Mid Holocene vegetation reconstruction from Vanevan peat (south-eastern shore of Lake Sevan, Armenia)

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ABSTRACT

A sediment core has been retrieved from Vanevan peat (south-eastern shore of Lake Sevan, Armenia), which is today disconnected from Lake Sevan thanks to an artificial shallowing of the lake. Based on 5 radiocarbon dates, Vanevan record covers the Mid Holocene (from ca. 7800 to ca. 5100 cal. BP). The Late Holocene is today absent in the peat stratigraphy due to modern peat exploitation by surface mining. This study focuses on a multi-proxy approach including pollen, charcoals, and pollen-inferred climate reconstruction.

An open-land, steppic vegetation is recorded up to ca. 7700 cal. BP, followed by a more forested landscape during the Mid Holocene (up to ca. 5700 cal. BP), and ending again with an open-land vegetation (to the end of record, 5100 cal. BP). This vegetation dynamics responds to general climate changes documented in the Near East. Whether human activities are documented since ca. 7500 cal. BP (Late Neolithic) in Vanevan, they remain marginal and probably did not affect the area. Early Holocene dry climate, which caused the steppic environment to be widespread through the Near East, is strongly related to low late spring precipitation ($P_{May-Jun} = 180$ mm). Mid Holocene forested landscape and increasing lake-level seem related to late spring precipitation (+28%), which is the main change in estimated climate parameters. This has to be linked with reinforcement of the Westerlies and less active Siberian High, which are inversely involved in the following, dry phase starting at ca. 5700 cal. BP.

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1. Introduction

Located between the Black and Caspian Seas, Armenia is the most mountainous country of the Lesser Caucasus. The mean elevation is 1830 m and 75% of its area ranges from 1000 to 2500 m. Climate varies from a contrasted continental to mountainous influences. Steppic vegetation is widespread today, and only 8% of Armenia is covered by exploited and deteriorated forests (it was 18% in the 18th century, Sayadyan, 2011), mostly concentrated in

the northeast and southeast (Chorbajian, 2006). The main challenge is to know if vegetation was always steppic or if a forest phase may have existed during the Holocene. Although a forested phase is documented during the Mid Holocene in recent studies across Georgia (e.g. Connor and Kvavadze, 2008; Messager et al., 2013), only low resolution pollen analyses (Takhtajyan, 1941; Tumanyan, 1971; Tumajanov and Tumanyan, 1973; Sayadyan et al., 1977; Sayadyan, 1978) suggest that forests once existed in Armenia. Moreover, these studies (in Russian) are not up to today's standards (no or few dates on molluscs, up to 40% unidentified palynomorphs). According to Moreno-Sanchez and Sayadyan (2005), they support the idea that broadleaf deciduous forests existed 6000 years ago around Lake Sevan. If a forested landscape was to be confirmed for the Mid Holocene, we then have to decipher the start of deforestation and to understand the respective roles of human

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impact and/or climate change in the establishment of modern vegetation. It is of great importance in such a mountainous area where the environment is marked by strong human pressures and drastic climate conditions.

Although the economy gained productivity during the 8th millennium BP in Armenia (Chataigner, 2007; Chataigner et al., 2012), Early-Mid Holocene human impact is not evident in palaeoenvironmental data. We must rely on authors (e.g. Turner et al., 2010; Roberts et al., 2011) to state that Early Holocene human activity such as deforestation, slash and burn, over-grazing, seem to be responsible for desertification in the entire Near East. The Near East certainly contains various stories considering longitudinal and latitudinal ranges, with varying topography between two seas. Armenia, with its central position in the Lesser Caucasus, requires accurate studies to document past environmental changes and their drivers.

Carefully following this aim, we provide a study from Vanevan peat, which is part of Gilli wetland (Jenderedjian, 2005), located in the Sevan Lake watershed. Before Lake Sevan's artificial water-level drop for irrigation and electricity production, which began in 1933 (Gulakyan and Wilkinson, 2002), Gilli wetland was the most important inland waterfowl area in the Transcaucasus Region (Jenderedjian, 2005). Therefore, Vanevan is of major interest as a paleoenvironmental archive from the Lake Sevan shoreline. In the present study, we rely on hygrophyte composition changes occurring in the wetland and on a wider range to terrestrial vegetation changes in order to characterize both pacing and amplitude of fluctuations. In this way, climate reconstructions inferred from pollen assemblages and charcoal history are used to discuss climate and anthropogenic forcing. Furthermore, past drivers for vegetation changes throughout the Holocene in the Near East are subject to debate between possible changes in influences of the Indian summer monsoon (Djamali et al., 2010) or of the westerlies (Roberts et al., 2011).

2. Study area

2.1. Geological setting

Vanevan peat (40°11.748 N 45°40.099 E; alt. 1919 m a.s.l.) is located south-east of Lake Sevan (1898 m a.s.l.; Fig. 1a), ~3.2 km from the modern shoreline (Fig. 1b). Lake Sevan is the biggest lake in Armenia, 1257 km^2 and 33.4 km^3 in 2006. It is one of the highest mountainous freshwater lakes in the world. Quaternary tectonics formed this lake (Meybeck et al., 1997; Ollivier et al., 2010). The catchment area is about 5000 km^2, where 28 rivers feed the lake, while the outflowing Hrazdan River connects through Araxe River to the Caspian Sea. Higher evaporation (800 mm·year^{-1}) than direct precipitation (360 mm·year^{-1}) causes a negative balance and a slow turnover (50 yrs; Meybeck, 1995). Annual precipitation in the coastal belt is between 350 and 446 mm, and around 800 mm in the mountain zones (Baghdasaryan, 1958). The use of its water for agriculture and electricity production caused a water lowering (19 m) and volume loss (40%). Since then, eutrophication impacted faunal and floral in and around the lake (Lind and Taslakyan, 2005). The Gilli wetland (1500 ha), from where Vanevan peat belongs, is in an alluvial-paludal area influenced by torrential activity. The lowering of the lake for irrigation and electricity, as well as field drainage for agriculture caused peat drying, and it is currently exploited (Tumanyan, 1971; Jenderedjian, 2005) by milling of the surface (Fig. 2).

2.2. Present climate and phytogeography

The Vanevan area is characterized by a mountain climate with mild summers and extremely cold and snowy winters. Dry and cold winters are controlled by Siberian Highs, with breaks which cause the westerlies to temporarily bring snow over the Lesser Caucasus. In summer, Saoudian Highs can break in the south and bring relatively more humid air. Rains are provided by westerlies and originate from the North Atlantic (Berg, 1950). The meteorological station of Sevan city is the closest station from Vanevan with on line data spanning a sufficient time window (http://www.worldweather.org). The study zone is characterised by a low annual temperature (3 °C), with a minimum in January (−8 °C) and a maximum in August (15 °C). Annual precipitation is about 500 mm with 128 precipitation days on average (Fig. 3). Mountain-valley circulations, due to differential heating, can produce thundershower activity (particularly in late spring, i.e. May−June), while snow retards the rise of air temperature.

According to the bioclimatic classification of Zazanashvili et al. (2000), Lake Sevan belongs to the South Uplands type in which Anatolian−Iranian components predominate in the plant communities' floristic composition. It includes two zones: hemi-xeric upper mountain forest and woodland (*Quercus macranthera*, *Pyrus* spp., *Acer hyrcanum*, *Juniperus polycarpos* in combination with mountain steppes; up to 2300 m) and subalpine woodlands (*Quercus macranthera* in combination with herbaceous vegetation; up to 2800 m). The east Caucasus type develops on the northern slope of the mountain chain (Sevan range) north-east of Lake Sevan (Fig. 1b). It includes several zones: Lower Mountain (*Fagus orientalis*, *Carpinus caucasica*; up to 1200 m), Mesic beech forest (up to 2000 m) and Subalpine elfin wood (*Quercus macranthera*, *Pinus kochiana* and birch in combination with subalpine herbaceous vegetation; up to 2700 m).

Focusing on the lake Sevan surroundings, Bohn et al. (2000) consider this area a mountain semi-arid bioclimatic zone. Around Vanevan (Fig. 4), the major vegetation types are Stipa-steppes (M11: mountain type/Pre- and Transcaucasian feather grass steppes). Their composition is both highly varied and species-rich
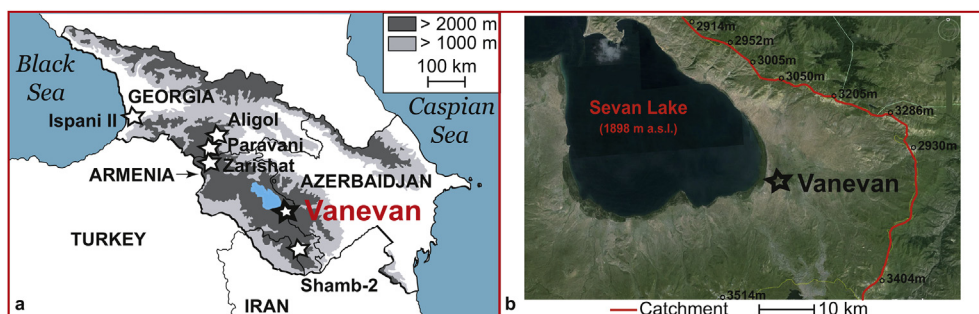

Fig. 1. a) Location map of Caucasus and sites cited in the text; b) location map of Vanevan Site.

Fig. 2. Peat exploitation by mechanical milling of surface at Vanevan (2011).

with many endemics (Table 1). To the west of Vanevan, steppe is composed of species from meadow steppes and mountain steppes (M4: Transcaucasian altimontane herb-grass- and meadow steppes). To the east of Vanevan, open krummholz forests and open woodlands persist, with endemic trees species, shrubs and grasslands (C46), while alpine grasslands (B58) are present at higher altitudes. North of Lake Sevan are Transcaucasian colline-montane juniper open woodlands (*Juniperus polycarpos*, *J. foetidissima*), partly in combination with *Pistacia mutica*-open woodlands (K33). In the Vanevan peatland, today's vegetation is dominated by sedge taxa (such as Cyperaceae, Juncaceae and *Phragmites*). This wetland dries up at the end of summer.

four sections (A: 0–56 cm; B: 36–92 cm; C: 72–128 cm; D: 108–164 cm) (Fig. 5). From base to top (based on visual observations), this core contains sandy silt (164–150 cm), which becomes more argillaceous at 156 cm, organo-mineral clays between 150 and 132 cm, organic clays between 132 and 41 cm, and peaty sediment above.

The chronology is based on five Accelerator Mass Spectrometry (AMS) ^{14}C ages (Table 2), performed on organic materials. Unfortunately, no datable macrofossils were found at the base, so the AMS ^{14}C age is determined on bulk sediment samples. Macrofossils were collected from sediment samples sieved with a 100 μm mesh screen. Radiocarbon ages were calibrated in cal. BP

Table 1
Description of formation complexes, units, vegetation types and taxa list around Lake Sevan (after Bohn et al., 2000).

Unit	Formation complexe	Vegetation type and main taxa observed	Taxa list
M11	Steppes	Pre- and Transcaucasian feather grass steppes	*Stipa tirsa*, *S. pulcherrima*, *S. daghestanica*, *S. transcaucasica*, *S. araxensis*, *S. pontica*, *S. holosericea*, *S. hohenackeriana* with *Elytrigia gracillima*, *Astragalus haesitabundus*, *A. gjunaicus*, *Medicago daghestanica*, *Onobrychis transcaucasica*, *Linaria megrica* and *Bothriochloa ischaemum*-steppes with *Onobrychis ruprechtii*, *O. kachetica*, *Salvia daghestanica*, *Hyssopus officinalis subsp. angustifolius*, *Medicago caerulea*, *Polygala transcaucasica*, alternating with tomillares (*Thymus daghestanicus*, *T. karamarjanicus*, *T. tiflisiensis*, *Thymus kotschyanus*, *Scutellaria orientalis*) and thorn-cushion communities (*Astragalus aureus*, *A. denudatus*, *A. microcephalus*, *A. uraniolimneus*)
M4	Steppes	Transcaucasian altimontane herb-grass- and meadow steppes	Meadow steppes and the mountain steppes (*Stipa tirsa*, *S. pulcherrima*, *Festuca ovina*, *Carex humilis*, *Poa densa*, *Bromus variegatus*, *Onobrychis altissima*, *O. transcaucasica*, *Serratula biebersteiniana*, *Prangos ferulacea*, *Aster ibericus*) with *Medicago papillosa*, *Astragalus hyalolepis*, *Linaria kurdica*, *Salvia armeniaca*, alternating with thorn-cushion communities (*Astragalus aureus*, *A. microcephalus*, *A. lagopoides*) and tomillares (*Thymus rariflorus*, *T. kotschyanus*, *Scutellaria orientalis*)
C46	Montane open woodlands	Open krummholz forests and open woodlands	Endemic trees species (*Quercus macranthera*, *Acer trautvetteri*, *Betula litwinowii*), schrub (*Juniperus communis subsp. hemisphaerica*, *J. sabina*), grasslands (*Festuca woronowii*, *Bromus variegatus*, *Anemone fasciculata*) with *Trifolium bordzilowsky*, partly tall-forb communities (*Milium effusum*, *Gagea orientalis*, *Lilium armenum*), alternating with dry grasslands (*Festuca ovina*, *Carex humilis*) with *Medicago papillosa*, true steppes (*Festuca valesiaca*, *Stipa tirsa*, *S. pulcherrima*), partly with thorn-cushion mountain vegetation (*Astragalus aureus*, *A. lagopoides*)
B58	Alpine vegetation	Alpine grasslands	*Festuca woronowii*, *Nardus stricta*, *Carex tristis*, *Bellardiochloa polychroa*, *Scabiosa caucasica* with *Agrostis lazica*, *Bromus variegatus subsp. villosulus* and small herb communities (*Carum caucasicum*, *Campanula tridentata*) with *Gentiana pontica*, alternating with shrub (*Rhododendron caucasicum*), rock and scree vegetation
K33	Xerophytic coniferous forests and scrub	Transcaucasian colline-montane juniper open woodlands and *Pistacia mutica* open woodlands	*Juniperus polycarpos*, *J. foetidissima*, partly in combination with *Pistacia mutica*

3. Methods

3.1. Core sampling, lithostratigraphy and chronology

The coring of the Vanevan sequence was performed in 2011 using a Russian corer. A 164 cm long core was drilled, recovered in

by the Calib 7.0 software using the calibration curve IntCal13 (Reimer et al., 2009). Dates are expressed as intercepts with 2σ ranges. The age-depth model is constructed using an interpolated linear curve (Fig. 5) by the 'Clam' model developed by Blaauw (2010).

Table 2
AMS-radiocarbon dates with 2σ range of calibration from cores of Vanevan peat. MC = master core.

Sample ID	Lab. code	Material	AMS ^{14}C age BP	Depth MC (cm)	Cal yr BP (2σ)
A-10.5	Ly-10435	Terrestrial organic	4580 ± 30	10.5	5066–5181
A-24.5	Poz-46337	Terrestrial organic	4745 ± 35	24.5	5328–5586
B-14.5	Poz-46338	Terrestrial organic	5630 ± 40	50.5	6314–6487
C-28.5	Poz-46340	Terrestrial organic	6050 ± 35	100.5	6795–6991
D-22.5	Poz-46341	Terrestrial organic	6500 ± 40	130.5	7319–7483
D-42.5[a]	Poz-52961	Bulk	9860 ± 380	150.5	10,298–12,530

[a] Age rejected (see text).

3.2. Pollen analysis

3.2.1. Pollen samples

Thirty-six samples were taken at various intervals (2–6 cm) through the core. For each sample, 1 cm^3 of sediment was processed following the standard methods in palynology using HF, HCl, KOH baths (Fægri and Iversen, 1989) and heavy liquid flotation using zinc chloride. After treatment, the residue was suspended in glycerol, mounted onto microscope slides and counted under a light microscope at a standard magnification of ×500 and ×1000. Two samples were sterile (at 150 and 160 cm depth).

Pollen flora was identified using photo atlases (Reille, 1992–1998; Beug, 2004) and the reference collection at University of Rennes 1. The pollen diversity is established as 108 taxa with a mean taxonomic diversity of 41 taxa. Poor in the three lower samples (18 taxa), the diversity increases at 149 and 147 cm (36 taxa) and especially between 145 and 35 cm (38–59 taxa). It decreases at the top (24–42 taxa).

A total of 26,205 spores and pollen were counted with an average sum of 771 per sample (259–5698). A minimum of 151–1192 terrestrial pollen grains, excluding wetland plants (Cyperaceae and aquatics) and spores of pteridophytes, was counted for the poorest and the richest samples, respectively. Palynofacies (algae, microscopic charcoal and organic matter) was observed during the counting.

Pollen values were calculated as a percentage of total land pollen excluding Cyperaceae, aquatic plants and fern spores (Fig. 6) but Fig. 7 presents a synthetic pollen diagram where Poaceae are also excluded. The pollen diagrams (Figs. 6–7) were produced using Gpalwin software (Goeury, 1997). Local pollen assemblage zones were identified on a visual basis and verified with cluster analyses using Past software (Hammer et al., 2001). The Pollen Indicator of Human Activities (Fig. 7) was calculated with the frequencies of Cerealia-type, Secale, Linum, Centaurea cyanus, Papaver, Rumex acetosa, Convolvulus, Polygonum group and Plantago group (Behre, 1981; Brun, 2011).

3.2.2. Pollen-based climate reconstruction

Quantitative estimates of temperature and precipitation are inferred from Vanevan pollen data with the Modern Analogue Technique 'MAT' (Fig. 7) which has already been tested in Armenia from the Zarishat pollen assemblages (Joannin et al., 2014). In the MAT (Guiot, 1990), the similarity between each fossil sample and modern pollen assemblage is evaluated by a chord distance. Estimates of past climatic parameters are calculated by taking a weighted average of the values for all selected best modern analogues (here 8). To reduce uncertainties in the climate reconstruction, which often occur with steppic pollen assemblages, we have applied to the analogue selection a constraint by biomes. A biome is assigned to each modern and fossil pollen sample following a procedure based on a plant functional type–pollen data attribution Peyron et al. (1998). Winter and late spring precipitation (P$_{win}$, P$_{May–Jun}$; Fig. 7) are the hydrological parameters that are assumed

to have the strongest relationship with pollen data in Armenia (Joannin et al., 2014). In southern Georgia, statistical analysis showed that rainfall was the parameter most strongly correlated with pollen composition (Connor and Kvavadze, 2008). The temperature of the coldest month (MTCO) is reconstructed for comparison with previous studies because this variable imposes a limit on the growth of plants. To reduce the potential effect of spatial autocorrelation (Telford and Birks, 2005), we have used the same modern pollen dataset than for the Zarishat reconstruction, which includes the update of the European modern pollen dataset by adding 45 surface samples from southern Georgia (Connor et al., 2004; Connor and Kvavadze, 2008). The updated dataset used here contains 3058 surface samples.

3.3. Macroscopic charcoal analysis

Macroscopic charcoal samples of 1 cm^3 were taken contiguously. Samples were soaked in a 3% (NaPO$_3$)$_6$ solution for a minimum of 2 days before wet sieving through a 160-μm screen. The remaining particles were bleached in a 10% NaOCl solution to aid in distinguishing charcoal from dark organic matter. The sieving method is assumed to represent local-scale fires, i.e. 1 km from the fen (e.g. Carcaillet et al., 2001; Higuera et al., 2007). Identification, counting and area measurements of charcoal particles were undertaken using a 20× stereoscope coupled with a digital camera and image-analysis software (Regent Instruments Canada Inc.).

4. Results and interpretation

4.1. Age model

One ^{14}C age (D-42.5 at depth 150.5 cm) was excluded from the age–depth model (Fig. 5), having both low organic content and
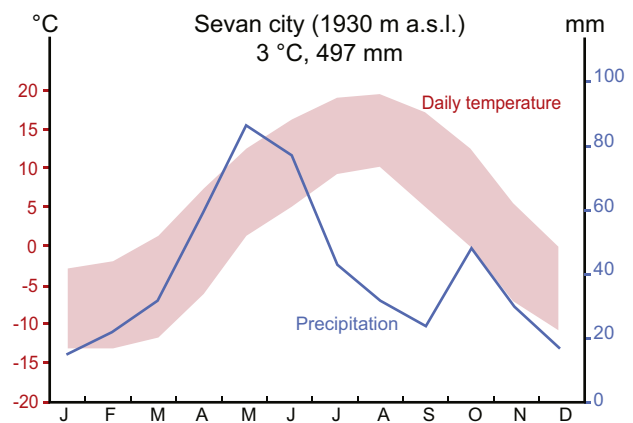
Fig. 3. Ombrothermic diagram of the meteorological station of Sevan, ca. 70 km from Vanevan peat. Records of minimum and maximum mean daily temperature and precipitation span the last 30 years.
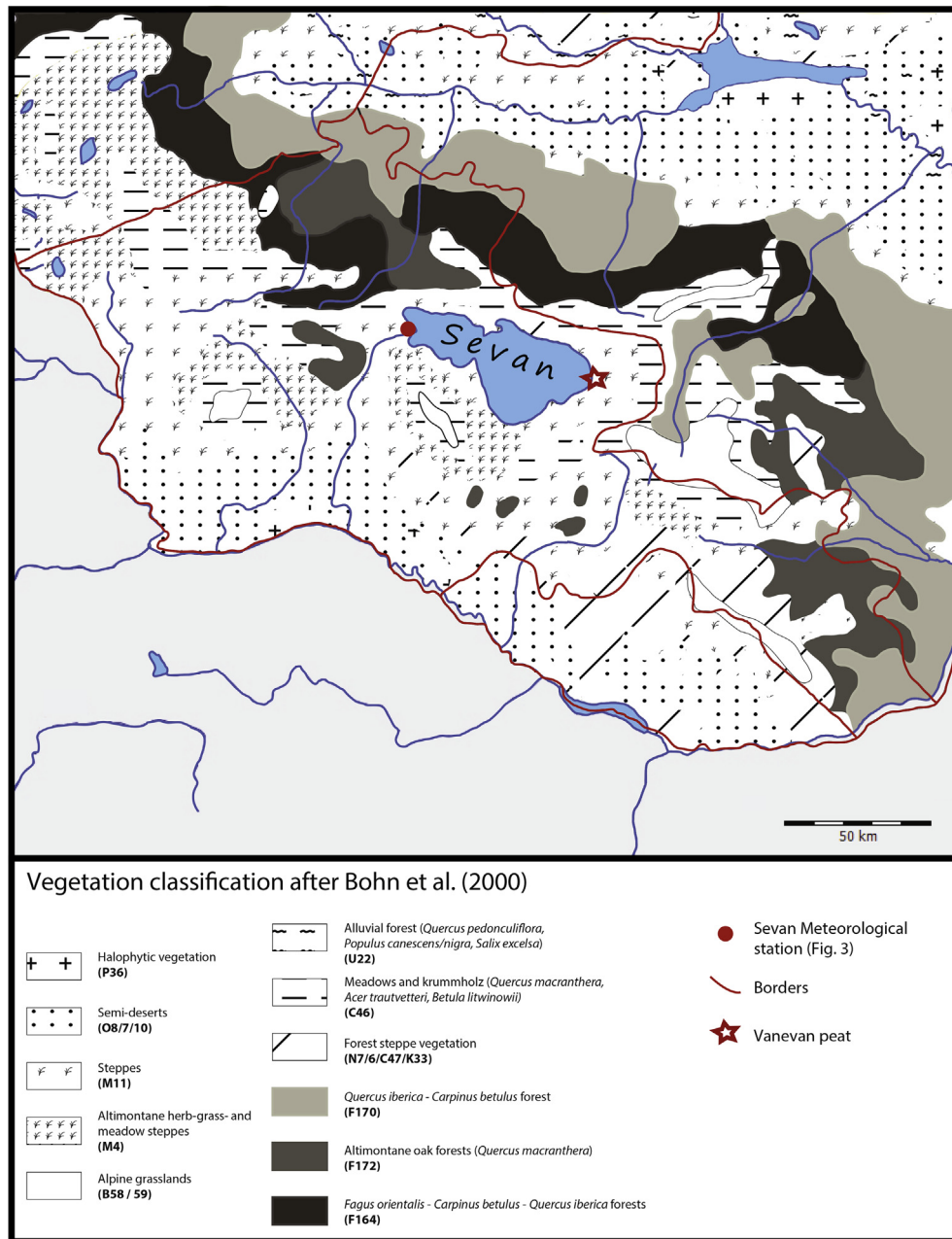
Fig. 4. Vegetation map of Lesser Caucasus (after Bohn et al., 2000).

large error margin (9860 ± 380; Table 2). The age–depth model is extrapolated to the base of the core. Considering the unexpected age obtained at 24.5 cm (4745 ± 35) and keeping in mind the possible effect of present-day peat exploitation observed at 300–400 m away from the coring site (Fig. 2), we obtained an extra ^{14}C date at 10.5 cm depth. The accuracy of this age (4580 ± 30) suggests no reversion of the sediment surface. This suggests sediment removal over the coring area. We decided to stop the pollen count at 5 cm depth. Tumanyan (1971) mentioned peat extraction in Gilli area. This also caused removal of the uppermost part of the peat at his coring location.

Sedimentation rate varies from base to top. It is 0.5 mm·y^{-1} from 160 to 145 cm, then 0.6 mm·y^{-1} up to 100.5 cm. Between 100.5 and 50.5 cm, the accumulation rate increases to 0.98 mm·y^{-1}. The interval 50.5 to 24.5 cm includes a major lithological change,

with peat accumulation causing the sedimentation rate to decrease to 0.28 mm·y^{-1}. For the uppermost section, the rate increases (0.63 mm·y^{-1}).

Based on this age-model, the Vanevan record covers about 3000 years from ca. 7800 to ca. 5100 cal. BP. The early Holocene is absent due to sterility of basal pollen samples and the late Holocene is not available in the coring area. The average temporal resolution for the pollen analysis is estimated as 79 y between samples (min to max: 33 to 176 y between samples).

4.2. Pollen analysis

4.2.1. Pollen sequence

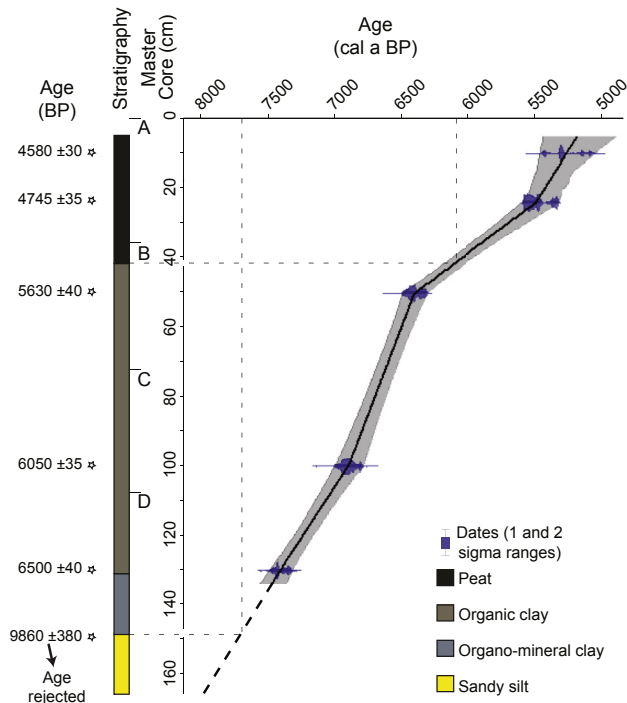Five main LPAZs (Local Pollen Assemblage Zones) have been distinguished in the Vanevan pollen record (Figs. 6–7).

Fig. 5. Lithology of cores A to D and age—depth model based on calibrated radiocarbon ages (dots with 2-sigma errors) (AMS, see Table 2) from Vanevan.

LPAZ Van 1 (depth: 155—151 cm) is recorded in the sandy silt, spanning the period from 7800 to 7740 cal. BP. It is dominated by taxa from open areas (Cichorioideae, Chenopodiaceae, Poaceae and Asteraceae) and steppic taxa such as *Artemisia*.

Hygrophilous vegetation is sparse and only includes Cyperaceae. The tree component is rare, essentially composed of *Ephedra distachya* t., *Juniperus* then *Pinus*. Low but continuous amounts of *Quercus* and *Ulmus* are recorded. LPAZ Van 1 ends with slight increases of Cyperaceae and *Quercus*, while *Betula* appeared.

LPAZ Van 2 (depth: 149—135 cm) is recorded in the organo-mineral clay, spanning the period from 7700 to 7470 cal. BP. This zone records a general tree expansion, where all tree taxa from LPAZ Van 1 increase (except *Pinus* and *Ephedra distachya* t.) with the appearance of numerous tree taxa such as *Betula, Carpinus, Fagus, Ostrya* t., *Tilia, Fraxinus, Acer, Hippophae, Alnus* and *Salix. Quercus* is the most dominant tree taxa, followed by *Juniperus*, which attains its maximum in this zone. Poaceae and *Artemisia* increase while Cichorioideae, Chenopodiaceae and Asteraceae strongly decrease. Similarly to tree taxa, herbs also become richer, adding heliophilous taxa (Brassicaceae, *Rumex, Polygonum, Plantago*) and hygrophytes (*Sparganium, Potamogeton, Typha, Myriophyllum*, Ranunculaceae, Liliaceae, Rosaceae, *Filipendula*). First occurrence of *Cerealia*-type is recorded. Subdivision into two subzones (Van 2a, depth: 149—147 cm and Van 2b, depth: 145—135 cm) highlights the decrease of Cichorioideae, Chenopodiaceae and *Thalictrum*. Additionally, LPAZ Van 2 shows continuous appearance of algal taxa such as *Botryococcus* and *Pediastrum*.

LPAZ Van 3 (depth: 131—100 cm) is recorded in the organic clays, spanning the period from 7400 to 6890 cal. BP. and divided into three subzones (Van 3a, depth: 131—125 cm; Van 3b, depth: 121—110 cm and Van 3c, depth: 105—100 cm). On the whole, Van 3 records a decrease in *Juniperus*, and a maximum development of *Hippophae. Quercus* is still the dominant tree taxa, along with *Ulmus* and *Carpinus*. Noteworthy is the presence of *Phyllirea-Olea* and *Pistacia* pollen grains. Considering herbs, increases of *Thalictrum*

and hygrophytes are recorded while cereals (*Cerealia*-type and *Secale*) are regularly seen in the pollen assemblages. Van 3a mainly shows *Quercus* increase, Van 3b its decrease and Van 3c *Juniperus* and *Hippophae* decreases while *Carpinus* increase. Van 3b also shows higher amounts of Cyperaceae and aquatic taxa, the last becoming more diversified before declining in Van 3c. Algal taxa *Botryococcus* and *Pediastrum* are continuously present during Van 3.

LPAZ Van 4 (depth: 95—35 cm) is recorded in the organic clays and at the base of the peat, spanning the period from 6840 to 5860 cal. BP. This period is divided into three subzones (Van 4a, depth: 95—85 cm; Van 4b, depth: 80—45 cm and Van 4c, depth: 40—35 cm). Overall, this period is characterized by increasing Chenopodiaceae, Cichorioideae, Asteraceae and Cyperaceae along with decreasing Poaceae, *Sparganium* and hygrophyte taxa. Van 4a mainly shows a slight increase in *Quercus* and *Betula*. Van 4b shows an increase in *Artemisia*. Van 4c records less diversified tree taxa, but a slight increase in *Carpinus* pollen. This subzone also records strong increase in *Sparganium* together with weaker increases of *Typha* and other aquatic taxa (*Myriophyllum spicatum, M. verticillatum, Polygonum amphibium, Lemna, Utricularia*). Van 4 shows *Pediastrum* algae are discontinuously present.

LPAZ Van 5 (depth: 30—5 cm) is recorded in the peaty sediment, spanning the period from 5680 to 5190 cal. BP and divided into three subzones (Van 5a, depth: 30—25 cm; Van 5b, depth: 20—10 cm and Van 5c, depth: 5 cm). On the whole, this zone is marked by a decrease in tree taxa, both in quantity and in percentage abundance. A strong increase in Poaceae and ferns is recorded while aquatics decrease. Cyperaceae remains rather abundant, although its percentage is strongly varying. As the Poaceae pollen grains may be the product of grass or *Phragmites*, by less or more local vegetation, the pollen diagram can be observed after excluding Poaceae (Fig. 7). *Quercus* remains stable, while *Juniperus* and *Carpinus* increase as well as *Artemisia* and Chenopodiaceae. In Van 5a, pollen indicators of human activities decrease. Van 5b shows slight increases of *Pinus* and decreases of *Juniperus* and *Carpinus*. Aquatics almost disappear and ferns develop. Van 5c shows a decrease in Poaceae amount and the fern maximum (together with sporangium observed in this sample). Van 5 shows algal taxa disappearance.

4.2.2. Pollen-based climate reconstruction

For all samples, 8 modern analogues have been selected for the climate reconstruction. These modern analogues are mainly located in southern Georgia and in Armenia cold steppes for the Early/Mid Holocene climate reconstruction (ca. 7800 to 5800 cal. BP), and they are located in Georgia, Armenia, Russia, and Tibet for the late Holocene (ca. 5700 to 5200 cal. BP) The climate reconstruction appears robust for all the sequence: the adopted threshold is 65.59, and the Chord distance which measures the quality of the modern analogues is low, except for two samples corresponding to 7800 cal. BP.

During the 2700-year-long record, the mountain climate of Sevan seems to be well reconstructed and the values reconstructed for the coldest month are (for the Mid-Holocene to 5750 cal. BP) higher than today's values (Fig. 7). The first part of the record (from ca. 7700 to 5750 cal. BP) is climatically stable (even if a decreasing temperature trend is evident) and shows higher values than the second part (from ca. 5750 cal. BP onwards). The shift at ca. 5700 cal. BP resulted in a considerable change of the climate conditions, both in terms of precipitation ($\Delta P_{May-Jun} = -120$ mm) and temperature ($\Delta_{MTCO} = -4\ °C$). Considering the seasonal parameters for precipitation, it appears that the winter precipitation is stable and plays a minor role. In contrast, an increase is evident in late spring
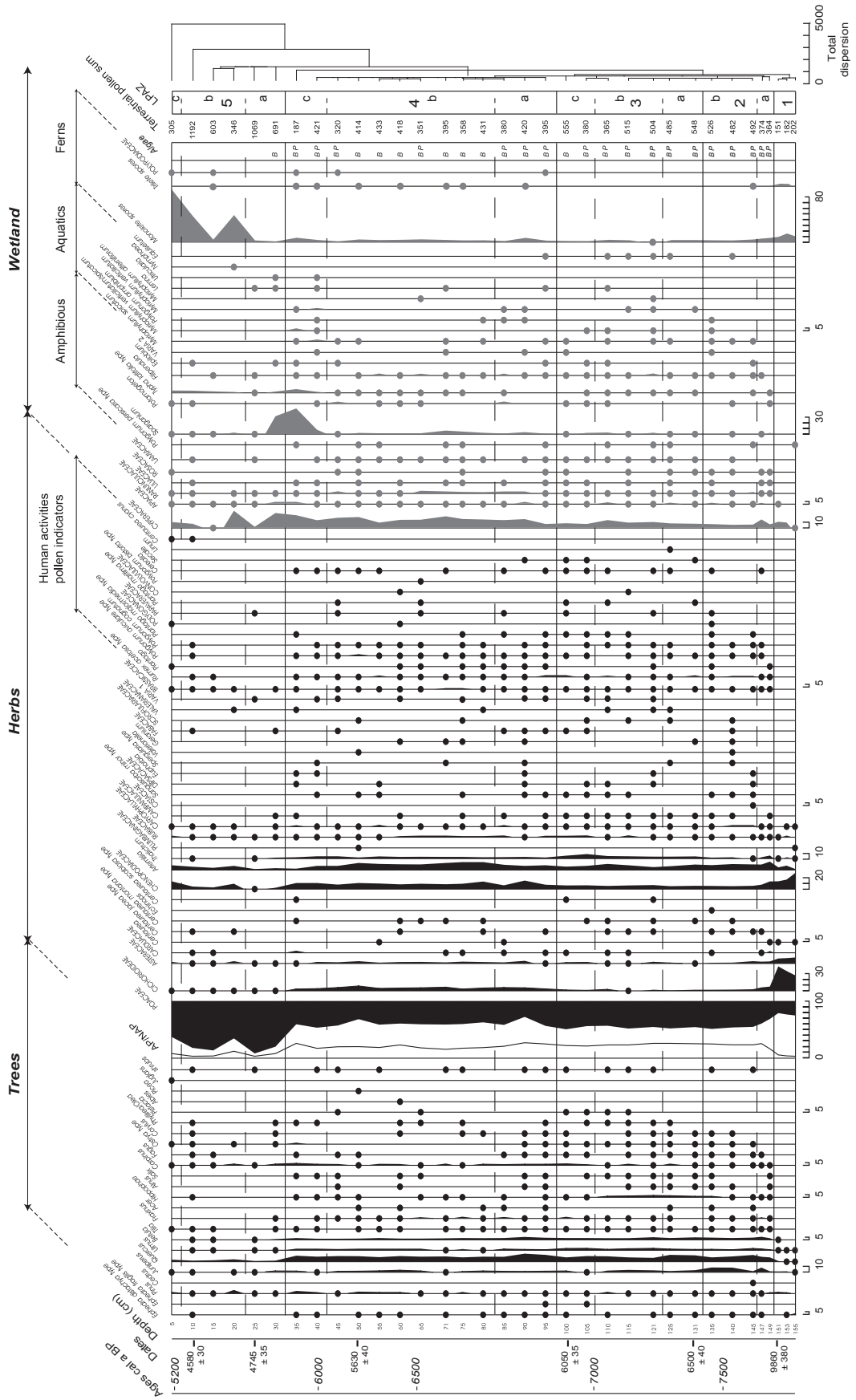
Fig. 6. Pollen diagram against depth showing percentages of pollen taxa. Pollen zones are based on Past software. Shrubs: *Vitis*, Rosaceae, Rhamnaceae. Varia 1: *Haplophyllum*, *Erodium*, *Calystegia*, *Symphitum*, *Saxifraga aizoides* type, *Cuscuta*, *Matthiola*, Onagraceae, *Colchicum*, Primulaceae. Varia 2: *Teucrium*, *Sanguisorba officinalis*, *Rumex aquaticus* type, *Lythrum*. Algae: *B* = *Botryococcus*; *P* = *Pediastrum*. LPAZ: Local Pollen Assemblage Zones, AP: Arboreal Pollen, NAP: Non Arboreal Pollen. Pollen values lower than 1% are represented by dots.
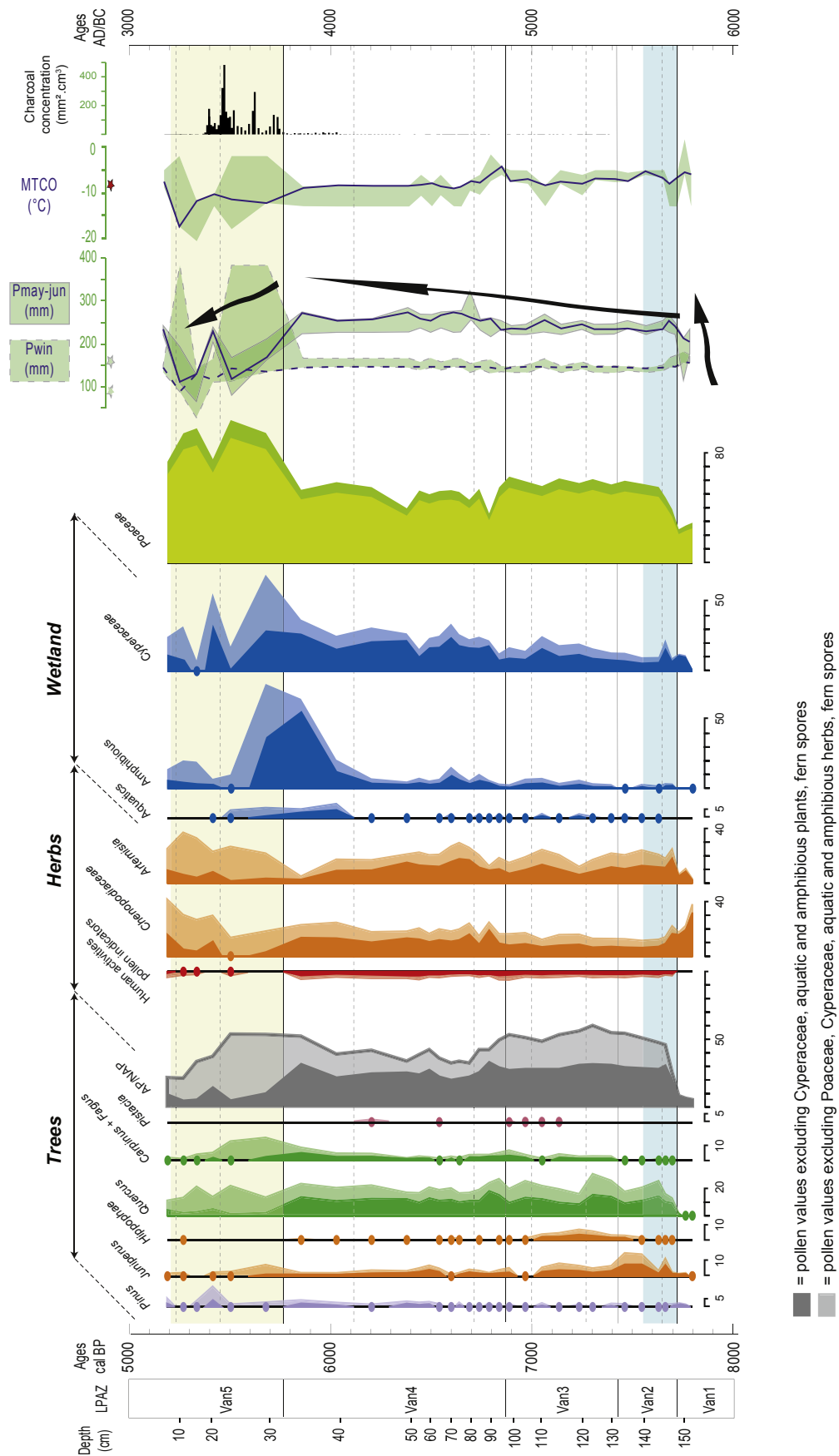
Fig. 7. Pollen diagram against age showing percentages of main pollen taxa or group of taxa. Depth and pollen zones from Fig. 6 are reported. Quantitative estimates of temperature and precipitation and macrocharcoal concentration are shown. Red and green stars indicate present day MTCO and winter and late spring (May–June) precipitation, respectively. Yellow and blue shadings are used to represent arid and humid phases, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

precipitation at the beginning of the Mid Holocene (ca. 7700 cal. BP). Precipitation strongly decreases at 5700 cal. BP.

4.3. Macroscopic charcoal analysis

Charcoal particles are found down to 128 cm in the core. As there are no charcoals at the base of the sequence, the fire activity provides a 2200-year-long record (Figs. 7–8). Unfortunately, variations in CHAR (Charcoal Accumulation Rate) with unpredictable background component prevent reconstruction of fire episodes.

Fig. 8 also includes length-to-width ratio against time. Ratio values <0.5 indicate that fires mostly burned sedge and grassland vegetation (Aleman et al., 2013).

Therefore, two phases are shown by concentration of charcoal and by length-to-width ratio. First, from the base (i.e. 128 cm) to ca. 5750 cal. BP (40 cm), no fire activity is detected and length-to-width ratio values are dispersed. Second, abundant charcoals from ca. 5750 to 5400 cal. BP show four burning peak maxima and a plateau in ratio values from 40 cm onward.

5. Discussion

Today located on the verge of Lake Sevan (1898 m a.s.l.), the Vanevan sequence (1919 m a.s.l.) was retrieved from the littoral zone, which is of estuarine type. Before the artificial lowering (~20 m) that recently occurred, this marsh was connected to Lake Sevan (Sayadyan, 2002; Jenderedjian, 2005). Considering its past, Vanevan may have experienced various episodes as part of the lake (but never under deep water) transitional to a suspended peat relatively independent. These variations have implications for the pollen types which are trapped in the sediment. Although pollen from ligneous taxa are usually favoured in the pollen record compared to herbaceous taxa (e.g. Sugita, 1993; Sugita et al., 1999), highly diversified hygrophilous taxa indicate a more local component in pollen origins, although long-distance transported tree pollen certainly exist.

5.1. A steppic environment until 7700 cal. BP

The lowermost part of the sequence is dominated by detritic sedimentation (sandy silt) and by herbs: Cichorioideae, Poaceae, and Chenopodiaceae. High amounts of Cichorioideae can be considered as taphonomically biased, as this pollen grain is less easily corroded than other grains (e.g. Bottema, 1975; Hall, 1981; Havinga, 1984; Lebreton et al., 2010). According to Havinga (1984), dominance of Cichorioideae is associated with low taxa diversity and inconsistencies in the pollen assemblage. At Vanevan, taxa diversity is low, but pollen assemblage consistency appears robust as several steppic taxa are observed (such as *Artemisia*, Chenopodiaceae, Caryophyllaceae, Carduaceae, Rubiaceae…), together with trees such as *Ephedra distachya* t., and *E. fragilis* t.. Contemporaneously, similar pollen assemblages existed at Zarishat fen (Joannin et al., 2014) and Lake Paravani (Messager et al., 2013). Therefore, Cichorioideae are widespread before ca. 7700 cal. BP, although their values are probably reinforced by corrosion.

These samples show open vegetation, dominated by steppe meadows (Compositeae, Chenopodiaceae, Poaceae and *Artemisia*). Trees are probably absent from direct surroundings as attested by rare tree pollen grains and rather low prevalence of *Pinus* and *Juniperus*, which are long-distance transported pollen grains (Connor et al., 2004). Vanevan (1919 m a.s.l.) is not occupied by aquatic vegetation, as few Cyperaceae grow. Sandy-silt sedimentation, which refrains spreading of hygrophytes, can indicate velocity of moving waters or more likely ephemeral fens on alluvial deposits (as observed in the higher elevated Zarishat fen, Joannin

et al., 2014). In the first case, relatively deep water coincides with wet conditions pointed out by Roberts et al. (2001, 2011) for the Early Holocene. This conclusion is based on paleohydrological records, cave carbonates and marine cores, and extends over both the East Mediterranean and Middle East (from Greece to Iran). However, Sayadyan (1978, 2009) and Sayadyan and Aleshinskaya (1991) reported a progressive increase of water level based on mollusc assemblages from the Norashen site (northwest of Sevan Lake). This increase started after a low-stand (terrace located at 1861.5−1865.5 m a.s.l.) during the estimated time interval 10,000 to 8000 cal. BP. It attains a high-stand (estimated between 8000 and 6000 cal. BP; (terrace located at 1919.4−1923.4 m a.s.l.)) during which water level starts to decrease at around ca. 7000 cal. BP (according to online NOAA data). If these studies are not up to today's standards, they are a useful indication to corroborate the possibility of a very high water level before 7700 cal. BP.

Open-land vegetation observed south east of Sevan Lake matches similar pollen assemblages from Lesser Caucasus and Anatolia: in Armenia (Shamb-2 travertine, Ollivier et al., 2011; Zarishat, Joannin et al., 2014), in Georgia (Paravani, Messager et al., 2013), in Turkey (Van Lake, Van Zeist et Woldring, 1978; Eski Acigol, Roberts et al., 2001; Wick et al., 2003) and in Iran (Zeribar, Van Zeist and Bottema, 1977; Lake Urmia, Bottema, 1986; Mirabad, Stevens et al., 2006; Djamali et al., 2010). Similar open-land vegetation assemblages are also confirmed in pollen records in a synthesis from the Balkan peninsula to Southern Siberia (Wright et al., 2003), in lowland Bulgaria (Connor et al., 2013; Filipova-Marinova et al., 2013), in the Black Sea marine record 22GC3 (Shumilovskikh et al., 2012), in Caspian Sea (e.g. Leroy et al., 2013, 2014), in Central Asia at lake Sonkul (Mathis et al., 2014) and in the Eurasian synthesis including different biotic (e.g. pollen and diatoms) and abiotic proxies (e.g. $\delta^{18}O$ and lake-level) developed by Chen et al. (2008).

Steppic meadows indicate dry climate conditions, corroborated by *Ephedra* pollen occurrences (Wick et al., 2003). Such dry climate during Early Holocene (ca. 12000−8000 cal. BP) is observed by all previously cited authors; Chen et al. (2008) extended it to all Arid Central Asia (ACA). Several authors (Van Zeist and Bottema, 1977; Bottema, 1986; Wick et al., 2003; Connor and Kvavadze, 2008; Djamali et al., 2008; Litt et al., 2009; Joannin et al., 2014) link this arid climate to low spring precipitation to ca. 8000−7500 cal. BP. The Vanevan record confirms this general climate scenario as the pollen-based climate reconstruction records low May−June precipitation ($P_{May-Jun}$ = 180 mm) compared to annual precipitation (P_{ann} = 635 mm) (Figs. 7 and 8). The causes of such conditions are still under debate. According to Djamali et al. (2010), it is due to a typical Mediterranean continental climate (mainly winter-dominated precipitation) in which spring precipitation is reduced or eliminated by northward shifts of the inter-tropical convergence zone (ITCZ) and subtropical anticyclonic belt that prevented the eastward penetration of the North Atlantic and Black Sea lows. Chen et al. (2008) relate arid conditions to water deficit due to North Atlantic low sea surface temperature (SST) and low temperature of high altitude air masses. Wick et al. (2003) and Joannin et al. (2014) hypothesised that strong Siberian Highs most probably blocked westerly winds (and precipitation) and caused dry late springs. More data are needed to correctly address these hypotheses, as the Vanevan record only starts at the end of this phase.

5.2. A forested landscape between 7700 and 5700 cal. BP

Since 7700 cal. BP, the deciduous trees and Poaceae increase rapidly along with a decrease of Cichorioideae and Chenopodiaceae. Sustainability of the sedimentary deposition relies on a brief transitory period (from ca. 7700 to 7630 cal. BP) including Chenopodiaceae and steady increasing *Quercus* in spite of the usually
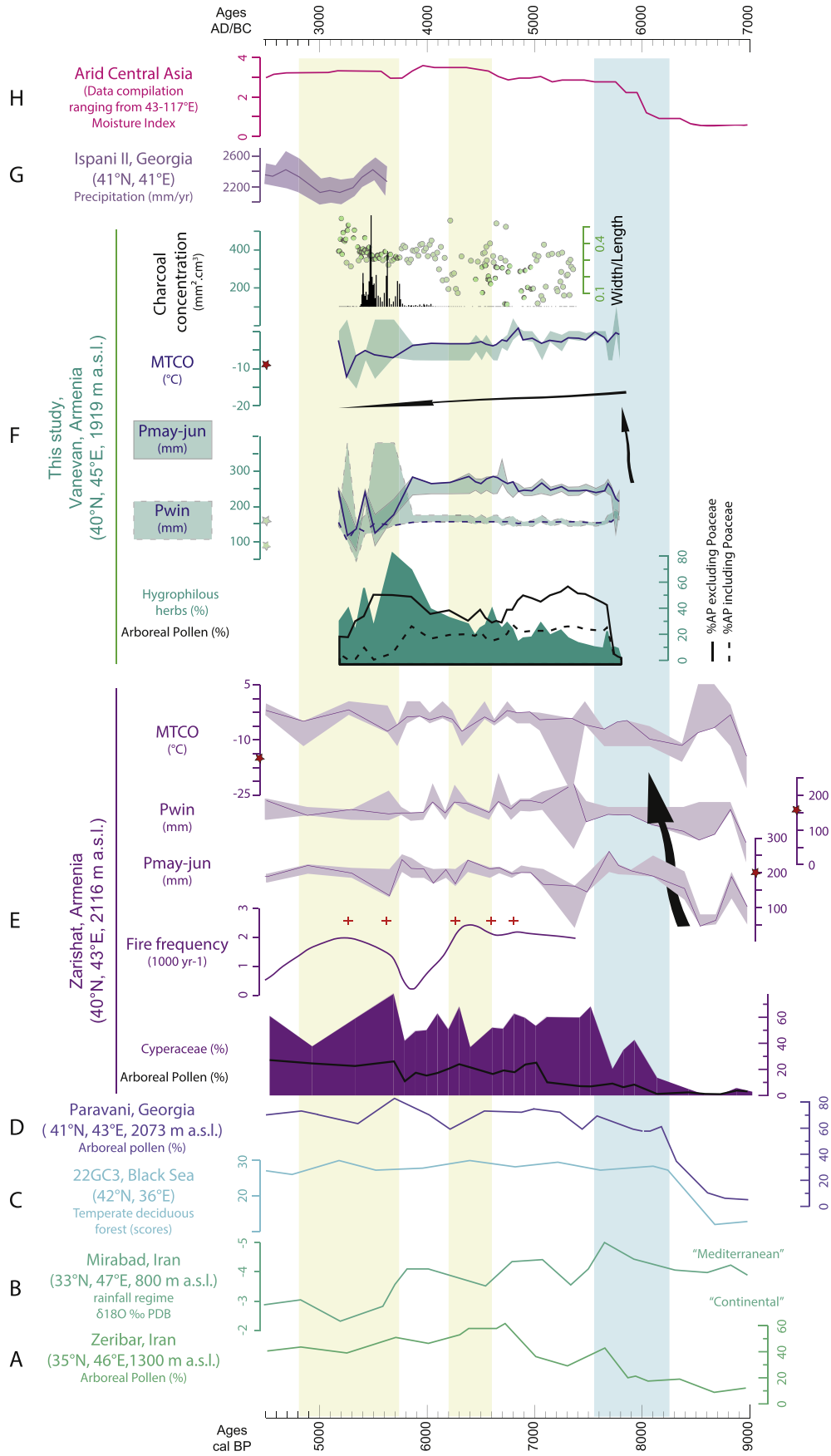
observed transitory step of light-demanding pioneer taxa (e.g. Leroyer et al., 2011; Joannin et al., 2013). Similar and contemporaneous rapid environmental changes have been documented in other records in the Near East (Fig. 8; e.g. Stevens et al., 2006; Shumilovskikh et al., 2012; Messager et al., 2013; Joannin et al., 2014).

During the following two thousand years (from ca. 7700 to ca. 5700 cal. BP), the amount of tree pollen grains varies between 30 and 40%. Pollen assemblages are dominated by *Quercus* associated with numerous deciduous trees (*Ulmus, Betula, Tilia, Fraxinus, Fagus, Carpinus*), while *Pinus* percentage is low (<2%). Increasing ligneous taxa might suggest woodland development in the surroundings of Lake Sevan. Studies focussing on modern samples from Georgia (Connor et al., 2004) show that *Pinus* rate dominates in samples from subalpine zone while *Quercus* is dominant only where oak is well established (i.e. wood-land). Pollen records (Paravani and Zarishat) suggest more forested conditions than today (2073 m a.s.l.; Messager et al., 2013) and higher than the tree-line (2116 m a.s.l.; Joannin et al., 2014), respectively. There, *Pinus* is better recorded than at Vanevan. The synthesis developed by Connor and Kvavadze (2008) for Georgia shows that today's subalpine zones were more forested by deciduous trees during the Mid Holocene. Therefore, we can interpret the tree pollen recorded at Vanevan as significantly showing more forested surroundings than today. Compared to works done in Georgia (transects from lowlands to montane), we cannot definitely recognize long-distance transported pollen grains from lower altitudinal vegetation zones due to different topographical characteristics of the Vanevan surroundings (circled by mountain ranges). This highlights that tree pollen grains recorded are mainly growing in the direct surroundings.

At Vanevan, dominance of *Quercus* suggests *Quercus macranthera*, which is well established today in Armenia (Bohn et al., 2000). Until 7470 cal. BP, *Juniperus* is well recorded. This taxon is today part of the hemi-xeric upper montane forest (Zazanashvili et al., 2000) but stands of *Juniperus polycarpos* and *J. foetidissima* occurred on the northern border of Lake Sevan (Fig. 4; Bohn et al., 2000). Between 7300 and 6890 cal. BP, *Phyllirea-Olea* followed by *Pistacia* are recorded first discontinuously and then continuously. These taxa are under-represented in pollen assemblages (van Zeist and Woldring, 1978; Bottema, 1986), and therefore they may have been part of the forest ecosystem. Today, stands of *Pistacia mutica* are observed north of Lake Sevan associated with junipers (Bohn et al., 2000). Since ca. 7600 cal. BP, *Carpinus* (*C. betulus = Carpinus* and C. *orientalis = Ostrya* type; Beug, 2004) and *Fagus* are recorded. *Carpinus* increased after ca. 6900 cal. BP but *Fagus* and *Ostrya* (C. *orientalis* type) disappeared between ca. 6700 and 6400 cal. BP. They are today localised on northern slopes of the northward montane range (Fig. 4; Bohn et al., 2000). Variable occurrences of *Abies* and *Picea* are recorded around ca. 6500 cal. BP and 6380 cal. BP, respectively. *Picea* is contemporaneously recorded in Zarishat (Joannin et al., 2014) but appears earlier in Paravani (Messager et al., 2013) as well as *Abies*, which develops since 8200 cal. BP. From 6600 cal. BP, opening associated with reinforcement of *Pinus*, decreases or disappearances of several ligneous taxa, and an increasing of steppic meadows as well as a change in steppe composition (i.e. previously Poaceae and *Artemisia*, then Chenopodiaceae and Cichorioideae) occurred.

From ca. 7700 to ca. 5700 cal. BP, Vanevan was progressively colonised by aquatic vegetation reaching an optimum, both in abundance and diversity between ca. 7240 and ca. 7060 cal. BP. Establishment of three species of *Myriophyllum* indicate relatively deep and well-oxygenated water (1–6 m; Fare et al., 2001). This is confirmed by the recording of fresh water algae such as *Botryococcus* and *Pediastrum*. Shallower water is inhabited by amphibious plants such as Cyperaceae and *Filipendula* (Haslam et al., 1982). From ca. 6840 cal. BP onwards, *Myriophyllum* becomes rarer, replaced by *Sparganium, Potamogeton* and Cyperaceae. This change, which signs a shallowing of water, becoming mesotrophic (Cook, 1990), ends with the development of *Sparganium* and *Typha* from ca. 6030 to ca. 5700 cal. BP. Shallowing, which continued with fresh water algae, may therefore be produced by two factors: organic matter accumulation through plant growth or lake level fall. Sayadian and colleagues report a regressive phase of Lake Sevan from ca. 7000 to ca. 6200 cal. BP (still containing mollusc shells) and eventually reaching its maximum low-stand between 6200 and 4000 cal. BP. At this time, the lake was at lower altitude (terrace located at 1894.5−1896.5 m a.s.l.; Sayadyan, 2009) than the Norashen site, which contains a cultural horizon of remnants of ancient building (rich in artefacts: ceramics, stone and animal bone tools; Sayadyan, 1978) (third millennium BC according to Sayadyan et al., 1977).

From ca. 7670 cal. BP onward, *Cerealia*-type (as described by Beug, 2004 and Tweedle et al., 2005) is sporadically recorded at Vanevan followed by two periods of continuous occurrences (7060−6890 cal. BP, 6440 to 5860 cal. BP). *Secale*-type is also observed. In European pollen analysis, they are associated with ruderal plants and suggest agro-pastoral activities (Behre, 1981). According to Badalyan et al. (2010), plant domestication dates back to the 8th millennium BP. An obsidian source (Khorapor), probably used since the Neolithic, is located not far from Vanevan (~20 km southward; Chataigner and Gratuze, 2014). However, major uncertainty remains when discussing cereals in Caucasia, as there are wild and diverse cereals, some of them being possibly used for alimentary purposes but not cultivated during the Neolithic (Connor et al., 2004). Furthermore, several Poaceae in the Middle East provide pollen grains of *Ceralia*-type (van Zeist et al., 1975; van Zeist and Wolring, 1978). Concerning *Secale*-type pollen grains, Frederiksen and Petersen (1998) have documented wild rye (*S. cereal ssp. ancestrale*) and herbs *S. sylvestre* and *S. vavilovii*, with pollen indistinguishable from the cultivated species *S. cereale*. Ruderal herbs can also be part of steppic vegetation and therefore are not human induced (Behre, 1990; Wick et al., 2003). Therefore, without other indications such as forest openings or pastoral activities indicated by non-pollen palynomorphs (van Geel and Aptroot, 2006), it cannot be established that farmers were living on the lakeshores, although this hypothesis is plausible but not yet documented.

The pollen-based climate reconstruction shows after ca. 7700 cal. BP an increase in annual precipitation (not shown, ΔP_{ann} = 85 mm, +13%) mainly due to spring precipitation ($\Delta P_{May-Jun}$ = 50 mm, +28%) (Fig. 7). Mean temperature of the coldest month (MTCO) stabilised at −7.5 °C. Increasing precipitation, particularly in spring, is therefore documented to be the main change at the onset of the Mid Holocene. This change is also recognised by a rapid afforestation (Fig. 8) in the Lesser Caucasus (Connor and Kvavadze, 2008; Messager et al., 2013; Joannin et al.,

Fig. 8. Comparison of paleorecords from Zeribar (A; Stevens et al., 2001), Mirabad (B; Stevens et al., 2006), 22GC3 (C; Shumilovskikh et al., 2012), Paravani (D; Messager et al., 2013), Zarishat (E; Joannin et al., 2014), Vanevan (F; this study), Ispani II (G; Connor and Kvavadze, 2008) and Central Asia [biotic (e.g. pollen and diatoms) and abiotic proxies (e.g. δ^{18}O and lake-level); H; Chen et al., (2008); including Lake Van (Wick et al., 2003)]. Macrocharcoal concentration is given together with length-to-width ratio. Yellow and blue shadings are used to represent arid and humid phases, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2014), in Anatolian Plateau (Wick et al., 2003) and in Northern Iran (Stevens et al., 2001, 2006) where climate conditions are more humid than today. According to Chen et al. (2008), a more humid Mid Holocene period extended eastward across Asia to China. Sediments from Vanevan contain more organic matter, suggesting a stronger surface biological activity and lower runoff in the more forested catchment. Similar processes are reported in Esci Acikol (Roberts et al., 2001), Lake Van (Wick et al., 2003) and Lake Paravani (Messager et al., 2013). The Zarishat catchment, though smaller, also records lower erosion probably due to slopes stabilised by meadows (Joannin et al., 2014). In the studied area (i.e. Lesser Caucasus), Mid Holocene climatic optimum relies primarily on more effective precipitation brought during spring (May to June) by the Westerlies. This period marks the installation of present day climate over East Anatolia and North Iran, with rainy late springs and cool/warm and dry summers. Today's precipitation along the Eastern Black Sea (Georgia, North Armenia) results from depressions preferentially following the track over Black Sea. The Near East precipitation regime change coincides with the opening of the Black Sea corridor, which led to the conversion of lacustrine waters to marine waters in the Black Sea at around 8300–8000 cal. BP (e.g. Filipova-Marinova et al., 2013) and certainly changed evaporation rates over Black Sea. Therefore, it has been highly debated that the Black Sea corridor opening is the cause of this climate shift (Shumilovskikh et al., 2012). Without disregarding effects of such a change on the Black Sea, the geographical extent of the climate change is more likely to be related to a change in the climate mechanism equilibrium at a larger geographical scale; reinforcement of the Westerlies, and less active Siberian Highs.

5.3. Palaeoecological changes from 5700 to 5100 cal. BP

Poaceae increases and diminishing values of trees in the uppermost part of the Vanevan record can be explained in different ways. One explanation could be the human impact by deforestation. However, pollen indicators of human activity disappeared. In the case of pastoral activities without cereal cultivation, it is possible to note a decrease in arboreal pollen but no increase of anthropogenic pollen indicators. Without a coprophilous fungal spores record (van Geel and Aptroot, 2006), this hypothesis cannot be documented. We suppose that Poaceae increase is not a consequence of forest opening. Moreover, archeological remains around Sevan Lake date to the Early Bronze Age (Sayadyan, 1978).

A second explanation is to interpret Poaceae pollen grains as belonging to *Phragmites*, associating this taxon with the peat-land dynamic which started during the Mid-Holocene (ca. 7000 cal. BP). After *Sparganium* development, which provides organic matter to accumulate, helophytes develop in turn (*Carex* and *Phragmites* or *Molinia*, then ferns). A nearby origin for pollen is corroborated by findings of pollinia and fern sporangies. In this hypothesis, organic matter accumulation is the only driver of the local hygrophilous vegetation change and therefore, by the odds of relative percentage, caused an artificial decrease of the surrounding vegetation signal. Poaceae must be excluded from the pollen sum when calculating other pollen percentages (Fig. 7). In this case, woodlands were still dominated by *Quercus* (i.e. hemi-xeric upper mountain forest and woodland according to Zazanashvili et al., 2000) with more developed *Carpinus* and *Juniperus* stands. If *Juniperus* may have come from the lake surroundings as today, *Carpinus* development may indicate transport from the northern slopes of the Sevan range (<10 km). From ca. 5400 cal. BP, only *Quercus* is well developed while steppes were widespread. However, in this second explanation, one must question how hygrophilous vegetation succession can accommodate one to several meters of water

rapidly (from ca. 6000 to ca. 5700 cal. BP; Fig. 7) by producing less than 10 cm of sediment. Another way to explain a hygrophilous vegetation succession is to consider lake shallowing. A water-level decrease of Sevan Lake is discussed by Sayadyan (1978, 2009) in the Norashen site between ca. 6200 and 4000 cal. BP. This coincides, in several paleoenvironmental records in the Near East (synthesized in Fig. 8), with forest openings (Zeribar, Paravani), declining precipitation (Mirabad, Ispani II) and increase in fire frequency (Zarishat) and activity (Vanevan).

Therefore, a third explanation for the Poaceae increase is that this pollen is provided both by local vegetation (i.e. *Phragmites*) and by open-land grasslands that developed at a time of drying, particularly indicated by the Lake Sevan regressive phase (Sayadyan, 1978, 2009). In this hypothesis, dry climate is the driver of the lake low-stand, which is itself the dominant driver of the rapid peat-land vegetation succession. This scenario would involve an intermediate forest regression, compared to presented curves in Figs. 7 and 8. In this interval of high Poaceae percentage, macro-charcoals show increasing fire activity. As particle size is very regular (Fig. 8), fire seems to affect only one source of bio-fuel, which is likely to be local and affecting Cyperaceae and *Phragmites* (i.e. a part of Poaceae). This has also been observed in the Zarishat wetland (Joannin et al., 2014), and linked to drying climate conditions rather than human induced fire. At Vanevan, disappearance of human activity pollen indicators suggests no human impact on this fire activity.

At ca. 5200 cal. BP, increase of human activity pollen indicators and *Centaurea cyanus*, a plant related to cereal culture in central Europe, may show evidence for human presence and impact in the Lake Sevan surroundings. This human settlement is indicated by Early Bronze Age archeological findings (Sayadyan, 1978). Nevertheless, a few pollen grains of *Centaurea cyanus* are a poor indicator of human activity. Moreover, anthropogenic pollen indicators do not exceed the values during the Mid-Holocene. Therefore they cannot be interpreted only as indicators of human activities. At that time, humans seemed not to depend upon fire (few charcoals).

From ca. 5700 cal. BP, pollen based climate values also shows dramatic precipitation decreases, both annually and during late spring ($P_{May–Jun}$ = 135 mm). This dry phase may have induced cultural changes across the Middle East (Roberts et al., 2011). The mechanism behind this phase remains unclear. According to Joannin et al. (2014), dry phases observed during the Mid (and Late) Holocene in Armenia may be related to centennial-scale variation of Westerly activity (NAO-like). This mechanism would imply a stronger Siberian High to block depressions through the Lesser Caucasus.

6. Conclusion

The study of Vanevan Peat (1919 m a.s.l.) provides a record of past environmental changes in and around Lake Sevan. Modern peat exploitation caused the disappearance of the uppermost part of the core, which fortunately revealed a well preserved core section covering approximately 8000 to 5000 cal. BP. Sampling resolution and a robust age model documents vegetation history in Armenia, where studies are particularly rare. The present investigation therefore completes the pollen study at Zarishat (Joannin et al., 2014), by documenting open-land vegetation to ca. 7700 cal. BP, followed by a more forested landscape during the Mid Holocene (to ca. 5700 cal. BP) than today and ending with open-land vegetation to 5100 cal. BP. These successive phases are evident through records of pollen-based terrestrial vegetation, climate reconstruction and non-terrestrial vegetation, the last being related to Lake Sevan water-level changes.

This delayed afforestation recorded in Vanevan peat is a pattern that has now been recognized widely through the Near-East indicating dry climate conditions. Arid climate is linked to low late spring precipitation corroborated by estimated low May–June precipitation compared to annual precipitation. Strong Siberian Highs most probably blocked westerly winds (and precipitation) and caused dry late springs. During the following two thousand years, a more forested landscape is recorded while Vanevan was progressively colonised by aquatic vegetation reaching an optimum, between ca. 7240 and 7060 cal. BP. From ca. 7670 cal. BP, *Cerealia*-type is recorded but without other indications such as forest openings. More evidence is needed to certify that farmers were living on the lakeshores at this time. Afforestation and Poaceae developments rely on strong climate changes. The pollen-based climate reconstruction shows increasing annual precipitation mainly driven by late spring precipitation. This marks the onset of lower seasonality, related to a change in the climate mechanism equilibrium: reinforcement of the Westerlies and less active Siberian Highs.

Strong palaeoecological changes are recorded from ca. 5700 to ca. 5100 cal. BP, resulting in the Poaceae increase. This pollen could be provided both by open-land grassland and by local vegetation (i.e. *Phragmites*) that developed at a time of shallowing related to a Lake Sevan regressive phase. These high Poaceae percentages coincide with an increase in fire activity which seems to affect only one source of local bio-fuel, for which Cyperaceae and *Phragmites* are good candidates. Disappearance of human activity pollen indicators suggests no human impact on this fire activity, which is linked to dry climate. From ca. 5700 cal. BP, the pollen-based climate reconstruction also shows precipitation decrease both annually and during late spring ($P_{May-Jun} = 134$ mm). This dry phase previously observed in Armenia may be related to centennial-scale variation of Westerly activity (NAO-like). This mechanism would imply stronger Siberian Highs to block depressions coming through the Lesser Caucasus.

These conclusions mainly link palaeoenvironmental changes in the Vanevan wetland as well as in the surroundings of Lake Sevan with a climate hypothesis. Human impact for the pre-time Bronze Age is not well documented by our study or by archeological studies. However, the scarcity of such studies is a matter of concern. Volcanism is another possible hypothesis, but has not been discussed here because of lack of information. Lake Sevan is surrounded by many volcanoes, some expected to be active in the Holocene (Karakhanian et al., 2003). This hypothesis relies on basalt flows that possibly affect lake-level by damming the outlet. Whether the climate explanation appears satisfactory due to similar characteristics throughout the Near-East, more studies from the Sevan area with a wider disciplinary spectrum (archeology, volcanism) are mandatory to precisely balance relative effects of all those components on lake-level changes and environmental and human issues.

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