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1 **Human responses to environmental change on the southern coastal**
2 **plain of the Caspian Sea during the Mesolithic and Neolithic periods**

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33 **Abstract**

34 This paper presents results of a multidisciplinary research initiative
35 examining human responses to environmental change at the intersection of
36 the southern coastal plain of the Caspian Sea and the foothills of the Alborz
37 Mountains during the terminal Pleistocene and early Holocene. Our palaeo-
38 environmental analysis of two sedimentary cores obtained from a lagoon in
39 close proximity to four caves, occupied by human groups during the transition
40 from hunting and gathering to food-producing ways of life in this region,
41 confirms Charles McBurney's 1968 hypothesis that when Caspian Sea levels
42 were high, Mesolithic hunters were reliant on seal and deer, but as water
43 levels receded and a wide coastal plain emerged, hunters consumed a
44 different range of herbivorous mammalian species.

45 Palynological evidence obtained from these two cores also
46 demonstrates that the cool and dry climatic conditions often associated with
47 the Younger Dryas stadial do not appear to have been extreme in this region.
48 Thus, increasingly sedentary hunting and gathering groups could have drawn

49 on plant and animal resources from multiple ecological niches without
50 suffering significant resource stress or reduced population levels that may
51 have been encountered in neighbouring regions. Our analyses of botanical,
52 faunal and archaeological remains from a recently-discovered open-air
53 Mesolithic and aceramic Neolithic site also shows an early process of
54 Neolithization in the southern Caspian basin, which was a very gradual, low-
55 cost adaptation to new ways of life, with neither the abandonment of hunting
56 and gathering, nor a climatic trigger event for the emergence of a low-level,
57 food-producing society.

58 **Key words (3-7 words)**

59 Palynology; Archaeology; Caspian Sea levels; Vegetation dynamics; Human
60 response; faunal and botanical evidence; Neolithization; Pleistocene-
61 Holocene transition; Palaeogeography; Middle East

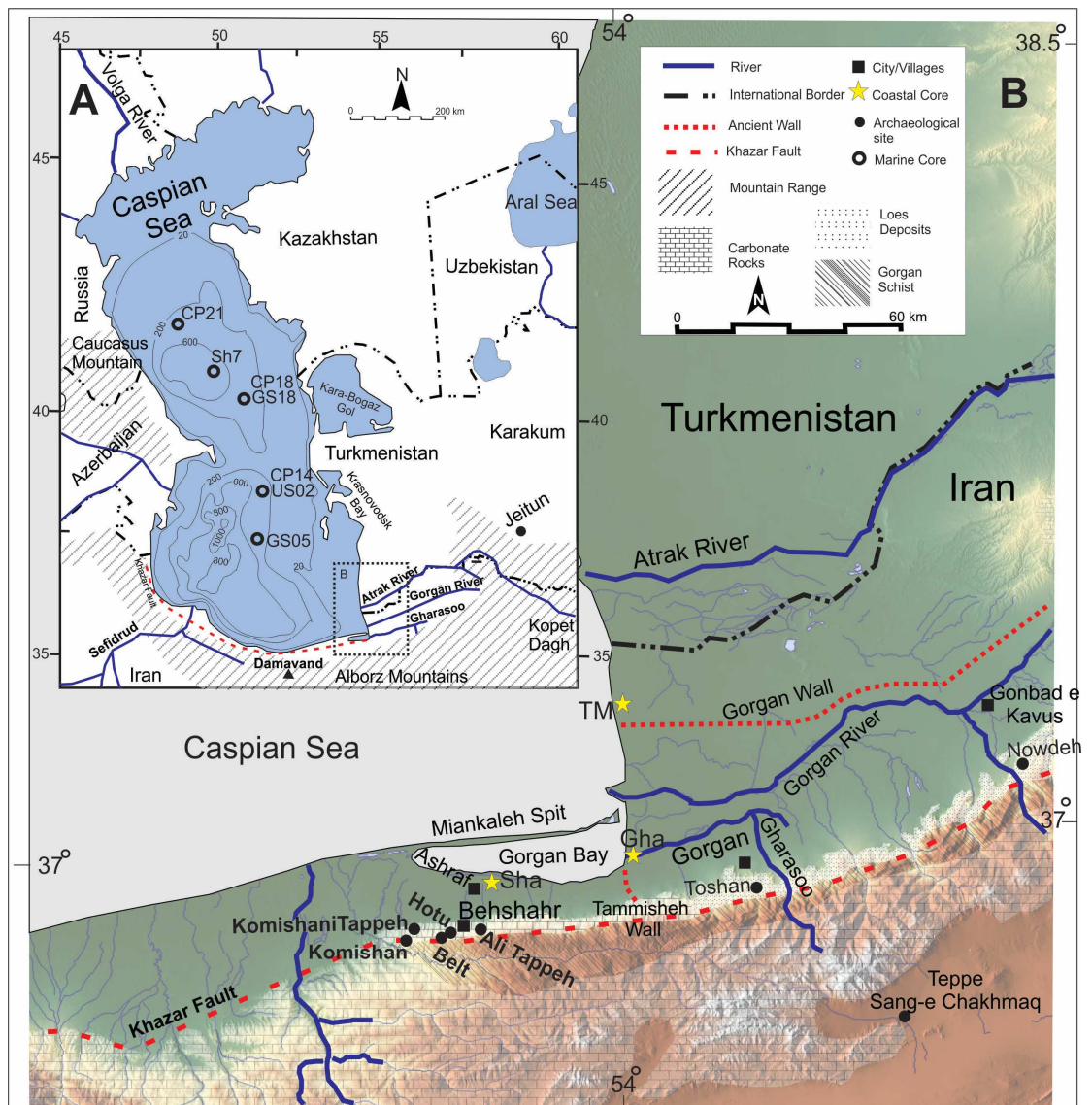
62 **1 Introduction**

63 Many studies have been conducted to reveal the history of the Caspian
64 Sea (CS) level changes and to reconstruct terrestrial palaeoenvironments
65 using coastal and marine archives (Leroy et al., in press). However, the
66 impact of environmental changes on early human communities in the region
67 remains poorly understood.

68 Researchers have long been interested in examining the prehistoric
69 ways of life of foraging groups and early food-producing societies between the
70 CS and the Alborz Mountains and Kopet Dagh in northern Iran and southern
71 Turkmenistan (Pumpelly, 1905; Arne, 1935; Okladnikov, 1949, 1956; Coon,
72 1951, 1952, 1957; Movius, 1953; Masson, 1957; McBurney, 1964, 1968) (Fig.
73 1A and B). The region is rich in archaeological remains. Lower Palaeolithic
74 tools have been found in the lower valley of the Sefidrud River, a major
75 waterway draining into the southern Caspian basin (Fig. 1A; Biglari et al.,
76 2004), while Mousterian tools point to Neanderthal occupation of the Keyaram
77 Cave in the central Alborz (Berillon et al., 2007a) and the eastern shore of the
78 Caspian north of Krasnovodsk Bay (Fig. 1A; Okladnikov, 1949; Dolukhanov et
79 al., 2010). The open-air site of Garm Roud 2 on the northern slopes of the
80 Alborz has yielded a lithic assemblage of bladelets, burins and scrapers, as
81 well as bones of red deer and aurochs with evidence of butchery by humans
82 dated to approximately 35,000 yr BP (Berillon et al., 2007b). The coastal plain
83 is also rich in younger archaeological sites, including four caves adjacent to
84 the southern coastal plain of the CS have also yielded abundant evidence of
85 human occupations during the Mesolithic and/or early Neolithic periods
86 (Coon, 1951, 1952, 1957; McBurney, 1964, 1968; Vahdati Nasab et al., 2011),
87 and animal bones from these sites provide an opportunity to reconstruct
88 changes in diet of the region's prehistoric inhabitants. In a comparison of
89 frequencies of faunal remains recovered from three of these caves, McBurney
90 (1968) proposed that the proximity of the Caspian shoreline would have had a
91 substantial influence on the range and number of animals available for human
92 subsistence.

93 The Alborz Mountains in northern Iran offer a diverse range of
94 environments with north-facing slopes that capture precipitation from air
95 masses coming from the CS (Fig. 1A). This humid region represents a

96 teaming pocket of life in an otherwise arid Middle East. Today, the coastal
 97 plain between the modern cities of Behshahr and Gorgan is the eastern-most
 98 region with sufficient precipitation for diversified agriculture, before lands
 99 become progressively drier the closer to their proximity to the Karakum Desert
 100 in western Turkmenistan (Molavi-Arabshahi et al., 2016) (Fig. 1A). The
 101 northern Alborz Mountains end in a relatively narrow coastal plain whose
 102 width varies in accordance with CS levels (Mamedov, 1997; Naderi Beni et
 103 al., 2013a,b). Sea level changes along with orography facilitated great
 104 biodiversity throughout the region, and provided glacial refuges for plants,
 105 which in turn contributed to both animal and human subsistence during late
 106 prehistoric periods (Leroy and Arpe, 2007; Arpe et al., 2011).
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Fig. 1: Location maps.

1A: Map of the Caspian Sea, with main marine cores.

1B: Detailed map of the SE corner of the southern Caspian basin showing major geological formations and locations of the sedimentary coring sites and Mesolithic and Neolithic archaeological sites mentioned in the text.

116 The aim of this study is to reconstruct past changes in terrestrial and
117 coastal environments, with an emphasis on human interactions with the
118 landscapes on which they lived during the terminal Pleistocene and early
119 Holocene. Consequently, we obtained two sedimentary cores, each
120 approximately 17 m in long from the sites of Shahkileh and Gharasoo,
121 adjacent to a shallow lagoon, the Gorgan Bay, on the southern coastal plain
122 of CS in close proximity to five archaeological sites (Fig. 1B). The results are
123 integrated herewith in context of a radiocarbon chronology associated with
124 bioarchaeological data from a recently-discovered open-air Mesolithic and
125 aceramic Neolithic site at Komishani Tappeh (Fig. 1B).

126 2 Regional setting

127 The CS is currently 28 m below modern ocean levels, with the Alborz
128 Mountains rising up to 5670 m asl at the Damavand volcano (Fig. 1A). Our
129 study area is located between the uplifting mountains and the subsiding
130 southern Caspian basin (Brunet et al., 2003) (Fig. 1A). Since the Last Glacial
131 Maximum pronounced changes in CS levels may have reached 150 m in
132 amplitude (Leroy et al., in press).

133 High water levels up to 50 m asl occurred in the early stages of the
134 early Khvalynian, that is poorly dated but is most likely post Last Glacial
135 Maximum (Makshaev et al., 2015; Arslanov et al., 2016). This is followed by
136 highstands reaching 35 and 22 m asl around 16-14 cal. ka BP. Then in the
137 Late Khvalynian (14-12 cal. ka BP), water levels reached only 0 and 12 m bsl
138 (Makshaev et al., 2015; Arslanov et al., 2016). A sharp drop (to perhaps as
139 much as 113 m bsl) occurred with the Mangyshlak lowstand at the beginning
140 of the Holocene lasting from one millennium in the deep-sea basin (Leroy et
141 al., 2014) to three millennia in the shallow north basin (Bezrodnykh and
142 Sorokin, 2016). This is followed by a further rapid increase to a highstand of
143 unknown height, and ultimately to late Holocene intermediate levels beginning
144 approximately 4000 years ago (Leroy et al., 2013a, 2019, in press; Naderi et
145 al., 2013a,b). Even minor changes in water levels have a strong influence on
146 the south-eastern coast of the CS, especially where it is close to the
147 mountains in the south or where water is shallow in the south-east (Naderi
148 Beni et al., 2014) (Fig. 1A).

149 The two sedimentary cores examined in this study were obtained from
150 the southern and eastern shores of Gorgan Bay in an area of undifferentiated
151 Quaternary: either flood plain or old terraces (Fig. 1B) (Amini, 2012). This
152 ~400 km² tectonically controlled, shallow bay (maximum 4 m depth) spans 70
153 km on its east-west axis, and is for the most part closed to the greater
154 expanse of the CS (Amini et al., 2012). The Miankaleh Spit, a series of sandy
155 dunes that reach a maximum of 4 m above modern CS levels, separates the
156 brackish waters of the bay (0-11 psu) from the CS (12-13 psu) (Fig. 1B). North
157 of the Miankaleh Spit, the water depth is quite shallow (less than 50 m) and
158 remains so, as it merges with the wide shelf of the eastern Caspian coast
159 (Fig. 1A). In the east, the Gorgan Bay is connected to the CS by a narrow inlet
160 (Leroy et al., 2018; Kouhanestani et al., 2019). The freshening of the bay is
161 due to water inflow from rivers originating in the Alborz Mountains. Several
162 perennial and ephemeral streams flow into the bay, of which the Gharasoo (or
163 Qara-Su, Qareh-Sou) is the largest (Fig. 1B). The river has a drainage area of

164 1638 km² and its length is 89 km (Kurdi et al., 2013). Currently the river mouth
165 of the Gharasoo is made up of fine sandy sediment (Gharibreza et al., 2018).
166 It has been hypothesized that the river course would extend into the bay
167 during periods of regression in CS levels (Ownegh, 2010).

168 Surface sediments of the bay change from fine sand to mud that is
169 finer in the west with some patches of coarse sand and sandy mud in the
170 northern parts (Lahijani et al., 2010; Amini et al., 2012). The average of total
171 organic carbon in the bay sediment is about 27% that decreases coastward to
172 around 18% and peaks up to 29% in the central parts of the bay (Amini et al.,
173 2012). Average carbonate content of the sediment is around 36% that
174 increases to around 40% in the Miankaleh Spit and is less than 34% in the
175 southern coast of the Gorgan Bay (Amini et al., 2012).

176 Apart from Gorgan green schist and dolomite outcrops that are
177 exposed south of the bay and at the foothills of the Alborz, limestone is the
178 predominant rock type of the catchment basin (Fig. 1B), which provides
179 detritic carbonates to the Gorgan Bay (Lahijani et al., 2010, in press). These
180 karstic limestones (Parent et al., 2012) are host to several caves that were
181 occupied by humans during the terminal Pleistocene and early Holocene
182 (Coon, 1951, 1952; McBurney, 1968). Belt, Hotu, Ali Tappeh and Komishan
183 Caves overlook the coastal plain of the CS from heights ranging between 45
184 to 58 meters asl (Fig. 1B). Detailed analyses of the karstic processes resulting
185 in formation of these chambers has yet to be undertaken. However, Coon
186 (1951, 1952) and McBurney (1968) both suggested that the caverns they
187 excavated were originally shaped by marine erosion. The dissolution of
188 carbonate rock could have been facilitated by wave erosion during prolonged
189 CS highstands and the mixing of rain and lake waters saturated with different
190 amounts of carbon dioxide (Karkanis and Goldberg, 2017). Carbonate
191 bedrocks are also found to the east of the Gorgan Bay in the Kopet Dagh.
192 Carbonates are carried by strong winds and westward-flowing rivers to the
193 sea and contribute to form a marine sediment rich in detritic carbonates
194 (Lahijani et al., in press).

195 The south-eastern coastal plain is currently intensively cultivated with
196 rare remnants of alluvial forests: *Alnus glutinosa* associated with *Populus*
197 *caspiaca*, *Pterocarya fraxinifolia*, *Ulmus minor*, *Cornus australis*, *Alnus*
198 *subcordata*, *Diospyros lotus*, *Buxus hyrcana* and *Ilex spinigera* (Akhani et al.,
199 2010). North of the Gharasoo River, a dry region contains salt-rich soils and
200 halophytic vegetation. Large *Phragmites australis* communities grow inside
201 and around the bay, with dense communities of submerged aquatic plants
202 such as *Ruppia maritima*. The coastal zone is composed of *Salicornia*, *Aster*
203 *tripolium* and *Suaeda crassifolia*. Furthermore, species of *Juncus*, *Typha*,
204 *Tamarix* and *Alhagi maurorum* grow over saline soils around the Gorgan Bay.
205 A series of east-west vegetation belts cover the northern slopes of the Alborz
206 Mountains. From bottom to top, these belts start with alluvial forests in the
207 west, grading in the east progressively into a steppe with *Artemisia* and
208 *Astragalus* at sea level. This belt is succeeded by a lowland forest (rich in
209 Tertiary relict species) up to ~500 m, then by the oak, hornbeam and beech
210 mountain species up to ~2000 m. A slightly drier *Quercus macranthera* forest
211 succeeds this up to ~2500 m, with *Juniper* woodland and the alpine meadows
212 at higher elevations (Akhani et al., 2010; Encyclopaedia Iranica, no date).

213 North of the Gharasoo River, semi-arid climate conditions prevail: dry
 214 and hot in the summer and cool in winter, with mean annual precipitation of
 215 300 mm and mean annual temperature of 17.5 °C (Honardoust et al., 2011).
 216 The climate to the west is wetter and cooler, with up to 1850 mm of annual
 217 precipitation and mean annual temperatures between 15.5 and 16 °C (Molavi-
 218 Arabshahi et al., 2016).

219 **3 Previous palynological and archaeological** 220 **investigations**

221 **3.1 Regional palynology and the Shahkileh and Gharasoo** 222 **sequences**

223 Four previous palynological datasets span parts of the last 14,400
 224 years (Fig. 1A). Three of them are offshore: the combined sequence of cores
 225 GS05-CP14-US02 in the south basin (Leroy et al., 2007 and 2013a), the
 226 combined sequence of cores GS18-CP18 in the middle basin (Leroy et al.,
 227 2007 and 2014; Tudryn et al., 2016; Leroy et al., 2019), and core Sh7 in the
 228 North of the middle basin (Leroy et al., 2019). The TM sequence is from a
 229 coastal lagoon (palaeo-Gomishan) in the SE corner of the CS, only 35 km
 230 North of the coring site of Gharasoo (Fig. 1B; Leroy et al., 2013c). Modern
 231 pollen spectra at the site of the two cores and the caves were previously
 232 published in Leroy et al. (2013a). They show the dominance of *Alnus* and
 233 *Carpinus betulus*, and a good representation of *Fagus* and *Quercus*.

234 Moreover the modern sites near Gharasoo have high Amaranthaceae values.
 235 The two cores (Shahkileh and Gharasoo), lithological descriptions and
 236 sedimentological analyses were part of the doctoral thesis of Amini (2012).
 237 Initial chronological information has been briefly published (Amini et al., 2012):
 238 comprising two radiocarbon dates on each core.

239 **3.2 Archaeological sites**

240 Archaeological, faunal and botanical remains from Belt, Hotu, Ali
 241 Tappeh and Komishan Caves and the recently-discovered open-air site at
 242 Komishani Tappeh (Fig. 1B) provide a window into human behaviour in
 243 response to changes in environmental conditions during the terminal
 244 Pleistocene and early Holocene (Coon, 1951, 1952; McBurney, 1968; Vahdati
 245 Nasab et al., 2011; Fazeli Nashli and Gregg 2018; Fazeli Nashli et al., in
 246 preparation). Stone tools broadly similar to those of the Mesolithic
 247 Trialetian culture of the Caucasus, Eastern Anatolia, Transcaspia and the
 248 Iranian Plateau (Kozłowski, 1996) were recovered from basal and subsequent
 249 hunter-gatherer occupations of these five sites. This chipped-stone industry
 250 includes a variety of lithic elements such as asymmetric triangles, geometrics,
 251 backed flakes and backed bladelets, scrapers, perforators and lamelles
 252 Dufour. Jayez and Vahdati Nasab (2016) have recently isolated these lithic
 253 assemblages as a geographic variant of the Trialetian culture distinctive to
 254 northern Iran and western Turkmenistan and renamed them as belonging to
 255 the “Caspian Mesolithic”. With the exception of Ali Tappeh Cave, the
 256 Mesolithic occupations of the sites listed above are all overlain by aceramic or
 257 pottery-bearing Neolithic horizons. Summaries of these horizons can be found

258 in **Tables 1** and **2** along with radiocarbon ages (BP) and calibrated dates BC
259 (2 sigma) of charcoal or bone obtained from within them.

260 **3.2.1 Belt and Hotu Caves**

261 Coon excavated Belt and Hotu Caves (sites within 100 m of each
262 other) to depths of six and twelve m respectively over a course of nine weeks
263 in 1949 and 1951 (Coon, 1951, 1952). Radiocarbon assays of twenty charcoal
264 samples from eleven Mesolithic and nine Neolithic levels at these sites were
265 undertaken by Libby (1951) and Ralph (1955) (Table 1).
266

Site	Lab number	Material	Trench	Cultural / climate phase	Fauna / environment identified	¹⁴ C BP	Calibrated BC	Reference
Belt Cave	C-492	Charcoal	21-28	Lower Mesolithic 1949	Seal, gazelle, horse, deer, canid	8244 ± 740	9401-5719	Libby 1951; McBurney 1968
Belt Cave	C-574	Charcoal	15-16	Upper Mesolithic 1949	Gazelle, sheep / goat, auroch, deer	8800 ± 515	9401-6631	Libby 1951; McBurney 1968
Belt Cave	C-524	Charcoal	10	Mesolithic/Neolithic 1949	N/D	10875 ± 630	12530-9120	Libby 1951; McBurney 1968
Belt Cave	C-494	Charcoal	N/D	Pottery Neolithic 1949	Seal, gazelle, sheep / goat, pig	8325 ± 740	9461-5788	Libby 1951; McBurney 1968
Belt Cave	P-19	Charcoal	C	Soft ware Neolithic 1951	Seal, gazelle, sheep / goat, pig	7225 ± 420	7140-5360	Ralph 1955; McBurney 1968
Belt Cave	P-19a	Charcoal	C	Soft ware Neolithic 1951	Seal, gazelle, sheep / goat, pig	7620 ± 510	7789-5556	Ralph 1955; McBurney 1968
Belt Cave	P-19b	Charcoal	C	Soft ware Neolithic 1951	Seal, gazelle, sheep / goat, pig	7650 ± 475	7682-5633	Ralph 1955; McBurney 1968
Belt Cave	P-26	Charcoal	C	Aceramic Neolithic 1951	N/D	7910 ± 485	8014-5996	Ralph 1955; McBurney 1968
Belt Cave	P-26a	Charcoal	C	Aceramic Neolithic 1951	N/D	8140 ± 490	8349-6059	Ralph 1955; McBurney 1968
Belt Cave	P-24	Charcoal	C	Gazelle Mesolithic 1951	Gazelle, sheep / goat, auroch, deer	9050 ± 590	10167-6820	Ralph 1955; McBurney 1968
Belt Cave	P-24a	Charcoal	C	Gazelle Mesolithic 1951	Gazelle, sheep / goat, auroch, deer	8610 ± 525	9189-6481	Ralph 1955; McBurney 1968
Belt Cave	P-27	Charcoal	C	Mesolithic Loess 1951	N/D	12640 ± 850	15635-11116	Ralph 1955; McBurney 1968
Belt Cave	P-20	Charcoal	C	Seal Mesolithic 1951	Seal, gazelle, horse, deer, canid	11740 ± 825	14571-9875	Ralph 1955; McBurney 1968
Belt Cave	P-20b	Charcoal	C	Seal Mesolithic 1951	Seal, gazelle, horse, deer, canid	11900 ± 775	14655-10432	Ralph 1955; McBurney 1968
Hotu Cave	P-35	Charcoal	HA39-41	Soft ware Neolithic 1951	Sheep / goat, auroch, deer, canid	4870 ± 330	4399-2880	Ralph 1955; McBurney 1968
Hotu Cave	P-36	Charcoal	HB	Soft ware Neolithic 1951	Sheep / goat, auroch, deer, canid	6575 ± 440	6396-4582	Ralph 1955; McBurney 1968
Hotu Cave	P-37	Charcoal	HD	Sub-Neolithic 1951	Sheep / goat, auroch, pig, canid	8310 ± 515	8745-6216	Ralph 1955; McBurney 1968
Hotu Cave	P-12	Charcoal	HD	Mesolithic (vole) 1951	Vole	9465 ± 610	10721-7514	Ralph 1955; McBurney 1968
Hotu Cave	P-38	Charcoal	HD	Mesolithic (vole) 1951	Vole	9500 ± 610	10724-7540	Ralph 1955; McBurney 1968
Hotu Cave	P-39	Charcoal	HD	Mesolithic (seal) 1951	Seal, gazelle, sheep / goat,	12215 ± 865	15303-10688	Ralph 1955; McBurney 1968
Ali Tappeh Cave	GX-0691	Charcoal	C21	Younger Dryas	Gazelle, sheep / goat, horse, canid	10520 ± 410	11262 - 9251	McBurney 1968
Ali Tappeh Cave	GX-0699	Charcoal	A1	Younger Dryas	Gazelle, sheep / goat, horse, canid	10780 ± 320	11407 - 9801	McBurney 1968
Ali Tappeh Cave	GX-0693	Charcoal	Sg14a	Allerød	Seal, sheep / goat, auroch, canid	10315 ± 410	11093 - 9119	McBurney 1968
Ali Tappeh Cave	GX-0694	Charcoal	BB	Allerød	Seal, sheep / goat, auroch, canid	11640 ± 410	12888 - 10770	McBurney 1968
Ali Tappeh Cave	GX-0695	Charcoal	Sg12	Allerød	Seal, sheep / goat, auroch, canid	11330 ± 410	12390 - 10432	McBurney 1968
Ali Tappeh Cave	GX-0696	Charcoal	A13	Allerød	Seal, sheep / goat, auroch, canid	11460 ± 370	12363 - 10686	McBurney 1968
Ali Tappeh Cave	GX-0700	Charcoal	A7	Allerød	Seal, sheep / goat, auroch, canid	11240 ± 360	12022 - 10564	McBurney 1968
Ali Tappeh Cave	GX-0689	Charcoal	63/16	Allerød	Seal, sheep / goat, auroch, canid	11380 ± 410	12481 - 10489	McBurney 1968
Ali Tappeh Cave	GX-0690	Charcoal	A26a	Older Dryas	Gazelle, sheep / goat	12410 ± 480	14145 - 11458	McBurney 1968
Ali Tappeh Cave	GX-0692	Charcoal	C17	Bolling	Gazelle, sheep / goat, canids	12430 ± 600	14547 - 11245	McBurney 1968
Ali Tappeh Cave	GX-0697	Charcoal	A10	Oldest Dryas	Gazelle, sheep / goat, auroch	12510 ± 380	13991 - 11757	McBurney 1968

267
268

269 **Table 1: Radiocarbon assays from Coon's 1949 and 1951 excavations at Belt and**
270 **Hotu Caves and McBurney's 1963 and 1964 excavations at Ali Tappeh Cave for 2**
271 **sigma (95.4%). In bold: dates used for figure 6. In italics: horizons with evidence of**
272 **human predation on seals or of highstand.**

273

274 Radiocarbon assays of charcoal from basal Mesolithic levels at Belt
275 and Hotu Caves place the earliest Mesolithic hunter-gatherer occupations of
276 the sites between 14655-10432 cal. BC and 15303-10688 cal. BC,
277 respectively (Table 1). Coon's description of five enigmatic unfired clay cones
278 (1951: 75) acknowledges a Mesolithic "interest in clay" at Belt Cave, which is
279 also evidenced at Hotu Cave in a "lump of fired clay showing textile or
280 cordage marks" (Coon, 1952: 247) and a fired clay "goddess figurine
281 recovered from its "Pleistocene gravels"" (Dupree, 1952: 253). An assay of
282 charcoal from a hearth associated with two human skeletons recovered from
283 Gravel IV at a depth of 9.5 m in Hotu Cave yielded a radiocarbon age of 9500
284 ± 610 BP (Ralph, 1955), which when calibrated falls between 10724 and 7540
285 cal. BC (Table 1). More recent AMS analyses of collagen surviving in a tooth
286 from skeletal remains of another individual recovered from the same Gravel IV

287 layer has yielded a radiocarbon age of 8855-8637 cal. BC (Table 2)
 288 (McAuley, 2013; Beta Analytic, 2013).
 289

Site	Lab number	Material	Trench	Cultural / climate phase	Fauna / environment identified	¹⁴ C BP	Calibrated BC	Reference
Hotu Cave	Beta-344447	Human	HD	Mesolithic (vole) 1951	Vole	9480±40	8855-8637	Beta Analytic 2013
Hotu Cave	Poz-811124	Human	HD	Mesolithic (vole) 1951	Vole	7250 ± 40	6218-6034	Lazaridis et al. 2016
Ali Tappeh Cave	BM-2726	Charcoal	N/D	Basal Mesolithic	<i>Caspian transgression</i>	11240±210	11512-10775	Hedges et al. 1994
Ali Tappeh Cave	BM-2727	Charcoal	N/D	Basal Mesolithic	<i>Caspian transgression</i>	11300±190	11532-10806	Hedges et al. 1994
Ali Tappeh Cave	OxA-3194	Charcoal	AT64-A17a	Basal Mesolithic	<i>Kuma / Bekdash transition 0 bsl</i>	10800±120	11051-10506	Hedges et al. 1994
Ali Tappeh Cave	OxA-3190	Charcoal	AT64-C11	N/D	<i>Bekdash regression min -55 bsl</i>	10520±100	10731-10149	Hedges et al. 1994
Ali Tappeh Cave	OxA-3192	Charcoal	AT64-A4	End of Mesolithic	<i>Sartas raised beach -11 to -17 bsl</i>	10180±110	10291-9441	Hedges et al. 1994
Ali Tappeh Cave	OxA-3191	Marine shell	AT64-Sg9	N/D	<i>Bekdash regression min -55 bsl</i>	11680±110		Hedges et al. 1994
Ali Tappeh Cave	OxA-3193	Marine shell	AT64-C15	N/D	<i>End of Kuma phase</i>	12640±110		Hedges et al. 1994
Komishan Cave	OxA-22611	charcoal	N/D	Most recent Mesolithic	Gazelle, saiga, pig, canid, birds, fish	10 800±45	10811-10711	Vahdati Nasab et al. 2011
Komishan Cave	OxA-22572	charcoal	N/D	Earliest Mesolithic	Gazelle, saiga, pig, canid, birds, fish	12000±60	12096-11777	Vahdati Nasab et al. 2011
Komishani Tappeh	MAMS-35605	Bone	1. 20	Aceramic Neolithic	Sheep / goat, bird, barley, tuber	9071 ± 33	8309-8242	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35615	charcoal	4. 14	Mesolithic	Sheep / goat, bird, barley, legume	9276 ± 26	8620-8483	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35614	charcoal	4. 13	Aceramic Neolithic	Sheep / goat, bird, barley, legume	9310 ± 26	8634-8529	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35609	charcoal	2. 20. 1	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9260 ± 31	8606-8347	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35610	charcoal	2. 21	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9298 ± 26	8626-8460	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35611	charcoal	2. 23. 4	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9319 ± 26	8639-8533	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35612	charcoal	2. 25. 1	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9297 ± 26	8626-8466	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35613	charcoal	2. 25. 4	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9261 ± 28	8605-8429	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35616	charcoal	4. 15	Mesolithic	Sheep / goat, pig, bird, oat, legume	9335 ± 30	8657-8539	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35608	charcoal	2.16. 4	Mesolithic	Sheep / goat, pig, bird, barley, tuber	9697 ± 27	9256-9242	Fazeli Nashli et al. in prep
Komishani Tappeh	MAMS-35617	charcoal	4. 16	No cultural materials	No faunal / botanical macro remains	13470 ± 50	14472-14062	Fazeli Nashli et al. in prep

290
291

292 **Table 2:** AMS radiocarbon ages of materials from Hotu, Ali Tappeh and Komishan
 293 caves from the 1990s and 2010s and Komishani Tappeh for 2 sigma (95.4%). In
 294 bold: dates used for figure 6. In italics: evidence of human predation on seals or of
 295 highstand. N/D: no data.

296

297 An assay of charcoal from a level at Belt Cave identified by Coon as a
 298 transitional Mesolithic - Neolithic horizon raises the possibility of the
 299 emergence of food production at this site between 12530 and 9120 cal. BC.
 300 However, in many instances the hurried methods used in excavation prevent
 301 us from clearly differentiating between hunting and gathering and food-
 302 producing occupations at these rock shelters (Gregg and Thornton, 2012).
 303 The lack of rigour in the recording and curation of finds also restricts our
 304 ability to determine whether innovations in subsistence practices at Belt and
 305 Hotu Caves, such as the emergence of 'soft ware' pottery vessels (Dyson,
 306 1991; Gregg and Thornton, 2012), originated at these sites or were adopted
 307 from cultures in adjacent regions. Beyond brief mentions in Coon's (1951 and
 308 1952) preliminary reports of the discovery of sickle blades, stone mortars,
 309 pestles, querns and a small number of unidentified seeds in aceramic and
 310 pottery-bearing Neolithic levels at Belt Cave and pottery-bearing Neolithic
 311 levels at Hotu Cave, these artefacts and botanical specimens remain
 312 unpublished. We have been unable to locate these either in the collections of
 313 the University of Pennsylvania Museum or those of the National Museum of
 314 Iran. The earliest Neolithic level identified by Coon at Belt Cave is an
 315 aceramic horizon falling between 8349 and 6059 cal. BC; whereas the earliest
 316 Neolithic level identified by Coon at Hotu Cave is a pottery-bearing horizon
 317 falling between 6396 and 4582 cal. BC (Table 1).

318 3.2.2 Ali Tappeh Cave

319 Following discovery of Ali Tappeh Cave in 1962, McBurney undertook
 320 a preliminary sounding in 1963 and excavated three pits in 1964, all to depths
 321 of approximately 6.1 m. These excavations revealed 3.35 m of undisturbed

322 Mesolithic levels overlain by 2.75 m of Iron Age and later period deposits,
323 many of which appeared to have been pitted and infilled during various later
324 periods in antiquity (McBurney, 1968: 388). Unlike Belt and Hotu Caves,
325 neither aceramic nor pottery-bearing Neolithic levels overlay the Mesolithic
326 occupations at Ali Tappeh. McBurney (1968: 388) attributes the high yield of
327 Mesolithic chipped-stone and bone tools and faunal remains at Ali Tappeh
328 Cave to “greater time and care in specimen recovery” than at Belt and Hotu
329 Caves, and to the repetitive sieving of sediments through a series of
330 progressively smaller meshed screens, rather than the single ½” mesh utilized
331 in Coon’s excavations. Fine bone needles, shell tools and small stone
332 ornaments were recovered through this sieving process (Payne, 1968; Manca
333 et al., 2018), but flotation of sediments was not undertaken in order to isolate
334 and identify botanical macroremains.

335 Radiocarbon assays of eleven charcoal or wood samples from ten
336 Mesolithic levels undertaken at Geochron Inc. in Boston in 1965 (Table 1;
337 McBurney, 1968), suggested that the Mesolithic deposits at Ali Tappeh Cave
338 could date to a period spanning from 12400 to 10750 uncalibrated BP.
339 Subsequent AMS radiocarbon analyses of charcoal from the basal and most
340 recent Mesolithic levels at Ali Tappeh Cave, and our calibration of radiocarbon
341 ages of these horizons indicate that hunter-gatherer groups visited and
342 potentially occupied the rockshelter between 11500 and 9400 cal. BC (Table
343 2: BM-2726 and OxA-3192; Hedges et al., 1994).

344 **3.2.3 Komishan Cave**

345 Excavations conducted by Vahdati Nasab and colleagues in 2009
346 revealed highly-disturbed and potentially-looted stratigraphic levels containing
347 mixtures of Iron Age, Bronze Age and Chalcolithic pottery and Neolithic flint
348 tools overlying an undisturbed Mesolithic horizon (Vahdati Nasab et al., 2011;
349 Jayez and Vahdati Nasab, 2016). Two charcoal samples recovered from the
350 earliest and latest Mesolithic occupations yielded AMS ¹⁴C radiocarbon ages
351 of 12096-11777 cal. BC and 10811-10711 cal. BC (Vahdati Nasab et al.,
352 2011).

353 **3.2.4 Komishani Tappeh**

354 In 2017, road-building activities exposed a multi-component prehistoric
355 site within 150 m of Komishan Cave, necessitating salvage excavations and
356 providing two of us (Fazelli Nashli and Gregg, 2018) with the opportunity to
357 investigate the emergence of food-producing ways of life in northern Iran. Our
358 excavation of two trenches (TR1, TR2; Fig. SI 1) adjacent to the area exposed
359 by road builders revealed stratified Bronze Age and Chalcolithic levels
360 overlying a succession of aceramic Neolithic and Mesolithic deposits bearing
361 a ground stone pestle buried to a depth of approximately seven meters
362 beneath the talus slope at the mouth of Komishan Cave. Our concurrent
363 excavation of another trench (TR4; Fig. SI 2) in a suspected looter’s pit on the
364 coastal plain within 500 m of Komishan Cave also revealed undisturbed,
365 stratified aceramic Neolithic and Mesolithic deposits buried to a depth of
366 approximately 4.5 m.

367 AMS radiocarbon assays of nine charcoal samples and one bone
368 specimen recovered from seven Mesolithic and two Neolithic horizons

369 revealed successive occupations falling between 9200 and 8200 cal. BC
370 (Table 2). An additional charcoal sample, recovered from a basal level in
371 Trench 4 devoid of any identifiable cultural materials, yielded a much earlier
372 age of 14340-14177 cal. BC. While it may be conceivable for Mesolithic
373 hunter-gatherer encampments in northern Iran to fall within this timeframe, the
374 low percentage of carbon (2.2%) recovered from the sample leads us to doubt
375 the reliability of this assay. Assays of a bone specimen and charcoal
376 recovered from aceramic Neolithic contexts bearing small flint blades and
377 pressure-flaked, single-platform cores in Trenches 1 and 4 fall between 8600
378 and 8200 cal. BC, making Komishani Tappeh significantly older than any
379 other Neolithic site in the Caspian basin, and one of the earliest Neolithic sites
380 in Iran (Fazeli Nashli et al., in preparation). Charcoal from the upper-most
381 Mesolithic horizon able to be dated in Trench 2 yielded the earliest age of
382 9256-9242 cal. BC (Table 2, MAMS-35608), which is 600 to 700 years earlier
383 than four other charcoal samples from lower stratigraphic levels. A colluvial
384 layer below Neolithic clay-walled architecture and a clay hearth in Trenches 1
385 and 2 may suggest a hiatus rather than continuity between the aceramic
386 Neolithic and Mesolithic sequences. However, since no stratigraphic
387 unconformity occurs between the aceramic Neolithic and Mesolithic
388 sequences in Trench 4, we suspect that the colluvium was transported from
389 upland areas during a flash flood or a prolonged period of wet climatic
390 conditions, and may be confined to the talus slope in front of Komishan Cave
391 (Fazeli Nashli et al., in preparation).

392 3.3 Faunal and botanical assemblages

393 In Coon's reports on 1949 and 1951 excavations at Belt and Hotu
394 Caves, faunal remains from Neolithic occupations were almost exclusively
395 sheep and goat (Coon, 1951). Gazelle, which had been abundant in Upper
396 Mesolithic levels, were notably absent from the Neolithic levels. Goat and
397 aurochs had also begun to appear towards the top of the Upper Mesolithic
398 horizon; whereas, Lower Mesolithic horizons were dominated by red deer,
399 Caspian seal and water birds. To Coon, the faunal remains of sheep and
400 goats from Mesolithic levels at Belt Cave were morphologically
401 indistinguishable from those of domesticated species found in later Neolithic
402 levels. However, the high ratio of young animals in the faunal assemblage led
403 Coon to suspect "goat herding began in the Mesolithic" (Coon, 1951: 41).

404 In a comparison of faunal remains from Ali Tappeh Cave with the
405 published data from Belt and Hotu Caves, McBurney (1968) hypothesized that
406 a link existed between the diet of its prehistoric inhabitants and the width of
407 CS coastal plain. Frequencies of animal bones from these three sites support
408 McBurney's contention that when water levels were high and the coastal plain
409 was narrow, Mesolithic hunters were reliant on seal and deer; whereas when
410 water levels receded and a wide coastal plain emerged, hunters consumed
411 different range of species, including auroch, onager, boar, gazelle, sheep and
412 goat. To McBurney, the concentration of Neolithic inhabitants of Belt Cave on
413 sheep and/or goat to the virtual exclusion of gazelle suggested an interesting
414 prelude to domestication associated with the emergence of pottery at the site.
415 With the simultaneous appearance of large quantities of pottery and the first
416 morphological evidence of domesticated sheep and goats, "the entire faunal
417 and industrial spectra change as if it were overnight" (McBurney, 1968: 408-

418 409). The ratio of sheep and goat remains jumps from 12 to 84%, while
419 gazelle drops from 62 to 8%, and aurochs from 22 to 0%.

420 Shirazi's (unpublished data) analyses of wood charcoal recovered
421 during McBurney's excavations at Ali Tappeh Cave have revealed a diverse
422 range of plant taxa recovered from the Mesolithic occupation levels of the site.
423 Probably also some semi-desert or salinity-rich habitats (goosefoot family)
424 developed in the vicinity. The anthracological assemblages (Shirazi,
425 unpublished data) indicate the most commonly utilised species were obtained
426 from a riparian habitat, followed by the open steppe-forest vegetation
427 represented with a diversity of light-loving small trees and shrubs. The oak
428 may have originated from a steppe-forest habitat nearby the riparian zone
429 where sufficient water was available, while some semi-desert or salinity-rich
430 habitats (goosefoot family) were developed in the vicinity.

431 Analyses of faunal remains from Komishan Cave by Mashkour et al.
432 (2011) have also provided us with a window into the species exploited by
433 Mesolithic hunters (gazelle, saiga, boar, canid, bird, fish) potentially between
434 12000 and 10700 cal. BC. Unfortunately, much of the data in this study come
435 from heavily disturbed and undated contexts attributed to later periods.

436 New botanical and faunal macro-remains obtained from well-dated
437 Mesolithic and aceramic Neolithic contexts at Komishani Tappeh are
438 presented below.

439 4 Material and Methods

440 4.1 Cores: Sedimentary, palynological and dating methods

441 A 17.39 m long core was taken in 2010 using a Swedish K_750 drilling
442 machine with casing and liners in sections of 50 cm and diameter of 15 cm
443 made of PVC tube. The coring operation was conducted when the sea level
444 was slightly higher than today, i.e. ~27.3 m bsl (Chen et al., 2017). The
445 Shahkileh core is located at 36°45'41.40" N, 53°35'54.10" E, at an elevation of
446 23 m bsl, in a field, 700 m S-SE of the old Shahkileh (Ashraf Port) and 2.2 km
447 from the Gorgan Bay (Fig. 1B). The same method was utilized to obtain a
448 16.10 m long core on the eastern coast of the Gorgan Bay at the Gharasoo
449 river mouth. The core is located at 36°49'40.16" N, 54° 2'38.61" E, at an
450 elevation of 27 m bsl, c. 600 m far from the coast, along the current river
451 (Fig.1B).

452 The cores were split and photographed and visually classified into
453 different units based on their texture, colour and shell content (Amini, 2012).
454 For each unit, representative sub-samples were obtained. A Horiba-LA 950
455 Laser Scattering Particle Size Distribution Analyser at the laboratory of the
456 Iranian National Institute for Oceanography and Atmospheric Science
457 (INIOAS) was used to measure the sediment grain size. Total organic matter
458 content was calculated by adding Hydrogen Peroxide (Schumacher, 2002)
459 and carbonate content was measured by acid attack and a Bernard calcimeter
460 (Lewis and McConchie, 2012). Sediment was classified based on grain-size
461 results according to Folk (1980) using the Sedplot software (Pope and
462 Eliason, 2008).

463 The palynological sample volume was between 2 and 2.5 ml. Initial
464 processing of samples involved the addition of sodium pyrophosphate to

465 deflocculate the sediment. Samples were then treated with cold hydrochloric
466 acid (10%) and cold hydrofluoric acid (32%), then HCl again. The residual
467 fraction was screened through 125 and 10 µm mesh sieves. Final residues
468 were mounted on slides in glycerol and sealed with varnish. *Lycopodium*
469 tablets were added at the beginning of the process for concentration
470 estimation in number of pollen and spores per ml of wet sediment (without
471 non-pollen palynomorphs or NPP). The average pollen sum is 335 for the
472 Shakhileh sequence and 318 for the Gharasoo sequence, considering only
473 terrestrial taxa. The percentages of all taxa are calculated on the terrestrial
474 pollen sum. The coprophilous spores here include: *Apiosordaria*,
475 *Chaetomium*, *Podospora*, *Sordaria* and *Sporormiella*. The taxonomy and the
476 ecological preferences of the CS dinocysts have been detailed in [Leroy et al.](#)
477 [\(2013c\)](#). An additional form with a morphology between *Galeacysta etrusca*
478 and *Spiniferites cruciformis* A was found. Detailed diagrams are presented in
479 [Fig. SI 3 and 4](#), while diagrams with selected taxa are kept in the main text.
480 The diagrams were plotted using Psimpoll with a 10x exaggeration curves and
481 black dots for values lower than 0.5% ([Bennett, 2007](#)). The P/D ratio is the
482 ratio of the concentration of pollen on that of dinocysts ([McCarthy and Mudie,](#)
483 [1998](#)).

484 Radiocarbon dating of the cores was obtained from the Radiocarbon
485 Laboratory of Poznan and the Chrono Centre of Queen's University of Belfast
486 They were made on six samples of shells and one on plant fragments in the
487 Shakhileh sequence and eight from shells in the Gharasoo sequence. The ¹⁴C
488 ages were calibrated using INTCAL13 and MAR13 ([Stuiver et al., 2018](#)).
489 Various reservoir effects have been quoted for the CS radiocarbon dates;
490 refer to discussion to see how this has been taken in account here. The
491 Lateglacial interstadial and stadial ages are taken from [Rasmussen et al.](#)
492 [\(2014\)](#).

493 **4.2 Archaeobotanical and faunal remains and radiocarbon dating**

494 For archaeobotany, we recovered 362 litres of sediment from aceramic
495 Neolithic and Caspian Mesolithic contexts in Trenches 1, 2 and 4 in
496 Komishani Tappeh ([Fig. SI 1 and 2](#)), and used machine flotation to collect
497 both light and heavy fractions samples from these sediments at a field facility
498 nearby the site. Samples were subsequently examined with a stereoscopic
499 microscope at the Laboratory for Archaeobotany at the Department of Cultural
500 Heritage in Baden-Württemberg in order to isolate the identifiable
501 morphological characteristics of different botanical macroremains. This was
502 done by using the reference collection of the laboratory and with reference to
503 illustrations in seed atlases, identification manuals and archaeobotanical
504 reports, such as: [van Zeist and Bakker-Heeres \(1982, 1984, 1985\)](#), [van Zeist](#)
505 [et al. \(1984\)](#), [Cappers et al. \(2006, 2009\)](#) and [Jacomet \(2006\)](#).

506 Bone samples were recovered from Trench 4 ([Fig. SI 2](#)) both by hand
507 and through use of machine flotation. Hand-recovered animal bones and light
508 and heavy fractions were subsequently examined at the Zooarchaeological
509 Laboratory at the University of Edinburgh. Mammalian identifications were
510 made using the Edinburgh University osteological reference collections,
511 supported by published guides ([Schmidt, 1972](#); [Prummel and Frisch, 1986](#);
512 [Zeder and Lapham, 2010](#); [Zeder and Pilaar, 2010](#)). Bird remains were
513 identified using the comparative collections of the Natural History Museum,

514 Tring, UK. Bones not identified to species have been awarded an animal-size
515 category or labelled indeterminate. Identifications reported are provisional.
516 Some of these may change as further work is undertaken. The material is
517 quantified by the number of identified specimens (NISP).

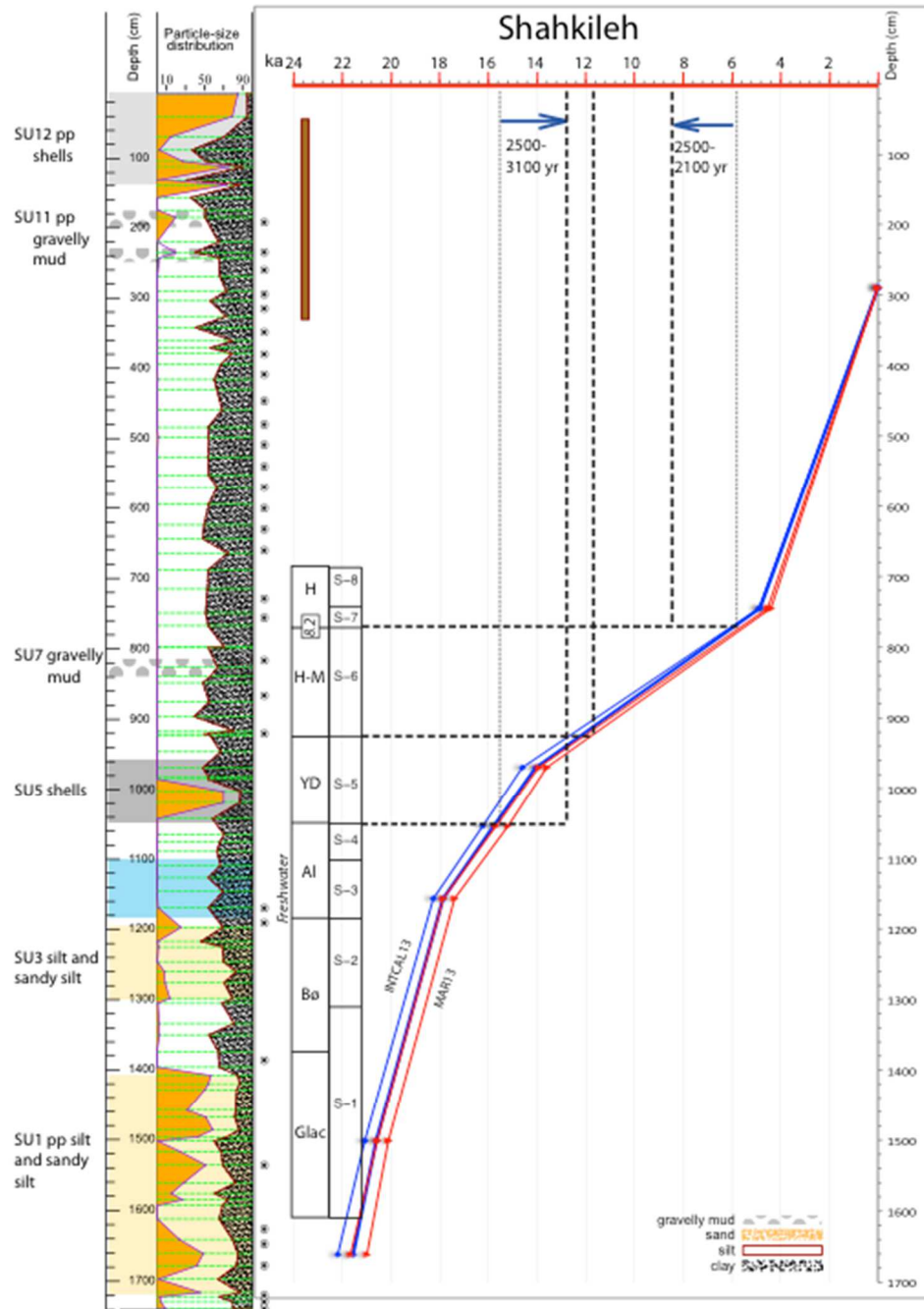
518 Radiocarbon dating of archaeological horizons in the caves and the
519 open-air site were compiled from the literature and can be assigned to three
520 groups: i) the dates made in the 1950s and 1960s with very large error bars,
521 ii) the dates obtained in the 1990s and iii) the more recent dates with narrower
522 errors made in the 2010s. Most of the dates were made on charcoal, some on
523 bones and only two on marine shells. The radiocarbon assays from Coon's
524 1949 and 1951 excavations at Belt and Hotu Caves employed Libby's initial
525 calculation of the half-life of ^{14}C of 5568 ± 30 years. Published radiocarbon
526 ages, provided by [Libby \(1951\)](#) and [Ralph \(1955\)](#), have been recalculated
527 using the more accurate Cambridge half-life for ^{14}C of 5730 ± 40 years ([Gregg
528 and Thornton, 2012](#)). These radiocarbon ages and those initially published for
529 Ali Tappeh by [McBurney \(1968\)](#) have been calibrated at 95.4% (2 sigma)
530 probability using the Oxcal program (v4.3) of C. Bronk Ramsey and the
531 INTCAL13 dataset ([Reimer et al., 2013](#)). The AMS radiocarbon ages of
532 materials from Hotu, Ali Tappeh and Komishan Caves from the 1990s and
533 2010s and the recently-discovered Komishani Tappeh have been calibrated at
534 95.4% probability using the Oxcal program (v4.3) of C. Bronk Ramsey and the
535 INTCAL13 dataset ([Reimer et al., 2013](#)) and the Calib program (v7.10) of
536 Reimer ([Stuiver et al., 2018](#)).

537 These dates, after eliminating the two dates on marine shells,
538 suggested to be influenced by natural hydrocarbons, and one date, GX-690,
539 deemed unreliable by its author (see [Hedges et al., 1994](#)), were organised
540 according to increasing BP ages.

541 **5 Results**

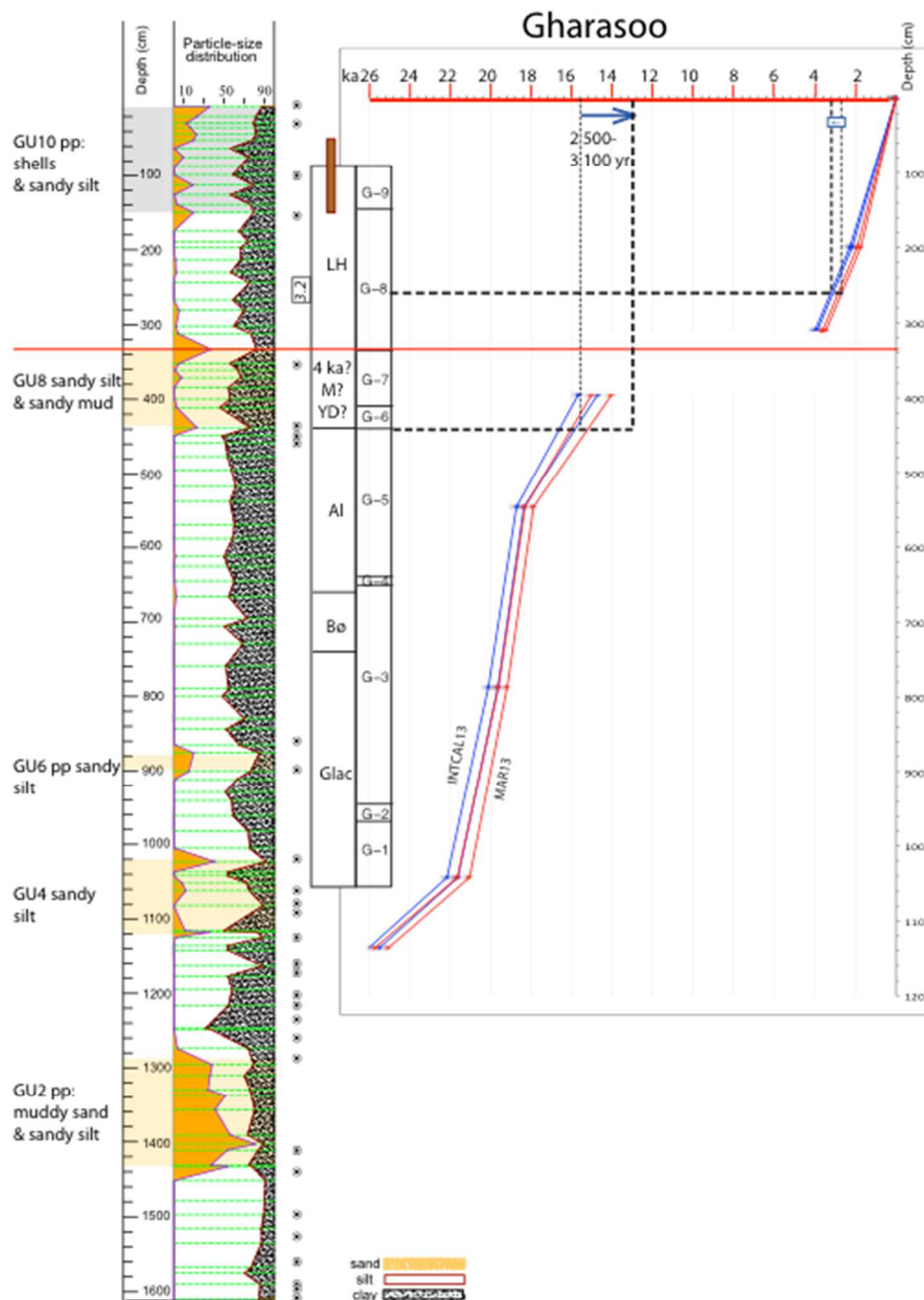
542 **5.1 Core lithology and dates**

Fig. 2A Leroy et al.



543

Fig. 2B Leroy et al.



544
 545 **Fig. 2:** Chronology of Shahkileh (Fig. 2A) and Gharasoo (Fig. 2B) sequences. Details
 546 of dates in Table 3. Black dot with circle: barren palynological samples. Light dash
 547 lines are ages from radiocarbon dates, whilst heavy dash lines are ages suggested
 548 by palynology.
 549

550 The lithology of the two cores consists of silt and clay with occasional
 551 shell-rich horizons, sandy silt or muddy silt. The lithological changes of the
 552 Shahkileh sedimentary succession (Fig. 2A and SI 5) are classified in twelve

553 units. Units SU1, SU3, SU5 and SU 11-12 contain sand and/or shells. Units
 554 SU 7 and SU11 (840-815, 252-224 and 200-175 cm) are differently made by
 555 gravelly mud with some low roundness limestone gravels belonging to the
 556 Alborz Upper Jurassic carboniferous formations. The other units consist of
 557 clay and silt in more or less equal proportions. Generally, the colour of the
 558 sedimentary succession is olive grey to greyish brown. Only units SU10
 559 (upper part), SU11 and SU12 are brown to yellowish brown. The structures
 560 are mostly massive, uniform, non-layered or rarely faintly layered. Organic
 561 matter (OM) % varies between 1 and 6%, and is especially low in unit SU10
 562 and high in unit SU4. Carbonate content varies between 10 and 40% with a
 563 maximal value in units SU4 and SU12.

564 The Gharasoo sequence (Fig. 2B and SI 5) is divided in ten lithological
 565 units. Units GU2 GU4, GU6, GU8 and GU10 contain some sand and/or shells
 566 without any gravel content. The rest of the sedimentary succession is silty
 567 clay or clayey silt. The colour changes from olive grey to greyish brown. Only
 568 the top of unit GU10 turns to brown. The structures are mostly massive,
 569 uniform, with alternating non-layered and faintly layered horizons. Total OM
 570 varies between 1 and 4%. Carbonate content oscillates between 15 and 40%
 571 with a maximum value in unit GU9.

572 The fifteen dates show no reversal, except the date at 714 cm in
 573 Gharasoo, which is considered as an outlier (Table 3, Fig. 2B). The remaining
 574 fourteen datings suggest that the base of the core of Shahkileh is clearly older
 575 than 22 cal. ka BP and the top reaches the last centuries. The base of the
 576 Gharasoo core is close to 25 cal. ka BP and the top likely close to the present.
 577 The late Holocene part of the cored sequences will be presented elsewhere.
 578

Core	Lab number	cm depth	Material	uncal ¹⁴ C BP	uncertainty	INTCAL13 AD-BC	MAR13 AD-BC	INTCAL13 BP	MAR13 BP
Sha	POZ-38792	290	shells	103.42 pMC	0.36			AD 1951-1959*	
Sha	UBA-39063	745-741	broken shells & 1 very small gasteropod	4328	21	2922	2510	4872	4460
Sha	UBA-36129	970	plant fragments	12300	51	12291	11820	14241	13770
Sha	UBA-32446	1054	gastropod and bivalves	13311	66	14061	13470	16011	15420
Sha	UBA-32447	1157	9 bivalve valves	14842	65	16101	15649	18051	17599
Sha	UBA-32448	1501	1 Theodoxus	17278	74	18885	18403	20835	20353
Sha	POZ-38790	1661	shells	18040	100	19907	19377	21857	21327
Gha	POZ-38787	199	shells	2225	30	279	AD121	2229	1829
Gha	UBA-36126	310	broken bivalves	3634	25	1996	1584	3946	3534
Gha	UBA-32875	396	broken bivalves	12775	124	13275	12521	15225	14471
Gha	UBA-32449	546	a broken bivalve	15282	74	16605	16141	18555	18091
Gha	UBA-36127	714	broken bivalves	6722	29				
Gha	UBA-32450	787	bivalves	16494	73	17949	17468	19899	19418
Gha	UBA-32451	1042	1 bivalve	18062	78	19935	19409	21885	21359
Gha	POZ-38786	1136	shells	21450	140	23814	23446	25764	25396

579
580

581 **Table 3:** Radiocarbon dating of the Shahkileh (Sha) and Gharasoo (Gha) sequences
 582 for 2 sigma (95.4%). Star: post-modern age suggested by T. Goslar, Poznan
 583 laboratory (pers. comm., 2019).
 584

585 5.2 Palynology of the Shahkileh sequence

586 The palynological sequence (58 good samples interspersed by 12
 587 barren samples, Fig. 3 and Fig. SI 3) extends from 1610 to 680 cm depth, with

597 Glacial period. The thick dash line and the thick CONISS zone boundaries are used
598 for the diagram interpretation.
599

600 **Palynological zone S1 from 1610 to 1369 cm**

601 Tree pollen such as *Alnus*, *Fagus*, *Quercus* and *Ulmus-Zelkova* are
602 well represented. A maximum of *Amaranthaceae* characterises this zone.
603 *Artemisia*, *Poaceae*, and *Asteraceae Liguliflorae* are abundant. In the spores,
604 the monolete psilate are continuously present. Numerous reworked
605 palynomorphs are observed. The pollen concentration is low, mostly less than
606 5000 pollen grains per ml.

607 The dinocysts are relatively abundant and are largely dominated by a
608 large peak of *Impagidinium caspiense*, but most of the other taxa known for
609 the CS at that time are present too (*Pyxidinoopsis psilata*, *Spiniferites*
610 *cruciformis* forms A and B, with a type close to *Galeacysta etrusca*, *S.*
611 *belerius*, *Caspidium rugosum* and *C. rugosum rugosum*, one occurrence of
612 *Lingulodinium machaerophorum* and some *Brigantedinium*).
613 *Pentapharsodinium dalei* is absent though from this sequence.

614 **Palynological zones S1 from 1369 to 1309 cm and S2 (1309-1182 cm)**

615 *Ephedra* has the lowest values of the diagram. *Fagus* reaches several
616 times maximal values (up to 21%), while the representation of *Alnus*, *Quercus*
617 and *Ulmus-Zelkova* remains as in the previous zone. *Carpinus* and *Betula*
618 have become quasi continuously present. *Buxus* has three occurrences and
619 *Lonicera* has two single but high peaks. AP reach often as high as 40%.
620 *Amaranthaceae* decrease, while *Poaceae* and *Cyperaceae* increase to
621 maximal values. The end of zone S1 has several samples with very high
622 values of reworked elements (up to 94%).

623 *Typha-Sparganium* and *Gloeotrichia* are frequent, especially in zone
624 S2.

625 **Palynological zones S3 (1182-1102.5 cm) and S4 (1102.5–1046 cm)**

626 *Alnus* percentages decrease progressively throughout zones S3 and
627 S4. *Betula* marks a clear bell-shape maximum in zone S3. After a maximum
628 at the beginning of zone S4, *Fagus* decreases. *Quercus* has significantly high
629 values. *Fraxinus excelsior-t* is frequent. Overall, AP % are often high.
630 *Amaranthaceae* carry on declining. *Liguliflorae* percentages, after reaching a
631 minimum, start increasing in zone S4, this most likely explains why the
632 CONISS analysis indicates the strongest change in this sequence in between
633 zones 3 and 4 at 1102.5 cm. *Tubuliflorae* also increase in zone S4. *Artemisia*
634 percentages are maximal, although always below 25%. *Poaceae* values have
635 dropped significantly. Fungal spores, *Glomus* and most other fungal spores
636 have low values especially in zone S3. Reworking reaches the lowest
637 percentages of the whole diagram. Pollen concentration is very high, often
638 above 25,000 pollen grains per ml.

639 In the aquatics, *Potamogeton* pollen marks some regular occurrences
640 in these two zones. The fern spores are infrequent, as well as most other
641 aquatic plants. *Botryococcus* reach extremely high values: up to 190 % of the
642 pollen sum. The dinocysts % are low, and not diverse, especially in zone S3,
643 although their concentration is extremely high, often above 40,000 cysts per
644 ml. Foraminifera linings form for the first time a continuous curve in zone S4.

645 **Palynological zone S5 (1046-920.5 cm)**

646 Most tree pollen grains are low, leading to the lowest AP% of the
 647 diagram. Liguliflorae are high, frequently above 25%. After an initial peak at
 648 27%, *Artemisia* declines throughout this zone. Poaceae are high, as in zone
 649 S2. Reworked elements increase slowly through the zone. Concentration has
 650 fallen back, except in one sample. *Glomus* reaches a maximum several times.

651 In the aquatics, *Myriophyllum* has an irregular presence. The fern
 652 spores and the two taxa of *Typha* are back as in zone S2. *Botryococcus* are
 653 low again, except in one sample. *Spirogyra* and *Zygnema* occur in low values
 654 at the beginning of the zone. Dinocysts are back as in zone S2. The
 655 concentrations are low except in one sample. Foraminifera are frequent in the
 656 first part of this zone only.

657 **Palynological zone S6 (920.5 – 766 cm)**

658 CONISS indicates the second most important change at the transition
 659 between zones S5 and S6, i.e. at 920.5 cm. Most tree percentages rise gently
 660 again, especially *Quercus*. The Liguliflorae are still very high. Poaceae are
 661 low from now on, mostly below 10%. In a couple of samples, monolete psilate
 662 spores reach values as high as 32 %. Concentration is low, and four barren
 663 samples have been encountered. Reworking is high, especially at the
 664 beginning of the zone. Fungal spores increase and reach the extremely high
 665 percentages of 200 %.

666 *Anabaena* starts occurring more frequently. *Botryococcus* are
 667 extremely reduced. *I. caspiense* are low, while *Spiniferites cruciformis*
 668 reach often 5 %. *Caspidinium rugosum rugosum* is more abundant. The cyst
 669 concentration is quite low now and remains so for the rest of the diagram.

670 **Palynological zones S7 (766-742 cm) and S8 (742 – 680 cm)**

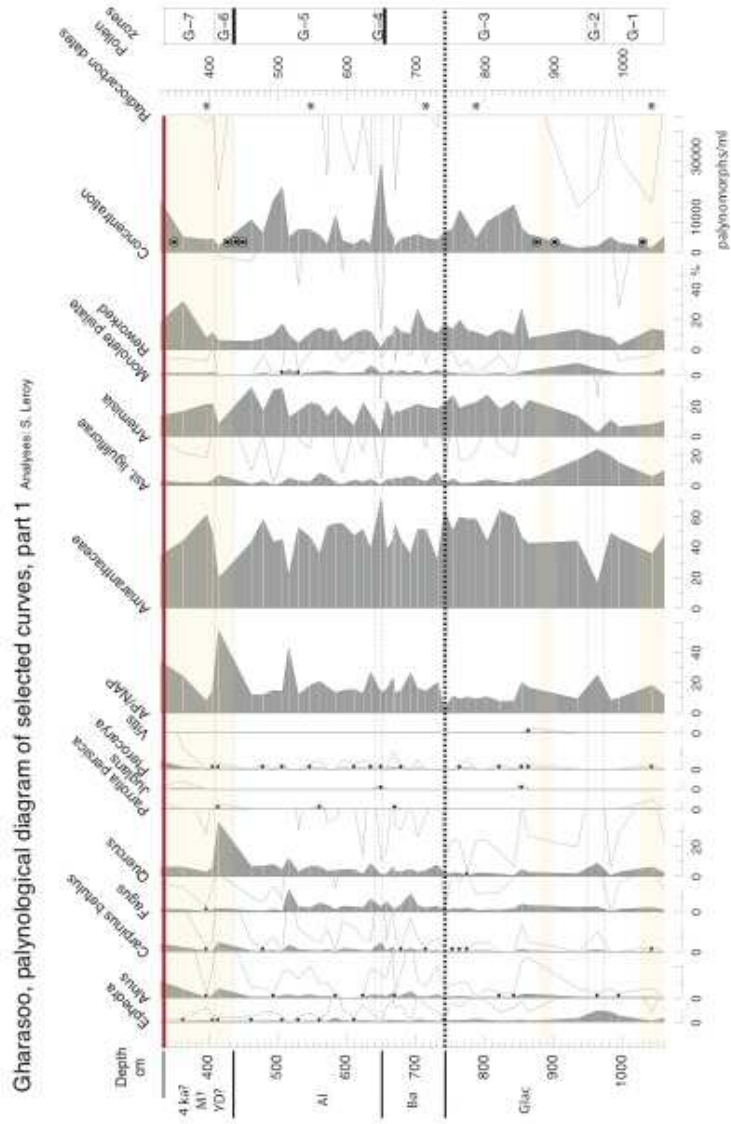
671 Most tree pollen values increase, specifically *Quercus*, *Fagus*, *Alnus*,
 672 *Pterocarya*. AP reach more than 70%. Amaranthaceae, Asteraceae
 673 Liguliflorae, *Artemisia* and Poaceae have a weak representation. A peak of
 674 reworking occurs towards the top of zone S8. Concentration is low especially
 675 in zone S7 that also contains one barren sample. Fungal spores are
 676 extremely high in zone S7, as at the end of zone S6. *Sordaria* reach a
 677 maximum at the end of zone S8.

678 *Anabaena* is still present. Between zones S7 and S8, a clear decrease
 679 of the dinocysts occurs.

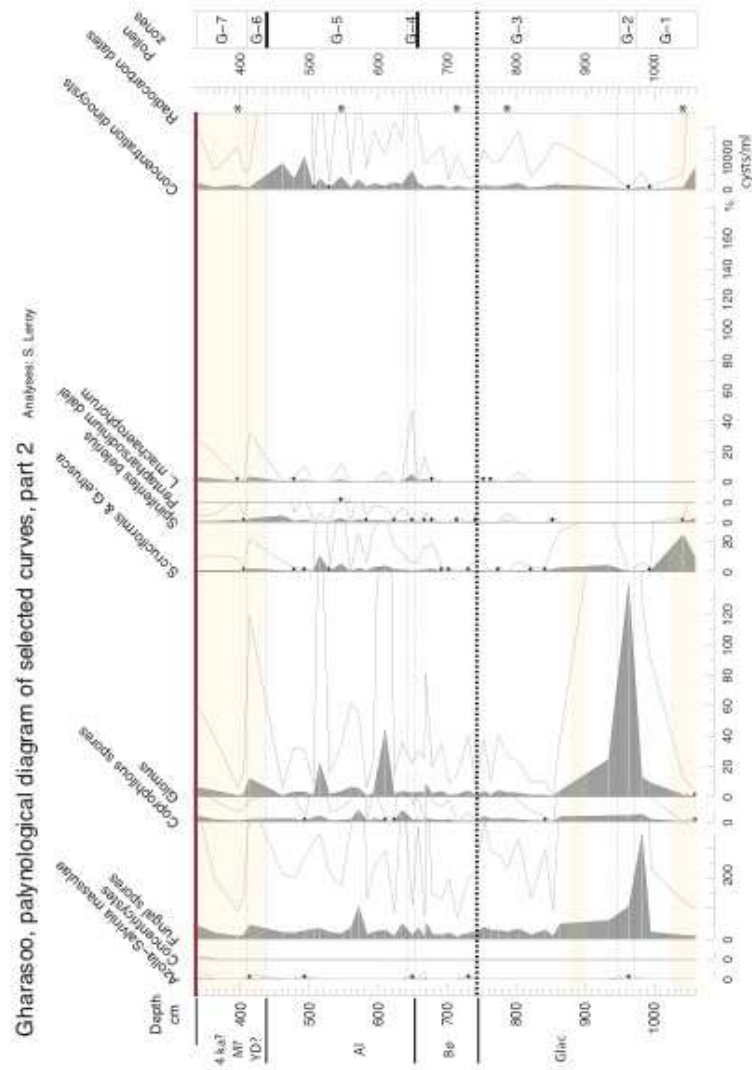
680 **5.3 Palynology of the Gharasoo sequence**

681 The palynological sequence (52 good samples interspersed by nine
 682 barren samples) extends from 1060 to 89 cm depth, with 19 barren samples
 683 at the bottom and two at the top (Fig. 4 and Fig. SI 4). Only the diagram below
 684 the hiatus at 336 cm depth (i.e. palynological zones G1 to G7) is relevant to
 685 this paper.

Leroy et al. fig. 4A



Leroy et al. fig. 4B



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Fig. 4: Gharasoo palynological diagram with selected curves (full diagram in Fig. SI 4). Black dot with circle: barren palynological samples. Yellow strips: sandy. 3.2 in a black box marks the beginning of *L. machaerophorum* at 3.2 cal. ka BP (Leroy et al., 2013b). YD: Younger Dryas, AI: Allerød, Bø: Bølling, Glac: Glacial period. The thick dash line and the thick CONISS zone boundaries are used for the diagram interpretation.

695 **Palynological zones G1 (1060-972.5 cm), G2 (972.5-948.5 cm) and G3 from**
 696 **948.5 to 736 cm**

697 *Ephedra* percentages display a maximum. Some tree pollen, such as
 698 *Alnus*, *Carpinus betulus*, *Fagus*, *Quercus* and *Ulmus-Zelkova*, are present.
 699 Amaranthaceae are dominant, increase across the three zones and reach a
 700 maximum (64%) before 736 cm depth. Zone G2 is defined due to a maximum
 701 in a bell-shaped curve of Liguliflorae. *Artemisia* is abundant. Concentration
 702 increases across the three zones. Fungal spores are abundant and reach a
 703 peak at the end of zone G1, whereas *Glomus* peaks in zone G2.

704 In the aquatics, *Typha-Sparganium* and *Botryococcus* occur regularly.
 705 The dinocyst concentration is low. Most taxa are present, except *L.*
 706 *machaerophorum* and *P. dalei*, which are quasi absent.

707 **Palynological zone G3 from 736 to 653 cm**

708 *Carpinus betulus* becomes continuous. *Fagus*, *Quercus* and *Ulmus-*
 709 *Zelkova* increase slightly. *Buxus* occurs twice. Amaranthaceae decrease
 710 sharply while *Artemisia* decreases slightly across this part of zone G3.

711 **Palynological zones G4 (653-641.5 cm) and G5 (641.5-437 cm)**

712 *Ephedra* presence becomes discontinuous. *Fagus* is well represented
 713 until the middle of zone G5, when it drops and leaves the space to *Quercus*
 714 and *Fraxinus excelsior*. *Artemisia* re-increases to maximal values in the
 715 second part of zone G5. A single high peak of Amaranthaceae justifies the
 716 identification of zone G4.

717 In the aquatics, *Typha* tetrads after a last occurrence disappear from
 718 the record. *P. psilata* is irregularly present and has its last occurrences in this
 719 zone. At the end of the zone, *S. belerius* has higher percentages than before.
 720 Dinocyst concentration increases in the second half of zone G5, driven by *I.*
 721 *caspiense*.

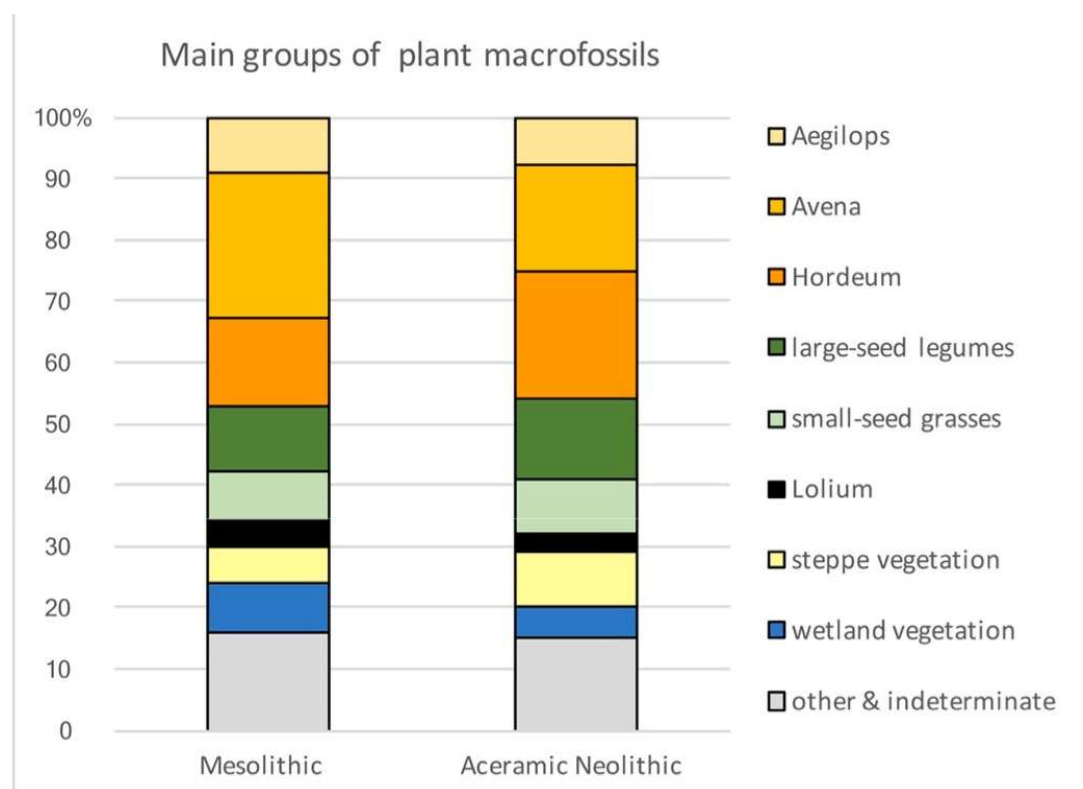
722 **Palynological zones G6 (437-409 cm) and G7 (409-336 cm)**

723 Only four samples make this double and motley zone, with three barren
 724 samples at its beginning and a barren one at its end. Zone G7 ends with the
 725 strongest change in the dispersion dendrogram.

726 The last occurrences of *Elaeagnus* and *Hippophae* are found here.
 727 After a single high peak of *Quercus*, its values fall back. *Betula* has the last
 728 occurrences of the diagram. Amaranthaceae are high at the beginning of zone
 729 G7, but falling afterwards. Reworked values are high at the end of zone G7.

730 In the aquatics, it is noteworthy to underline the continuous presence of
 731 *S. belerius*, although declining. *L. machaerophorum* has irregular and weak
 732 presence. The dinocyst concentration is low again.

733 For chronological purpose, it is additionally essential to indicate that, at
 734 260 cm, *P. dalei* and *L. machaerophorum* are increasing to reach
 735 progressively high values, e.g. 184% at 191 cm for *L. machaerophorum*.

736 **5.4 Archaeobotanical and faunal results at Komishani Tappeh**

737

738

739 **Fig. 5:** Komishani Tappeh: Overview chart of the archaeobotanical evidence.

740 Percentage proportions of the main groups plant macrofossil finds. Fig. 5 (left):

741 Mesolithic: 214 l of sediment, 25 samples, 2415 identifiable plant remains. Fig. 5

742 (right): Neolithic: 125 l of sediment, 13 samples, 2921 identifiable plant remains

743

744 The study focussed on samples from the lower sequences of the
 745 trenches in order to give an overview on archaeobotanical assemblages
 746 belonging to the Caspian Mesolithic and aceramic Neolithic. Archaeobotanical
 747 analyses of 41 sediment samples (Trench 1, contexts 10 to 23 (9 samples),
 748 Trench 2, contexts 4 to 25 (30 samples) and Trench 4, contexts 11 and 13 (2
 749 samples)) yielded 5489 identifiable specimens (Fig. 5). No clear difference
 750 between the macrobotanical composition of the two different chronological
 751 periods was observed in the studied materials. In some instances, the
 752 preservation of plant macroremains did not allow for identification beyond the
 753 family level. The botanical assemblage is dominated by large to medium-size
 754 seeds from grasses such as *Avena* (wild oats) and *Hordeum* (wild barley),
 755 and large-seed legumes and to lesser extent *Aegilops* (goat grass) (Fig. 5
 756 and SI 6).

757 The underground energy storage organs of an unidentified rhizome or
 758 tuber and the seeds of the wetland rush *Bolboschoenus* are present (Fig. SI
 759 6). Twenty seeds of *Hyoscyamus*, a toxic and psychoactive plant commonly
 760 known as henbane, were recovered from aceramic Neolithic context 13 in
 761 Trench 1 (Fig. SI 6).

762 Bone samples recovered from Mesolithic (contexts 13-14) and aceramic
 763 Neolithic (contexts 8-13) in Trench 4 represent largely consistent and
 764 comparable preservation (Fig. SI 2). Bones surfaces are characterized by

765 good states of preservation, 'ginger' colour and 'spikey' pre-depositional
766 fractures (fragments retaining sharply angular margins to ancient breaks;
767 [O'Connor, 1991, 234-235](#)), with relatively low levels of carnivore gnawing and
768 weathering, suggesting relatively quick burial of material which has not
769 suffered significant re-working. Bone samples from later disturbed layers
770 (contexts 2-5) exhibit variable states of preservation. This material is
771 frequently covered in heavy surface concretions and bones are friable and
772 more poorly preserved than the earlier layers. These samples are
773 characterised by quantities of human bones with extensive surface
774 concretions ([Table SI 1](#)). A smaller percentage of materials from these
775 disturbed contexts appears well-preserved and resemble those from lower
776 levels. However, less taxonomic diversity occurs in contexts 2, 3, 4 and 5 than
777 in aceramic Neolithic and Caspian Mesolithic levels, which may represent the
778 narrower diet breadth of later farming communities.

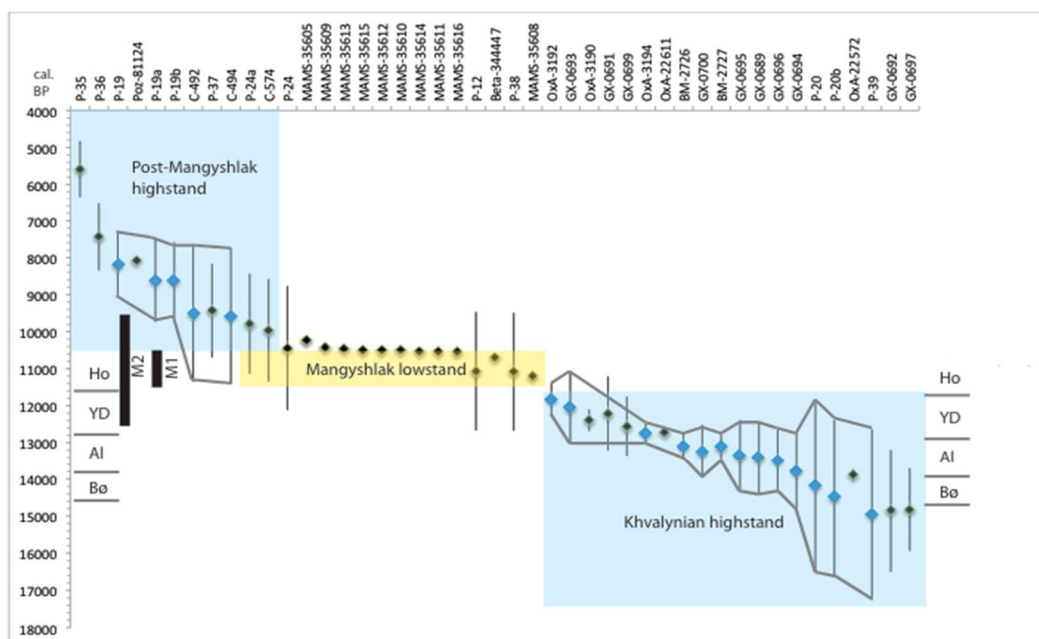
779 Faunal materials from both aceramic Neolithic and Caspian Mesolithic
780 contexts in Trench 4 are characterized by a taxonomic diversity reflecting the
781 broad spectrum of diets known from other Mesolithic and aceramic sites in the
782 Near East ([Table SI 1](#)). The mammalian faunal assemblage from these levels
783 is dominated by sheep and goat remains. However, our small sample size
784 currently prevents us from creating herd mortality profiles and drawing
785 meaningful conclusions as to the wild or domesticated status of either
786 species. Waterbirds dominate avian taxa recovered from Mesolithic context
787 14 and aceramic Neolithic horizons 8 through 13, which provides evidence for
788 the persistence of foraging beyond the emergence of small flint blades and
789 pressure-flaked, single-platform cores in the Caspian basin circa 8600 cal.
790 BC.

791 Analyses of stable carbon and nitrogen isotope values of 20 animal bones
792 indicated that collagen was sufficiently well preserved in twelve specimens to
793 compare the ratios of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ through the sequence ([Text SI 1, table](#)
794 [SI2 and fig. SI 7](#)). Ratios of these isotopes are a proxy for animal diet, which
795 can provide useful insights into animal management practices and
796 environmental conditions prevalent during different periods ([Lee-Thorp, 2008](#)).
797 Data from these analyses demonstrate that ruminant species consumed
798 predominantly C_3 plants in the Mesolithic and aceramic Neolithic periods ([Text](#)
799 [SI 1, table SI2 and fig. SI 7](#)). C_4 plants account for less than 0.5% of native
800 species within the modern-day phytogeographic region where Komishani
801 Tappeh is situated ([Bocherens et al., 2000:106](#)).

802 **5.5 Radiocarbon dates of the archaeological sites**

803 Forty-seven dates spanning from c.14,800 to c. 5600 cal. BP were
804 used. Only five of them had no faunal or environmental data attached to them.
805 Although the large statistical variability of early radiocarbon dating techniques
806 restricts the ability to use them, eighteen samples provided evidence of seal
807 bones or an indication of transgression ([Tables 1 and 2](#)). The latter dates
808 appeared to be arranged in two age groups: one group in the Late
809 Pleistocene and one group around 11,400 to 7300 cal. BP, but more likely
810 9580 - 8100 cal. BP ([Fig. 6](#)).

811



812
 813 **Fig. 6:** Radiocarbon ages in cal. BP of archaeological deposits with evidence of
 814 human predation on seals or of highstand in blue and of herbivorous mammals in
 815 black. Ho: Holocene, YD: Younger Dryas, Al: Allerød, Bø: Bølling, M1: Mangyshlak
 816 lowstand in deep-sea basin (Leroy et al., 2014), M2 in shallow north basin
 817 (Bezrodnykh and Sorokhin, 2016). Vertical black boxes: extent of the Mangyshlak
 818 lowstand.

819 6 Interpretation

820 6.1 The sequence of Shahkileh

821 The base of the Shahkileh sequence starts with a sand unit (SU1) that
 822 is barren of pollen until 1610 cm depth, and of an age close to the Last Glacial
 823 Maximum (Fig. 2A). The Gorgan Bay is very small or has perhaps even
 824 disappeared. Pollen zone S1 largely overlaps with the upper part of this sandy
 825 unit. The spectra are interpreted as representing a very open landscape with
 826 some trees in sheltered areas, such as the slopes of the mountain valleys.
 827 This period is suggested to belong to a glacial phase.

828 The end of zone S1 and zone S2 see the development of vegetation
 829 cover. This is interpreted as the start of an interstadial, Bølling-type. Some
 830 sand and sandy silt are found in unit SU3. Further vegetation development
 831 occurs in zones S3 and S4, which would correspond to a second interstadial
 832 phase, Allerød-style. The sediment is fine-grained.

833 From 1182 to c. 1102.5 cm (zone S3 going into S4), a phase with
 834 strong signs of fresh water (*Potamogeton*, high *Botryococcus*, low diversity of
 835 dinocysts that are dominated by *I. caspienense*) and lack of erosion (low fern
 836 spores, low reworking, well preserved and abundant palynomorphs, low
 837 fungal spores) is visible. The landscape corresponds to a forest steppe along
 838 the coast. This is most likely still in the Allerød interstadial. The Gorgan Bay is

839 probably very large due to a high stand. It is even possible that the Miankaleh
840 Spit does not exist.

841 Then the climate deteriorates and the vegetation cover opens (zone
842 S5). The first part of this phase is rich in shells (unit SU5), but the second part
843 is back to a fine-grained sediment. Zone S5 is attributed to the Younger
844 Dryas, with a first brief shallow part (Zygnemataceae and shell-rich layer) and
845 a deeper second part.

846 With zone S6, the forest redevelops. This is the beginning of the
847 Holocene. The start of the *Anabaena* curve, at base of zone S6, has been
848 elsewhere interpreted as the sign of the beginning of the Holocene (Leroy et
849 al., 2013c, 2014). Zone S6 contains a gravely mud unit (SU7) corresponding
850 to a high-energy environment. It is well-marked by a maximum of psilate fern
851 spores. The number of barren samples also contributes to suggest periods of
852 temporary emersion. Thus overall, zone S6 might fit with the Mangyshlak
853 lowstand, with the gravely mud corresponding to the lowest stand.

854 Zones S7 and S8 show a rapid development of diverse coastal and
855 altitudinal forests. The absence of *L. machaerophorum* in zones S7 and 8
856 suggest that they could still be older than 3200 years ago (Leroy et al.,
857 2013b). It is proposed that the limit between zones S6 and S7 represents the
858 regional increase in humidity subsequent to the 8.2 ka event (Messenger et al.,
859 2013; Joannin et al., 2014). The Gorgan Bay is again probably very large.

860 Then the rest of the sequence is barren of pollen. Towards the top
861 starting around 325 cm, the sediment is oxidised, and from 139 cm it is shelly
862 (unit SU12pp). The lagoon in Shakhileh has filled in. The top metres of the
863 Shakhileh core with the gravely mud horizons and the shell layers may also
864 have been subjected to significant human impact due to the proximity of a
865 Sasanian wall, i.e. the Tammisheh Wall, and a Safavid harbour, i.e. the Ashraf
866 harbour (Nokandeh et al., 2006; Naderi et al., 2013b).

867 6.2 The sequence of Gharasoo

868 Although the interpretation of Gharasoo sequence is less clear than
869 that of Shakhileh, the following may be proposed. The base of the sequence
870 starts with barren units: two fine-grained units (units GU1 and 3) and two
871 sandy/silty ones (units GU2 and 4) of a possible Last Glacial Maximum age
872 (Fig. 2B). The coarse sediment suggests a low water level and an input by the
873 Gharasoo River. The open vegetation at the base of the sequence (zones G1,
874 2 and 3 until 736 cm) belongs to a glacial period. It contains several
875 sandy/silty layers (units GU4 and GU6pp). Then the warming of the
876 interstadial, Bølling-like, is felt with tree cover increase. Pollen zone G4 is only
877 one sample long, is a brief erosive event, and could potentially be related to
878 one of the brief colder phases of the Bølling-Allerød interstadial. The Allerød
879 is marked by the development of a range of deciduous trees, especially *Fagus*
880 and *Quercus*. Zones G6 and G7 are highly disturbed owing to the occurrence
881 of sand (unit GU8). It could correspond to the Younger Dryas (in the offshore
882 cores GS05 and GS18, *S. belerius* occurs no later than the Late Pleistocene),
883 although the retroactive effect of the successive Mangyshlak and the 4 ka
884 lowstands (for the latter see discussion) could have been superimposed and
885 caused further disturbance to this unit.

886 Then an important hiatus occurs at 336 cm. Although the late Holocene
887 part of the sequence will be presented elsewhere, it is useful to note that the

888 start of both occurrences of *P. dalei* and *L. machaerophorum* at 260 cm. The
 889 latter has been dated in the TM sequence at 3200 years ago (Leroy et al.,
 890 2013a,b).

891 **6.3 Archaeobotanical and faunal assemblages from Komishani**

892 **Tappeh**

893 Preliminary analysis of the well-preserved botanical and faunal
 894 assemblages from Komishani Tappeh provides a window into human
 895 exploitation of plants and animals from diverse ecological niches at the
 896 intersection of the southern coastal plain of the CS and the foothills of the
 897 Alborz Mountains during the early Holocene.

898 **6.3.1 Archaeobotanical assemblages**

899 Most of the large seeds (*Avena*, *Hordeum*, *Aegilops*, *Stipa* and legume
 900 seeds) likely entered archaeological horizons at the site through intensive
 901 collection and processing for human consumption (Weide et al., 2018) and
 902 correspond well to the pattern of pre-Neolithic plant exploitation in the region
 903 (Arranz-Otaegui et al., 2016). This composition with dominance of large seeds
 904 and their percentage value (over 50% for both periods) is very similar with
 905 what is observed in other Iranian pre-pottery Neolithic sites like East Chia
 906 Sabz (53%) and at Chogha Golan (55%) (Riehl et al., 2012).

907 Elements of the steppe vegetation like *Adonis*, *Stipa* and *Nesslia* occur
 908 regularly in the archaeobotanical assemblages and indicate that this habitat
 909 was common in the surrounding of the site. *Adonis* and *Nesslia* are known as
 910 a weed species incorporated in cultivated field systems in later periods
 911 (Whitlam et al., 2018). *Stipa* is usually avoided by animals because its awns
 912 and whole florets are dangerous when swallowed by causing damage to the
 913 intestines. Therefore Hillmann (2000) proposed that *Stipa* was gathered and
 914 processed by people during the Epipalaeolithic and early Neolithic in the Near
 915 East for consumption. The abundant *Stipa* finds at early Neolithic Sheikh-e
 916 Abad, western Iran (Whitlam et al. 2018: 826-27), can also be interpreted as
 917 evidence for human use of this large-seed wild species as a staple food.

918 *Phalaris* species have been observed to be seasonal forage for
 919 herbivorous mammalian species (Goodin and Northington, 2013). Thus the
 920 abundant botanical remains of *Phalaris* and other small-seed species, less
 921 numerous in archaeobotanical finds (like *Astragalus* spp., *Chenopodium* spp.,
 922 *Malva* spp., *Medicago/Trifolium* and *Rumex* spp.), are indicators for the use of
 923 dung as fuel at archaeological sites (Van Zeist et al., 1984; Charles, 1996;
 924 Whitlam et al., 2018) and thus indirectly suggest increasing intensity of animal
 925 management at Komishani Tappeh.

926 The underground storage organs of *Bolboschoenus* have recently been
 927 identified as the source of flour in bread from a 14,000-year-old Natufian
 928 hunter-gatherer encampment in northern Jordan (Arranz-Otaegui et al., 2018).
 929 Its seeds occur frequently in the samples, most probably because they were
 930 processed for food consumption through roasting (Hillmann, 2000) and thus
 931 preserved in the cultural layers in charred state as observed in Chogha Golan
 932 (Weide et al., 2017). This plant could potentially have been used as a food
 933 resource and for matting and dwelling construction at Komishani Tappeh. The

934 finds of *Hyoscyamus* raise questions concerning its potential use for
 935 medicinal, spiritual or ritual purposes. The plant usually comes from areas
 936 close to humid disturbed habitats, rich in nutrients. So together with
 937 *Bolboschoenus*, they represent the use of wetland areas that probably were
 938 plentiful in the coastal plains near the site.

939 **6.3.2 Faunal assemblages**

940 Although the recovered faunal sample size is small, several
 941 observations can be drawn from the assemblage. A clear similarity in the
 942 taphonomic preservation and composition of the remains is observed between
 943 the Mesolithic and the Early Neolithic, indicating a degree of continuity.

944 The diverse environments in the region are represented by the different
 945 taxa in the assemblage. For example, the water birds would have access to
 946 the coastal water bodies. In terms of the caprines, although wild goats tend to
 947 inhabit higher altitudes than sheep, both species may be found at any altitude
 948 and their ranges reflect more their habitat preferences. Wild bezoar goats are
 949 adapted to rocky substrates and steep slopes, habitats where their
 950 morphology enables them the agility to escape predators (Korshunov, 1994;
 951 Shams et al., 2010; Weinberg, 2001). Extant populations of Asiatic mouflon
 952 (*Ovis orientalis*) inhabit moderately to very arid habitats and particularly
 953 grasslands, including mountains, foothills and rolling steppes (Bashari and
 954 Hemami, 2013; Valdez, 2008). These habitat preferences mean that minimal
 955 competition for food resources exists between wild sheep and goats
 956 (Korshunov, 1994). It would be expected for these animals to follow seasonal
 957 migrations to make use of available resources at different altitudes throughout
 958 the year (Korshunov, 1994; Shams et al., 2010). Hunted animals would
 959 therefore represent habitats accessible from Komishani Tappeh and also
 960 perhaps indicate seasons of hunting.

961 **7 Discussion**

962 **7.1 Varying radiocarbon reservoir effect in the two core sequences**

963 The two sites are in a lagoon, at times directly influenced by the CS, at
 964 other times under a more terrestrial influence. Hence it is difficult to decide
 965 what calibration curve to choose (INTCAL13 or MAR13). Moreover, it is
 966 already known by investigations north of the Miankaleh Spit along a surface
 967 transect that the reservoir effect is higher than the 400 yr used for the MAR13
 968 calibration curve and may vary between 670 and 750 yr (Leroy et al., 2018).

969 When we examined the chronological sequence of the two pollen
 970 diagrams in the context of other Caspian sequences, we came to doubt the
 971 radiocarbon ages obtained from the Shahkileh and Gharasoo cores. In the
 972 Shahkileh sequence, the pollen diagram suggests three rather precise dates
 973 (Fig. 2A): the beginning and the end of the Younger Dryas and the 8.2 ka shift
 974 (Weninger et al., 2006). Only the end of the Younger Dryas is consistent with
 975 the radiocarbon chronology, while the beginning of the Younger Dryas
 976 suggested by its radiocarbon age is much too old, i.e. by ~2500-3100 yr, and
 977 the 8.2 ka climatic shift is much too late, i.e. by ~2100-2500 yr. The
 978 palynology of the Gharasoo sequence (Fig. 2B) suggests that the radiocarbon
 979 date for the beginning of the Younger Dryas is similarly too old by ~2500-3100

980 yr; while the start of the *L. machaerophorum* and *P. dalei* curves at 3.2 ka is
981 slightly too young.

982 We propose that much like the Black Sea (Soulet et al., 2011), the
983 radiocarbon reservoir effect varies with time in this CS lagoon. Changes in
984 reservoir effect in the Black Sea have been linked to basin hydrology. When
985 the basin is closed, inorganic carbon is increasingly brought by rivers and the
986 reservoir effect increases. Another varying contribution over time is the input
987 of inorganic carbon by rivers according to the weathering intensity in the river
988 catchment (Soulet et al., 2011). These two factors likely played a significant
989 role on the S-E coast of the CS where: 1) the lagoon, at times open – at times
990 confined, received varying amounts of river water; and 2) carbonates from the
991 Kopet Dagh were deposited during the glacial periods when winds were
992 strong and loess formed, as attested for example in the nearby Neka and
993 Toshan regions (Frechen et al., 2009; Vlamincx et al., 2018) (Fig. 1B).

994 7.2 Water levels, archaeological dates and bones

995 Both cored sequences show low water levels in the glacial period (most
996 likely the Last Glacial Maximum), followed by high levels in the interstadial.
997 Both records have an important hiatus or period of emersion starting in the
998 mid-Holocene. In Shahkileh, the top c. 7 m of sediment are barren of
999 palynomorphs; while, in Gharasoo, sedimentation and pollen preservation
1000 start again after ~>7-8 millennia (not presented here). Shahkileh has slightly
1001 more terrestrial and fresher waters than Gharasoo. The latter sequence has
1002 occasional occurrences of *Ruppia*, an aquatic plant of brackish waters and
1003 less *Potamogeton*, *Myriophyllum* and *Botryococcus*. The concentration in
1004 dinocysts is higher in Gharasoo. Overall this is confirming that the mouth of
1005 the lagoon is closer to Gharasoo, as today, and that Shahkileh is usually in a
1006 sheltered position behind a spit and readily influenced by freshwater.

1007 The interruption between the two groups of archaeological dates with
1008 seal bones or indicators of highstand fits well the age of the Mangyshlak
1009 lowstand (Leroy et al., 2013c, 2014; Bezrodnykh and Sorokin, 2016) (Fig. 6;
1010 Tables 1 and 2). The large coastal plain in front of the caves extended
1011 hundreds km northward (Fig. 1A), as the bathymetry north of the Miankaleh
1012 Spit is very shallow (mostly less than 20 m) (Leroy et al., 2018), Gorgan Bay
1013 itself would have been much reduced or non-existent. The oldest group of
1014 dates with seals and highstand indicators in the Late Pleistocene corresponds
1015 to the Khvalynian highstand, whereas the youngest group of dates suggest
1016 the post-Mangyshlak highstand (Leroy et al., 2019; in press).

1017 7.3 The Last Glacial Maximum and the 4 ka questions

1018 For the Last Glacial Maximum, the literature shows contradictory
1019 information about the water levels in the CS, highstand or lowstand (Leroy et
1020 al., in press). Using the ages proposed by the pollen diagram and applying a
1021 correction of 2500-3100 years, the bottom of each core reaches the Last
1022 Glacial Maximum. In both localities, the sediment is sandy and barren of
1023 palynomorphs, suggesting a lowstand. This is in agreement with the Last
1024 Glacial Maximum when CS level reached 50 to 113 m bsl, which is equivalent
1025 to the Eltonian, Atelian or Enotayevian lowstand, various names according to
1026 different authors (Varushchenko et al., 1987; Chepalyga, 2007; Svitoch, 2009;

1027 [Yanina 2014; Yanina et al., 2018](#)). Moreover the results of climate modelling
 1028 by [Arpe et al. \(2011\)](#) are also in favour of a lowstand for the Last Glacial
 1029 Maximum.

1030 In the Shahkileh sequence, the sediment is barren of palynomorphs
 1031 after c. 4 cal. ka BP, probably by oxidation caused by temporary emersion. In
 1032 the Gharasoo sequence, an especially long hiatus occurs between <12.9 (end
 1033 of Allerød) and >4.0-3.5 cal. ka BP (radiocarbon date at 310 cm). This may
 1034 result from the retro-active effect of the Younger Dryas, 4 ka event and
 1035 Mangyshlak lowstand leading to erosion of the underlying sediment ([Leroy et
 1036 al., 2013a](#)). An important change in dinocyst assemblage from low salinity to
 1037 more brackish has been noted in three deep-sea sequences: in the south
 1038 basin (cores CP14, GS05), in the middle basin (core GS18) and in the north
 1039 of middle basin (core Sh7) ([Leroy et al., 2007, 2013 c, 2014, and 2019](#)). Along
 1040 the coast, this 4 ka period is moreover marked by barren levels topped by
 1041 gypsum, due to emersion in a lagoon of the SE of the south Caspian basin
 1042 (core TM) ([Leroy et al., 2013a](#)). Thus overall six sites show evidence of deep
 1043 changes in the CS at 4 ka. It has been recently suggested that its origin could
 1044 be found in hydrographic changes with a sharp reduction of the Amu-Darya
 1045 inflow to the CS and the end of a humid period over the Karakum Desert
 1046 ([Leroy et al., 2019](#)) due to the decrease of meltwater into rivers flowing from
 1047 the Hindu-Kush to the Karakum, such as the Murghab River ([Fig.1A](#)).

1048 **7.4 Vegetation and herbivorous animals**

1049 When comparing the two sequences, it appears that Shahkileh has
 1050 higher AP% than Gharasoo in the Pleistocene. *Elaeagnus*, a small tree of dry
 1051 lands, is frequent in Gharasoo. Amaranthaceae percentages are commonly
 1052 higher in Gharasoo in agreement with modern spectra ([Leroy et al., 2013a](#)).
 1053 *Buxus* makes a brief appearance in the Bølling phase of the two sequences.
 1054 The AP% is higher in the Shahkileh sequence than the Gharasoo one (in a
 1055 more eastward position), and higher in the Gharasoo sequence than in core
 1056 TM (further to the North and further away from the mountains) ([Leroy et al.,
 1057 2013a](#)). This thus reflects well humidity gradients along the southern coast
 1058 from the west to the east and along the east coast from the south to the north,
 1059 as is the case today.

1060 The Mesolithic charcoal assemblages found in the Ali Tappeh Cave
 1061 (Shirazi, unpublished data) fit rather well the Younger Dryas pollen spectra of
 1062 the Shahkileh sequence. Especially as it reveals the abundance of flowering
 1063 species of the Rosaceae family, which are often undetectable through pollen
 1064 analysis, but may have provided hunter-gatherers with a source of edible
 1065 fruits, such as plums, peaches, apricots, or almonds. A comparison of pollen
 1066 and macroremains is inadequate due to the low taxonomical resolution of
 1067 pollen analysis. However, it should be noted that Cerealia-t. pollen occurs
 1068 continuously but irregularly in the Lateglacial of both cored sequences.

1069 A feature of both sequences is the continuous presence and the
 1070 diversity of the deciduous trees during the pre-Holocene period, i.e. not only
 1071 *Acer*, *Alnus*, *Betula*, *Carpinus betulus*, *Fagus*, *Quercus*, *Tilia*, but also
 1072 *Pterocarya* and *Ulmus-Zelkova*. The existence of refugia during the Last
 1073 Glacial Maximum at the foot of the Alborz Mountains was hypothesised from
 1074 climatic modelling ([Leroy and Arpe, 2007; Arpe et al., 2011](#)). It is likely that,
 1075 during the Younger Dryas, this niche-rich region was also a refuge, although

1076 no climatic models are available at the moment to corroborate this. During the
 1077 Younger Dryas, only a slight drop of the arboreal cover was observed: AP %
 1078 drop to 19%, compared to values of 33 % before and 30 % after (Shahkileh
 1079 sequence). Thus, this forested steppe vegetation is reflective of climatic
 1080 conditions far from the extremes of glaciation, and which would have been
 1081 conducive to the survival of a wide range of mammalian species and
 1082 persistence of human occupation of the region.

1083 The diverse vegetation cover reconstructed from palynology,
 1084 anthracology and archaeobotany is suitable to sustain the range of
 1085 herbivorous mammals found in the bone assemblages (Tables 1 and 2).
 1086 Nowzari et al. (2007) have observed that Goitered gazelle (*Gazella*
 1087 *subgutturosa*) prefer *Astragalus* and *Ebenus* for food and shelter, and feed on
 1088 plant communities dominated by *Bromus danthoniae* and *Stipa barbata* (the
 1089 latter may be eaten before flowering, not afterwards, see earlier comments)
 1090 during autumn and *Astragalus* spp., *Poa bulbosa*, *Aegilops umbellulata*, and
 1091 *Bromus danthoniae* in winter. *Artemisia* spp. and *Astragalus* spp. are also
 1092 found in most habitats of wild sheep (*Ovis orientalis*) in Iran today, where, as
 1093 Bashari and Hemami (2013) have noted, the higher risk of predation on plains
 1094 results in preferential feeding on upland pastures. Similarly, Morovati et al.
 1095 (2014) conclude that the most important factors affecting desirability of
 1096 habitats for wild goat populations (*Capra aegagrus*) are the ratio of distances
 1097 to rocky cliffs and slopes, and distance to water and food resources such as
 1098 *Artemisia sieberi*. The preferred habitats of wild aurochs remain uncertain, as
 1099 *Bos primigenius* and its descendant species are known to have occupied a
 1100 broad range of niches, including river valleys and deltas, deciduous forests,
 1101 deserts, upland steppes and grasslands (Van Vuure, 2005). Red deer (*Cervus*
 1102 *elaphus*), once abundant on the forested northern slopes of the Alborz and
 1103 western slopes of the Zagros in historically known periods, are now confined
 1104 to a number of remote wooded reserves in the central and eastern Alborz
 1105 (Encyclopaedia Iranica, 2005).

1106 7.5 Environment – human interactions

1107 7.5.1 The McBurney hypothesis

1108 The continuous presence of spores from coprophilous fungi in the
 1109 Shahkileh and Gharasoo sequence confirms the presence of grazing
 1110 herbivorous mammals (Cugny et al., 2010). This continuity is only interrupted
 1111 in the Shahkileh record by indicators of freshwater aquatic organisms
 1112 (*Potamogeton* and *Botryococcus*) and still water (fine-grained sediment and
 1113 the maximum of organic matter in unit SU4, and the absence of erosional
 1114 indicators) in the first part of the Allerød interstadial. At that point the coastal
 1115 plain was likely to have been very narrow, which might explain the presence
 1116 of seal bones in the basal Mesolithic occupation levels at Belt, Hotu and Ali
 1117 Tappeh Caves (Fig. 6). The close proximity of the Caspian shore likely
 1118 facilitated easy transport of seal from hunting grounds to the caves where
 1119 they were consumed in an increasingly sedentary pattern of resource
 1120 procurement.

1121 If the gravelly mud in unit SU7 of the Shahkileh core indeed
 1122 corresponds to the greatest extent of the Mangyshlak lowstand, the coastal

1123 plain would have been much wider than at present. The absence of seal
 1124 bones in archaeological horizons corresponding to this period at Belt, Hotu,
 1125 Ali Tappeh and Komishan Caves suggests that Mesolithic hunters and
 1126 gatherers had difficulties in accessing this animal (Fig. 6). Consequently, the
 1127 inhabitants of these rock shelters came to rely on a much broader range of
 1128 mammalian species, including gazelles, aurochs, sheep, goats and equids,
 1129 adapted to the open vegetation covering the greatly enlarged coastal plain
 1130 and nearby foothills of the Alborz Mountains.
 1131 This confirms the two parts of McBurney hypothesis.

1132 **7.5.2 Early Neolithization**

1133 The botanical, faunal and archaeological evidence from Komishani
 1134 Tappeh strongly suggests that the management of wild plant and animal
 1135 resources preceded the local emergence of a low-level food-producing society
 1136 on the southern coastal plain of the CS during the early Holocene.
 1137 Continuities in the botanical and faunal assemblages of Mesolithic and
 1138 Neolithic horizons demonstrate that the process of Neolithization occurred
 1139 over a prolonged period between 9200 and 8200 cal. BC. Coupled with a
 1140 botanical assemblage dominated by large to medium-size seeds, such as wild
 1141 oats, wild barley, goat grass and leguminous seeds, the first appearance of
 1142 ground stone tools in the region comes from the earliest Mesolithic level able
 1143 to be dated at the site (9200 cal. BC). The aceramic Neolithic levels bearing
 1144 small flint blades and pressure-flaked, single-platform cores at the site all fall
 1145 between 8600 and 8200 cal. BC.

1146 This early process of Neolithization in the southern Caspian basin was
 1147 most likely facilitated by favourable environmental conditions at the time as
 1148 well as those preceding it. Unlike other localities in southwest Asia where
 1149 lacustrine and pollen records indicate water levels dropped dramatically and
 1150 vegetation turned to semi-arid (Wick et al., 2003; Wasylkova, 2005; Stevens
 1151 et al., 2012), our evidence shows that the cool and dry conditions often
 1152 associated with the Younger Dryas (Jones et al., 2019) do not appear to have
 1153 been as extreme in this region. Thus, increasingly sedentary hunting and
 1154 gathering groups could have drawn on plant and animal resources from
 1155 multiple ecological niches at the intersection of the southern coastal plain of
 1156 the CS and the foothills of the Alborz Mountains, without suffering significant
 1157 resource stress or reduced population levels that may have been encountered
 1158 in neighbouring regions (Baird et al., 2013).

1159 Palynological evidence for the development of deciduous forest (mostly
 1160 oak) found in the Shahkileh sequence in zones S7 and S8 is similar to that in
 1161 core GS 18 after 8.2 cal. ka BP (in the middle CS basin) and in core GS05
 1162 after 8.4 cal. ka BP (in the southern CS basin) (Fig. 1A). These indicators of
 1163 climate amelioration fit well with the emergence and/or dispersal of
 1164 agricultural ways of life throughout western central Asia. Wetter climatic
 1165 conditions (called the Liavliakan phase) have been recorded between ~8.8
 1166 and 4.5 cal. ka BP (published as 8 to 4 ¹⁴C ka BP) in lands between the
 1167 foothills of the Kopet Dagh and the western edge of the Karakum Desert
 1168 (Lioubimtseva et al., 1998). These climatic conditions likely facilitated the
 1169 adoption of agriculture at the late Neolithic agricultural village of Jeitun
 1170 between 6400 and 5600 cal. BC (Masson, 1957; Harris et al., 1993; Harris,

1171 2010) (Fig. 1A). No clear-cut trajectory for the dispersal of agricultural or
1172 agropastoral ways of life from the Near East to other regions in Asia has been
1173 established (Gangal et al., 2014). However, recovery of Caspian ‘soft’ ware
1174 pottery fragments from otherwise aceramic contexts and basal pottery-bearing
1175 horizons at Sang-e Chakhmaq (at c. 130 km east of Behshahr, on the
1176 southern flank of the Alborz Mountain and at c. 1400 m elevation, Fig. 1B)
1177 (Nakamura, 2014; Tsuneki, 2014) supports the idea that pottery making was
1178 adopted on the southeastern flanks of the Alborz Mountains from an
1179 independent centre of ‘Neolithization’ in the Caspian basin in the 7th
1180 millennium BC (Gregg and Thornton, 2012). On the north-eastern foothills of
1181 the Alborz Mountains, the recovery of unfired and fired clay objects from
1182 Mesolithic levels at Belt and Hotu Caves (Coon, 1951,1952; Dupree, 1952),
1183 not only attests to a ‘Mesolithic interest in clay’ as Coon suggested, but also
1184 allows for the potential independent invention of pottery in this region during
1185 later Neolithic periods (Gregg and Thornton, 2012).

1186 8 Conclusions

1187 These investigations have identified a significant problem with
1188 radiocarbon dating of organic materials of marine origin in a southern Caspian
1189 lagoon during the Late Pleistocene, due to the large reservoir effect resulting
1190 from carbonate inputs from the Kopet Dagh and the foothills of the Alborz
1191 Mountains. Nevertheless, the two sequences of Shahkileh and Gharasoo do
1192 provide sedimentological and palynological evidence for environmental
1193 change during the terminal Pleistocene and early Holocene, a time period
1194 when major transformations in human subsistence and social practices,
1195 including related innovations in chipped stone, ground stone and ceramic
1196 technologies, emerged and dispersed throughout the region.

1197 The Shahkileh and Gharasoo sequences record a period of high CS
1198 levels in the Late Pleistocene. In Shahkileh, specifically in the Allerød
1199 Interstadial, a phase of abundant freshwater and a decline of the herbivore
1200 grazing indicators is found. This evidence of high CS levels, when coupled
1201 with the earliest seal-bearing occupations of Ali Tappeh Cave dating between
1202 11,500 and 10,500 cal. BC, supports the first part of McBurney’s hypothesis
1203 that when CS levels were high and the coastal plain was narrow, Mesolithic
1204 hunters were reliant on seal and deer. The sequences provide evidence of
1205 three lowstands, the Last Glacial Maximum, the Mangyshlak, and the 4 ka
1206 event, before the local infilling of the lagoon. The Mangyshlak lowstand would
1207 have greatly enlarged the coastal plain and provided habitats for the broad
1208 range of mammalian species found in faunal assemblages of the Mesolithic
1209 and/or Neolithic occupations of Belt, Hotu, Ali Tappeh and Komishan Caves
1210 and Komishani Tappeh, thus supporting McBurney’s second contention that
1211 as water levels receded and a wide coastal plain emerged, hunters consumed
1212 different range of species, including auroch, onager, boar, gazelle, sheep and
1213 goat.

1214 A combination of palynology, anthracology and plant macroremains, rare
1215 for the studied region, allowed the reconstruction of vegetation. The presence
1216 of animal bones attested of the occurrence of herbivorous animals and their
1217 use by prehistoric population in the Mesolithic and Neolithic periods. All
1218 proxies indicated the diversity of ecological niches and the continuous

1219 presence of wetlands. During the Younger Dryas, a diverse range of
 1220 deciduous trees persisted in this region indicating climatic conditions
 1221 favourable for a broad variety of plant and animal food resources, and hence
 1222 for human survival. This may explain the early process of Neolithization on the
 1223 southern coastal plain of the Caspian Sea, which had its roots in a relatively
 1224 benign impact of the Younger Dryas stadial.

1225 Faunal, botanical and archaeological evidence from Komishani Tappeh
 1226 demonstrate that this process of Neolithization was a very gradual, low-cost
 1227 adaptation to new ways of life, with neither the wholesale abandonment of
 1228 hunting and gathering, nor a climatic trigger event for the emergence of a low-
 1229 level, food-producing society. This evidence shows that Mesolithic hunters
 1230 and gatherers were targeting sheep and goat populations, collecting wild oats
 1231 and wild barley and legumes and using ground stone tools as early 9200 cal.
 1232 BC. Whereas, evidence recovered from Neolithic occupations of this site
 1233 indicate its inhabitants continued to rely on wild plant and animal resources for
 1234 at least 400 years following the first appearance of small flint blades and
 1235 pressure-flaked, single-platform cores circa 8600 cal. BC.

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