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The environmental and cultural background for the reoccupation of the Armenian Highlands after the Last Glacial Maximum: The contribution of Kalavan 6

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Keywords

Last Glacial Maximum, Paleoenvironmental reconstruction, Upper Paleolithic, Mobility pattern

Abstract

This paper introduces the first long climatic terrestrial record from the Last Glacial Maximum (LGM here after) to the Holocene in the Armenian Highlands and Southern Caucasus. The open-air late Upper Paleolithic site of Kalavan 6 was embedded within this sedimentological sequence. The results of our excavations are presented together with environmental and climate results. Luminescence dating provides a chronological framework for the reoccupation of the Armenian Highlands after the LGM, while two paleo-vegetation proxies characterize the environment: pollen assemblages and leaf waxes. Based on the pollen data, a quantitative climate reconstruction (temperatures and precipitation) is offered here. The techno-typological characterization of the lithic assemblages is presented together with the sourcing of the entire obsidian assemblage by portable X-ray fluorescence, providing insights into the occupants' exploited territories. Such a framework of both environmental reconstruction and hunter-gatherer behaviors enables us to contextualize possible links between population dynamics during the LGM and the post-LGM environmental oscillations. We suggest that, during the LGM between 24 and 19 ka, the combination of declining temperatures and the extension of the winter season limited the feasibility of occupation in the region. The occupation of the region resumed when the environmental circumstances ameliorated. These results support our interpretation that temperatures and the duration of the seasons conditioned the past hunter-gatherers' occupation of the region.

1. Introduction

The climate of the Last Glacial Maximum (LGM) was drastically different from the present-day conditions: global ice volume peaked and associated sea level was at its lowest. Variations in insolation due to orbital parameters, global ice volume variations, and trace gases were the main drivers of differences in atmospheric circulation (Clark et al., 2009). The most widely accepted chronology for the LGM is from 24 to 19 ka, with the highest peak around 21 ka cal BP (Clark et al., 2009; Hughes and Gibbard, 2015; Osman et al., 2021; Rasmussen et al., 2014). However, the timing of this global climatic event and its local manifestations varies greatly, particularly within South Western Asia, where it is widely debated and depends mainly on the proxies examined (Djamali et al., 2008; Fleitmann et al., 2009; Goldsmith et al., 2017; Kwiecien et al., 2009; Müller et al., 2022; Orland et al., 2012; Pickarski and Litt, 2017; Rowe et al., 2012; Shumilovskikh et al., 2014; Stevens et al., 2012; Stockhecke et al., 2016; Ünal-İmer et al., 2015).

The coalescing of the European terrestrial and Paleolithic records, the LGM is usually interpreted as a period when hunter-gatherer populations were contracted into refugia, mainly in Southern Europe (Banks et al., 2009; Burke et al., 2018; Cascalheira, 2019; Cascalheira et al., 2020; Renard, 2011; Tallavaara et al., 2015). Recent genetic studies indicate that, during the LGM, there was a demographic decline and bottleneck, whereas those isolated populations expanded rapidly during the ensuing deglaciation (Bortolini et al., 2021; Posth et al., 2017; Wren and Burke, 2019). Similar scenarios of population dynamics have been suggested for SW Asia based on genetic data rather than on a comparison of Paleolithic records (Broushaki et al., 2016; Gelabert et al., 2021; Jones et al., 2015; Lazaridis et al., 2016; Platt et al., 2017).

When considering the Paleolithic record of the Armenian Highlands and Southern Caucasus during Marine Isotopic Stage 2 (MIS hereafter, 29–14 ka), it is common to differentiate between pre-LGM industries and later ones (Fig. 1). This understanding is principally based on three stratigraphic sequences at western Georgia cave sites containing both pre- and post-LGM occupation layers: Dzudzuana cave (Bar-Yosef et al., 2011); Satsurbliia rock shelter (Pinhasi et al.,

2014); Bondi cave (Pleurdeau et al., 2016; Tushabramishvili et al., 2012), and a single sequence of pre-LGM occupations at the Armenian Aghitu 3 cave site (Kandel et al., 2017). The four pre-LGM layers are dated to 27–24 ka. Additionally, three sites only contain post-LGM occupation layers: the open-air site of Kalavan 1 in Armenia (Montoya et al., 2013) and the Gvardjilas Klde and Kotias Klede caves in western Georgia (Kot et al., 2020; Meshveliani et al., 2007). The dates of these post-LGM sites range between 18 and 13 ka (Bar-Yosef et al., 2011; Kot et al., 2020; Montoya et al., 2013; Pinhasi et al., 2014; Pleurdeau et al., 2016).

Further south, in the Zagros mountains, a similar chronological break was suggested between pre-LGM late Bardosian assemblages and post-LGM with Zarzian microlithic assemblages (Asouti et al., 2020; Garrod, 1930; Olszewski, 1993a, 2012; Shidrang, 2018; Shidrang et al., 2016; Wahida, 1999). Our current understanding, in the Armenian highlands, Southern Caucasus and the Zagros, there is a chronological gap of c. 5000 years, between 24,000 to 19,000, which coincides with the LGM event.

In stark difference to the Armenian highlands, Southern Caucasus, and Zagros records, the Levantine record for the LGM shows an increase in known sites, their size, and their material cultural diversity (Bar-Yosef, 1970; Bar-Yosef and Vogel, 1987; Belfer-Cohen and Goring-Morris, 2014; Garrard and Byrd, 2013; Maher et al., 2012). Based on stylistic readings of the microlithic assemblages, an enhanced variability was observed in the Levantine record (Bar-Yosef, 1970; Bar-Yosef and Vogel, 1987; Belfer-Cohen and Goring-Morris, 2014; Byrd and Garrard, 2017; Garrard and Byrd, 2013; Goring-Morris, 1987, 1995). This variability, in turn, was interpreted as indicating increasing territoriality reflecting demographic growth due to the compaction of populations into a refugium coinciding with the onset of the LGM, c. 24 ka (Belfer-Cohen and Goring-Morris, 2014).

Questions regarding variable impacts of environmental conditions during the LGM and their effects on population dynamics and cultural manifestation in SW Asia have rarely been put forward in the literature. The possible ebb and flow of past hunter-gatherers' populations, contracting to the Levant during the height of the LGM, when conditions preventing large areas such as Anatolian Plateau, Armenian Highlands and the Zagros from being occupied. While, during the

amelioration after the LGM, those “empty” regions were reoccupied. Yet, few in-depth comparative inter-regional studies of lithic assemblages between the different geographical locales enable testing such scenarios (Belfer-Cohen and Goring-Morris, 2014). Recent climate simulations for Turkey and the Southern Caucasus suggest dry conditions during the LGM that could have impacted population dynamics (Ludwig et al., 2017; Ludwig and Hochman, 2022; but see Shumilovskikh et al., 2014; Wolf et al., 2022). The rarity of quantitative climate reconstructions of the LGM from proxy data in comparison to the period prior or later (e.g., Chevalier et al., 2020), hinders our ability to link climatic factors to hunter-gatherers population dynamics. Yet such quantitative climate characterization may provide a possible explanation of the 5000 years of occupational gap during the LGM in the Armenian highlands, Southern Caucasus, and Zagros in comparison to the flourishing record in the Levant.

This paper investigates the archaeological context and environmental conditions (vegetation, climate) at Kalavan 6 (Armenia) from the LGM to the Mid-Holocene, based on a multi-proxy study. We introduce the results from the 2017 and 2019 excavations at Kalavan 6, a site located along the Barepat river (Fig. 1b; Montoya et al., 2013). First, the site's stratigraphy is presented; the complete sedimentological sequence with texture, calcimetry, and elemental analysis using XRF, enabled us to better constrain the dynamics of these stratigraphic deposits and their sedimentary sources in connection with paleohydrology and climate. In addition, micromorphological analysis was conducted to study the environmental components and human activities on a local level and in the watershed of the Barepat river. The chronology of the sequence is based on luminescence (pIRIR) dating. We also aim to reconstruct paleo-vegetation changes from two proxies—pollen assemblages and leaf waxes—to better characterize the environment. Third, climate changes are also investigated with a quantitative climate reconstruction (temperatures and precipitation) based on these pollen data. Last, the technotypological characterization of the lithic assemblages is presented together with the sourcing of the entire obsidian assemblage by portable X-ray fluorescence (pXRF), providing an overview of the occupants' exploited territories.

This paper introduces a long-term terrestrial and human behavioral record from the LGM to the Holocene for the first time in the Armenian Highlands and Southern Caucasus. Such a quantitative environmental estimate together with the chronological framework enabled us to contextualize possible links between population dynamics during the LGM and the post-LGM environmental oscillations. In addition, our results shed light on the mobility and land-use patterns of those occupations in Kalavan 6 and elsewhere within the Armenian highlands.

2. The site of Kalavan 6

In 2017 and 2019, a team from the Institute of Archaeology and Ethnography (National Academy of Sciences, Republic of Armenia) and the Monrepos Archaeological Research Centre and Museum for Human Behavioural Evolution (Germany) conducted a series of trench excavations to assess the geomorphological dynamics and the possibility of conducting large-scale spatial excavations. The excavation of the main trench in 2017 exposed a sequence of nine sedimentary units that included two archaeological layers: one mid-Holocene and one late Upper Paleolithic (Fig. 2). Subsequently, the excavation of two 1-m² squares (A10 and A11) adjacent to the trench revealed the continuation of the late Upper Paleolithic archaeological horizon observed in the main trench (Fig. 2). In 2019, four additional squares (D8, D9, E8, E9) were excavated 2 m, east of the 2017 trench (Fig. 2) to assess the extent of the site toward the east, where the slope of the terrace is more moderate (compared to Barepat river).

3. The geological and geomorphological setting

The site of Kalavan 6 (Fig.1) is located on the right bank of the Barepat river, about 10 meters from the current thalweg (Fig. 1b). The Barepat river is a third-order stream with a catchment area of 58.8 km² for a perimeter of 37.5 km. The talweg's altitudes vary from 2300 to 1217 m asl over 16 km (maximum slope = 28%; average slope = 7.5%; Malinsky-Buller et al., 2021). The elongated morphology of the watershed (Gravellius compactness coefficient of 1.36; Gravelius, 1914) implies restitution of meteoric water spreading out over time and average speeds capable

of triggering torrential floods. The watershed lithology varies and comprises Cretaceous limestones, Paleogenic sandstones, volcanogenic rocks, conglomerates, and metamorphic rocks. Furthermore, the Barepat watershed includes numerous springs mainly artesian, through fracturing of the substrate with water supply linked to karst reservoirs and hydrothermal springs in places and some disseminated Pleistocene and Holocene travertine deposits (Malinsky-Buller et al., 2021; Montoya et al., 2013).

The Barepat River is part of a hydrological system connected, step-by-step, to the Caspian Sea, first via the Getik and Aghstev rivers, then via the Kura river. Although some clues persist, it remains challenging to measure the possible influence of these large and rapid fluctuations in the Caspian Sea's base level on the morpho-sedimentary organization of the Barepat Valley. (Ollivier et al., 2016, 2015) suggested at a regional level that a significant number of first- and second-order tributaries of the Kura (such as the Aghstev in our case) have recorded the retroactive effects of significant variations in the relative level of the Caspian Sea since at least the Middle Pleistocene (but see von Suchodoletz et al., 2018, 2016 for an alternative view). In addition, tectonic uplifting of the Kalavan area (2 to 4 mm/year) is within the lower average rates for the Southern Caucasus and Armenian Highlands (Mosar, 2008). Given the speed and scale of morpho-sedimentary dynamics in mountain environments, the Caspian Sea's base level should have had a limited impact.

The morpho-sedimentary evolution of the valley has resulted in the tiering and fitting of five levels of alluvial terraces and/or retouched tributaries torrential fans (labeled T1 to T5 in Montoya et al. 2013). The Middle Paleolithic site of Kalavan 2, dated to MIS 3–4 (45–60 kya), is positioned in the T2 (Malinsky-Buller et al., 2021), whereas the archaeological site of Kalavan 6 lies on the T3 terrace. The latter was covered by erosion contact with slope deposits (landslides and mass movement) dated to the mid-Holocene (Joannin et al., 2022; Montoya et al., 2013, see further details below).

4. Methods

4.1.1. Grain size by image-sizing

Grain size characteristics in the range of 5 μm to 2 cm were assessed using the Analysette 28 Fritsch Imagesizer particle sizer to determine the textural properties of the 11 samples retrieved in the Kalavan-6 excavation. Measurements were carried out in two stages: 1) wet measurements for sediments between 5 μm and 3 mm and 2) dry measurements for grain sizes between 20 μm and 20 mm. Sample preparation included an initial 250 μm wet sieve to separate the wet and dry fractions to be measured and to improve data quality. The fraction larger than 250 μm was dried at 50°C for 24 hours, weighed and measured using the dry method. For the fraction smaller than 250 μm , approximately 5 g of sediment was wet processed directly. In order to combine the wet and dry data sets and to present the proportions of fine and coarse sediments, particle size proportions were calculated by weighing the percentage classes of each data set based on the masses of the respective fractions (> 250 μm and < 250 μm).

4.1.2 Sediment Portable X-Ray Fluorescence Spectroscopy (pXRF) Analysis

Sediment samples from 11 levels were retrieved during the Kalavan 6 2017 and 2019 excavations and analyzed. The sediments were preliminarily dried at 50°C for 48 hours. Elemental analysis was conducted using an Olympus Vanta C series pXRF instrument with a geochemical calibration under the 2-beam soil mode, configured to measure Mg, Al, Si, Ca, S, P, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, W, Zn, Hg, As, Pb, Bi, Se, Th, U, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, and Sb. This data can define the distinct elemental signatures of the morpho-sedimentary events recorded in the sedimentary sequences. The elements with atomic numbers below 11 (Na and lighter), not individually detected, were combined as light elements (LE) by the instrument's software.

In order to verify the accuracy of the instrument, four control samples underwent elemental analyses by inductively coupled plasma optical emission spectroscopy (ICP-EOS, Agilent 5800 VDV model) in the elemental Chemistry platform of the CEREGE UM 34 laboratory. The comparison was performed for the following ten major elements: Al, Ca, Fe, K, Mg, Mn, P, Si, Sr, and Ti. Except

for Mg, Mn, and P, which are not always detected by the pXRF, the trends are relatively identical; the average difference in the results obtained through the two methods is only 0.79 %. The literature also testifies to the accuracy of pXRF measurements compared to ICP-OES or ICP-MS measurements (Al Maliki et al., 2017; Arne et al., 2014; Kilbride et al., 2006). Finally, the pXRF results and the average concentration of these elements in Earth's upper continental crust (UCC) (Wedepohl, 1995) were compared to better highlight any possible anomalies.

4.1.3 Digital calcimetry

The carbonate content of the 11 levels of the Kalavan 6 excavation was assessed using a FOGII Digital Soil Calcimeter™ on 1 g of sediment that had been dried and crushed for 24 hours. These sediments were then combined with a solution of HCl (6 M). Prior to analysis, the calcimeter was calibrated using 0.8 g of a commercially available standard containing 99.1% pure calcium carbonate.

4.2. Micromorphological Analysis

Micromorphological analyses were carried out on a series of four 6 × 9 cm thin sections made by the Thomas Beckmann Laboratory (Germany) using their standard protocol for micropedological study (Murphy, 1986). The description and interpretation of the micromorphological features followed the methodology and analysis principles used mainly by Bullock et al., 1985; FitzPatrick, 1984; Kubiëna, 1938; Mùcher, 1973; Stoops, 2003. Observations were made through a Dino-Lite AM4515ZT-Edge digital microscope combined with a Dino-Lite BL-ZW1 backlight polarizer. Different focal length modes allow a good representation and definition of all the thin sections of surfaces observed in polarized and cross-polarized lights. Successive magnifications of c. 63× and c. 184× were systematically applied to establish the complete characteristics of the selected samples at different scales.

4.3 Luminescence chronology

To get insights into the timing of sediment deposition (and burial), luminescence dating (Aitken, 1998) was conducted on three samples collected from Units 5, 7, and 8 at Kalavan 6. The dose equivalent (De) estimation was calculated with a methodological approach similar to the one used for Kalavan 2 (Malinsky-Buller et al., 2021). In that instance, the fine-grain material (4–11 µm,

polyminerals) was found to be most suitable for getting a sufficiently high signal-over-noise luminescence ratio. Also, the shown dose recovery test results and presented fading (g) values indicated that the pIRIR225 protocol (Buylaert et al., 2009; Thomsen et al., 2008) applied to the fine-grain material were found to provide reliable results (Malinsky-Buller et al. 2021). In the present study, an additional fading test was applied to sample L-Eva 1696, and the negative g-value of -0.6 highlights once more that fading does not have to be taken into account for the pIRIR225 signal for the investigated samples.

4.4. Pollen analysis and climate reconstruction:

4.4.1. Pollen extraction and counting

Pollen extraction from the deposits required large samples and several concentration steps. Ten samples, each weighing 80g on average, were successively treated using HCl and HF, then successively concentrated using 10 µm mesh sieve and density liqueur separation ($ZnCl_2$) before adding glycerine and mounting the slide. Pollen slides were analyzed under a light microscope at 400× magnification. Pollen types were identified using reference atlases (Beug, 2004; Reille, 1992).

4.4.2 Pollen-inferred climate reconstruction

Climate changes were quantitatively reconstructed from pollen assemblages through the Modern Analogue Technique (Guiot, 1990), a method widely tested for the Mediterranean region (e.g. Cheddadi et al., 1997, Peyron et al., 2017; Cromartie et al., 2020). The method consists of selecting the set of modern pollen data that most closely resembles each fossil pollen data. Dissimilarity coefficients measure the difference between fossil pollen samples and the potential modern "analogue" samples. Once a set of modern samples has been selected as analogue, climatic parameters are attributed to each fossil sample as the weighted average of the modern samples' analogue climates. The strength and uncertainties of the Modern Analogue Technique are discussed by Chevalier et al. (2020). Four analogues have been selected for the Kalavan climate reconstruction to provide quantitative estimates of two climate parameters: (1) the temperature of the coldest month and (2) the annual precipitation.

4.5. Leaf wax and vegetation

N-alkanes, a component of the epicuticular wax in terrestrial plants, are a widely-used environmental proxy due to their resistance to degradation (i.e., insolubility in water, chemical inertness) and their potential to reconstruct past vegetation and hydrology. In the Southern Caucasus, the distribution of *n*-alkanes has been demonstrated to differentiate between soils formed under deciduous vegetation and grasses (Bliedtner et al., 2018; Trigui et al., 2019). Typically, in eastern Georgia, the *n*-alkanes in soils with grasses have higher average chain length (ACL) values (~30) than the *n*-alkanes in sites with deciduous trees and shrubs (~29) (Bliedtner et al., 2018), though this pattern is not clear in similar studies in Armenia (Trigui et al., 2019). Grassy soils also typically have nC_{27}/nC_{33} ratios <1, whereas deciduous soils have nC_{27}/nC_{33} ratios >1. Modern soils in the Caucasus with both grassy and deciduous vegetation have high odd-over-even predominance (OEP), a measure of alkane preservation (Brittingham et al., 2017), which indicates that modern soils in the Armenian Highlands and Southern Caucasus have not undergone significant bacterial or thermal alteration.

4.6. The lithic assemblage techno-typological analysis

The techno-typological analysis of the site's lithic assemblage follows the essential criteria suggested by Tixier (1963) for analyzing microlithic industries and integrates the microlithic tools categories defined by Barrière et al. (1972) and Bader (1984) based on lithic-tools variability during the Late Upper Paleolithic–Epipaleolithic in Western Europe and the Caucasus.

4.7. Obsidian sourcing

Geochemically identifying the volcanic origins of obsidian artifacts from Kalavan 6 provided a means to recognize the mobility and interactions of mobile foraging groups at this time. The location of this site with regard to obsidian sources in surrounding areas (Fig. 8) and nearby deposits of other raw materials (e.g., cobbles in river beds) makes it particularly interesting when considering proposed links between lithic technology and materials (e.g., whether lithic types reflect emic categories or merely etic groups due to resharpening and reshaping (Dibble, 1995). An initial sample of Kalavan 6 artifacts was analyzed in 2017 with

pXRF in Yerevan, and these results were sufficiently compelling to conduct additional analyses. Consequently, during the 2019 season, we sourced 133 obsidian artifacts in our Kalavan field lab. These analyses followed pXRF protocols that we have previously published (Frahm et al., 2020; Frahm and Brody, 2019; Frahm and Tryon, 2018). Because most of the obsidian artifacts are small, ratios between elements were used to account for their size and morphology effects (Frahm, 2016). Fig. 9 is a scatterplot of Zr/Nb vs. Y/Nb used for source identifications.

5. Results

5.1. Sedimentology and Stratigraphy

Nine sedimentological units were unearthed in a section exposed in 2017 (Fig. 2). At the bottom, Unit 9 (Fig. 2) was exposed for over 20 cm without reaching the bottom. This unit is composed of silty sandy sediments with subangular gravels. The matrix is dominated by silt-sized grains at c. 74%, followed by sand-sized particles at c. 26%. The CaCO₃ content is c. 8%. Above it, Unit 8 also comprises silty sand deposits filled with carbonate aggregates, suggesting a low degree of pedogenesis process. The matrix is dominated by silt-sized grains at c. 88%, followed by sand-sized particles at c. 12%. The CaCO₃ content is c. 0%.

Unit 7 is sandy silty with numerous lightly carbonated roots, indicating the initial stages of pedogenesis. The matrix consists of silt-sized grains at c. 75%, followed by sand-sized particles at c. 25%. The CaCO₃ content is c. 11%. Unit 6, composed of silty-sandy sediments with roots and a little more carbonated than Unit 7, points to a stronger pedogenesis process. The matrix consists of silt-sized grains at c. 65%, followed by sand-sized particles at c. 35%. The CaCO₃ content is c. 13%. Unit 5 is a silty-sandy with various sub-rounded to sub-angular carbonated roots, 1 mm maximum length, and very coarse and coarse sand. The matrix consists of silt-sized grains at c. 69% and sand-sized particles at c. 31%. The CaCO₃ content is c. 18%.

Unit 4 comprises three sub-phases of paleosol formation. The matrix consists of silt-sized grains at c. 65% and sand-sized particles at c. 35%. The CaCO₃ content is c. 10%. The main Paleolithic horizon extends both Unit 5 and Unit 4c (the bottom paleosol) with a vertical thickness of c. 20 cm. The Paleolithic horizon includes a

rich lithic collection and a small faunal assemblage of c. 20 fragments representing mainly *Ovis/Capra* and possibly *Sus* (L. Kindler, pers. observation). Those species also dominate the faunal assemblages in the nearby site of Kalavan 1 (Bălăşescu et al., 2017). Unit 3 contains silty sandy sediments with gravels and carbonated pebbles. The matrix consists of silt-sized grains at c. 58% and sand-sized particles at c. 41%. The CaCO₃ content is c. 12%. Two main periods are represented in the ceramic assemblage found within Unit 3, the Late Chalcolithic 1 (4300–4000 cal BCE) and the Kura Arax tradition (2900–2400 cal BCE). Unit 2 contains sandy silty sediments with carbonated nodules and various heteromeric pebbles 1–15 cm of a wide axis, with angular to sub-angular morphology. The matrix consists of silt-sized grains at c. 88% and sand-sized particles at c. 12%. The CaCO₃ content is c. 14%. Unit 1 is the topsoil composed of silty sand sediments. The matrix consists of silt-sized grains at c. 77% and sand-sized particles at c. 23%. The CaCO₃ content is c. 2.9%.

Grain size analysis provides information on the textural composition of the sediments and their evolution throughout the sequence. In the Kalavan 6 section, the grain size analysis of the 11 samples shows that the samples are mainly composed of silts, sands and to a lesser extent gravel. The silt content is very high at the base of the section (over 75% on average), but gradually decreases toward the upper parts of the sequence, to c. 45% in Unit 2. The composition of the sediments therefore becomes increasingly rich in coarse material such as sand and gravel. This trend can be correlated with the facies and the results of elemental and carbonate analyses. Those lines of evidence support the interpretation that the transition between Units 4 and 5 represents a change in the depositional mechanisms from alluvial phases at the base to colluvial-pedogenic phases in the middle and upper part of the section.

The 2019 excavation season uncovered a stratigraphic sequence comprising only four sedimentological units (Fig. 2). Units 1a–1b, 2, and 3 from the upper part of the sequence of the main 2017 trench were better preserved, most likely owing to the more moderate slope. Unit 1a–1b is about 90 cm thick in this part of the terrace compared to 10–20 cm in the main trench section in squares D8–D9. The lower portion (Unit 1b) was denser with silty sand sediments. Unit 2 is

characterized by the abundance of gravel, mostly angular. The sediments are fairly dense, brownish/gray, with an absence of archaeological material. Unit 3 displayed a dense fine-grained light brown sediment over c. 70 cm, with carbonate concretions, and included no archaeological material as well.

The boundary of Unit 3 and Unit 6 is demarcated by sharp contact formed as the result of a structure composed of large stones and slabs (40×20×10 cm average size) found together with ceramic fragments and a single bone fragment. This structure, dating to the Kura Arax period, was cut into Unit 6. Unit 6 was exposed to a maximum thickness of about 70 cm, where excavations ceased. The sediments are yellowish/brown loose fine-grained sediment, which occasionally contains carbonate concretions. No lithic artifacts were found in Unit 6, as was also the case in the main trench of 2017. Most likely, the Kura Arax construction activities removed Units 4b, 4c and 5, and thus also the late Upper Paleolithic horizon in those four squares dug during 2019.

5.2. pXRF analysis on the Kalavan 6 sedimentary sequence

In the Kalavan 6 sequence, the major elements measured by pXRF (Fig. 3 and sup. table. 1) were Si, Ca, Al, Fe, Mg, and K. Their distributions and proportions reflected the lithological characteristics of the Barepat watershed, as it is seen in the Kalavan 2 archaeological excavation trenches (Malinsky-Buller et al., 2021). The mean values of the major elements are lower than their average concentration in Earth's upper crust, with the exception of Ca which is also higher from Unit 9 to Unit 4b (average = 6.15%), than the value in Unit 4a to Unit 1 (average = 3.32%). This is also true for Si, K, and Al, which are at their lowest values in Units 1 (Si = 2.2%; K = 0.9%; Al = 0.75%) and 4a (Si = 2.15%; K = 0.8%; Al = 0.7%). The higher percentage of Al in units below Unit 1 and 4a might be indicative of pedogenic processes leading to Al leaching downwards.

The highest contents of magnesium, not detectable below 3000 ppm by pXRF, are observable in the lower part of the sequence from Unit 9 to Unit 4b, where they reach significant values between 1.3% and 2.1%. Among the trace elements (Fig. 3 and sup. table. 1), Ti, Mn, S, and Cr are given the most consideration. Titanium is present in all the units of the sedimentary sequence but

at lower values in Units 4a and 1. Manganese is also present in all units, with the lower values in Units 4a and 1. It should be kept in mind that Titanium (Nesbitt and Markovics, 1997) is generally considered an erosion marker and that Manganese concentration is often correlated with the circulation of water (water table fluctuations, continuous runoff, and others). Sulfur is present in all units but in greater quantities at the level of the most pedogenized units, particularly in Unit 1. When local values of environmental origin are not especially high, Sulfur is closely bound to organic soil horizons and their vegetation cover (Biederbeck, 1978). Chromium, like Manganese, is missing in most colluvial and pedogenetic units (from Unit 3 to Unit 1) and is not part of the *in situ* lithology (absent in the Unit-4a rock). Finally, the highest values regarding light elements (LE) occur in Units 4a and 1, reflecting their pedogenic nature.

5.3. Micromorphological synthetic analysis on the Kalavan 6 sedimentary sequence

Four thin sections were sampled in Units 4c (MM 6.2) and 5 (MM 6.1, MM 5.1, MM 5.2, see Table 1). These units correspond to the archaeological horizon of the Kalavan 6 section. A complete description and interpretation of the different thin sections are available in Table 1 and Fig. 4. The description of the micromorphological analysis is presented from bottom to top.

The thin section MM 5.1 (Unit 5) shows moderate to discrete frost microstructures (Fig. 4). The sediment is a mix of alluvial deposits from the river (subrounded elements and the presence of manganese) and some colluvial supply from nearby slopes (Table 1). A very slight pedogenesis can be distinguished (diffused organic material). Some traces of anthropogenic activity are also visible in the presence of isolated flint fragments (Fig. 4 and Table 1).

The thin section MM 5.2 (Unit 5) also shows moderate frosted microstructures, sometimes covering a wide area (Fig. 4). The sediment is a mix of alluvial deposits from the river (mineralogy of the coarse fraction) and records further colluvial supply from nearby slopes than in MM 5.1 as observed in the banded distribution (Table 1). The main characteristic remains of MM5.2 is the pedogenic development demonstrated by a significant degree of bioturbation

through abundant root traces with neocalcans and calcium carbonate granules (Table 1).

The thin section MM 6.1 (Unit 5) shows remains of human activities as observed by obsidian fragments and trampling-like microstructure. The obsidian was fractured *in situ* in accordance with the compaction of the sediment (Fig. 4 MM6.1 polarized light B). The biggest particles are subangular and of colluvial or anthropogenic (obsidian, flint) origin. The sub-rounded particles are remnants from alluvial runoff (Table 1, Fig. 4).

The thin section MM 6.2 (Unit 4c) shows more colluvial sediment with some alluvial particles (Table 1). Evidence for pedogenetic development is attested by the well-bioturbated areas. In addition, the presence of particles in a columnar manner suggests that only minor, local movement has occurred, thus supporting stabilized conditions (stasis).

5.4. The luminescence chronology of the Kalavan 6 sequence

The pIRIR225 results delivered dates of 14.3 ± 1.1 ka for Unit 5, 16.4 ± 1.2 ka for Unit 7, and $18.3 \text{ ka} \pm 1.3$ for the boundary of Units 8 and 9 (Table 2); these suggest that the archaeological layer dates from c. 14.3 ± 1.1 ka, similar to Kalavan-1 C₁₄ dates (Montoya et al., 2013).

5.5. Paleovegetation proxies

5.5.1. Leaf wax (*n*-alkanes) analysis

The distribution of *n*-alkanes in Kalavan 6 generally indicates grassy, open environments. In Units 7 to 9, the average chain length (ACL) values of *n*-alkanes are above 30, which is within the range of modern soils in grassy regions in the Areguni Mountains (Brittingham et al., in prep) and Georgia (Bliedtner et al., 2018) (Fig. 5). ACL values of *n*-alkanes in Units 5 (29.8) and 4a (29.7) are slightly below 30 (Fig. 6). These values are at the lower range of modern grassy soils and the higher range of modern soils in deciduous forests (Brittingham et al., in prep, Bliedtner et al., 2018). However, the odd-over-even predominance (OEP) of the *n*-alkanes in Units 5 (3.9) and 4a (3.8) is significantly lower than in the other units. Lower OEP values indicate degradation of *n*-alkanes, and values below 4 are rare in modern soils in the area (Fig. 5), potentially indicating reworking. Studies have shown that degradation of alkanes, whether through bacterial alteration (Zech et

al 2011, Brittingham et al 2017) or thermal alteration (Wang et al 2017) can decrease ACL. Therefore, these lower ACL values and OEP values in Units 5 and 4a may indicate degraded *n*-alkanes sourced from grass. Therefore, these lower ACL values, coupled with lower OEP values, in Unit 5 and 4a may be indicative of degraded *n*-alkanes sourced from grass. Further work on the carbon and hydrogen isotope values of these *n*-alkanes may help distinguish between degraded grass and deciduous signals.

5.5.2 Pollen analysis

Five samples contained enough pollen, with a standardized pollen sum greater than c. 150 grains (Units 7, 6, 4c, 4b, 3; see Table 3). Pollen assemblages from the Kalavan 6 sequence indicate an open landscape dominated by steppes and grasslands. From base to top, pollen assemblages document vegetation dominated by Amaranthaceae steppe (also including *Artemisia* steppe to a lesser extent) in Units 7 and 6 (Fig. 10), then changing to a dominance of Cichorioideae (associated with Poaceae). Meanwhile, trees are limited to riparian taxa (*Salix* mainly) and eventually reach 34% with the addition of pines recorded in Unit 3.

5.6. Climate reconstruction

The modern pollen dataset used here contains 3267 modern pollen assemblages (Dugerdil et al., 2021). Based on dissimilarity coefficients and error calculation, four modern pollen samples were retained as analogues, due to their close similarities to the results from Kalavan. For the analogue selection, we also applied a constraint by biomes to distinguish warm from cold steppes (Tarasov et al., 1998). The selected analogues are mainly located in Armenia (Robles et al., 2022) and Georgia (Connor et al., 2004); a few analogues are located in Eurasia.

The results Fig. 10 show two different periods: a cold/dry period (Units 7 and 6) with mean temperatures of the coldest month around -13°C and low annual precipitation (between 100 and 400 mm); and a warm/wet period (Units 4c and 4b) characterized by mean temperatures of the coldest month around -5°C and precipitation close to 580 mm. The values associated with the second period are very close to modern climate values recorded by the Chambarak weather station (temperatures of -5.2°C in January and annual precipitation of about 583 mm;

reported in Joannin et al., 2022). The most recent sample (U3) shows anomalously high temperature and precipitation values, which are probably biased by high percentages of *Pinus* in the pollen assemblage.

5.7. The lithic assemblage of Kalavan 6

To date, the late Upper Paleolithic horizon at the contact of Units 4c–5 has been exposed across four sq m. The assemblage comprises 213 lithic artifacts made mainly on obsidian (n=156, 72.3%) and siliceous rocks (n=59, 27.7%) (Table 4). It is primarily composed of the debris category (Table 4: 65.2%), consisting mainly of artifacts smaller than 2 cm. The debitage is dominated by bladelets (34.1%) and blades (27.7%), while flakes make up about a quarter of this assemblage (Table 4). A single core made of local siliceous rock and the few core trimming elements suggest that on-site knapping was limited. The absence of primary elements (i.e., items bearing cortex) could also support this observation. Retouched tools make up 12% of the assemblage (Table 4) and are made mostly of obsidian (92.3% of the tools). The ratios of blades/bladelets per tool and flakes per tool (1.1 and 0.4, respectively) suggest a preference for blades and/or bladelets blanks. The low proportions of debitage per tool and core trimming elements per tool (ratios of 1.8 and 0.1, respectively) indicate that tool production was also limited and that most retouched tools, blades, and bladelet blanks were most likely brought to the site. Microlithic tools are the most dominant category (Table 5) and comprise mostly backed bladelets shaped by abrupt retouch; most were found broken (Fig. 7: 1). Microlith fragments that could not have been attributed to a specific subtype due to their fragmentary state are also common. Bladelets with complete or partial fine retouch also attend the toolkit (Table 5; Fig. 7: 2). The high frequency of broken microliths might be an outcome of their use as parts of composite tools, as was observed in another paneocontemporaneous site of Neve David from the Levant (Groman-Yaroslavski et al., 2020).

The toolkit of Kalavan 6 also comprises two microgravettes; one of them, retrieved broken, was labeled as a variant of this type (Fig. 7: 3). The microgravette points at the site were shaped by unipolar abrupt retouch, forming a straight back, and were pointed by fine retouch on the opposite lateral edge on the dorsal, ventral,

or both faces. The points also displayed basal modification on their ventral face in the form of flat and invasive scars, possibly done by pressure (Schechter et al., 2016). The only complete microgravette also displays a pointed base formed by an oblique truncation (Fig. 7: 4, following the definition of Barrière et al., 1972: Fig. 4: 5–6, 8–9). The flat, invasive scars and pointed base shape suggest that these points were aimed to be mounted on composite hunting gear. A fragmentary state characterizes most of the backed bladelets, which might raise the possibility that at least some of them could have been microgravettes before their breakage (Fig. 7: 1). The similar width ratios documented at Kalavan 1 for the microgravettes (4–6 mm) and the broken-backed microliths (3–8 mm) might support this suggestion (Montoya et al., 2013). The single complete microgravette measures 22.1 mm long and 4.8 mm wide, and the broken specimen has a similar width (4.1 mm). These measurements fall within the microgravettes range from Kalavan 1 (length 22–29 mm; width 4–6 mm), and they are also shaped similarly, including ventral basal modification in some cases (Montoya et al., 2013: 628).

The second most common tools is the retouched blades (Table 5; Fig. 7: 5–7). Most of them are modified by continuous fine retouching on a single lateral edge, whereas one specimen displayed a partial fine retouch. The last and most unique specimen of this category is a retouched and denticulated blade (Fig. 7: 7), which is almost completely modified by fine, alternate, or bifacial retouch, while additional denticulation was applied on one of its lateral edges. Other tool categories also attend this toolkit but in fewer numbers (Table 5).

It is not yet clear whether the observed pattern of two separate reduction sequences for blades and bladelets observed in Kalavan 1 (Montoya et al., 2013) also appears in Kalavan 6. However, the reliance on obsidian as raw material and the focus on backed microliths (including microgravettes) of comparable dimensions and manufacturing methods are similar in the two chronologically contemporary sites (see above). The chronological and techno-typological similarities raise the possibility that the sites of Kalavan 1 and Kalavan 6 might be affiliated with the same lithic tradition of hunter-gatherers that inhabited the Armenian Highlands around 16–14 ka cal BP.

5.8. Obsidian artifact sourcing

The obsidian sources recognized among the Kalavan 6 artifacts occur throughout the Armenian highlands. Over half (n=79, 59%) of the artifacts originated from the southeastern Gegham mountains, specifically the Geghasar source. Of particular interest is that primary outcrops of this obsidian source lie at high elevations (2800–3100 m asl). If Geghasar obsidian was collected from the outcrops, where large blocks of excellent raw material were readily available, it would imply high-elevation utilization of the second-highest mountain range (after Mount Aragats) during summers (when it was not buried under snow), presumably in pursuit of prey animals seeking a cool climate with steppe vegetation. If, however, obsidian was collected from possible alluvial secondary deposits that might have existed, it could instead have been acquired at lower elevations. Indeed, both scenarios are possible even for the same groups, who would have needed to move seasonally. Either way, these artifacts reflect a movement of about 60–70 km linearly between Geghasar and Kalavan 6, a distance that increases to over 150 km on foot, given the topography involved.

An additional clue to the movements of the Kalavan 6 residents is found in their use – or relative lack thereof – of obsidian from their volcanic sources along the Hrazdan River. These two volcanoes northwest of Geghasar – Gutansar and Hatis – are the most archaeologically significant obsidian sources in central Armenia, but they are represented by only a few artifacts at Kalavan 6: two artifacts (1.5%) from Gutansar and one (0.75%) from Hatis. These are considerably lower proportions of Gutansar and Hatis obsidian than we recently identified at the Middle Paleolithic open-air site of Kalavan 2 (Malinsky-Buller et al., 2021), where, in some units, Gutansar and Hatis were the sources for more than two-thirds of the obsidian artifacts (e.g., 62.3% from Gutansar and 15.1% from Hatis in Trench 2). The Hatis artifact and one of the two Gutansar artifacts are chips, while the other Gutansar artifact is a tool, notably a microgravette. One other obsidian microgravette among the sourced artifacts is derived from Geghasar. These sources reflect transport across c. 50 km linearly and over 130 km on foot. These two volcanoes are closer to Kalavan 6 than Geghasar, but the number of Geghasar

obsidian artifacts is 26 times greater than the number from Gutansar and Hatis combined.

We also identified obsidian from two of the three Tsaghkunyats mountain range sources at Kalavan 6: Kamakar (n = 20, 15.0%) and Ttvakar (n = 7, 5.3%). These artifacts include varied lithic types, principally chips but also flakes, bladelets, and a CTE. Like Geghasar, Tsaghkunyats obsidian is available from primary outcrops as high as 2400 m asl and secondary deposits as low as 2000 m asl. These two obsidian sources are about 50–60 km linearly and over 120–140 km on foot from the site. Thus, most obsidian artifacts at Kalavan 6 (n = 109, 82%) derive from the obsidian sources about 50–60 km linearly west and south of the site and over 120–150 km on foot.

Two sources in the Syunik mountain range of southern Armenia are the origins of twelve obsidian artifacts: Sevkar (n = 9, 6.8%) and Satanakar (n = 3, 2.3%). In addition, there is one artifact, a chip, from the Pokr Arteni obsidian source to the west. The Syunik obsidian sources and Pokr Arteni are about 120–130 km linearly from Kalavan 6, but these distances increase to over 200 km on foot along the most direct routes.

The remaining few artifacts originated from more distant obsidian sources to the southwest of Kalavan 6. One artifact – a chip – is attributed to Meydan Dağ (also known as Gürgürbaba Tepe), an obsidian source in what is now northeastern Turkey. The source is about 220 km linearly from the site. This distance rises to over 300 km on foot, making it a potential candidate for inter-group exchange rather than intra-group mobility. It is worth noting that an artifact of Meydan Dağ obsidian was identified in the youngest UP layer at Aghitu 3 (Kandel et al., 2017). Lastly, ten obsidian artifacts (7.5%), including small chips and bladelets, match the Kars-Digor obsidian sources of northeastern Turkey, which lie about 160 km linearly and over 200 km on foot from Kalavan 6.

These data suggest that the residents of Kalavan 6 primarily carried obsidian tools and raw materials from Geghasar in the southeastern Gegham range. The small number of artifacts from the northwestern Gegham obsidian sources – Gutansar and Hatis – hint that the path from Geghasar to Kalavan 6 might not have followed the Hrazdan river. An open issue, however, is whether

Geghasar obsidian was collected from primary outcrops at high elevations or secondary deposits at lower elevations. Resolving this question may necessitate rock magnetic characterization tests applied to Gutansar obsidian artifacts at Lusakert Cave I and Nor Geghi 1 (Frahm et al., 2016, 2021). Less frequently, the obsidian originated in the Tsaghkunyats range to the west. Obsidians from distant sources, such as Meydan Dağ, might have been acquired through mechanisms other than collecting during seasonal and/or annual movements (e.g., exchange).

6. Discussion

6.1. The environmental background of post-LGM occupation in the Kalavan region

The sites of Kalavan 1 and 6 are located at around 1620 masl. Together, the sedimentary sequence of those sites encompasses a long-term terrestrial environmental record from the LGM to the Holocene. This is the first record in this region to characterize the environmental conditions during the LGM and up to the Holocene. Such an environmental framework enables positioning the past occupation of the region after the LGM.

The Kalavan 6 sequence is a succession of alluvial deposits originating from the floodplain of the Barepat river (Units 9 to 4b) and colluvial levels (Units 4a-1). The elemental analyses carried by pXRF out on the sediments of the Kalavan 6 stratigraphic sequence give a more nuanced reconstruction of the sedimentary and environmental dynamics in the Barepat. The results provide supporting evidence for defining: 1) elemental markers of alluvial origin; 2) elemental markers of colluvial origin; 3) elemental markers under the pedological influence; and 4) a probable supply of the waters of the Barepat river by the waters of Lake Sevan over the long term.

The more distant inputs derive from alluvial and/or mixed alluvial and colluvial origins from the entire Barepat River watershed. Thus, those sediments contain the most elemental variety. On the other hand, the units that contain colluvial and/or pedogenic deposits, of which the lithological components are rather local, show a significant drop in the elements Al, Ca, Si, and K. In addition, the micromorphological evidence complements the elemental analysis and

differentiates between the sources according to the roundness of the sedimentary grains.

The calcimetric results for each unit show similar variations to those observed in the elemental analysis. In Units 9 to 5 the CaCO₃ content increases from 10% to almost 20%, except for Unit 8 where no CaCO₃ is detected. At units 4c to 4a, there is a marked decrease from 20% to 5%, corresponding to the most pedogenized facies. This decrease probably corresponds to the reduction of easily mobilized carbonates under pedogenic processes. Then, from unit 4a to unit 2, the CaCO₃ content increases, reaching 15%, and then decreases to 2% in unit 1.

Grain size analysis provides additional support for the changes in the depositional mechanisms. The silt content is very high at the base of the section, over 75% on average, but gradually decreases to about 45% in Unit 2. The composition of the sediments therefore becomes increasingly rich in coarse materials such as sand and gravel. This trend can be correlated with the facies and the results of elemental and carbonate analyses, which support a transition from alluvial phases at the base of the section to colluvial-pedogenic phases in the middle and top of the section.

A similar stratigraphical situation was found at Kalavan 1, c. 300 m from Kalavan 6. The base of the sequence at Kalavan 1, layers 12 to 8, consists of an initial phase of early alluvial deposits. In the second phase, layers 7 to 2 are related to the contributions from the slopes, which progressively covered the flat area of the alluvial terrace. The first Palaeolithic occupations were established at the beginning of this colluvial process (Unit 7) on a sub-horizontal surface slightly sloping toward the Barepat River, similar to Units 5 and 4c at Kalavan 6 (Montoya et al., 2013). Chronologically, the bottom part of the sequence in Kalavan 1 (Units 12-11) can most likely attributed to the LGM period, dated to c. 21 ka. Importantly, pollen results were obtained from Unit 11 (see below).

At Kalavan 6, the bottom part of the sequence at the contact of Units 9 and 8 is dated to 18 ± 1.3 ka, and Unit 7 to 16.4 ± 1.2 ka, reflecting the aggradation of the Barepat river after the LGM maximum extension. The late Upper Paleolithic Layer at Kalavan 6, Unit 5, where the archaeological layer was deposited, is dated to 14.3 ± 1.1 ka. In Kalavan 1, the occupation layer is dated to 14,000 BP uncalibrated

(Montoya et al., 2013). Unit 4 and 3 at Kalavan 6 are ascribed to the mid-Holocene and attributed, based on the ceramics, to the late Chalcolithic (4300–4000 cal BCE) and Kura- Araxes (2900–2400 cal BCE).

Two complementary proxies were used in the reconstruction of vegetation changes through time. As discussed in Malinsky-Buller et al. (2021), pollen reflects the wider region since pollen grains are transported by wind, while leaf wax remains represent accumulation within the watersheds of the Barepat River. Indeed, the combined pollen assemblage succession observed for Kalavan 6 and 1 mimics the pollen record of Lake Van in eastern Turkey (Pickarski et al., 2015). At Kalavan 1, the Unit-11 sample, below the main archaeological unit, attributed to the LGM, yielded a pollen signal of open vegetation with 89% herbs (steppe), with an *Artemisia* steppe more developed than the Amaranthaceae steppe (Montoya et al., 2013). Pollen grains from temperate trees are sparse but significant (11% of the total). Such a spectrum resembles the LGM pollen assemblage from Lake Van when the *Artemisia* steppe was dominant (Litt et al., 2009; Pickarski et al., 2015).

The rise of Cichorioideae in Units U4c and U4b echoes (but surpasses) this taxa development documented at the end of the Lateglacial in Zarishat (Joannin et al., 2014), Vanevan (Robles et al., 2022) and Lake Van pollen records (Litt et al., 2009). In those three lake archives, pollen assemblages exhibit a co-dominance between steppe taxa Cichorioideae- Amaranthaceae -*Artemisia*. Cichorioideae is a robust pollen grain often overrepresented in erosive conditions (Lebreton et al., 2010) and also overrepresented in pollen spectra within archaeological sites (Litt et al., 2012), which seems to be the case at Kalavan 6 and was previously observed at Kalavan 2 (Malinsky-Buller et al., 2021). The pollen's low chronological resolution does not allow us to precisely attribute Lateglacial Interstadial or Younger Dryas. The increase in pine proportion recorded in Unit U3 compares to the mid-Holocene recorded in Armenia (Cromartie et al., 2020; Joannin et al., 2022, 2014; Leroyer et al., 2016; Robles et al., 2022) and Georgia (Messenger et al., 2017, 2021). However, such an amount of pine (34%) has never been recorded in Armenia and is probably overrepresented due to the large dispersion of *Pinus* pollen in open environments.

For the Holocene, the Kalavan climate trend follows the reconstruction from Zarishat (Joannin et al., 2014). The Armenian Highlands were sensitive to global climate changes but differed from Anatolia post-LGM records with delayed tree development (Cromartie et al., 2020; Joannin et al., 2014; Leroyer et al., 2016; Messenger et al., 2017; Robles et al., 2022). Pickarski et al. (2015) hypothesized the resumption of the westerly activity with enhanced precipitation and locally rising temperatures for the recorded expansion of an oak steppe forest at Lake Van.

LGM variations in rainfall and temperatures of Armenia are reconstructed from the pollen data of Kalavan 6 and 1. The pollen-based climate reconstruction from Kalavan 1 and 6 shows a first cold/dry period, post-LGM, followed by a warm/wet period with a final switch to the Holocene units. The absolute values of these Holocene units are close to present-day meteorological station values.

The LGM was probably drier than today's in South and Eastern Europe. Palaeo-precipitation values remain under debate and are mostly unknown (Bartlein et al., 2011; Cleator et al., 2020; Doğan, 2010; Peyron et al., 1998; Şenkul and Doğan, 2013). (Sarkaya et al., 2008) estimated that if temperatures during LGM were 8.5–11.5°C lower than modern, precipitation was up to 1.9 times more than that of today. Candaş (et al., 2020) on the other hand based on an ice sheet numerical model, have suggested that the precipitation during the LGM in Turkey should be the same as today. In contrast, general circulation models (CGMs) suggest drier conditions during the LGM compared to today. Ludwig et al. (2017) have characterized the regional atmospheric circulation for LGM conditions over Europe. They have shown that Southwestern Europe was wetter under LGM conditions than today, while Southeastern Europe was much drier. They also simulated lower precipitation than today for Southern and Eastern Europe and suggested that for Eastern Europe, during the LGM, all seasons show a reduction in rainfall, with the strongest relative reduction occurring in summer (Ludwig et al., 2017). Ludwig's results agree well with regional pollen-inferred climate reconstructions that also show reduced precipitation over Eastern Europe (see Bartlein et al., 2011), corroborated by proxy-based LGM reconstruction (Cleator et al., 2020).

At Lake Van, Stockhecke et al. (2021) have estimated the hydroclimate variations of LGM using molecular biomarkers proxies from $\delta_2\text{H}$ -values of leaf-wax *n*-alkane C_{29} . This study's results reconstruct a drier period during the LGM with increased evapotranspiration and aridity during stadials/glacials, in agreement with the results of the Kalavan sequence. Alternatively, Wolf et al. (2022) have suggested that an increase of westerly pathways crossing the Black Sea in an eastward direction was responsible for higher moisture availability in the Southern Caucasus area during MIS-2, along with more moderate temperatures. A higher moisture transfer to the eastern downwind areas, perhaps with the formation of some "humid island" southeast of the Black Sea.

Stockhecke et al. (2021) have also estimated LGM temperature changes. They reconstructed cold conditions with temperatures 4°C lower than today. Candaş et al. (2020) and Sarıkaya (et al., 2008) reconstructed even colder conditions with a temperature $10\text{--}9^\circ\text{C}$ lower than today. The cooling agrees well with the overall cooling in Anatolia and the wider eastern Mediterranean region, as simulated by Ludwig et al. (2017). In the Armenian highlands, the LGM–today difference (anomaly values) is close to $6^\circ\text{--}7^\circ\text{C}$ for the coldest month, with changes in the annual precipitation that certainly prevail in the local environmental conditions. Those environmental conditions provide a possible explanation for the environmental circumstances that may led to the occupation hiatus in the Armenian Highland between 24 and 19 ka. The comparison of those environmental conditions, probably longer and colder winters during the LGM, while the conditions during the post-LGM period are more similar to the current conditions today offers a possible linkage between the ecological manifestation, environmental deterioration, and depopulation of the region that has previously relied on inference.

6.2. Articulating Kalavan post-LGM industries in the local and inter-regional context

Within the Paleolithic record of the Armenian Highlands and Southern Caucasus, there is an occupation hiatus coinciding with the LGM (24–19 ka). The known sites are either dated before those age ranges (Bar-Yosef et al., 2011; Kandel

et al., 2017; Pinhasi et al., 2014; Pleurdeau et al., 2016; Tushabramishvili et al., 2012) or later, (18 ka and later; Bar-Yosef et al., 2011, Kot et al., 2020; Montoya et al., 2013; Pinhasi et al., 2014, Pleurdeau et al., 2016; Tushabramishvili et al., 2012, and this paper).

The lithic assemblages of those two periods share a common emphasis on bladelet production, yet there are techno-typological changes that suggest discontinuity and a possible cultural break. In the pre-LGM assemblages, tools were modified mainly by fine or nibbling retouch (e.g., Ouchtata), preserving the original blank shape (Bar-Yosef et al., 2011; Kandel et al., 2017; Pinhasi et al., 2014; Pleurdeau et al., 2016). In contrast, in the post-LGM assemblages, tool modification was based regularly on abrupt/semi-abrupt retouch forming bladelet tools with a steep back with the introduction of the microgravettes points (see Fig. 6; Montoya et al., 2013).

Within Kalavan 6 assemblages, the classification of two microgravettes should be considered a minimal account, as most of the backed bladelets are broken. Similarities between the width ratios of the microgravettes and the broken-backed bladelets were documented at Kalavan 1 (Montoya et al., 2013). Thus, some of the broken-backed bladelets could have been microgravettes before their breakage (Fig. 8: 1). At Dzudzuana B and Satsurblia A/II, some technological variability in the production of the microgravettes was suggested, expressed by the implementation of proximal oblique truncation and/or bipolar retouch (Bar-Yosef et al., 2011; Pinhasi et al., 2014). However, Kalavan 1 and 6 microgravettes share similarities in their metric proportions and ventral basal modification (Montoya et al., 2013: 628). One of the microgravettes originated from the Geghasar obsidian source, the most common source represented at the site. The other microgravette came from Gutansar volcano, c. 50–60 km linearly from Kalavan 6; however, these distances increase to over 120–140 km on foot based on topography.

The mode of occupation at Kalavan 6 may also have an impact on the variability observed. It has been argued that a shorter, less intensive occupation could result in a higher frequency of tools and a narrower range of tool types, as reflective of a limited set of activities compared to a long and more intensive occupation (i.e., a residential base) (Bicho and Cascalheira, 2020; Henry, 1995;

Kuhn, 1992). Considering these arguments, the relatively high frequency of tools (12%), dominated by microliths and retouched/backed blades, hints at the ephemeral nature of the occupation at Kalavan 6. The technological indices (see above; debitage: tools, CTE's: tools, blades/lets: tools, flakes tools) suggest that knapping at the site was limited and for the restricted manufacture of blade/let tools made mostly on blanks which were brought into the site. These observations correlate well with the suggested brief occupation.

Montoya et al. (2013) proposed that Kalavan 1 is related to seasonal hunting activity. (Torneró et al., 2016) isotopic studies of the caprine teeth suggest that Kalavan 1 was a seasonal short-term hunting campsite during autumn, coinciding with the migration of wild herds from the alpine meadows to the valley (Torneró et al., 2016). Unlike Kalavan 6, the lithic assemblage of Kalavan 1 suggests more pronounced knapping activity and tool manufacturing (Montoya et al., 2013: Tables 1–2), as indicated by the number of cores (n=57) and the debitage-per-tool index (19.0).¹ Interestingly the tool-per-core index at Kalavan 1 stands at 2.1. The significant gap between K6 and K1 (19.0 vs. 2.1, respectively) might suggest that at K1, usable cores were carried out of the site, or pre-knapped blanks were brought and retouched. At Kalavan 6, a similar blank import was also indicated but in higher frequencies (see above).

Additional insights into the mobility patterns can be gained from the obsidian sources represented at Kalavan 6, which reflect a vast exploited territory yet follow a noteworthy pattern (Fig. 9). Most obsidian artifacts from Kalavan 6 (n = 109, 82%) derive from obsidian sources 50–60 km linearly west and south of the site and over 120–150 km on foot. Furthermore, the most frequent source, Geghasar (n=79, 59%), is not the closest one. Gutansar and Hatis volcanoes are closer to Kalavan 6, but the number of Geghasar obsidian artifacts is 26 times greater than Gutansar and Hatis combined. The furthest sources are in present eastern Turkey: Kars-Digor (about 160 km linearly from Kalavan 6, over 200 km

¹ In the techno-typological analysis by Montoya et al. (2013), Krukowski microburins were included in the tool category. Krukowski microburins are deemed a waste product of microliths manufacture and are thus considered debitage in our evaluation. Accordingly, the Kalavan 1 counts used in the indexes calculations above are as follows: Kalavan 1 Debitage n = 2257, Tools n = 119.

on foot) and Meydan Dağ (about 220 km linearly, over 300 km on foot). Significantly, those obsidian sources also shed light upon the elevational gradient of the occupants' mobility, as most outcrops are located at 2400–3100 m asl. If utilized as a primary source, such outcrops suggest they were seasonally visited when not buried by snow. Those sources presumably included other resources, such as prey animals seeking a cool climate with steppe vegetation from the spring to autumn.

During the LGM, the climatic conditions, when the temperatures were between 4° and 10°C lower than today (see above), together with the possible extension of the winter season, may have had a cascading effect on the pre-LGM Paleolithic societies. Such an environmental deterioration may have caused a disintegration of the settlement system and mobility of the Upper Paleolithic societies before the LGM (e.g., (Frahm et al., 2019; Kandel et al., 2017). The behavioral and climatic evidence from Kalavan 6 provides insights into the re-establishment of novel hunter-gatherers' lifeways after 19 ka, when conditions ameliorated.

A similar chronological gap in occupation was suggested in the Zagros between pre-LGM late Bardosian assemblages and post-LGM Zarzian-associated microlithic assemblages (Asouti et al., 2020; Olszewski, 1993b, 2012; Shidrang et al., 2016; Wahida, 1999). However, the possible five millennia of occupational hiatus in the Zagros, although it coincides with the LGM, has not been linked to a specific reconstruction of environmental conditions like those suggested in this paper. Instead, the possible occupational hiatus in the Zagros is mainly based on missing radiocarbon dates.

In the Levant, in sharp contrast, the occupational record between 24 and 19 ka exhibits a polarized picture during the LGM, with more and larger sites and more diverse material culture. The nomenclature of those microlithic industries reflects this diversity with a variety of names, such as Late Ahmarian/Masraqan, Nebekkian, Nizzanan, and Kebaran (Bar-Yosef, 1970; Bar-Yosef and Vogel, 1987; Belfer-Cohen and Goring-Morris, 2014; Byrd and Garrard, 2017; Garrard and Byrd, 2013; Goring-Morris, 1995). However, finding supporting evidence in the

material culture for an expansion or movement from the Levant to the Southern Caucasus and Armenian Highlands is extremely difficult.

Searching for inter-regional links between a hypothetical source (i.e., Levantine early Epipaleolithic sites) and sink (i.e., later Southern Caucasus and Armenian highlands) is elusive. For example, the “type fossil” of the post-LGM Southern Caucasus and Armenian Highlands industries—the microgravette point—appears in some LGM Levantine industries in various quantities. Microgravette points appear in Nebekian (e.g., Goring-Morris, 1995; Henry and Garrard, 1988), Nizzanan (Byrd and Garrard, 2017; Garrard and Byrd, 2013; Goring-Morris, 1987, 1995), and Kebaran assemblages (Bar-Yosef and Vogel, 1987; Goring-Morris, 1995). In each of those assemblages, the microgravette points are part of a great variety of microlithic tool types. In both the Nebekian and Nizzanan assemblages, those points were manufactured with the microburin technique (e.g., (Byrd and Garrard, 2017; Garrard and Byrd, 2013; Goring-Morris, 1987, 1995; Henry and Garrard, 1988), unlike instances in the Southern Caucasus and Armenian Highlands. The chronological and geographical distributions of microgravette points are widespread. They appear as early as c. 30 ka from southern France up to the Russian plain, thereby hampering their use as a chronological and cultural marker (Douka et al., 2020; Lengyel et al., 2021; Reynolds et al., 2015).

Recent genetic studies point to a possible demographic decline in the Armenian Highlands and Southern Caucasus during the LGM, followed by rapid expansion and reoccupation (Broushaki et al., 2016; Jones et al., 2015; Lazaridis et al., 2016; Platt et al., 2017). Currently, there seems to be an occupation break before and after the LGM in the Southern Caucasus and Armenian highlands. Yet, only circumstantial evidence, such as the number and size of known sites in the Levant, supports a contraction scenario into the Levant during the LGM. Similarly, evidence supporting a source population in the Levant for a post-LGM expansion cannot be demonstrated in the material evidence. Future research needs to test such a hypothesis by directly comparing the techno-typological variability of Late Upper Paleolithic industries in one region with those in neighboring regions. Such

a study can shed further light on the cultural mosaic and population dynamics of Southwest Asian hunter-gatherer societies in this time frame.

7.2. Conclusions

This paper positions the occupation at Kalavan 6, located at 1620 m asl, within a chrono-climatic framework as well as a detailed geomorphological and stratigraphic setting. Occupied at c. 16 ka, during ameliorated environmental conditions, the site reveals the remnants of highly mobile lifeways. Obsidian sourcing reveals a vast exploitation area whereby the site's occupants routinely covered distances of over 120–150 km on foot, with more distant sources preferred over closer ones. Kalavan 6 and Kalavan 1 cultural materials share similar affinities to various sites in the Southern Caucasus, including a prevalence of microgravete points and bladelets with abrupt retouching. Our results here also portray the likely environmental circumstances that led to the occupation hiatus in the Armenian Highland between 24 and 19 ka, offering a possible linkage between the ecological manifestation, environmental deterioration, and depopulation of the region. As our results allow us to reconstruct, it was a combination of the decline in temperature and the extension of the winter season that reduced the feasibility of the region's occupation at the height of the LGM. The amelioration of conditions after the LGM later enabled the reoccupation of the region with novel exploitation strategies and new networks. The attempt, though, to identify possible “sink and source” cultural relationships between the Armenian Highlands and the Levant failed to provide any strong links. Such a lack of compatibility between these two regional material cultures highlights an important direction of future research in both regions.

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Figure captions

Fig. 1. A: Location map of Kalavan 6 among the Southern Caucasus MIS 2 sites. (1): Satsurbliia rock shelter (Georgia); (2): Gvardjilas Klde (Georgia); (3): Bondi cave (Georgia) (4): Dzudzuana cave (Georgia) (5): Kalavan 1 (Armenia); (6): Kalavan 6 (Armenia) (7): Aghitu 3 (Armenia) B: Location of Kalavan 1, 2, and 6.

Fig. 2. A. Map of excavation areas at Kalavan 6. B. Sections of Units 1–9, Kalavan 6.

Fig. 3. Geochemical distribution of elements per sedimentary units conducted with pXRF (portable X-ray fluorescence). A: Distribution of major geochemical elements (Al, Ca, Fe, K, Mg, and Si). B: Distribution of trace geochemical elements (As, Cr, Cu, Mn, Mo, Nb, Ni, P, Pb, Rb, S, Sr, Th, Ti; V, Y, Zn, Zr). C: Distribution

of light elements (LE) not measured in detail by the pXRF (H, He, Li, Be, Bore; C, N, O, F, Ne, Na). D: Distribution of Mg, present only from Unit 9 to Unit 4b, with values between 1.3 and 2.1%.

Fig. 4. Micromorphological samples pictures with details on the main micromorphological features: Ob= Obsidian flake ; Fl= Flint; Bo= Bone ; Co= Compaction traces ; Vo= Void ; Mn= Manganese ; Bi= Bioturbation ; Ro= roots (with neocalcans); Mol= Mollusca and/or Lumbricina calcium carbonate granules; Fm= Frost microstructure ; Ve= Veins of Magnesium, gypsum and/or calcite ; Sl= sandy lens.

Fig. 5. ACL and OEP values of modern grassy soils (yellow), modern deciduous forest (green), and geological samples from Kalavan 6 (red).

Fig. 6. Alkane abundance in modern grassy soils (yellow), modern deciduous forest (green), and geological samples from Kalavan 6 (red).

Fig. 7: 1–2: Microliths fragments. 3–4: Microgravette points. 5–7: Retouched blades.

Fig. 8. Locations of obsidian sources relative to Kalavan 6. The circle next to each source presents the ratio or absence of obsidians from that source at Kalavan 6.

Fig. 9: Scatterplot of Zr and Y, both normalized to Nb to minimize size effects, for the sourced Kalavan 6 artifacts and corresponding geological reference specimens.

Fig. 10: A combined pollen diagram from Kalavan 6 and 1 and the analogical estimated mean temperature of the coldest month (MTCO) and mean annual precipitation (MAP)

Tables captions

Table 1. The description and interpretation of the micromorphological thin sections.

Table 2. Dose rates, equivalent doses (De), and pIRIR225 age estimates obtained at Kalavan 6. The dose rate was evaluated using high-resolution gamma spectrometry at the “Felsenkeller” laboratory (VKTA) in Dresden.

Table 3. Main pollen taxa and groups (%).

Table 4. General breakdown of the Kalavan 6 chipped stone assemblage.

Table 5. Breakdown of the Kalavan 6 tool assemblage.

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