the Shamb stratigraphy indicate a succession of lacustrine environments with pelagic diatoms or clay-silt deposits with fluvio-lacustrine indications (stream bottom or localised alluvial perturbations of the lacustrine sedimentary units). The palaeohydrology changed from high-energy to low-energy in a volcanic environment with explosive eruptions represented by the numerous pumice levels partly dated by Ar/Ar analysis.

4.3.2. Palaeovegetation

Palaeovegetation dynamics were reconstructed with reference to the Shamb and Uyts subgroup floras (Aghitu, Uyts, Tolors, Brnakot). The species identified from the Shamb stratigraphy are presented in Table 3.

Some of the species, preserved in the lacustrine sediments of the upper basin of the Vorotan River were growing near the shore of the palaeo-lake and others were arboreal species on northern slopes. Most of the shrubs were from open vegetation on southern slopes. Some herbaceous species are represented by fruits or seeds (e.g. *Carex*, *Daucus*, *Heracleum*).

These rich macrofloras do not indicate the steppic phases because the leaf remains of herbaceous species are not preserved. On the other hand, pollen grains of herbaceous plants are preserved alongside those of woody plants. The understanding of the evolution of the vegetation over time requires not only a good chronological definition, but also joint micro- and macroflora studies of the same horizons. Of the nearly 100 species of fossil plants of the Vorotan group, in present-day Armenia eight species are absent – *Osmunda regalis*, *Quercus castaneifolia*, *Quercus cerris*, *Alnus incana*, *Salix cinerea*, *Callitriche stagnalis*, *Potamogeton coloratus*, *Potamogeton compressus*. One species, *Populus gokhtuniae*, is extinct (Gabrielyan, 2002).

In the modern flora of the Sisian region (headwaters of the Vorotan river) more than 40 fossil species (e.g. *Acer hyrcanum*, *A. ibericum*, *Berberis vulgaris*, *C. betulus*, *L. caucasica*, *Malus orientalis*, *Prunus divaricata*, *Q. macranthera*, *Rosa spinosissima*, *V. lantana*, *Thymus kotschyanus*, *Lemna trisulca*) are present. All these species could be considered to be pre-Quaternary relicts.

During the Pleistocene in the Vorotan region, some species grew in mixed deciduous mountain and high mountain forests (e.g. *Acer laetum*, *Acer platanoides*, *Acer trautvetteri*, *C. betulus*, *Quercus iberica*, *Q. macranthera*, *Tilia begoniifolia*), while other taxa tolerating drier conditions had a sparser distribution (e.g. *A. ibericum*, *Celtis caucasica*, *Cotinus coggygria*, *J. polycarpos*, *Paliurus spina-christi*, *Pistacia* sp.). Some species present are mountain steppe bushes (e.g. *Spiraea hypericifolia*, *R. spinosissima*, *Lonicera iberica*), while near the rivers and marshes *Carex bohemica*, *O. regalis*, *Phragmites australis*, *Populus alba*, *Populus nigra*, *Salix triandra*, *Salix wilhelmsiana* probably occurred. Aquatic species (*C. stagnalis*, *Ceratophyllum demersum*, *L. trisulca*, *Myriophyllum spicatum*, *Potamogeton perfoliatus*, *Potamogeton pectinatus*) grew either in the lake or stagnant ponds.

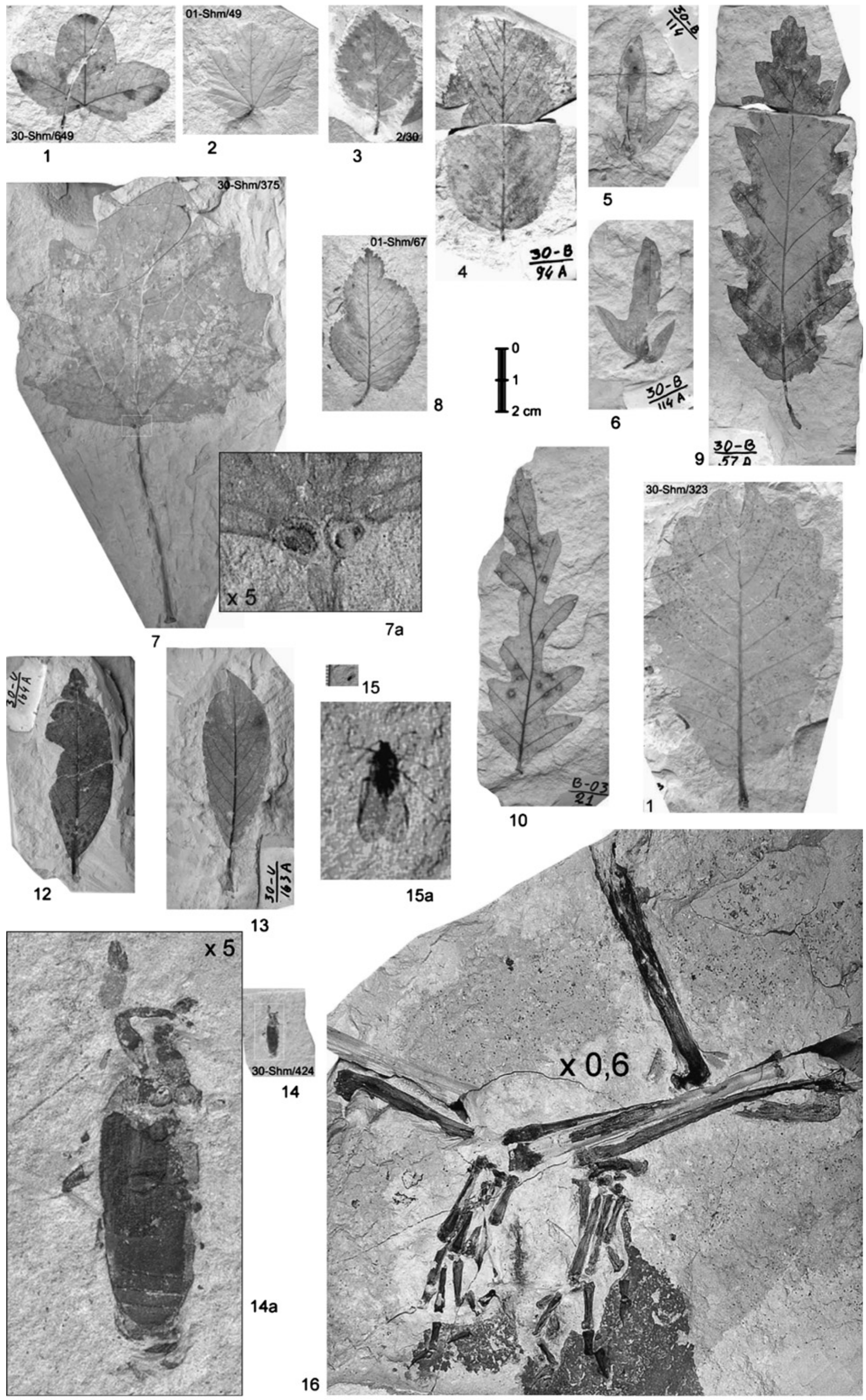
A palynological analysis of a hundred samples from the Shamb section (Joannin, 2007; Joannin et al., 2010) shows three units separated by two important gaps. However, the pollen diagram (Joannin, 2007; Joannin et al., 2010) indicates steppic phases, mainly with herbaceous species and *Artemisia*, alternating with forested phases with riparian and mesophilous taxa indicating a more humid climate.

4.3.3. Palaeoclimate

The macroflora studies show that, compared to the present day, there were warm, humid climatic conditions along the upper Vorotan River during the lower Pleistocene. The water zones were diminished and the composition of the water plants changed; the temperate forest vegetation was reduced as well. The sparse trees and shrub vegetation which always existed in the area are present today. More xerophytic or less thermophilous plants were preserved, corresponding to a dry continental climate. The vegetation in the region tends towards more xerophitisation, in relation to the continentalisation of the climate, compared to the beginning of the Quaternary period.

The preliminary palaeo-climatological results, based on the quantitative analyses of the fossil plants of the Uyts subgroup and the Shamb locality, and their comparison with corresponding species of modern vegetation (Mosbrugger and Utescher, 1997) were produced by Bruch and Gabrielyan (2002). For the Lower Pleistocene, the quantitative results provided the corresponding data; mean annual temperature (MAT) in the Sisian depression was 9.6–13.8 °C (6.6 °C today); mean annual precipitation (MAP) was 630–1180 mm (400–500 mm today). Other quantitative results provided corresponding data in the Shamb depression: mean annual temperature (MAT) was 12.9–13.8 °C (8–9 °C today); mean annual precipitation (MAP) was 630–1210 mm (350–400 mm today).

However, for the Lower Pleistocene, these results are related to only two leaf floras of the Sisian region. No pollen flora of that zone



Fossils remains of the Vorotan group localities

1 - *Acer ibericum* Bieb., Shamb locality,
2 - *A. hyrcanum* Fisch. et C.A.Mey., Shamb locality,
3 - *Betula pubescens* Ehrh., Shamb locality,
4-6 - *Carpinus betulus* L. (5-6 - fruits),Brnacot locality,
7 - *Populus gokhtuniae* I. Gabr., Shamb locality,
8 - *Ulmus minor* Mill., Shamb locality,
9 - *Quercus castaneifolia* C.A.M., Brnacot locality,
10 - *Q. cerris* L., Brnacot locality,
11 - *Q. iberica* Stev., Shamb locality,
12 - *Salix caprea* L., Uyts locality,
13 - *S. cinerea* L., Uyts locality,
14 - *Coleoptera sp.*, Shamb locality,
15 - *Diptera sp.*, Brnakot locality,
16 - *Lepus sp.* (bones), Uyts locality

Fig. 10. Fossils remains of the Vorotan group localities (leaves, insects and bones).

Table 3
List of Pleistocene macrofloras of the Sisian region.

	Taxa	Levels		Taxa	Levels
	GYMNOSPERMAE			*Rosaceae*	
	Cupressaceae		38	*Cerasus avium*	K
1	*Juniperus polycarpos*	D, F, G, H, L	39	*Crataegus* sp.	E
			40	*Malus* sp.	F
	ANGIOSPERMAE DICOTYLEDONES		41	*Prunus* sp.	F
			42	*Pyrus* sp.	E
	Ceratophyllaceae		43	*Rosa* sp.	E, F
2	*Ceratophyllum demersum*	B, E, F	44	*Sorbus armeniaca*	F
3	*Ceratophyllum* sp.	J	45	*Sorbus* sp.	F
			46	*Spiraea crenata*	B, F, G
	Berberidaceae		47	*Spiraea hypericifolia*	B, E, F, G
4	*Berberis* sp.	F, K	48	*Spiraea* sp.	D, F, H, J, K
	Polygonaceae			*Haloragaceae*	
5	*Polygonaceae* sp.	A	49	*Myriophyllum spicatum*	A, F
6	*Rumex obtusifolius*	F		*Myriophyllum* sp.	C, F, G, J
	Fagaceae			*Aceraceae*	
7	*Quercus boissieri*	F, G	50	*Acer campestre*	K
8	*Quercus castaneifolia*	F, K	51	*Acer hyrcanum*	F
9	*Quercus cerris*	K	52	*Acer ibericum*	C, D, E, F, G, K, L
10	*Quercus iberica*	C, E, F, G	53	*Acer laetum*	E, F, I, J, K
11	*Quercus macranthera*	E, F, G	54	*Acer platanoides*	F
12	*Quercus* sp.	E, F, H, J, K, L	55	*Acer pseudoplatanus*	F
			56	*Acer trautvetteri*	F
	Betulaceae		57	*Acer* sp.	H, J, L
13	*Alnus incana*	F			
14	*Betula pubescens*	F		*Rhamnaceae*	
15	*Betula* sp.	A, D, E, F, I, J, K, L	58	*Paliurus spina-christi*	F
16	*Carpinus betulus*	J, K			
				Anacardiaceae	
	Salicaceae		59	*Cotinus coggygria*	C, F, K
17	*Populus alba*	F, G			
18	*Populus x canescens*	F		*Apiaceae*	
19	*Populus gokhtuniae*	E, F	60	*Heracleum sosnowskyi*	F
20	*Populus nigra*	B, F, M	61	*Heracleum* sp.	E, F, J
21	*Populus* sp.	I			
22	*Salix aegyptiaca*	E, F		*Caprifoliaceae*	
23	*Salix alba*	E, F, K	62	*Lonicera iberica*	F
24	*Salix caprea*	F	63	*Lonicera* sp.	F
25	*Salix excelsa*	C, F			
26	*Salix pentandra*	E, F		*Oleaceae*	
27	*Salix wilhelmsiana*	E, F	64	*Fraxinus* sp.	F, J, K
	Tiliaceae			MONOCOTYLEDONES	
28	*Tilia begoniifolia*	F		*Potamogetonaceae*	
29	*Tilia* sp.	K	65	*Potamogeton compressus*	F
			66	*Potamogeton pectinatus*	F
	Ulmaceae		67	*Potamogeton perfoliatus*	B
30	*Celtis caucasica*	C	68	*Potamogeton* sp.	A, F, G, J, K
31	*Celtis* sp.	D, F, L			
32	*Ulmus glabra*	F		*Cyperaceae*	
33	*Ulmus minor*	E, F, G	69	*Carex* sp. cf. *C. bohemica*	F
34	*Ulmus* sp.	D, F, H, I, J, K, L			
35	*Zelkova carpinifolia*	F		*Poaceae*	
			70	*Phragmites australis*	B, F
	Brassicaceae		71	*Phragmites* sp.	G
36	*Thlaspi arvense*	A	72	*Poaceae* sp.	A, F, J
	Grossulariaceae				
37	*Ribes* sp.	E, F			

was taken into account for the quantitative analysis, which relates only to interglacial phases.

5. Quaternary landscape evolution synthesis

All the data collected allow, despite some gaps in the event chronology, a first attempt at an overall palaeoenvironmental and morphogenic synthetic reconstruction of southern Caucasus landscape evolution from the lower Pleistocene to the postglacial period (Fig. 11).

5.1. Lower Pleistocene

Grounded on eroded relief of metamorphic Cretaceous limestones and Eocene volcanic deposits (tufa breccia and porphyrite, Figs. 4 and 5), Quaternary basaltic flows (dams) and tecto-orogenic movements (antecedents of the downstream part of the valley) generated extensive lacustrine environments (Fig. 2). The lower Pleistocene lacustrine system of Shamb, with younger fluvio-lacustral facies, seems to be linked with the Darbas system (silicificated facies with diagenetic evolution) as a result of the

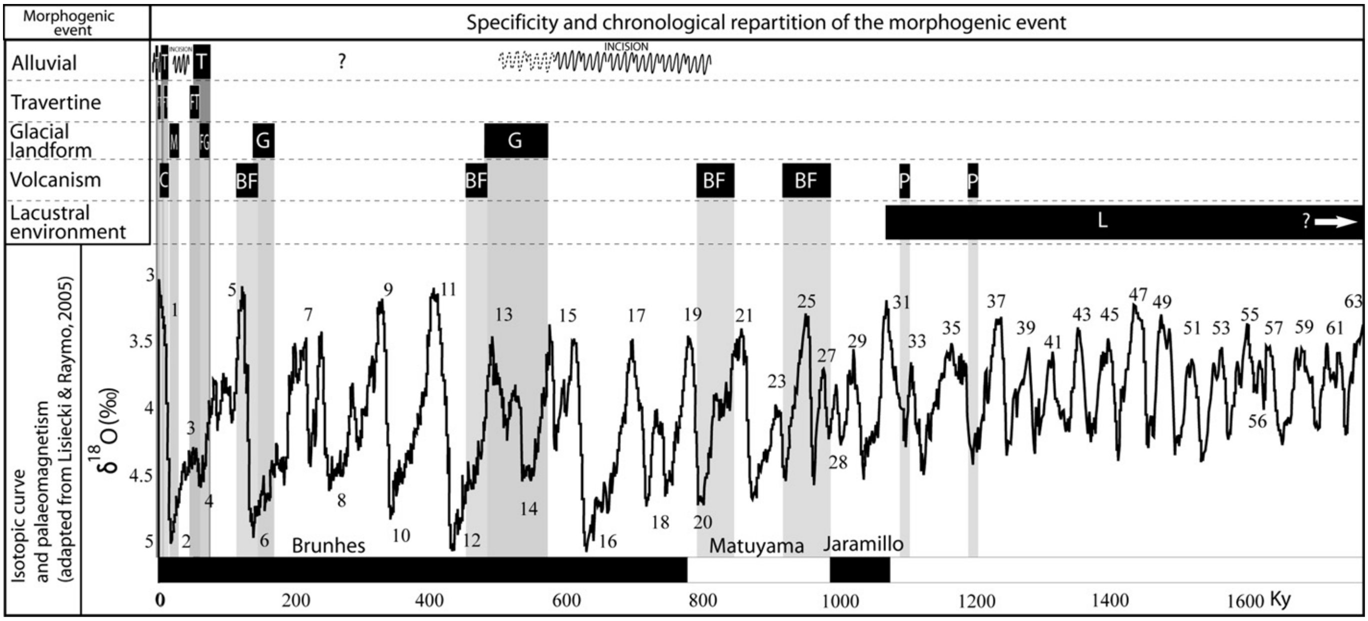


Fig. 11. Morphogenic synthetic reconstruction of southern Caucasus landscape evolution from the lower Pleistocene to the Postglacial period. Lacustral environment = L: lake Volcanism = P: pumices; BF: basaltic flow; C: volcanic cone; Glacial Landform = G: varying glacial evidence; FG: Fluvio-Glacial; M: Moraine Travertine; FT: Freshwater travertine; Alluvial = T: Terrace.

abandonment surface-1 and erosion surface-1 depicted in Fig. 5. Lakes extended throughout the Sisian and Shamb basins. As in the Pliocene, shallow waters, a volcanic environment and more temperate and humid climatic conditions than today generated the intensive development of diatoms and the accumulation of fluvio-lacustrine diatomite deposits between 1.7 and 1 Ma (Fig. 7). Explosive eruptions erosion of volcanic slopes led to the formation of pumice deposits and volcanogenic sandy layers in erosive contact (during short alluvial phases due to lake level fluctuations induced by tectonic or climatic variability) interstratified into these diatomaceous lacustrine deposits. The palynological analysis of the Shamb stratigraphy (Fig. 7, Joannin, 2007; Joannin et al., 2010) highlights the alternation between cold steppic phases with temperate and more humid forested phases, which could correspond to the confirmation of glacial–interglacial oscillations forced by the obliquity orbital parameter (41-ky cycles).

From 993 ± 22 ka to 819 ± 18 ka, basaltic lava flows from the nearby Yantapa, Dashtapa and Chobanmaz volcanoes covered the diatomaceous deposits (Fig. 2). During this event, the large lakes certainly vanished. This is indicated by the direct contact between basaltic flows and metamorphosed limestones, in some places near the lake deposits, which suggest a substantial erosion episode between 1 Ma and 942 ± 20 ka (Fig. 4). The deep burned area of contact between lava and diatomite in some places and the lack of associated pillow lava morphology support this conclusion.

After 819 ± 18 ka, major tectonic activity occurred, with antecedent movement represented by numerous normal faults concerning the diatomaceous lacustrine deposits and the dated basalts in the Shamb area (Figs. 4 and 5). During this geodynamic event, the Vorotan River began a major incision phase that could correspond to erosion surface-2 (Figs. 5 and 8).

5.2. Middle Pleistocene

Evidence for middle Pleistocene landscape evolution is less well known in the study area. However, in the Uyts–Shamb zone, a basaltic flow dated at 475 ± 11 ka covered glacial deposits that can be attributed consequently to the MIS 12 or 14 glaciation (Fig. 3). These deposits (Fig. 9) are represented by compressed, distorted lacustrine diatomaceous and sandy deposits oversaturated by glacial meltwater. The entire formation was thereafter mixed and covered by a moraine of striated basaltic blocks and fluvio-glacial material.

The geometric and chronostratigraphic organisation of these units in the Vorotan Canyon suggests major incision periods posterior to 819 ± 18 ka and at least prior to 475 ± 11 ka (Figs. 3 and 5). Following these incision stages, the paleovalley was occupied by glaciers and lava flows during the cold climate episodes and the eruptive volcanic phases of the middle Pleistocene. This vigorous morphogenic dynamic is related to the combined effects of the lower to middle Pleistocene climatic variability and tecto-orogenic activity.

5.3. Upper Pleistocene

After an undated incision phase, presumably related to the middle Pleistocene period, the upper Pleistocene testimonies evidence consists of fluvio-glacial deposits, attributed to MIS 6, covered with three Eemian basaltic flows (respectively dated at 126 ± 3 ka, 122 ± 3 ka and 111 ± 4 ka, Figs. 3 and 4) including breccia formations. After a period of apparent geomorphic stasis, fluvioglacial materials from MIS-4/2 accumulated on some nearby basaltic plateaux (Figs. 3 and 4) underlining the importance of the last glaciation's influence in the morphogenesis of southern Armenia. In some lateral valleys upstream from the Shamb formation, glacier advance has created moraines, "roches moutonnées" and erratic blocks (Fig. 8). Some cavities within Eemian or lower Pleistocene basaltic flows were filled with diatomaceous deposits and volcanic blocks during the same glacial progression (Fig. 4).

During MIS 3, favourable humid-temperate climatic conditions and bicarbonate-saturated waters produced travertine formations in the Shamb valley (Fig. 5). These travertinous sequences were dated to 53.68 ka (Table 2), corresponding to the well- documented Moershoofd-Pile interstadial, a succession of short-term warm and cold phases (Coope and Angus, 1975; Coope et al., 1997; Vandenberghe et al., 1998; Van Andel, 2002; Guiter et al., 2003). Recent works demonstrated the global continental effects of this climatic period at similar latitudes (although under a Mediterranean climate) in the red soil deposits of southern France (Ollivier, 2006).

A linear incision phase associated with the 53.68 ka travertine formation produced erosion surface-3 on the lacustrine diatomaeceous deposits of Shamb (Fig. 5) and probably the erosion surface-1 in the Uyts locality upstream (Fig. 3). Glacial advance and contraction into these valleys, during the cold conditions of the MIS-2, left two terraced moraine deposits at Shamb, indicating two climatic upheavals (Last Glacial Maximum?).

5.4. Postglacial period

The glacial–postglacial transition is recorded in the transverse valleys by periglacial slope formations, fluvio-glacial, and alluvial deposits. Compared to the Pleistocene large basaltic flows, the Postglacial local volcanic activity is typically illustrated by scoria cone development (Arpablur volcano with Holocene $^{40}Ar/^{40}K$ dating, Table 1 and Fig. 2; Spandarian cone in the upper valley). Postglacial warming is indicated by the development of Uyts (10.78 ka, Table 2, Fig. 3) and Shamb 2 (12.6 ka, Table 2, Fig. 5) freshwater travertines (corresponding as well to the Postglacial alluvial surface 1, Figs. 3 and 5). These carbonate formations are not thick and have fossilised grass imprints without any ligneous elements. Could these indicate the establishment of the present-day steppic climate during the Lateglacial/Holocene period?

After 10.78 ka, two linear river thalweg incisions separated by two alluvial accumulations occur. Considering the geometry of the different alluvial deposits along the area of the Vorotan valley studied, the second postglacial alluvial phase (Figs. 3 and 5) probably corresponds downstream to the Tatev hydrothermal formation level dated at 4.14 ka (Table 2, Figs. 1 and 8).

Currently, a new thalweg incision is occurring, dismantling the lower alluvial terrace levels of the valleys. The coupled effects of climatic changes (alternation of humid temperate to dry cold phases) and tecto-orogenic activities (antecedence with a high uplifting rate, Mitchell and Westaway, 1999) are probably the major driving forces of a tumultuous Caucasian Quaternary morphogenesis. Finally, the scale of these landscape mutations can be illustrated by the very deep valley incision (around 100 m deep) chronologically well-defined between 53.68 ka and 4.14 ka by the Shamb and Tatev travertine formations. However, questions remain about the impact of the human occupations on Holocene morphogenesis.

6. Conclusion

The surveys and specific studies carried out in Southern Armenia indicate the extreme complexity (multiplicity of parameters and large scale changes) of Quaternary morphogenesis in the region and the need to further develop research in this field. The existence of many lacustrine environments rich in plant remains since at least the Middle Pleistocene on the territory of what is today Armenia has been established. The fossil floras contained in these Quaternary deposits make it possible to reconstruct the evolution of the vegetation of this area over time. Today, the landscape is very open and the principal plant communities are steppe formations with *Artemisia*. Some remnants of forests survive in places on inaccessible northern slopes. The rich fossil floras indicate that the forest formations were dominant for long periods during the Quaternary.

However, these macroflora are represented only by woody plant remains. They do not provide information on the cold steppe phases dominated by herbaceous taxa which were too fragile to leave imprints. On the other hand, this steppe vegetation can be well observed in the pollen diagrams. The diatomaceous sediments provide good preservation of fossil pollen grains. The palynological analyses provide invaluable information on the evolution of the vegetation over time. A future comparison of the microflora and macroflora of the same lacustrine sites will provide further information and will enable better interpretation.

This preliminary Quaternary morphological scheme highlights the importance of volcanic events, evidence for repeated glaciations in southern Caucasus and the reflection of MIS 3 Interstadial and Postglacial warming through the development of travertine formations. All these field studies must be further pursued in order to obtain a better paleoenvironmental reconstruction, including the rhythms and modalities of the overall changes.

Archaeological surveys carried out during recent years indicate that prehistoric humans occupied several caves located at the base of lava flows and open-air sites, leaving behind lithic material and charcoal. The reconstitution of the Quaternary landscapes corresponding to these occupations and their evolution over time will provide information on the context in which early humans lived (Gabrielyan and Gasparyan, 2003; Gabrielyan et al., 2004; Gabrielyan et al., 2005; Liagre et al., 2006).

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