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1 **Palaeoenvironmental and chronological context of hominin occupations of the Armenian**
2 **Highlands during MIS 3: evidence from Ararat-1 cave**

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40 **Keywords**

41 Middle Palaeolithic, MIS 3, Geoarchaeology, Geochronology, Faunal Analysis, Armenia

42 **Abstract**

43 Archaeological and palaeoenvironmental evidence from the Armenian Highlands and wider southern
44 Caucasus region emphasises the significance of Marine Oxygen Isotope Stage 3 (c. 57-29 ka) as a crucial
45 period for understanding hominin behaviours amidst environmental fluctuations. Ararat-1 cave, situated in
46 the Ararat Depression, Republic of Armenia, presents potential for resolving emerging key debates regarding
47 hominin land use adaptations during this interval, due to its well-preserved lithic artifacts and faunal
48 assemblages. We present the first results of combined sedimentological, geochronological (luminescence
49 and radiocarbon), archaeological and palaeoecological (macrofauna, microfauna and microcharcoal) study
50 of the Ararat-1 sequence. We demonstrate sediment accumulation occurred between 52 – 35 ka and was
51 caused by a combination of aeolian activity, cave rockfall and water action. Whilst the upper strata of the

52 Ararat-1 sequence experienced post-depositional disturbance due to faunal and anthropogenic processes,
53 the lower strata remain relatively undisturbed. We suggest that during a stable period within MIS 3, Ararat-
54 1 was inhabited by Middle Palaeolithic hominins amidst a mosaic of semi-arid shrub, grassland, and
55 temperate woodland ecosystems. These hominins utilised local and distant toolstone raw materials,
56 indicating their ability to adapt to diverse ecological and elevation gradients. Through comparison of Ararat-1
57 with other sequences in the region, we highlight the spatial variability of MIS 3 environments and its on
58 hominin land use adaptations. This demonstrates the importance of the Armenian Highlands for
59 understanding regional MP settlement dynamics during a critical period of hominin dispersals and evolution.

60 1. Introduction

61 Marine Oxygen Isotope stage 3 (MIS 3, c. 57-29 ka; Lisiecki and Raymo, 2005) is a key interval for
62 understanding recent hominin dispersals in Eurasia. This period coincides with the Middle to Upper
63 Palaeolithic 'transition', commonly associated with the spread of anatomically modern humans into Eurasia
64 (Mellars, 2004; Higham et al., 2014; Hublin et al., 2015) and is characterised by sub-orbital scale climatic
65 variability and associated palaeoenvironmental change (Siddall et al., 2008; Van Meerbeeck et al., 2011;
66 Rasmussen et al., 2014). Emerging evidence from regions such as the Levant (Hovers and Belfer-Cohen, 2013;
67 Goder-Goldberger et al., 2020), southeast Europe (Fewlass et al., 2020; Hajdinjak et al., 2021; Hublin et al.,
68 2020; Pederzani et al., 2021; Chu et al., 2022), and southern Europe (Badino et al., 2020, Slimak et al., 2022;
69 Marín-Arroyo et al., 2023) suggest that variable climates and mosaic biomes were key factors in regional
70 hominin adaptations during this period. This emerging perspective highlights the importance of the intricate
71 interactions between hominins and local environmental conditions during this interval. However, regions
72 such as the Armenian Highlands have remained comparatively understudied despite the fact the region has
73 a rich Late Pleistocene archaeological record and is characterised by strong topographic, hydroclimatic and
74 ecological gradients that would have likely amplified environmental changes during intervals of global
75 climatic variability.

76 A growing number of open-air and cave sites in the Armenian Highlands and southern Caucasus (*sensu* Bailey,
77 1989) that contain either Middle Palaeolithic (MP) or Upper Palaeolithic (UP) lithic industries correlated to

78 MIS 3 have been subject to detailed geoarchaeological and chronological investigations (see Moncel et al.,
79 2015; Gasparyan and Glauberman, 2022 for a review). Current evidence from these sites suggests that MP
80 lithic technology may have persisted in the Armenian Highlands up to around 30 ka (Egeland et al., 2016;
81 Sherriff et al., 2019; Glauberman et al., 2020; Malinsky-Buller et al., 2021), and these populations were
82 occupying a diverse range of ecological niches and adapting their land use seasonally (Golovanova and
83 Doronichev, 2003; Adler and Thabramishvili, 2004; Adler et al., 2006; Moncel et al., 2015; Malinsky-Buller et
84 al.2021; Gasparyan and Glauberman, 2022). Evidence from the archaeological record appears to suggest that
85 elevation may played a key role in subsistence behaviour, relatively high-altitude sites such as Hovk-1 (2040
86 m asl; Pinhasi et al.,2008, 2011), and Kalavan-2 (1636 m asl; Malinsky-Buller et al.,2021) occupied
87 infrequently or at low intensities due to harsh winter conditions, whilst lower elevation sites such as Ortvale
88 Klde (530 m asl), were occupied more intensively due to the seasonal availability of migratory herds of prey
89 (Adler et al, 2006). However, a growing number of high elevation sequences (e.g., Cologne et al., 2013;
90 Gasparyan et al., 2014; Malinsky-Buller et al., 2020) do preserve archaeological evidence for more intensive
91 occupations, leading some authors to suggest that elevation is unlikely to be the singular control on
92 occupation intensity (Gasparyan and Glauberman, 2022). Rather, utilisation of local ecological niches and
93 toolstone raw material sources were possibly more important factors in shaping subsistence and land use
94 behaviours during MIS 3.

95 These adaptations occurred against the backdrop of climatic instability during MIS 3 as revealed by regional
96 palaeoclimatic records. These are principally based on pollen and geochemical evidence from the long
97 lacustrine sequence of Lake Van. These records show that the generally arid conditions of MIS 3 were
98 punctuated by short-lived phases of warmer/more humid conditions, resulting in vegetation fluctuating
99 between non-arboreal dwarf-shrub steppe and desert-steppe communities, and enhanced arboreal
100 vegetation dominated by oak steppe-forest (Litt et al., 2014; Stockhecke et al., 2016; Randlett et al., 2017)
101 Ecological reconstructions from archaeological and sediment sequences across the region hint at complexity
102 in local environmental conditions during MIS 3. Several sequences preserve evidence for relatively stable
103 conditions during the interval (Kandel et al., 2017; Malinsky-Buller et al., 2020; Ritcher et al., 2020), while
104 others show evidence for fluctuations in arid-humid conditions that may align with regional palaeoclimatic

105 records (Pinhasi et al, 2011; Glaberman et al., 2020a). Elucidating the complex interplay between the
106 environmental change during MIS 3 and its effects on MP hunter-gatherer populations in the Armenian
107 Highlands, however, requires the systematic study of archaeological remains and palaeoenvironmental
108 evidence from sequences that lie across the spectrum of altitudinal gradients and ecological niches observed
109 in the region.

110 One such site is Ararat-1 cave, which lies at an elevation of 1034 m asl on the eastern flanks of the Ararat
111 Depression in central Armenia. The site preserves stratified lithic artefact and faunal assemblages, making it
112 ideal to investigate local environmental conditions and hominin behaviours in the region. Here we present
113 the first results from the systematic excavation of the cave sediments. Through the application of
114 sedimentological and chronological (luminescence and radiocarbon) techniques which underpin the lithic
115 artefact and faunal evidence, we present; 1) a reconstruction of the depositional history of Ararat-1 cave, 2)
116 an assessment of the integrity of the Ararat-1 artefact assemblage and chronological framework, and 3) a
117 synthesis of palaeoenvironmental conditions at Ararat-1 and the surrounding environment during MIS 3.
118 Through the comparison of the Ararat-1 environmental and archaeological records to other late MP sites, we
119 provide new insights into environmental conditions and hominin behaviours during MIS 3.

120 **2. Site context**

121 Ararat-1 cave (39° 51' 3.7908" N, 44° 46' 8.6232" E, 1034 m asl) is situated 2 km east of the town of Ararat
122 on the northeast margins of the Ararat Depression. The cave is a sub-horizontal passage with a maximum
123 known length of c. 6 m, a width ranging from 4 m at the entrance to 1 m at the back of the cave, and a height
124 of c. 4 m from the 2019 cave surface. Whilst the cave systems in this area have yet to be systematically
125 mapped, it has been suggested that Ararat-1 forms part of a more extensive karstic system that extends along
126 the northeastern margin of the Ararat Depression.

127 The Ararat Depression is an intermontane basin formed as a consequence of the collision between the
128 Eurasian and Arabian tectonic plates from the Miocene onwards (Sosson et al., 2010; Avagyan et al., 2018).

129 The basin occupies an area of c. 1, 300 km², and is divided by the Araxes River, which flows in a NW-SE

130 direction through the basin and forms the current border between Armenia (to the north and northeast) and
131 Turkey (to the south and southwest). The north and northeast sector of the Ararat Depression is bounded
132 by the Aragats and Gegham volcanic complexes, both of which were active throughout the Quaternary period
133 (Arutyunyan et al., 2007; Lebedev et al., 2013; Sherriff et al., 2019; Gevorgyan et al., 2020). Mt. Ararat (Masis,
134 Ağrı Dağı) stratovolcano (5,185 m asl) and associated volcanic complexes lie to the south. The geology of the
135 northeastern sector of the basin is shown in **Figure 1**. The northeastern flank of the Depression is steep-
136 sided and formed of Paleogene-Devonian limestones, shales and quartzites which form the Urts Anticline.
137 Quaternary alluvial deposits are found at the base of the flanks; these extend southwest as fan formations
138 towards the centre of the basin (Avagyan et al., 2018). The basin itself is formed of Cenozoic interbedded
139 clays, gravels, sands, and lava which are capped by recent alluvial deposits formed by the Araks river.
140 Presently, the area is characterised by a semi-arid climate regime, with temperatures ranging from -5°C
141 (winter) to + 30°C (summer) and mean annual precipitation in the range of 300-400 mm (Volodicheva, 2002).
142 Vegetation is dominated by semi-desert and steppe communities, with temperate forest occurring locally in
143 the higher elevation area of the Urts anticline (Volodicheva 2002). The Ararat Depression has a long history
144 of archaeological investigations, focused principally on the Neolithic sites located in the centre of the basin
145 (Martirosyan-Olshansky et al., 2013; Petrosyan et al., 2014; Badalyan and Harutyunyan, 2014). Several
146 Palaeolithic sites have also been identified on the flanks of the Ararat Depression. These include the
147 sequences of Aghavnatun-1 and Dalarik-1, both of which have yielded Lower Palaeolithic lithic artefact
148 assemblages (Gasparyan et al., 2014; Gasparyan et al., 2023)., The open-air sites of Barozh-12, located on the
149 northwestern margins of the Ararat Depression has been systematically excavated by Glauberman et al.
150 (2020a, b). The site has yielded a high-density late MP obsidian artefact assemblage recovered from an
151 alluvial-colluvial sequence dated to 60.2 ± 5.7 to 31.3 ± 4 ka.

152 **3. Methods**

153 **3.1. Field methods**

154 In 2019, a 1 m² grid was established using a Leica FlexLine TS07 total station covering the cave platform and
155 interior. This allowed for the 3D recording of sample locations, sedimentary units, and archaeological and

156 macrofaunal remains by associating a local coordinate system and datum with the grid. A 10 m² area in the
157 northwest sector of the cave (grid squares J11-14, K11-13, L11-13) was selected for excavation during this
158 season (**Figure 2**). Each 1 m² square was excavated by hand in 50 mm thick 'spits' resulting in a trench
159 excavated to a depth of c. 2 m. Faunal remains and lithic material larger than 20 mm were recorded with
160 respect to the local grid coordinates and datum. All excavated sediment was dry sieved on-site using 5 mm
161 mesh and material recovered in the coarse fraction (i.e., larger than 5 mm) was retained for analysis. A c.
162 10% sub-sample of material excavated from square K12 was retained for floatation, in total 12 samples were
163 analyzed.

164 The north and west sections of the exposed trench were drawn and described following standard protocols
165 (**Figure 2**). 2 cm thick blocks of sediment were sampled contiguously through the trench for laboratory
166 analysis. 4 undisturbed blocks of sediment were sampled for micromorphological analysis from Units 2a, 2b,
167 2d, and 3. Due to the unconsolidated nature of the sediments, sampling had to be adapted on-site. Samples
168 from Units 2a and 2b were sampled using 10 x 6 cm stainless steel Kubiena tins, whilst Units 2d and 3 were
169 sampled through the extraction of 10 x 10 cm blocks using plaster of Paris. Five sediment samples were
170 collected from Units 2a-3 for pIR225 dating using opaque stainless-steel tubes hammered horizontally into
171 the west section face (**Figure 2**).

172 **3.2. Sedimentology**

173 Prior to laboratory sedimentological and geochemical analyses, contiguous 2 cm samples were combined to
174 create 4 cm sub-samples. The resulting 45 samples were then oven dried at 40°C and disaggregated using a
175 pestle and mortar. Dried samples were placed through a 2 mm mesh, and < 2mm sub-samples were retained
176 for sedimentological and geochemical analyses. Mass-specific magnetic susceptibility was measured using a
177 Bartington MS2 meter with MS2c dual frequency sensor at low (0.46 kHz, χ^{lf}) frequency, following the
178 protocol outlined in Dearing (1999). Percentage organic content was estimated from loss-on-ignition at
179 550°C (Heiri et al., 2001), and the percentage calcium carbonate equivalent was determined using a Bascomb
180 Calcimeter. Particle size analysis was undertaken using a Malvern Mastersizer 3000 laser granulometer with
181 a Hydro UM accessory following the protocol described in Glauberman et al., (2020a). Micromorphology

182 samples were prepared using standard impregnation techniques developed in the Centre for
183 Micromorphology at Royal Holloway, University of London. Thin sections were analysed using an Olympus
184 BX-50 microscope with magnifications from 20x to 200x and photomicrographs were captured with a Pixera
185 Penguin 600es camera. Thin section description followed terminology adapted from Bullock et al. (1985) and
186 Stoops et al. (2008).

187 3.3. Chronology

188 *Luminescence dating*

189 Luminescence measurements were undertaken using the pIR225 approach as applied at several other Late
190 Pleistocene sequences in Armenia (Glauberger et al., 2020a; Malinsky-Buller, et al., 2021). Given the high
191 aeolian inputs into the cave, the 4-11 μm polymineral fine-grain fraction was selected for analysis, with the
192 equivalent dose (De) rate estimated through the pIR225 approach adapted from Malinsky-Buller et al., 2021.
193 The method is described in full in **supplementary information 1**. Dosimetry data, equivalent doses and
194 luminescence age estimates are presented in **Table 3**.

195 *Radiocarbon dating*

196 Six charcoal samples and nine animal bones from units 2a-b, 2d, 4 and 5 were selected from the excavated
197 material for accelerator mass spectrometer (AMS) dating (Table 4). A full description of the methods is
198 provided in **supplementary information 1**. In summary, charcoal samples were pre-treated with the acid-
199 base-acid (ABA) protocol outlined in Dee et al, 2020 and dated at the Centre for Isotope Research (CIO) at
200 the Energy and Sustainability Research Institute (ESRIG) of the University of Groningen, (lab code GrM).
201 Collagen extraction of bone material was undertaken at the Max Planck Institute for Evolutionary
202 Anthropology using the ABA plus ultrafiltration protocol described in Fewlass et al. (2019) and Talamo et al.
203 (2021) Eight of the bones failed to yield any collagen and only one bone had a collagen yield of 8.5%, with
204 elemental (C%, N%, C:N) and stable isotopic values ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) falling within established ranges of well-
205 preserved collagen (van Klinken, 1999) (**SI 1, Table 1**). The collagen extract was AMS dated at the Klaus-
206 Tschira-AMS facility in Mannheim (MAMS).

207 3.4. Faunal remains

208 Macrofaunal remains recovered from the sequence were studied at the University of Ferrara and the
209 MONREPOS archaeological research centre. Taxonomic classification was aided by anatomical atlases and
210 comparative collections where necessary. Taphonomic alteration of the material was recorded using a
211 combination of the naked eye and low-powered microscopy and classified using established protocols
212 (Behrensmeyer 1978; Binford 1981; Blumenschine et al., 1996; Fernández-Jalvo and Andrews, 2016; Vettese
213 et al., 2020). Special attention was given to possible anthropogenic modification, with burn damage and
214 cutmarks described following the criteria of Stiner et al. (1995) and Lyman (2008) respectively.

215 Microfaunal remains were studied at the University of Winchester and the Catalan Institute of Human
216 Palaeoecology and Social Evolution (IPHES). Identification was aided through the use of a Zeiss SteREO
217 Discovery V8 (0.63x to 10x magnification) stereomicroscope, a digital camera (5 megapixels) with colour-
218 CMOS-sensor, and a Zeiss Smartzoom 5 (34x to 1010x magnification) 3D digital microscope. Taphonomic
219 alteration of the remains was classified following the criteria of Lyman (2008) and Fernández-Jalvo and
220 Andrews (2016). Macrofauna counts are presented as the number of remains (NR) number of identified
221 species (NISP), the minimum number of individuals (MNI) and the minimum animal unit (MAU). Microfaunal
222 counts are presented as NISP and NR.

223 3.5. Charcoal remains

224 Charcoal remains were mostly recovered through flotation, while 21 fragments were handpicked from the
225 wet sieving residue. Each charcoal fragment was fractured manually to provide transverse, tangential, and
226 radial sections for taxonomic identification using a Nikon Labophot-2 bright/dark field incident light
227 microscope with 50–500× magnification at the University of Las Palmas de Gran Canaria. Botanical
228 identification was performed using specialised plant anatomy atlases (Fahn et al., 1986; Parsapajouh et al.,
229 1987; Schweingrüber, 1976; 1990) and online databases (InsideWood, 2004), in addition to a reference
230 collection of modern charred woody taxa. All the available charcoal samples were analysed. Photography
231 and detailed observations of the anatomical and taphonomic features were carried out using a Zeiss EVO MA

232 15 scanning electron microscope (SEM) at the General Research Support Service (SEGAI), University of La
233 Laguna.

234 3.6. Artefacts

235 This study includes a general description of the artefact assemblage recovered from Ararat-1 to assess
236 stratigraphic patterning. The recovered lithics were inventoried at the Institute of Archaeology and
237 Ethnography of the National Academy of Sciences, Republic of Armenia (IAE NAS) according to size (<10 mm
238 and >10 mm), raw material, and class and technological categories. Results of a detailed attribute analysis of
239 each artefact following the protocol outlined in Hovers (2009) and Malinsky-Buller et al., 2020 are
240 forthcoming in a separate study. In addition to the lithic assemblage, ceramic fragments were also recovered
241 from the Ararat-1 sequence. These fragments were studied at the IAE NAS, where each fragment was
242 assigned a class and archaeological designation.

243 4. Results

244 4.1. Stratigraphy, sedimentology & micromorphology

245 Field sedimentological descriptions for the north and west profiles of the Ararat-1 trench are presented in
246 **Table 1** and section drawings are shown in **Figure 2**. The strata exposed during the 2019 excavation (Units 1,
247 2a-d, 3, 4, 5) are comprised principally of matrix to clast supported angular to very angular limestone pebbles
248 to cobbles in a fine-medium silt matrix. Carbonate coatings on clasts are common throughout the sequence.
249 Units 1-5 are differentiated based on the size and frequency of gravel clasts and concretionary fabrics.

250 Unit 5 is represented at the base of the sequence and the lowermost contact of this unit was not reached
251 during the 2019 excavation. The unit comprises matrix-supported angular to very angular limestone clasts in
252 a matrix of fine silt to clay. Unit 4 is characterised by massive, poorly sorted clast-rich angular to very angular
253 limestone pebbles to cobbles in a fine-medium silt matrix. Overlying this, Unit 3 is formed of massive,
254 moderately-poorly sorted, matrix-supported, angular to very angular limestone pebbles to cobbles in a
255 matrix of fine-medium silt. The matrix is carbonate-bonded and ferruginous mottling is present. Unit 2d has

256 comparable properties to Unit 4, whilst Unit 2c is comprised of massive, poorly sorted clast-rich angular to
 257 very angular limestone clasts in a fine-medium silt matrix. Clasts range in size from small pebbles to large
 258 cobbles. Units 2b-a are formed of massive moderately-poorly sorted matrix supported angular to very
 259 angular limestone clasts in a matrix of fine-medium silt. Unit 2b is generally more clast rich than 2a and the
 260 clast size is larger (2a: granules-fine pebbles, 2b: fine pebbles-cobbles). The uppermost unit (Unit 1)
 261 comprises massive humic fine-medium silt representing the modern cave floor.

262 **Figure 3** presents the results of the bulk sedimentological analysis through the Ararat-1 sequence. Broadly,
 263 the sequence is characterised by low organic content (1. -9.8 %), low χ^{lf} ($12.3-17.7 \cdot 10^{-8} \text{ m}^3 \text{ kg}^{-1}$) and relatively
 264 high CaCO_3 values (27.7-48.2 %). Whilst there are no substantial variations in CaCO_3 content among strata,
 265 differences occur in both magnetic susceptibility and organic content. χ^{lf} values show a broad difference
 266 between the upper and lower strata, where mean χ^{lf} values in Units 5-3 are $14.9 \cdot 10^{-8} \text{ m}^3 \text{ kg}^{-1}$. These values
 267 decrease through Unit 2d to $12.3 \cdot 10^{-8} \text{ m}^3 \text{ kg}^{-1}$, above which they increase to $15.9 \cdot 10^{-8} \text{ m}^3 \text{ kg}^{-1}$ in Units 2c-2b.
 268 Unit 2a is characterised by relatively high mean χ^{lf} values of $17.0 \cdot 10^{-8} \text{ m}^3 \text{ kg}^{-1}$. Organic content shows a slightly
 269 different trend, with relatively lower values through Units 4 - 3 (mean = 3.2 %), before increasing through
 270 Unit 2d to values of c. 5%. A mean value of 5.1% characterises Units 2a-2c. Unit 1, representing the modern
 271 cave floor is characterised by lower χ^{lf} ($14.6 \cdot 10^{-8} \text{ m}^3 \text{ kg}^{-1}$) and CaCO_3 (38.7 %), and elevated organic content
 272 (9.8 %) in comparison to the underlying units.

273 The particle size distribution of the <2mm fraction indicates that Ararat-1 sediments are poorly sorted (σ_6
 274 3.2-5.7), with a coarse silt-fine sand texture. Median particle size through the sequence range between 38 -
 275 75 μm . There is minimal variation in particle size through Units 2a-3, however, Unit 4 is characterised by a
 276 relatively higher proportion of clay relative to the overlying strata (Figure 4). Whilst the deposits are poorly
 277 sorted, and polymodal in their particle size distribution, it is interesting to note that modal particle sizes are
 278 consistent throughout the sequence, with the first modal grain size value falling in the range of 62-72 μm and
 279 the second modal grain size value falling in the range of 12-20 μm .

280 The main micromorphological properties of the Ararat-1 sediments (Units 3, 2d, 2b, 2a) are presented in
 281 **Table 2** with photomicrographs of key features shown in **Figure 4**. The overall microstructure of the sequence

282 is massive to vughy sandy silt loam, with a single-spaced porphyric – chitonic coarse-fine (c/f ratio at 20 μm)
283 related distribution with a ratio of 4:1 to 3:2. The groundmass is principally calcitic and organoclastic with
284 volcanic ash and exhibits a crystallitic-speckled b-fabric. Evident through the sequence are subtle changes to
285 the microstructure, with Unit 2a exhibiting a platy microstructure (**Figure 4a**), with both Units 2a and 3a
286 exhibiting a higher degree of porosity (c. 40-50% of the slide cover) in comparison to Units 2b and 2d (**Figure**
287 **4b**). Sub-vertical passage features are present in Unit 2d (**Figure 4c**), and zones of calcite depletion within the
288 groundmass occur in both Units 2b and 2d (Figure 5d).

289 The coarse fraction of the Ararat-1 sediments is dominated by angular to sub-angular spartic limestone clasts,
290 with the presence of rounded pedorelicts, volcanic material (ash and mafic lithic fragments) and carbonate
291 (tufa and speleothem) lithoclasts (**Figure 4e**) throughout all units. On occasion, limestone clasts show peculiar
292 alteration to clay (*sensu* Bullock et al., 1985), and some limestone clasts possess continuous clay-micritic
293 calcite coatings (**Figure 4f**). These coatings tend to be more frequent in Unit 3, and there is also evidence for
294 calcite-silt clast cappings and phosphatic continuous clast coatings within this Unit. Organic residues occur
295 throughout all units and take form as principally amorphous brown-black organic fragments and angular
296 charcoal fragments. Occasional charcoal fragments preserve plant tissue structure in Unit 2a (**Figure 4g**), and
297 plant tissue remains with groundmass infillings are present in Unit 2d. Bone fragments are present
298 throughout the sequence; they show minimal alteration (although breakage is common), and rarely they
299 show evidence of phosphomicritisation, with the occurrence of microspartic calcite pendant cements
300 (**Figure 4h**). Typical phosphate nodules are identifiable throughout the sequence (**Figure 4i**), and rare orthic
301 Fe/Mn nodules are present in Unit 2a and Unit 3. Spartic calcite coatings around voids are also present in
302 Unit 3.

303 4.1.1. Sedimentological interpretation

304 The roughly stratified and poorly sorted nature of the deposits at Ararat-1 is consistent with the deposition
305 of principally clastic sediments near the cave entrance (White, 2007). The angular limestone clasts forming
306 the significant volume of deposits represent the local transport and deposition of material, likely through a
307 combination of 1) debris flows within, or near the entrance to, the cave system, and 2) periodic rockfalls

308 within the cave. The sedimentological properties of the surrounding matrix are consistent with
309 predominantly aeolian sedimentation, with some contribution of material from debris flows. Such an
310 interpretation is supported by the polymodal particle size distribution of the strata, with the finer modal size
311 fraction consistent with the suspension of material by wind action. The presence of pedorelicts and
312 fragments of volcanic material at the microscale also indicate inputs of surficial material from the plateau
313 above the cave through the epikarst via water action. Transport of material from elsewhere within the karstic
314 system is also evidenced by the presence of tufa and speleothem lithoclasts. CaCO_3 values through the
315 Ararat-1 sequence are generally high, reflecting the contributions of the limestone bedrock lithology,
316 secondary carbonates formed within the sequence (carbonate clast coatings), and carbonate derived from
317 aeolian sources. The relatively low χ^{lf} values observable throughout the sequence likely reflect the high
318 abundance of diamagnetic carbonate material in the deposits (Dearing, 1999), but also contributions of other
319 mineralogies with the transport of non-carbonate material into the cave system through aeolian, debris flow
320 and infiltration processes. Differences in χ^{lf} values through the sequence are therefore suggested to
321 represent the differing contributions of these non-carbonate mineralogies.

322 Whilst there is evidence for stratification of the Ararat-1 deposits, broadly there are no large differences in
323 the bulk sedimentological parameters and micromorphological properties between units, suggesting no
324 significant shift in the style of sediment deposition through the sequence. Variations in the frequency and
325 size and clasts between strata are interpreted here to reflect the relative contributions of clastic sediment
326 supply. The clearest example of this is the angular to very angular clasts that characterise Unit 2c. These are
327 interpreted here to represent a large rockfall event within the cave which likely acted to seal the underlying
328 deposits from significant erosion.

329 There is evidence for syn- and post-depositional modification of the Ararat-1 sediments. This is reflected
330 principally by the presence of secondary carbonate features at both the macroscale (clast coatings) and
331 microscale (clast and void coatings and pendants cements), indicating the dissolution and translocation of
332 calcium down sequence due to water activity. Calcite depletion features observable in the upper strata and
333 generally higher abundance of secondary carbonate features in Unit 3 support such a hypothesis. The

334 presence of apatite nodules and phosphate cements within the sequence also indicates the translocation of
335 phosphate within the Ararat-1 sequence, through a combination of the dissolution of bone apatite due to
336 weathering processes and phosphate enrichment by animal excretory products (Karkanas and Goldberg,
337 2010). In both cases, the decay of organic matter/bone led to enhanced phosphate concentrations in water
338 percolating through the Ararat-1 strata, ultimately leading to the in-situ formation of phosphate minerals
339 (Shahack-Goss et al., 2004). Post-depositional disturbance of the sequence is also evidenced by the
340 occurrence of passage features indicating bioturbation of the sediments by faunal activity, and the platy
341 microstructure within the upper part of Unit 2a. Such a structure is commonly associated with trampling and
342 compaction of the cave floor by anthropogenic and/or faunal activity (Rentzel et al., 2017). Indeed, the
343 presence of ceramic and modern animal excrement found on the modern cave floor, and the presence of
344 both intrusive ceramics and modern bone material within Units 2a-2c (see sections 4.3 and 4.5 below)
345 supports such an interpretation.

346 4.2. Chronology

347 The results of pIR225 luminescence dating of Units 2a - 4 are presented in **Table 3**. Age estimates place the
348 interval of sediment accumulation in Ararat-1 between 52.4 ± 3.6 ka (Unit 4) and 35.1 ± 2.5 (Unit 2a) with no
349 evidence of a considerable temporal hiatus in the accumulation of the fine-grained fraction of Units 4-2a. ^{14}C
350 age estimates for the charcoal fragments and bone remains are presented in **Table 4**. The single bone
351 fragment from Unit 2b which preserved a high enough concentration of collagen to produce an age yielded
352 an estimate of cal AD 1680 – 1940 (2σ). Calibrated ^{14}C ages of the charcoal fragments from Units 2a and 2b
353 range from cal AD 607–675 (2σ) to modern. A single charcoal fragment from Unit 3 has yielded a calibrated
354 age of 44,660 – 42,370 cal BP (2σ).

355 The recent ages of the charcoal fragments and bone from the upper strata of the Ararat-1 cave sequence are
356 clearly at odds with the pIR225 luminescence ages obtained from the same strata which have yielded an age
357 range of 33.4 ± 2.5 ka (Unit 2b) and 35.1 ± 2.5 ka (Unit 2a) respectively. The elemental and isotopic
358 composition of the single bone fragment with good collagen preservation recovered from Unit 2b indicates
359 that the younger age estimate of this material is not the outcome of contamination. Instead, it implies the

360 fragment has intruded into the older sediment. Poor collagen preservation in other bone samples from the
361 sequence also suggests that taphonomic processes affecting the Ararat-1 upper strata may have led to these
362 young ages. This hypothesis is supported by the presence of bioturbation and modern root features, as well
363 as ceramic fragments recovered from Units 2a-2c at a maximum depth of 0.8 m below surface. The presence
364 of refits of medium-sized ungulate bone fragments recovered from Units 2a and 2c suggests that post-
365 depositional translocation of material through the Ararat-1 sedimentary has also taken place. All of these
366 lines of evidence indicate that more recent (Holocene) material has intruded into the Ararat-1 upper strata,
367 and the ^{14}C ages of the charcoal and bone from this part of the sequence reflect this. In contrast, comparable
368 ^{14}C age of the charcoal and pIR225 depositional age estimate of Unit 3 sediments, suggest that the lower
369 strata of Ararat-1 were less impacted by post-depositional processes and can provide more reliable ages of
370 deposition at the site.

371 **4.3. Macrofauna & microfauna remains**

372 The Ararat-1 macrofauna assemblage is comprised of 1050 bones and bone fragments (**Table 5**). These are
373 most abundant in Units 4 (NR= 328), Unit 3 (NR= 252) and Unit 2d (NR = 298). Units 2a - 2c yielded
374 comparatively fewer remains (NR 2a = 34, 2b = 26 and 2c = 96). The macrofaunal assemblage is characterised
375 by a high quantity of unidentified bone splinters (NR = 790) and isolated teeth (NR = 69). The majority (69 %)
376 of remains are 20 mm or smaller in size. Complete elements are represented by only three isolated teeth,
377 one astragalus, one sesamoid, two long bones (femur and metapodial) and one vertebra. Cortical surfaces
378 are poorly preserved with carbonate concentrations, dissolution and exfoliation observed across the majority
379 of bone surfaces. Throughout the sequence, there is evidence for water dissolution (ranging between 5 – 31
380 % NR in each unit) and root etching (ranging between 16 – 45 % NR in each unit). There is limited evidence
381 for cracking, polishing, or blunting of bones, and only one bone fragment (from Unit 2c) shows evidence of
382 rodent marks. Carnivore traces (pits, grooves, notches and gnaw marks) and digestion marks are present in
383 2 % of bone remains and are principally associated with Units 2c and 4 (**Figure 5**). A single coprolite measuring
384 32 mm³ was recovered from the lowest part of Unit 2d. Burning damage was also observed on 3.4 % of
385 remains, mainly from Units 2c and 3. Possible cutmarks were also identified on nine fragments of long bone

386 recovered from Unit 2d (a full summary of the macrofaunal taphonomic study is found in **supplementary**
387 **information 2**).

388 Due to the high levels of fragmentation and taphonomic modification of the macrofaunal remains from
389 Ararat-1, only 27 specimens could be taxonomically classified, representing seven species and 16 MNIs. The
390 predominant taxa represented are middle-class sized caprines (*Capra ibex* and *Cabra* or *Ovis*), which occur in
391 Units 2b (1), 2d (2), 3 (1) and 4 (6). Small carnivores include badger (*Meles meles*) recovered from Unit 2a,
392 lynx (*Lynx* sp), recovered from Unit 4, and fox (*Vulpes vulpes*) recovered from Units 2a, 2b and 2c. No large
393 carnivore remains were identified in the sequence. Large ungulates are represented by a single tooth of
394 *Equus* sp. recovered from Unit 4. A small number of lagomorph (NR = 4) and bird (NR = 4) remains were
395 recovered from Units 2d and 4 Units 2b, 2d and 3, respectively. A single refit on a dry bone fracture of a
396 medium-sized ungulate radius found in Units 2a and 2c was also identified in the remains.

397 The microfaunal assemblage of Ararat-1 comprises 2437 bone remains. Almost half the remains were derived
398 from Unit 2b, whilst 20.7 % of remains recovered from Unit 2a and 13.0 % from Unit 2c. Microfauna counts
399 for the rest of the sequence are relatively lower and account for 6.8 % (Unit 2d), 2.2 % (Unit 3), 3.6 % (Unit
400 4) and 1.1 % (Unit 5). 1733 specimens (79 % of total assemblage) were unidentifiable. Digestive modification
401 is identifiable on almost all the remains (99.8%) and is mainly concentrated on the epiphyses and articular
402 surfaces. Of these bones, 24.3% showed evidence of heavy and extreme digestion, whilst 39.7 % and 35%
403 showed evidence of moderate and light digestion, respectively.

404 Taxonomic classification of the microfaunal assemblage from Ararat-1 is shown in **Table 6**. The sequence is
405 characterised by a wide range of mammalian and herpetofauna taxa. Small mammals include the Afghan pika
406 (*Ochotona rufescens*), the southern white-breasted hedgehog (*Erinaceus concolor*) and the small five-toed
407 jerboa (*Allactaga elater*). Single occurrences of Anatolian ground squirrel (*Spermophilus xanthoprymnus*), the
408 European water vole (*Arvicola amphibius*), the common vole (*Microtus arvalis*), the bicolored shrew
409 (*Crocidura leucodon*), the Levantine mole (*Talpa levantis*), and Nehring's blind mole rat (*Nannospalax*
410 *xanthodont*) were also identified. Also evident are at least one species of the genus *Meriones* (possibly
411 *Meriones dahli*) and remains from the subgenus *Mus* sp. The herpetofauna is represented by the variable

412 green toad (*Pseudepidalea varibilis*), the Caucasian agama (*Paralaudakia caucasica*), the Levantine viper
413 (*Macrovipera lebetina obtuse*), as well as multiple snake species of the family *Colubridae*.

414 Together, the macrofaunal and microfaunal remains from the Ararat-1 sequence allow for inferences to be
415 made regarding the principal agents of accumulation and taphonomic alteration at the site. The presence of
416 lynx and fox in the lower Ararat-1 strata (Units 2d - 4) alongside coprolitic material and evidence of carnivore
417 marks on bones suggests that carnivore activity was the principal agent of faunal accumulation in the lower
418 part of the Ararat-1 sequence. Burnt bones and possible cutmarks on material derived from Units 2c and 2d
419 suggest that anthropogenic activity may have also contributed to the accumulation of faunal remains. The
420 absence of these features in the upper Ararat-1 strata (Units 2a - 2b), combined with a reduction in the
421 volume of larger faunal material suggests a shift in the principal mode of accumulation. The presence of a
422 high frequency of microfaunal remains, the majority of which have evidence of digestive modification,
423 indicates that avian predation was driving bone accumulation at the site. The digestion patterns evident in
424 the microfaunal assemblage are consistent with a large nocturnal avian predator, likely the Eurasian Eagle-
425 owl (*Bubo bubo*; Andrews and Andrews, 1990). Supporting this inference is the high diversity of faunal
426 material that exhibits digestive modification, combined with the fact that this taxon has a wide Eurasian
427 distribution, and a preference for rocky and mountainous areas with some woodland stands (Holt et al.,
428 2013).

429 The Ararat-1 faunal assemblage provides strong evidence of various taphonomic processes that have
430 affected the remains. While there is limited evidence of weathering, the high degree of fragmentation and
431 chemical alteration (dissolution and carbonate concentrations) of the bones suggests that post-depositional
432 physiochemical alteration has occurred. The high fragmentation of bones is the result of a combination of
433 breakage from high-energy sediment deposition within the cave and bioturbation of the sequence, primarily
434 by root growth and faunal activity. This is supported by the presence of badger in the upper strata of the
435 sequence and root moulds on many of the bone fragments, both of which strongly suggest that bioturbation
436 of the upper strata has taken place. The percolation of calcium-rich vadose waters from the cave system

437 through the Ararat-1 sequence is likely the primary cause of the observed chemical alteration of the surface
438 of the bone remains.

439 Notwithstanding these taphonomic modifications, the faunal remains from Ararat-1 allow inferences to be
440 made regarding prevailing environmental conditions at the time of sediment accumulation. Together, the
441 presence of caprines (such as *Capra ibex*), lynx and *Equus* spp. suggest rocky and open environments. The
442 occurrence of small mammalian taxa such as *Ochotona rufescens*, *Erinaceus concolor*, *Allactaga elater*, and
443 *Arvicola amphibius* indicates more of a mosaic landscape alternating between dry shrub and grassland and
444 temperate woodland. Given the inferred predation of these small mammals was by the Eurasian Eagle-owl,
445 then there was likely a water body within the hunting radius of this taxon (c. 40 km², Sándor and Ionescu
446 2009; Amr et al. 2016, Guillard et al. 2018). The absence of small mammalian fauna commonly associated
447 with humid conditions may also hint at relatively drier conditions at the Ararat-1 locale during the interval of
448 accumulation.

449 4.4. Charcoal remains

450 212 charcoal fragments from Ararat-1 were analysed. The number of charcoal remains recovered from each
451 stratigraphic unit is small, with half (n = 106) recovered from Unit 2c (**Table 7**). Biodegradation features
452 caused by fungi and bacteria are evidenced in the charcoal remains with a small number of fragments also
453 showing evidence of vitrification. Where possible, charcoal fragments were assigned a genus, family, or type-
454 level classification. The most representative taxa in the Ararat-1 sequence is *Rhammus* sp., followed by
455 Chenopodiaceae and *Prunus* sp. *Amygdalus*. The assemblage also yielded fragments belonging to
456 *Anacardiaceae*, *Asteraceae*, *Monocotyledoneae* and *Tamarisk* sp. (**Figure 6**).

457 The anthracological results from Ararat-1 should be interpreted cautiously given the low fragment numbers
458 per stratigraphic level (Chabal, 1992). Broadly, the assemblage is characterised by the presence of semi-arid
459 and arid taxa with low humidity requirements. Specifically, the presence of *Rhammus* sp. and
460 Chenopodiaceae indicates open-shrub vegetation and dry conditions with a severe seasonal moisture
461 deficiency. Evidence of vitrification (i.e., fusion of cellular tissue) may hint at the possibility of firewood

462 acquisition strategies involving deadwood (e.g., Vidal-Matutano et al., 2017). However, the preliminary
463 nature of the charcoal assemblage from Ararat-1 precludes a full interpretation of these findings.

464 **4.5. Artefact assemblage**

465 Two main artefact assemblages were recovered from the Ararat-1 sequence; a small ceramic assemblage
466 recovered from the upper strata of the sequence (Units 1-2c), and a larger lithic assemblage recovered
467 throughout the sequence.

468 The ceramic assemblages comprise a total of 55 fragments (**supplementary information 3**). 43 of these are
469 attributed to the Chalcolithic period, 9 to the Late Bronze Age, and 3 to the Early Medieval Period. Many
470 fragments represent body shards with a few that also preserve portions of vessel rims, necks, or bases. A
471 third of the assemblage was found on the surface (n = 17), whilst the majority were found within Unit 2a (0.1
472 - 0.3 m below surface). 4, fragments, all attributed to the Chalcolithic period, were found in Unit 2b (0.3 - 0.8
473 m below surface), whilst no fragments were recovered from below Unit 2b.

474 The Ararat-1 lithic assemblage is comprised of 661 artefacts, of which 134 are smaller than 10 mm (**Figures**
475 **7, 8**) The majority of these were recovered from Units 2c (n = 268, 40.6 %), 2d (n = 152, 23.0 %), and 2b (n =
476 91, 13.7%), with only a small number of artefacts recovered from Units 2a, 3 and 4. The lithic assemblage are
477 fresh and in mint condition with no signs of secondary modifications due to natural transportation. Chert
478 followed by obsidian are the dominant lithic raw materials, with single occurrences of dacite, chalcedony,
479 and quartzite (**Figure 8**). Evident in the sequence is the size-partitioning of lithic remains. The obsidian
480 component is comprised of a higher frequency of pieces < 10 mm in comparison to the chert, with retouched
481 pieces comprised of a high frequency of convergent scrapers (**Figure 7**). The chert component is generally
482 larger in size with representation of all stages of reduction sequence. Differences between the raw materials
483 suggest that two modes of technological organisation may have operated at Ararat-1 cave. Whilst chert was
484 principally transported onsite for initial reduction, the obsidian retouched pieces were likely transported to
485 the cave where they were maintained, rejuvenated, and transported again.

486 The techno-typological affinities of the Ararat 1 lithic assemblages are shared with other late MP assemblages
487 in the Armenian Highlands and southern Caucasus (Adler, 2002, Adler et al., 2012; Moncel et al., 2015; Frahm
488 et al., 2016; Glauberman et al., 2020; Malinsky- Buller et al., 2020; Malinsky-Buller et al., 2021). Similar
489 technological organisation related to the differences between local (chert) and far travelled (obsidian) raw
490 material have also been identified in other MIS 3-aged sites in the region, including Ortvale Klde, Georgia
491 (Adler et al., 2006; Adler, 2002; Moncel et al., 2015), Kalavan 2 (Malinsky-Buller et al., 2021) and Yerevan
492 cave (Gasparyan et al., 2014; Gasparyan and Glauberman, 2022; Yeritsyan, 1972; Yeritsyan and Semyonov,
493 1971).

494 **5. Discussion**

495 **5.1. Ararat-1 site formation processes**

496 Combined sedimentological, chronological, biological, and archaeological evidence from the Ararat-1
497 sequence provides evidence of site formation processes during the late Quaternary. Like other cave contexts
498 (e.g., Farrand, 2001; O'Connor et al., 2017), there is evidence of post-depositional modification of the Ararat-
499 1 sediments. This complicates the interpretation of the archaeological and environmental records derived
500 from the sequence. The consistency of the pIR225 ages across the sequence indicates minimal remobilisation
501 of aeolian material within the cave system. However, as previously discussed, the intrusion of Holocene
502 material into the Pleistocene sediments is evident, based on the presence of pottery fragments and charcoal
503 bearing a modern ^{14}C age in the upper part of the sequence. Furthermore, evidence of bioturbation is present
504 in the upper strata, indicates disturbance of this part of sequence as a consequence of biological activity.
505 Nevertheless, this disturbance appears largely confined to Units 1-2b, while the lower strata (Units 2c-5)
506 remain relatively undisturbed. We propose that the large rockfall event that resulted in the formation of Unit
507 2c may have sealed the lower strata, thus accounting for the reduced impact of recent anthropogenic and
508 biological activity on these units and the archaeological and faunal material contained within. Translocation
509 of fine-grained material within these underlying units is evident, although it is unlikely to have vertically
510 displaced faunal and archaeological remains from the site. However, it has led to the modification of bone
511 surfaces, resulting in a high number of unidentifiable remains. These translocation processes may have also

512 contributed to the redistribution of finer biological material (e.g., charcoal) within the sequence. Considering
513 these taphonomic uncertainties, there is evidence for temporal changes in the principal agents of
514 accumulation (geological, biological, and anthropogenic) at Ararat-1.

515 The earliest sediment accumulation phase identified at Ararat-1 is documented in Units 5-3. The basal pIR225
516 measurement of the sequence indicates that sediment deposition occurred by 52.4 ± 3.6 ka (Unit 4). The
517 duration of this phase, estimated at 4-14 kyr, is supported by a sole ^{14}C age obtained from a charcoal fragment
518 in Unit 3 (44,660-42,370 cal BP) and pIR225 ages from the same unit (44.3 ± 2.9 ka). Sedimentation during
519 this interval was the result of a combination of aeolian processes and high-energy cave debris flows and
520 collapse, as inferred from the bimodal size distribution of the cave sediments. The fragmented nature of the
521 faunal material recovered from these units (and the entire Ararat-1 sequence) may be attributed to the
522 periodic high-energy coarse-grained sedimentary inputs into the cave system, which could have caused bone
523 material to break and crush. Despite these modifications, the faunal evidence from these units indicates that
524 the cave was frequented by small carnivores during this period, supported by the presence of lynx remains,
525 likely carnivore coprolitic material, and modification of bone fragments. The low lithic artefact density in
526 these units suggests that the cave was only sporadically occupied by hominins during this time.

527 Although there is no clear evidence for significant changes in sediment deposition style, the archaeological
528 and faunal material retrieved from Units 2d-2b reveals a shift in the dominant agents of accumulation at
529 Ararat-1 at around 45 ka (Unit 2d: 45.1 ± 3.0 ka). The increased lithic artefact density found in these strata
530 suggests that they represent the primary MP occupation phase within the cave. The pIR225 estimates from
531 Unit 2b (35.1 ± 2.5 ka) suggest that this period of occupation could have lasted for between approximately
532 5-10 kyr, but the indirect association of the luminescence and charcoal ^{14}C dates with human activity
533 precludes a more precise estimate for the duration of hominin activity at the site until further chronological
534 data is available. There is evidence of on-site core reduction of chert, retouching of obsidian raw materials
535 and tools and potentially cut marked bone hinting at the ephemeral use of the site, possibly for processing
536 meat. While there are indications of burnt bone and a rise in macrocharcoal remains in these layers, further
537 anthracological data from the site is needed to evaluate the possibility of short-term, sporadic use of fire at

538 this site. The faunal assemblage from these strata reveals a decrease in larger mammalian remains, as well
539 as an increase in microfauna, indicating that the cave became predominantly a bird-nesting locale. The
540 abundance of microscale phosphatic features in the sediments from these strata further suggests heightened
541 faunal activity and associated excretory products. It is worth noting that ^{14}C ages derived from charcoal in
542 Unit 2b produced modern ages, indicating intrusion of modern material into these strata.

543 The third phase of sediment accumulation at Ararat-1 is characterised by a decrease in lithic artefact densities
544 and an increase in microfaunal remains within Unit 2a at 33.4 ± 2.5 ka. This indicates that the cave primarily
545 served as a bird-nesting location and the main contributors to faunal accumulation were raptors, likely the
546 Eurasian eagle owl. The presence of badger remains in this stratum may suggest that sediment mixing and
547 burrowing could have occurred (Mallye, 2011; Arilla et al., 2020), which is supported by micromorphological
548 evidence for faunal bioturbation. While low lithic artefact densities in this stratum may suggest sporadic
549 hominin occupation, the age and stratigraphic integrity of these artefacts remains uncertain due to the small
550 number of finds and evidence of mixing of more recent materials in this unit.

551 The most recent phase of sediment accumulation at Ararat-1 is represented by the presence of ceramic
552 fragments from the Chalcolithic-Middle Age periods, which were found on the modern cave floor and in Unit
553 1. Modern organic material and excrement in Unit 1 indicate that the cave has been occupied recently. This
554 recent anthropogenic and faunal activity has caused disturbance in the upper layers of the Ararat-1 sequence
555 (Units 1a-2b), as indicated by the presence of ceramic fragments in these units, and by the modern ^{14}C ages
556 of macroscale charcoal found in Units 2a-2b (cal AD 607 – 1634).

557 **5.2. Environmental and archaeological significance**

558 The Ararat-1 sequence provides a depositional history spanning c. 52-35 ka, with the main MP occupation of
559 the cave from c. 45 ka. Despite the evidence of disturbance in the cave sequence, we currently consider this
560 age to be accurate pending further chronometric study due to the homogeneity of ages from the two
561 independent absolute dating techniques (pIR225 and ^{14}C) in Unit 2d. This date coincides with ages estimates
562 of a range of late MP sites in the region, including Barozh-12 located on northern flanks of the Ararat

563 Depression (Glauberman et al., 2020 a,b), Bagratashen-1 located in the Debed Basin (Egeland et al., 2016),
564 and Kalavan-2 located in the northern flanks of the Areguni Mountains (Malinsky-Buller et al., 2021), and
565 Lusakert-1 cave, located in the Hrazdan River valley (Sherriff et al., 2019).

566 Sedimentological and faunal evidence from Ararat-1 provides a record of environmental conditions during
567 this occupation. The lack of substantial shifts in the style of sedimentation, combined with the absence of
568 significant turnover in faunal populations suggests quiescent conditions around the cave locale during the
569 interval of approximately 52-35 ka. The presence of significant aeolian inputs into the cave is indicative of
570 arid conditions that would have allowed for the mobilisation of fine-grained material from the Ararat
571 Depression and the wider area into the cave. Together, the macro- and microfaunal remains indicate
572 sediment accumulation under a semi-arid to arid climate regime during the MIS 3 period. The ecological
573 niches, consisting of a mosaic of xerophytic open shrub, grassland, and temperate woodland around the cave
574 locale, were like those found in the Ararat Depression today (Voldicehva, 2002). The prominent position of
575 the cave, overlooking the low-lying palaeo-Araxes floodplain, together with these diverse ecological niches,
576 would have been an appealing locale for MP occupation. Indeed, evidence for anthropogenic modification of
577 bone material and evidence of burning suggests that these local resources were used opportunistically by
578 hunter-gatherer populations.

579 The Ararat-1 lithic assemblage is comprised predominantly of chert and obsidian. Chert occurs locally in
580 outcrops of Jurassic-Cretaceous ophiolites (Avagyan et al., 2010) around Vedi village, c. 10 km north of the
581 cave. Alluvial fan deposits found on the western margin of the Ararat Depression close to the Ararat-1 cave
582 entrance also contain chert (Karambagalidis, pers. observation), derived from the sedimentary and ophiolitic
583 formations associated with the Urts Anticline. The prominent obsidian component in the Ararat-1 lithic
584 assemblages indicates that obsidian was also exploited during the interval of cave occupation. The nearest
585 obsidian sources are located at high elevations, including the Arteni volcanic complex on the western margins
586 of the Basin (1754 m asl), Mt. Geghasar in the Gegham Highlands (2800-3100 m asl), and the Gutanasar
587 volcanic complex in the Kotayk Plateau (1800 m asl), which lie 60-100 linear km away from Ararat-1. Although
588 results of the chemical characterisation of the Ararat-1 obsidian artefacts are forthcoming, its presence in

589 the Ararat-1 sequence indicates that these hunter-gatherer populations were able to access and use raw
590 materials from a range of ecological niches along altitudinal gradients.

591 Ararat-1 contributes to the increasing number of MP sequences in the Armenian Highlands and southern
592 Caucasus that allow for insights to be made regarding settlement organisation. Hunter-gather decision
593 making relating to mobility has been suggested to be influenced by a range of ecological factors, including
594 shifts in resource distribution and social demographic behaviours (Kelly, 2013). However, this is challenging
595 to elucidate using lithic artefact characteristics (e.g., Bicho and Cascalheira, 2020) and/or faunal proxy
596 evidence (Mitki et al., 2021). These challenges are further amplified when taking into consideration site
597 formation processes and broader landscape-scale geomorphological agents. For example, differences in
598 artefact densities at Ararat-1 (c. 30 n/m³) and the nearby site of Barozh-12 (c. 1700 – 8000 n/m³) may be
599 interpreted in the context of behavioural variability, with apparent more frequent occupations at Barozh-12
600 a consequence of proximity to raw material and ecological resources (Glauberman et al., 2020a). However,
601 the sediments at Barozh-12 have been subject to deflation processes, which may have acted to concentrate
602 lithic material, resulting in these high densities. Consequently, the use of artefact density as a behavioural
603 marker should be used cautiously and site formation need to be taken into consideration in these calculations
604 (Bar-Yosef, 1998). Further work at Ararat-1 will focus on utilisation of the multiproxy evidence derived from
605 the sedimentary sequence to achieve a better understanding of MP subsistence behaviours at the locale.

606 The evidence for stable conditions during MIS 3 at Ararat-1 may add to the growing body of evidence for
607 localised differences in environmental conditions during this period. For example, combined
608 sedimentological and biomarker data from Barozh-12 indicates increased aridity from 65-45 ka, followed by
609 a more humid phase from 33-28 ka (Glauberman et al., 2020a). Similarly, pollen and faunal evidence Hovk-1
610 suggest fluctuations between cold, dry, and open conditions around 55 ka, with more humid and vegetated
611 conditions around 33 ka (Pinhasi et al., 2008, 2011). Conversely, the micro-faunal assemblage from Kalavan-2
612 indicates more humid and vegetated conditions during early MIS 3 (60-45 ka; Malinsky-Buller et al., 2021),
613 whilst faunal remains from the Upper Palaeolithic site of Aghitu-3 suggest relatively warm and humid climate
614 conditions similar to present-day from 39-36 ka (Kandel et al., 2017). Although there is limited

615 palaeoenvironmental evidence for MIS 3 elsewhere in the Armenian Highlands, malacological evidence from
616 the loess-palaeosol sequences (LPS) in the Sevkar region shows a predominance of semi-desert and xerophilic
617 steppe taxa, indicating persistently arid conditions throughout MIS 3 (Wolf et al., 2016; 2022; Trigui et al.,
618 2019; Richter et al., 2020).

619 Whilst sites such as Barozh-12 align with regional palaeoclimatic records, the majority of data from the
620 Armenian Highlands contrasts with the palaeoclimatic reconstructions from Lake Van during MIS 3, which
621 exhibit fluctuations between relatively more arid and more humid conditions on a millennial scale (Litt et al.,
622 2014; Stockhecke et al., 2016; Randlett et al., 2017). This divergence in local environmental conditions during
623 MIS 3 could be due in part to site-specific preservation biases and chronological uncertainties, which limit
624 direct correlation and comparison of environmental records. However, these differences may indicate local
625 complexity in the expression of MIS 3 climates, with elevation being a contributing factor. Lower altitude
626 sites, such as the Sevkar LPS (c. 680 – 980 m asl), Ararat-1, and Barozh-12, appear to record relatively more
627 arid conditions during MIS 3 than sites located at higher altitudes, such as Hovk-1 cave and Kalavan-2.
628 Evidence from the Sevkar LPS suggests that elevation amplified the effects of regional climate change over
629 glacial-interglacial timescales. For instance, there is evidence for the contraction of forest communities into
630 mid-altitude areas and the expansion of steppe communities into higher and lower-elevation areas during
631 glacial/stadial periods due to enhanced aridity (Ritcher et al., 2020). This suggests that vegetation
632 communities were shifting their altitudinal distribution in response to climate change. Although it is not
633 possible to investigate these patterns within a single isotope stage such as MIS 3 at this time, it does suggest
634 a close relationship among climatic variability, elevation, and ecological change in the Armenian Highlands.
635 During MIS 3, local climatic variation would have resulted in a further diversity of ecological niches, providing
636 MP populations with a wide resource base, potentially allowing them to persist in the Armenian Highlands
637 much later than in other parts of Southwest Asia.

638 **6. Conclusions**

639 This study presents the first results of sedimentological chronological, faunal, and archaeological research on
640 the MIS 3 cave sequence of Ararat-1, located on the eastern margins of Ararat Depression, Armenian

641 Highlands. We demonstrated that sediment accumulation occurred between 52 – 35 ka and was caused by
642 a combination of aeolian activity, cave rockfall and water action. Whilst the upper strata of the Ararat-1
643 sequence have undergone post-depositional disturbance due to faunal and anthropogenic processes, the
644 cave sequence contains evidence for four phases of sediment accumulation during MIS 3 and the Holocene.
645 Evident through the sequence are changing agents of accumulation, with the locale being used principally by
646 carnivores, followed by more intensive hominin occupation and a subsequent interval on which the cave was
647 principally used as a bird of prey locale.

648 During a stable period within MIS 3, Ararat-1 was inhabited by hominins amidst a mosaic of semi-arid shrub,
649 grassland, and temperate woodland ecosystems. Hominins utilised both local and distant toolstone raw
650 materials, suggesting they had the ability to adapt to a wide range of ecological and elevation gradients.
651 Climatic reconstructions from Ararat-1 further highlight the spatial variability of MIS 3 environments and its
652 role in hominin land use adaptations, demonstrating the importance of the Armenian Highlands for
653 understanding regional MP settlement dynamics during a critical period of hominin dispersals and evolution.

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