1   **Phytolith analyses from Khil and Kaf Taht el-Ghar (Western Maghreb):**

2   **plant use trajectories in a long-term perspective**

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26   **Abstract**

27   In this paper we present the results of phytolith investigations at two archaeological sites in

28   northwestern Morocco: Khil (Tangier) and Kaf Taht el-Ghar (Tétouan). The two sites located in

29   Western Maghreb, one on the Atlantic and one on the Mediterranean coast, were investigated in the

30   framework of the AGRIWESTMED project. Phytolith analysis complemented archaeobotanical,

31   geoarchaeological and archaeological investigations to better identify plant use during the entire

32   occupation sequence. At Khil 16 samples have been studied, coming from two profiles excavated in

33   two different caves of the same system – *grotte B* and *grotte C* – that span a chronology comprised

34   between the early Neolithic and the historic period. At Kaf Taht el-Ghar, 15 samples were analysed

35   spanning from the Palaeolithic to the Historic period.

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37   Results show that at Khil plants are widely used from the very beginning of the Early Neolithic

38   sequence. The surrounding vegetation was exploited and both C3 and C4 grasses were used, inside

39   the cave. At the same time a wide array of other plants was utilised, such as palms and woody taxa.

40   Phytolith analysis at the site of Kaf Taht el-Ghar indicates that crop processing was most probably

41   not taking place on site. However, the predominance in the samples of C3 grasses morphologies

42   agrees with the finding of previous macro botanical studies that identified cultivated wheat and barley

43   in this cave deposits. A very interesting aspect of the phytolith assemblages of Kaf Taht el-Ghar is

44   the widespread use of palm leaves and their gradual disappearance through time that coincides with

45   an increase in the use of woody species.

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47   **Keywords:** Phytoliths; Neolithic; crop-processing; palm leaves.

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50   **1. Introduction**

51   The northern coast of Africa represents the natural interface between the African continent and the

52   Mediterranean Sea. Stretching from the Atlantic shores of Morocco up to Suez, Mediterranean Africa

53   has been a permeable crossroad between Europe, Asia, and Africa from ancient to present times. Due

54   to its geographical location, western Maghreb – the westernmost section of Mediterranean Africa -

55   holds a prominent position in the deep history of contacts and exchanges between Africa and Europe,

56   well before the historical and modern ages, when the Mediterranean Sea became the crossroads of

57   empires, states, and civilizations (e.g. Broodbank 2013). Recent studies have highlighted the role of

58   the Maghreb in early prehistory (Sahnouni et al. 2018) and the spread of anatomical modern humans

59   (Hublin et al. 2017). Yet, the overall picture of the transition to food production in the Maghreb is

60   still patchy. In this perspective, fresh research has specifically focused on the Holocene in the

61   Maghreb, investigating the arrival of the first Neolithic communities with cereals and legumes

62   towards the middle of the 6th millennium BC (Ballouche and Marinval 2003; Morales et al. 2013,

63   2016; Zapata et al. 2013, Martínez-Sánchez et al. 2018a, Martínez-Sánchez et al. 2021). The

64   Tingitana peninsula (where Khil and Kaf Taht el-Ghar are located) is probably one of the best studied

65   areas, with several sites investigated for archaeobotanical remains. A recent overview of the state of

66   research on the process of Neolitisation in this part of North Africa, suggests that domesticated crops

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67 were introduced from the southern Iberian Peninsula, together with Cardial wares (Martínez-Sánchez

68 et al. 2018b). In this paper we present the results of phytolith analysis and we highlight the trajectories

69 of plant exploitation and use at the sites of Khil and Kaf That el-Ghar, from the Paleolithic to Historic

70 times.

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72 *1.1 Context, environment and chronology of the samples analysed*

73   The two archaeological sites under study are located in the Tingitana peninsula, the northernmost

74 region of Morocco. Khil is placed on the North Atlantic coast and Kaf Taht el-Ghar next to the

75 Mediterranean shore (Figure 1). At both sites the prevalent climate is Mediterranean with oceanic

76 influences, with the highest rainfall between October and March and frequent dry spells during

77 summer. The Aridity Index (Tabucco and Zomer 2019; Zomer et al. 2007, 2008) at both sites is c.

78 0.55 defining the environment as dry sub-humid. Thus, today the prevalent vegetation at both sites is

79 the *maquis*-forest (Morales et al. 2016 and references therein).

80   Nowadays, North Africa is much drier than it was in the Early and Middle Holocene, when the

81 environment was more humid and 'green'. Different proxies point to climatic oscillations that

82 determined changes in both sea-level and vegetation, variably affecting ancient human societies (de

83 Menocal 2001, Kuper and Kropelin 2006, Clarke et al 2016). Sea level varied considerably from the

84 Last Glacial Maximum (c. 23-20kya), when the sea was up to 130m lower than by 4000-3000 BC,

85 when it reached its current level (e.g, Benjamin et al. 2017). Shifts in sea-level reflect more general

86 climatic trends that affected North Africa throughout the Holocene. Yet, along with regional

87 environmental dynamics, local phenomena must have played an important role and need to be

88 considered as well, since the physiography of specific setting (e.g., mountains, oases) might have

89 shaped local cultural dynamics (e.g. Cremaschi et al. 2014). A recent macro-scale approach has

90 reviewed the available data from the different regions of North Africa and pinpointed three main

91 phases marked by arid spells recorded continentally to better fit social, environmental, and economic

92 information available: Phase 1 - from the beginning of the Holocene up to the 6200 cal. BC climatic

93 arid spell, characterized by warm climate and by a foraging economy based also on marine resources;

94 Phase 2 – from 6200 to c. 4000 cal. BC, when the spread of domesticates from the Near East rapidly

95 reached the Maghreb following the onset of improved environmental conditions; finally Phase 3 –

96 from 4000 to c. 1000 cal. BC, which still remain poorly understood in the Maghreb due to the lack of

97 archaeological stratigraphies, and when the environment turned to present conditions. (Broodbank

98 and Lucarini 2019, and references therein).

99   Morocco, especially its eastern portion, has been the focus of several archaeobotanical

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100 investigations in recent years. Such investigations have identified the long persistence of a mixed

101 hunter-gatherers-fishers economy even during the Neolithic with no definite presence of domestic

102 plants and animals, contrary to what happens in western Maghreb (Portillo et al 2020 and references

103 therein). The extensive archaeobotanical analyses of charred macro-remains carried out at the sites of

104 Khil and Kaf Taht el-Ghar (Morales et al. 2016) show that cereals (emmer, free-threshing wheat,

105 naked barley), pulses (broad bean) and fruits (grape, mastic tree and myrtle) were being consumed at

106 these sites by 5500-5000 cal. BC. Similarly, at the site of Ifri n'Amr ou Moussa, wild pulses and fruit

107 of the mastic tree were identified in the Epipaleolithic layers, whereas in the Neolithic phase (dated

108 to 5100 cal. BC) seeds of domesticated cereals are found together with seeds and fruit of wild arboreal

109 species (Carrión Marco et al. 2018).

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111 *1.1.1. Khil*

112 The archaeological site of Khil is composed by a series of caves situated at the end of the Ashakar

113 Wadi, in Tangier province (Figures 1 and 2). It is a karstic formation where several caves of small

114 dimensions were inhabited, or sporadically used, in the past by small communities of agro-

115 pastoralists, fishers and shell-gatherers. From the archaeological evidence it seems possible to place

116 the beginning of the frequentation of this site in the mid-VI millennium, with a peak during the fifth

117 millennium, and occupation continuing up to historical times (Peña-Chocarro et al. 2012; Martínez

118 Sánchez et al. 2018b).

119 In September 2011 a joined team of Spanish and Moroccan archaeologists revisited the site in the

120 framework of a collaborative project between the Spanish National Research Council (CSIC) and the

121 National Institute for the Archaeological and Cultural Heritage Sciences (INSAP). The project aimed

122 at acquiring data to evaluate the role of the first agricultural communities in the area through the

123 systematic analysis of bioarchaeological material (charred seeds and wood, pollen and phytoliths,

124 faunal and micro-faunal remains) collected during the new excavations. On this occasion

125 interventions were carried out in three caves -*grotte* B, C and D- and systematic samples were

126 collected from the two that showed cultural material corresponding to the Neolithic period, *grotte* B

127 and C, in line with the aims of the study. The macro-botanical remains are dominated by broad bean

128 *(Vicia faba)* and naked wheat (*Triticum aestivum/durum*) grains (Morales et al. 2016).

129 Radiocarbon dates on short-lived specimens confirm an Early Neolithic phase dated to c. 5300-

130 5000 cal. BC and a Middle Neolithic phase sated to c. 4500-4000 cal. BC (Martínez-Sanchez et al.

131 2018a; Morales et al 2016). The proposed chronology of the two caves, with correlations between the

132 two sequences can be found in Table 1.

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Sixteen samples have been studied, coming from the two profiles (Figure 2 and Table 1). Four samples from *grotte* C belong to the historic period and were analysed as control samples. Of the remaining samples six were dated to the Middle Neolithic period (three from grotte C and three from grotte B) and six to the Early Neolithic (five from grotte C and one from grotte B). All samples were collected from the general deposit of the cave and represent different moments of anthropic occupation.

1.1.2 Kaf Taht el-Ghar

The archaeological site of Kaf Taht el-Ghar is located in the province of Tétouan (Figure 1 and 2). It is a karstic cave, situated in the Béni-Hosmar massif dominating over the Oued Martil Valley and the Mediterranean coast (Ballouche and Marinval 2003). The site was studied first in the fifties by a Spanish archaeological mission (Tarradell 1957-58) and then in the late eighties by a French-Moroccan archaeological team (Daugas et al. 2008) that established it as one of the oldest Neolithic sites in Northern Africa. Traces of domesticated species, both of plants and animals, were identified in the Early Neolithic levels (Ballouche and Marinval 2003). The authors found domesticated emmer, einkorn and naked wheat (*Triticum dicoccum*, *T. monococcum* and *T. aestivum/durum)* in a layer dated to the end of the VI millennium Cal BC.

The AGRIWESTMED team revisited the site in 2012 (Martínez-Sánchez et al. 2018a, Martínez-Sánchez et al. 2021) when four profiles were cleaned and sampled for bioarchaeological samples. In this occasion up to 42 stratigraphic units were identified and bulk sediment samples were collected for phytolith analysis from three of the four profiles (26 AB, 26 G and 26 JK, see Martínez-Sanchéz et al. 2021 for the full description of the excavation material and methods and details on the excavated trenches). For the present work, 16 samples were processed of which only 15 were then used for analysis (Figure 2 and Table 2). One sample was excluded because of the few phytoliths observed, which all belonged to categories that are not taxonomically significant. All the fifteen samples analysed come from the anthropogenic sediment of the cave, from layers of occupational deposition. Two of them were collected from fireplaces and were studied separately as they represent different types of deposits that involve specific strategies of plant use. The other samples examined cover the entire chronological sequence from the Palaeolithic to Historic periods.

2. Material and Methods

A total of 31 samples were analysed: 16 from Khil and 15 from Kaf Taht el-Ghar covering the

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166 entire chronology of occupation at both sites (see Tables 1, 2 for samples description and Tables 3

167 and 4 for details on phytoliths). Samples were collected from recently excavated sections at both sites.

168 Phytoliths were extracted from bulk sediment samples following the procedure described by Madella

169 et al. (1998) slightly modified to calculate the AIF (Acid-Insoluble Fraction, Albert and Weiner 2001)

170 and to adapt to recent studies about the aggressive effect of too concentrated chemicals and long times

171 of exposure (Cabanes et al. 2011). The sediment was dried in a drying cabinet until no loss of weight

172 was recorded, then 4 to 5 grams of material were subsampled for analysis. The full protocol used for

173 extraction as well as raw data can be found in the Supplementary Material (SM1, SM2 and SM3) and

174 are stored on GitHub.

175 Phytolith were mounted in permanent medium and observed under transmitted light microscope

176 with magnification between 20X and 40X. Phytoliths were counted up to 300 identified individual

177 morphotypes or, when not possible, the full slide was scanned. Identification was based on published

178 reference material (PhytCore database) and naming follows ICPN 1.0 (Madella et al. 2005)

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181 **3. Results**

182 *3.1 Phytolith taphonomy*

183 *3.1.1 Khil*

184 The phytolith assemblages from Khil generally presents a low level of taphonomic damage.

185 Indeed, the number of elongated cells identified is quite high (Figure 3) thus advocating for a

186 generally good preservation rate (Madella and Lancelotti 2012). Some evident signs of pitting, typical

187 of chemical erosion, and mechanical stress have been observed on the phytoliths during analysis, both

188 on elongated as well as on more resistant morphotypes like bulliforms and trichomes (Figure 4).

189 Taphonomic processes seem to have had a stronger effect on the assemblages of the later periods in

190 samples from *grotte* C, while no evident sign of damage has been observed on phytoliths from *grotte*

191 B or the earlier periods of *grotte* C.

192 Average values of phytolith indicators are generally higher for *grotte* B than *grotte* C: phytolith

193 concentration (463k/195k); number of morphotypes (15/7); inflorescence morphotypes (43/11);

194 leaf/culm morphotypes (81/8.5); woody morphotypes (9.75/3.25); palm morphotypes (73.5/3.8). The

195 relationship between the concentration of phytolith per gram of AIF and number of morphotypes

196 identified in the assemblage shows a low degree of correlation (Figure 5). This indicates that post-

197 depositional taphonomic processes do not affect the richness of the phytolith assemblages in a

198 significant way (Madella and Lancelotti 2012).

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3.1.2 Kaf Taht el -Ghar

The phytolith assemblages observed in Kaf Taht el Ghar show a higher rate of damage due to post-depositional processes. As summarised in Figure 6, short cells are definitely predominant in the assemblages, while elongated forms are rather scarce and silica skeletons almost absent. However, the assemblages show quite a high number of morphotypes and there is no direct correlation between the phytolith concentration and the number of morphotypes identified in the samples (Figure 7). Silica skeletons are present mostly in the Epipaleolithic samples, both in the general sediments and in the two fireplaces.

3.2 Phytolith concentration and morphology

3.2.1 Khil

The assemblages at Khil are characterised by a marked difference between *grotte* B and *grotte* C both in terms of phytolith concentration and morphology. The sediments collected in *grotte* B are much richer in phytolith content as well as in number of morphotypes identified (Table 3). Indeed, *grotte* B shows an average number of morphotypes that doubles that of *grotte* C. There is a generalized increase in plant diversity starting from the end of the Early Neolithic period and through all the Middle Neolithic Period (Figure 8). This increase is mainly due to the assemblages of *grotte* B, whereas in *grotte* C there seems to be very little activity related to plants until much later, during the Roman frequentation of the cave.

Sample EKH-B-2009, from *grotte* B, is particularly noticeable as it shows an overall concentration that is as high as the deposits of historic period of *grotte C* and it presents an amount of inflorescence indicators (elongate echinates and dendritics) that is highest among the samples studied. In addition, the silica skeletons of inflorescence are clearly of two different types indicating the presence of both C3 (wheat and barley type) and C4 (millet type) species. The presence of both C3 and C4 plants at the site is reflected also in the short cells assemblages (Figure 9). The subfamily Pooideae is by far the most represented however, chloridoids and panicoids are present, especially in the assemblages of *grotte* B. It is interesting to note the presence of exclusively panicoid type short cells in the assemblage of EKH-C-18, although the absolute amount is rather low, and the evidence is not statistically significant due to the scarcity of phytoliths observed in this sample (n=14). No panicoid short cells were observed in sample EKH-B-2009. However, in this same sample, silica skeletons of C4 inflorescence were observed thus indicating that this group of plants was collected since the earlier

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232 occupation of *grotte* B. Silica skeletons were in general scarce in the assemblages studied (Figure 3),

233 with the notable exceptions of samples EKH-C-15/3 and EKH-B-2009. Both contain silica skeletons

234 of grasses' inflorescence and leaf/culms, much more abundant in the sample coming from *grotte* B

235 than in the one coming from *grotte* C.

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237 *3.2.2 Kaf Taht el-Ghar*

238   Phytolith concentration per gram of AIF is in general quite low in the sediments of Kaf Taht el-

239 Ghar (Table 4). The two samples from fireplaces have double the concentration of the Epipalaeolithic

240 general samples, which present the highest concentration among the occupation levels. If fireplaces

241 are considered, only these and the Epipalaeolithic samples show a concentration above the mean.

242 When the mean is calculated excluding the fireplaces, only two occupational moments show a

243 concentration above the mean: Epipalaeolithic and Historic times. This is not *per se* an indication of

244 taphonomy, but it suggests that plants were not commonly used inside the cave.

245   A total of 19 different morphotypes have been observed in the samples from Kaf That el Gar. In

246 general, and excluding the two fireplaces, the number of morphotypes tends to increase in the most

247 recent samples. Indeed, from a mean of 1.5 in the Palaeolithic levels the number increases to 11 in

248 the Middle Neolithic and Historic levels. The notable exceptions are again the Epipalaeolithic

249 samples: the two fireplaces with a mean of 10 and the general occupations with 9 morphotypes (Table

250 4).

251   The most abundant morphotype observed by far in all sample is the globular echinate produced by

252 the leaves of Arecaceae family (palms - Figure 10b-d-e-g-h-). In Figure 11 these are represented on

253 a scale 100 times higher than for all other morphotypes and are particularly abundant in the

254 Epipalaeolithic fireplaces and in the earlier Neolithic levels. There is seemingly a decrease in the

255 presence of palm phytoliths as time progresses, up to the historic levels where they are very scarce.

256 At the same time,woody indicators (globular psilate, globular granulate, scalloped, sclereids,

257 parallelepipedal and irregular forms), although less represented in absolute terms, seem to follow

258 exactly an opposite trend. Their number starts to increase more or less when palms indicators start to

259 decrease.

260   Grasses are scarcely present in all the samples analysed and are in general represented by leaf/culm

261 phytoliths (elongate psilate, elongate sinuate and bulliforms). Inflorescence indicators (elongate

262 echinate and dendritics) are very few and practically only present in the upper levels of the Middle

263 Neolithic and Historic periods. In these same levels, leaf/culm indicators increase as well, following

264 the same trend as phytolith concentration.

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Three subfamilies of grasses are represented in the samples, Pooideae, Chloridoideae and Panicoideae (Figure 12) although Pooideae are predominant. Again, the highest variability is found in the fireplaces and in the Historic period samples. Interesting to note the presence of Panicoideae morphotypes (in this case two bilobates) in sample KTG 1.3 as they are the only encountered in all samples. However, the number of these morphotypes is so small that they are not statistically significant.

4. Discussion

4.1 Evidence of cereal processing and use

The results of phytolith analysis complement the information offered by charred macro-remains and add some interesting insights on the use of plant resources, as well as the general environmental trends in the Tingitana peninsula of Morocco during the Holocene. Especially at Khil, the general concentration of phytoliths, and the high number of morphotypes encountered, indicate that plant-related activities were definitely taking place inside *grotte* B. Morales et al. (2016) reports only a few macrobotanical remains from this deposit, the majority of the evidence at Khil being represented by two concentrations of broad beans recovered from *grotte* C, possibly the result of one episode of accidental burning. The concentration and diversity of phytoliths recovered from *grotte* B indicate, in accordance with the presence and abundance of cultural material recovered during excavation (Martínez-Sánchez et al. 2018a), that this cave was occupied more intensely than *grotte* C; in addition, it suggests that plant-related activities took place preferentially in this location. The high amount of both inflorescence and leaf/culm morphotypes shows that entire plants were brought into the cave. It is possible that plants were then processed on site to separate the leaves and culms from the edible parts but both components seem to have been used intensively at this location. Leaf/and culms could have been employed as bedding material or fodder for the animals while people consumed the grains. It cannot be excluded that phytoliths could have also entered the archaeological record via the deposition of animal dung. Rests of animal dung have been identified in contemporaneous archaeological sites in the region (Carrión Marco et al. 2018). However, the combined results of macrobotanical and microbotanical analyses, together with the characteristics of the phytolith assemblages, suggests that the observed phytoliths mostly arise from an important use of plants at the site.

The few silica skeletons encountered in the sediments of *grotte* B advocates for the exploitation of two different groups of grasses were exploited during the Neolithic period at El Khil: C3 types, such

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as wheat/barley and C4 types, such as millets (a group that includes wild and cultivated types). Studies have been published with guidelines to identify C3 cerals (e.g., Ball *et al* 1999, Portillo et al. 2006) and millets (e.g., Lu et al. 2009, Madella et al. 2016) on the basis of morphometric of elongate inflorescence phytoliths. Unfortunately, the number of cells per each silica skeleton, as well as the quality of preservation, did not allow performing morphometric analysis in order to distinguish the exact genus and/orspecies. However, short cell phytoliths confirm the importance at Khil *grotte* B of both groups and grasses are represented by three subfamilies:

1. Pooideae, which includes the main C3 cereals, high elevation grasses and lawn and pastures. This subfamily is identified in the assemblages by short trapeziforms, trapeziform sinuate, trapeziform polylobate and rondels.

2. Chloridoideae, which embodies the majority of draught-adapted short grasses. These include some of the common weeds of cultivated fields in the dry tropics (Piperno 2006, 28) as well as some of the edible "millets" (Madella et al. 2016). This subfamily is represented in the assemblage by elongate trapeziforms and saddle. Saddles are occasionally produced by other non-chloridoideae taxa, however these are normally classified as "tall" saddles (Neumann et al. 2019, Supplementary data File 1), which have not been identified during this study. Panicoideae, which are tall grasses of tropical origins and includes all the main millet type cereals (Madella et al. 2016) and many wild species. This subfamily is represented in the assemblage by bilobates. This morphotype, in its broad definition, can be produced by species in other subfamilies, specifically certain pooid grasses in the Tribe Stipae (a wild grass that could have been present near the site). However, Stipae bilobates are quite characteristic, with poorly separate lobes and trapezoidal longitudinal sections (Neumann et al. 2009, Supplementary data File 1), and such morphotypes have not been observed in the samples analysed.

Interestingly, the results of the study of macrobotanical remains showed no presence of C4 plants (Morales et al. 2016). This discrepancy between the absence of grains from C4 plants and the indication of their presence and consumption highlighted by alternative proxies (phytolith, starch, stable isotopes, etc), has been noted in several other contexts (see for example Delhon *et al*. 2020, Sureda *et al*. 2017). This discrepancy could be explained by differential preservation and recovery rates in the macrobotanical record whereby grains of C3 species, which are usually bigger than those of C4, have more chances to be part of the macrobotanical assemblages. A possible alternative, in the present case, is that C4 grasses were not collected for consumption.

At both sites the silica skeletons of grass taxa with edible grains do not display the neat transversal

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331 or curved fractures that have been associated with the process of threshing (Anderson *et al.* 2004).

332 However, in light of the macrobotanical evidence, most probably belong to cultivated/domesticated

333 crops since the earlier Neolithic deposits at Khil *grotte* B. In contrast, *grotte* C does not seem to be

334 an important location for plant-related activities until up to the Historic periods. In fact, it is notable

335 that *grotte* C displays a very low amount of phytoliths during the entire Neolithic sequence, even in

336 s.u. 12 and 13 that, according to the excavation report, represent frequent occupation episodes. On

337 the contrary, s.u. 8 and 10, which represent periods of abandonment, show a discrete amount of

338 phytoliths both of leaf/culm and inflorescence. Also interesting to notice is the amount of woody taxa

339 indicators observed in the upper layers of *grotte* C. These concentrations could probably represent

340 enrichment due to intense bioturbation, with phytoliths percolating from the layers above. The deposit

341 of *grotte* C in general, and especially the upper levels, seem more affected by post-depositional

342 taphonomic processes and this might be the reason for the scarcity of phytoliths observed in these

343 samples.

344 Carpological analysis conducted by Ballouche and Marinval (2003) and Morales and colleagues

345 (2016) detected the presence of domesticated wheat on site. Phytolith analysis, however, indicates

346 that little or no activity related to crop processing was taking place at Kaf Taht el-Ghar during the

347 time of occupation. The scarcity of inflorescence morphotypes might be caused by post-depositional

348 diagenetic processes. As shown in figure 6 elongated cell phytoliths are less than 40% in the richest

349 sample (historic period) and they are lower than 30% in the richest Neolithic level. The predominance

350 of short cells over elongated forms and the absence of silica skeletons might indicate a high rate of

351 phytolith post depositional damage (Madella and Lancelotti 2012). Indeed, elongated cells are usually

352 less silicified than short cells and generally more likely to be affected by chemical taphonomic

353 processes, especially the morphotypes produced in the floral part of the plants (Cabanes et al. 2011,

354 Cabanes and Shahack-Gross 2015). However, as shown by Figure 7, there is no correlation between

355 phytolith concentration and the number of morphotypes identified, thus suggesting that the

356 taphonomic processes –however present- did not seriously affect the richness of the assemblages

357 (Madella and Lancelotti 2012). If the scarcity of inflorescence morphotypes is not to be attributed to

358 taphonomy, it is most probable that second stages of crop processing were taking place outside the

359 cave or in other locations and grains were introduced clean after processing. On the contrary the

360 presence in the assemblages of leaf and culm indicators, although not abundant, might imply that

361 either the first stages of crop processing were happening inside or that some by-products of threshing

362 were indeed collected and transported inside the cave. Leaves and culms could have been used as

363 fodder for animals, as bedding or matting material as well as for fuel. Grasses are represented at Kaf

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364 Taht el-Ghar by three subfamilies: Pooideae, Chloridoideae and Panicoideae. However, C3 pooids

365 grasses are by far the most representative group of grasses identified in the phytolith assemblages,

366 they are well adapted to cool and wet climates and include the most common Near Eastern cereals,

367 such as wheat and barley (Piperno 2006). Unfortunately, no silica skeleton of this group has been

368 observed in the samples, which makes it impossible to determine whether the pooid plants that were

369 used at the site belong to such genera. Also, it is impossible to say whether they are the remains of

370 wild or domesticated species. The other two subfamilies are scarcely represented indicating that, if

371 used, they did not constitute an important resource.

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373 *4.2 The presence and use of palm leaves*

374 Throughout the sequence the amount of Arecaceae indicators is quite high both at Khil and at Kaf

375 Taht el-Ghar. These are represented by globular echinate forms, which are produced by the leaves of

376 palms. A few studies have used statistic applications of measurements of size and shape to globular

377 echinates in order to discriminate between different species of palms (Albert *et al.* 2009, Fenwick et

378 al. 2011). During this study, measurements could not be performed as most phytoliths showed signs

379 of burning and/or heat alterations (Figure 10-c). However, the most common species of Arecaceae in

380 the Mediterranean are *Chamaerops humilis* (dwarf palm*)*, *Phoenix sylvestris* and *Phoenix dactylifera*.

381 No palm remains were identified in the macrobotanical record at Khil and only one seed of

382 *Chamaerops humilis* was recovered from Kaf Taht el-Ghar (Morales et al. 2016). However, the dwarf

383 palm is very common along the Mediterranean littoral and palm are attested in the eastern part of

384 Maghreb where several seeds have been identified in the Neolithic levels at Ifri Oudadane (Morales

385 et al. 2016) and phytoliths from Arecaceae have been found in fireplaces at Ifri n'Amr ou Moussa

386 (Carrión Marco et al. 2018) and in the early sequence of Ifri el Baroud (Potí et al. 2019).

387 Apart from the consumption of the fruits of date palm, the leaves of all three species could be used

388 for different scopes in African rural communities such as huts (Scarin 1937, Despois 1946, Baroin

389 1993) matting (Tinthoin 1946), to make beds and other furniture (Dugast 1940), to embellish ritual

390 masks (Drewal and Drewal 1982) and to decorate pottery and other containers (Martínez-Sanchéz et

391 al. 2018a, Peña-Chocarro et al. 2015). Keepnets and nets for fishing made of palm leaves are reported

392 to have been in use until very recent times along the Tunisian coast. Although it is not possible to

393 state exactly what these palm leaves were used for, it seems they were present at Khil in both *grotte*

394 B and *grotte* C during the entire sequence although they tend to decrease in time. This might be an

395 indication of a climatic and/or environmental change or it might indicate a decrease in intensity of

396 use of these resources. At Kaf Taht el-Ghar palm leaves seemed to have been a very important

12

397 resource during the Epipaleolithic. The characteristic globular echinates are the most common
398 morphotype observed in the sediments analysed, present in all samples on a scale that is 100 times
399 higher than any other morphotype. Globular echinates are also very abundant in the two samples from
400 fireplaces indicating that palm leaves were possibly used for fuel or that items made with them were
401 -intentionally or unintentionally- burnt. Indeed, in these samples globular echinates have been
402 observed both as disarticulated and as articulated phytolith (silica skeletons) some of which appeared
403 as an agglutination of several semi-melted particles (Figure 10). This indicates that the temperature
404 achieved during combustion was quite high as phytoliths start to melt at about 900 °C. These
405 fireplaces might have served some specific purpose (palm leaves seem to produce a "slow" fire but
406 "bright" embers; Plinio translated by Domenichi 1612) and maybe they were used for some sort of
407 material transformation.

408   At present, it is difficult to discern whether the use of palm leaves is a choice or it is driven by
409 environmental factors. When the tendency of palm leaves indicators is compared with that of woody
410 taxa indicators, the two present opposite trends and the latter starts increasing only when the former
411 completely disappears (Figure 11). According to palynological studies of marine cores (Fletcher and
412 Sánchez Goñi 2008) the beginning of the Epipaleolithic at Kaf That el-Ghar coincides with the
413 beginning of the Younger Dryas, a phase of expansion of the desert. Therefore, it is not surprising to
414 see a high number of palm morphotypes, as palms are better adapted to arid conditions than other
415 woody taxa. However, if the use of palm versus other species was exclusively related to
416 environmental conditions, we should see an increase in woody taxa much earlier than what we
417 observed as the oceanic moist conditions sets in (c. 9700-3400 cal. BC, Fletcher and Sánchez Goñi
418 2008), thus suggesting a deliberate selection for the use of palms. The increase in woody taxa at Kaf
419 Taht el-Ghar seems to loosely follow the increase in humid conditions after the end of Younger Dryas
420 and the subsequent onset of arid conditions that are observed both in marine cores and in terrestrial
421 records of the Southeastern Iberian Peninsula (Fletcher and Sánchez Goñi 2008), albeit with a lag of
422 few millennia. In parallel, pollen analyses from Hahua Fteah seem to point to an increase in the
423 *maquis* vegetation indicators in the upper levels of the excavation (Facies 1 - from Paleolithic to
424 historic times, Inglis et al. 2013) that roughly coincides with the increase in woody taxa morphotypes
425 observed at Kaf Taht el -Ghar. However, as changes in the vegetations in the study area might be
426 very localised, more terrestrial paleoenvironmental records at local scale are needed to definitely
427 interpret the trends observed in the phytoliths.

428

429 **Conclusions**

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430   The analysis of phytoliths from *grotte* B and *grotte* C at the archaeological site of Khil, indicates

431   that this location is particularly important for the study of the beginning of agriculture in North Africa.

432   Especially *grotte* B contributes highly to our understanding of the people-plant relationship in this

433   area. From the very beginning of the Early Neolithic sequence there appear evidence of an intense

434   use of plants by the occupants of the cave. The surrounding C3 and C4 vegetation was exploited and

435   C3 crops were cultivated. At the same time a wide array of other plants is used, such as palms and

436   woody plants. The presence of palms along the entire sequence tends to decrease at the end of the

437   occupation, starting from the end of the Neolithic. Further localised palaeoenvironmental work, with

438   terrestrial proxies is needed to clarify whether this is due to a climatic variation or anthropic choice.

439   Phytolith analysis at the site of Kaf Taht el-Ghar indicates that crop processing was most probably

440   not taking place on site. However, the predominance of C3 plants in the samples agrees with the

441   finding of previous macro botanical studies that identified cultivated wheat and barley in this cave's

442   deposits. It is most probable that grains were imported and consumed clean after processing was

443   carried out in the vicinity but outside the cave. Indeed, the presence of culm/leaves grasses within the

444   deposits might indicate the preferential transport of these processing by-products to the cave and

445   thereby suggesting that threshing was performed in a location where by-products could then be

446   transported to the site.

447   An interesting aspect of the phytolith assemblages at both Khil and Kaf Taht el-Ghar is the

448   widespread use of palm leaves and their gradual disappearance through time as they are substituted

449   by woody species. Palm leaves could have been used as fodder, containers, baskets, matting, and fuel

450   or to make small furniture items. There is a high probability that palm leaves were used as fuel at Kaf

451   That el Gar where globular echinates were common in the two fireplaces analysed. However, it might

452   be hypothesised that if palm leaves were heavily exploited the fruit might have also been available

453   for the people to eat. Indeed, macro-remain analysis at Ifri Oudadane showed that date seeds from the

454   dwarf palm were frequent along the entire Neolithic sequence. It is to be supposed therefore that palm

455   dates were probably consumed also at Khil and Kaf Taht el-Ghar where extremely high

456   concentrations of globular echinate were found.

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463 for help with graphics and R.

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619 **Figures and captions**

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622
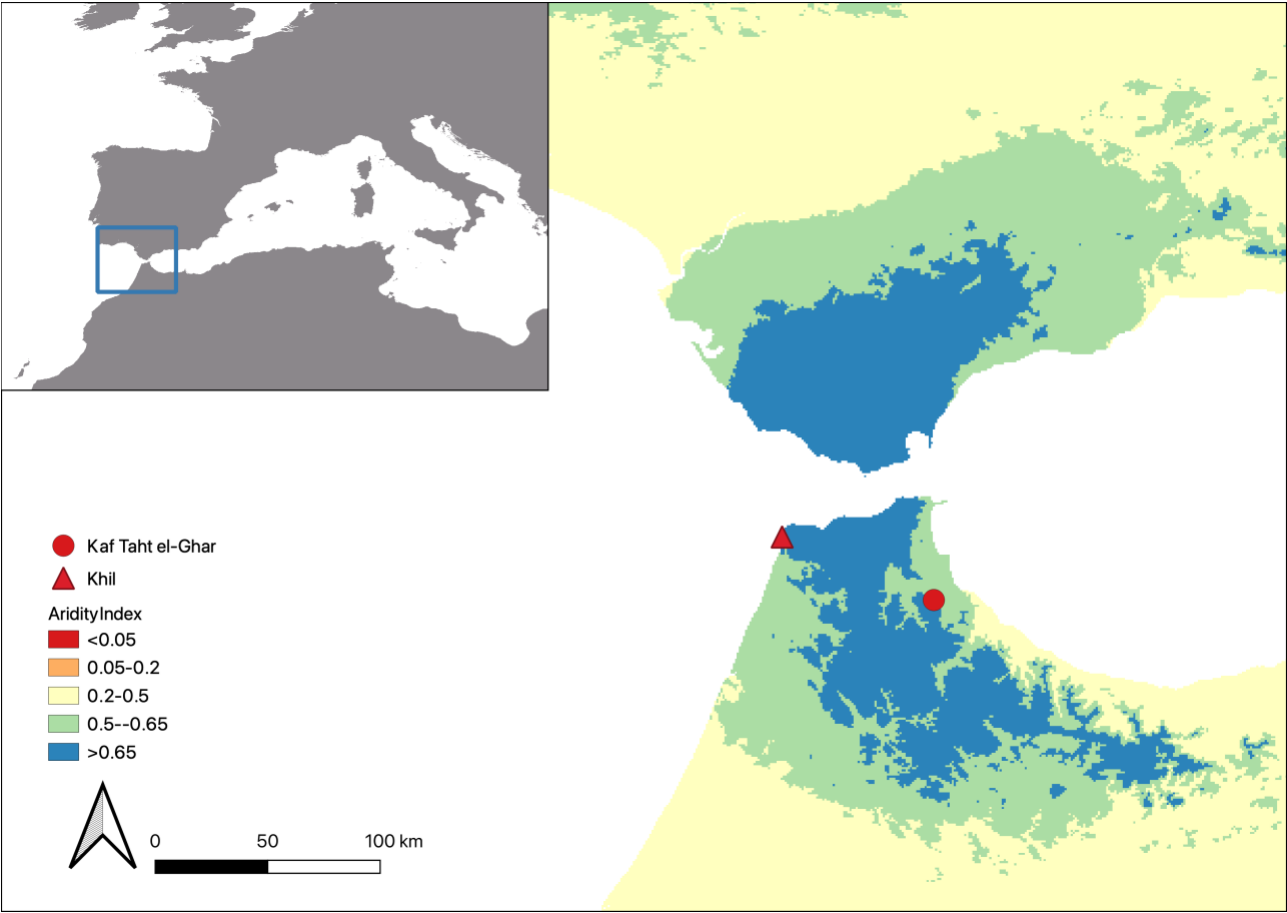
623 Figure 1. Location of the two archaeological sites anlaysed in the present work based on a map of Aridity Index values

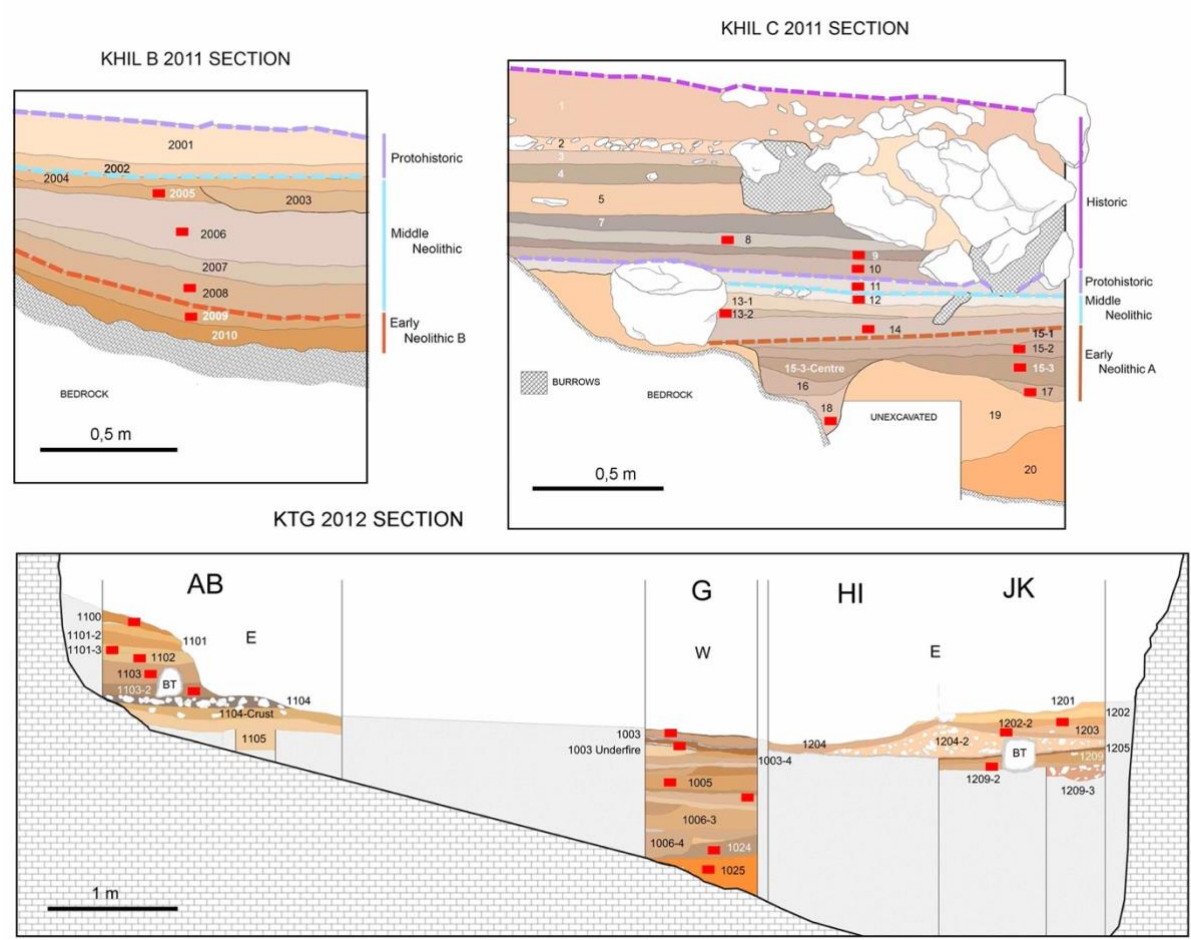624 (data extracted from Zomer et al. 2007, 2008).

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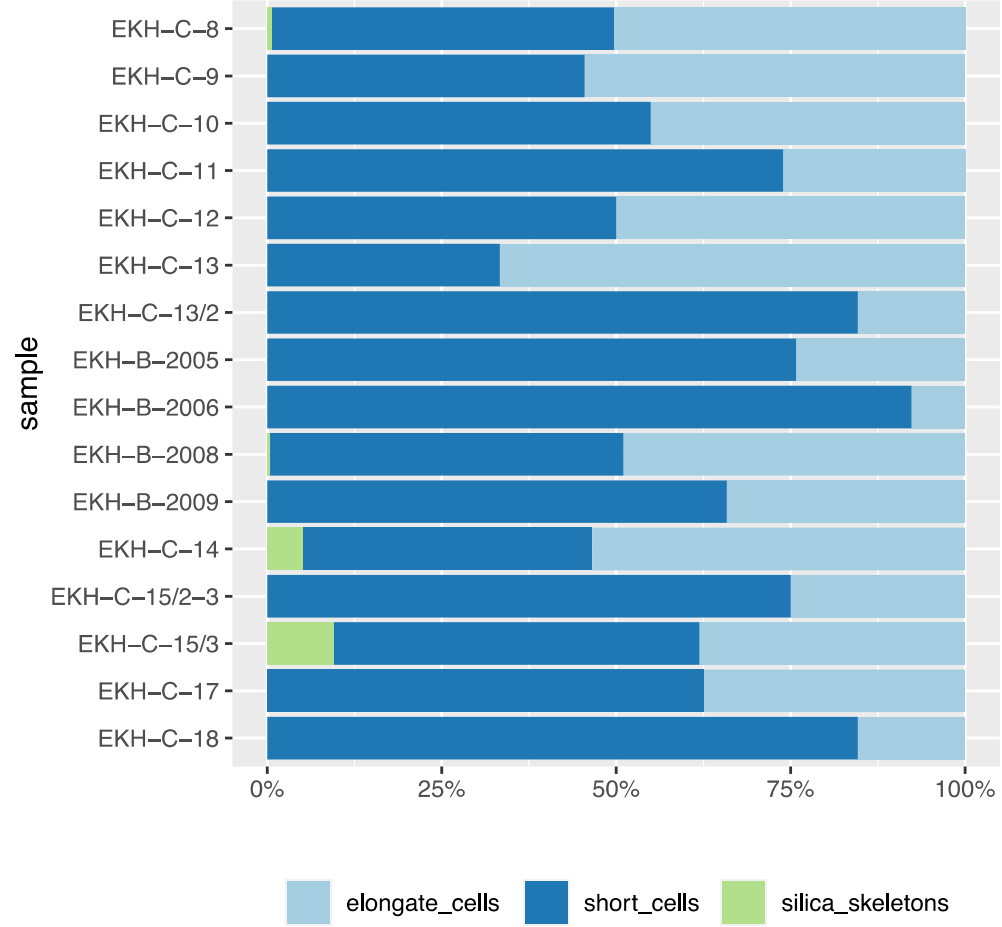628 Figure 2. Stratigraphy of the two sites under study and location of samples analysed.
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Figure 3. Khil: proportion of elongate cells, short cells and silica skeletons identified in the samples.
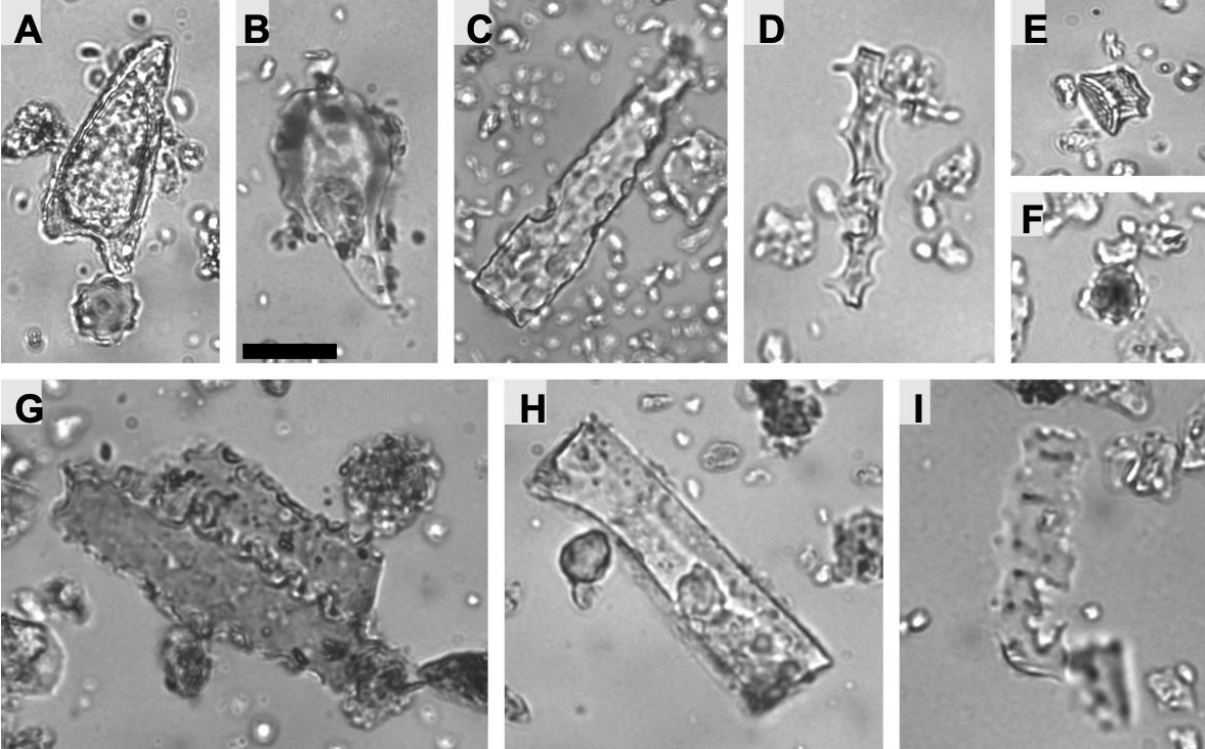
636
637 Figure 4. Khil: microphotographs of significant phytoliths morphotypes. A) globular echinate and trichome; B)
638 Trichome; C) Elongate psilate; D) Elongate echinate; E) Wavy -top rondel; F) Globular echinate; G) Silica skeleton (2
639 cells) of elongate echinate cells; H) Elongate not determined; I) Elongate (possible echinate). All the phytoliths in this
640 figure (except the globular echinates in A and F and the rondel in E) showing signs of chemical weathering. Scalebar in
641 B = 20μm (valid for all photogrpahs).
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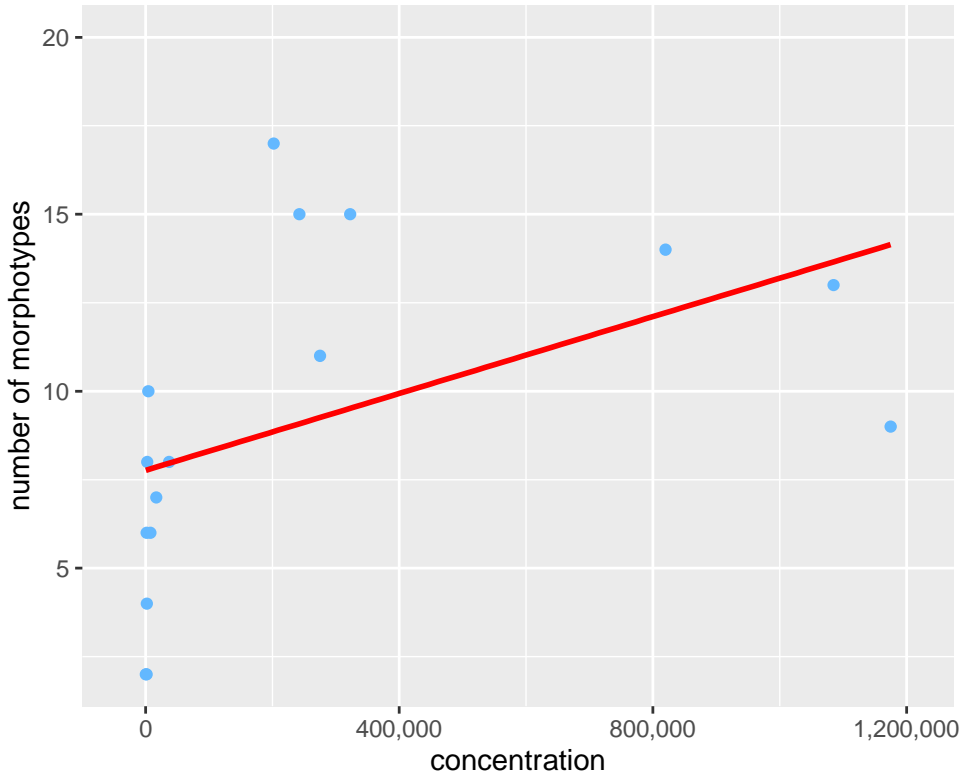
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645 Figure 5. Khil: correlation between the number of morphotypes identified during analysis (y axis) and the phytolith

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646   concentration per gram of AIF (x axis).
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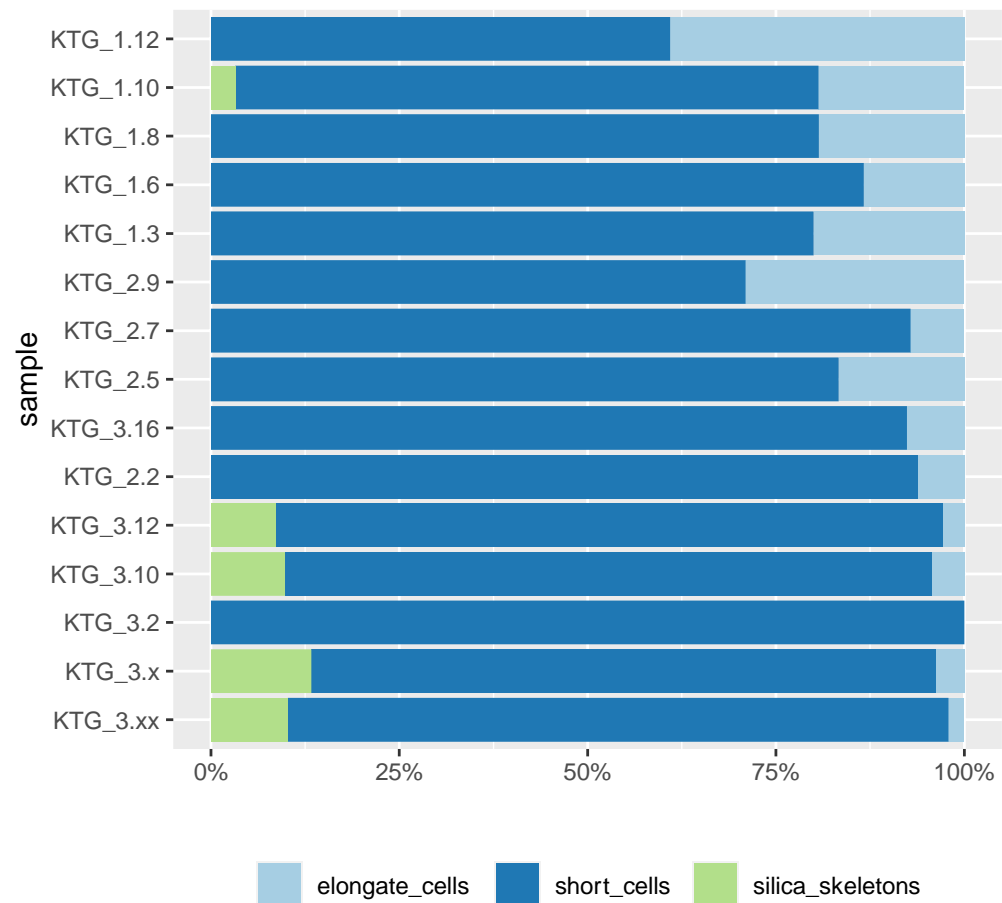
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650   Figure 6. Kaf Taht el-Ghar: proportion of elongate cells, short cells and silica skeletons identified in the samples.
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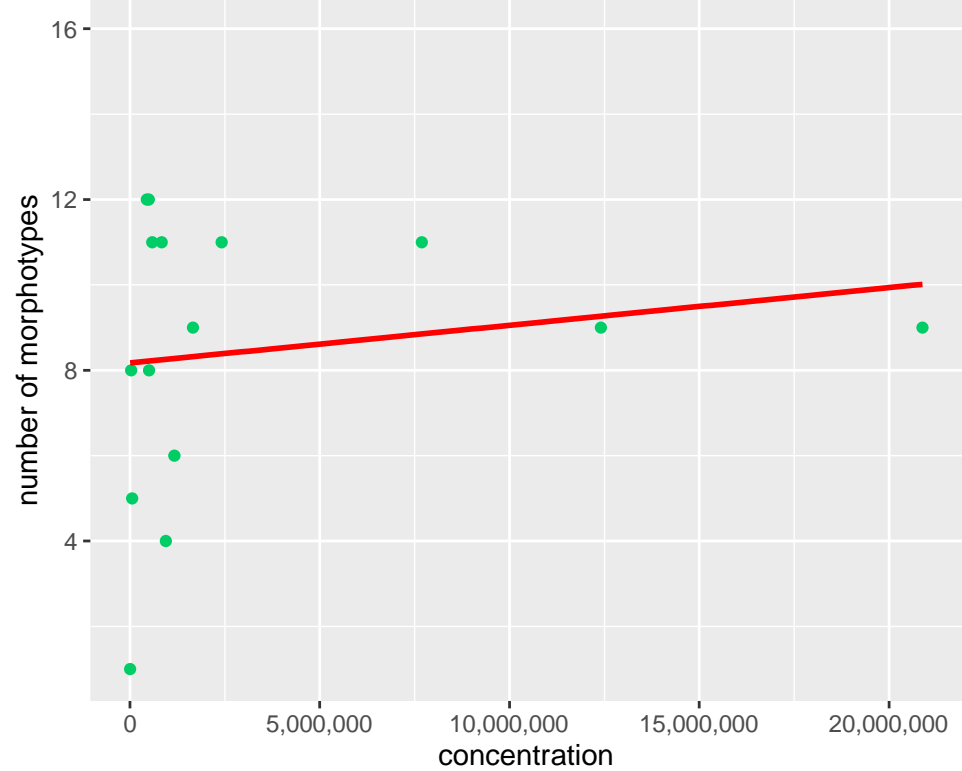
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654 Figure 7. Kaf Taht el-Ghar: correlation between the number of morphotypes identified during analysis (y axis) and the
655 phytolith concentration per gram of AIF (x axis).
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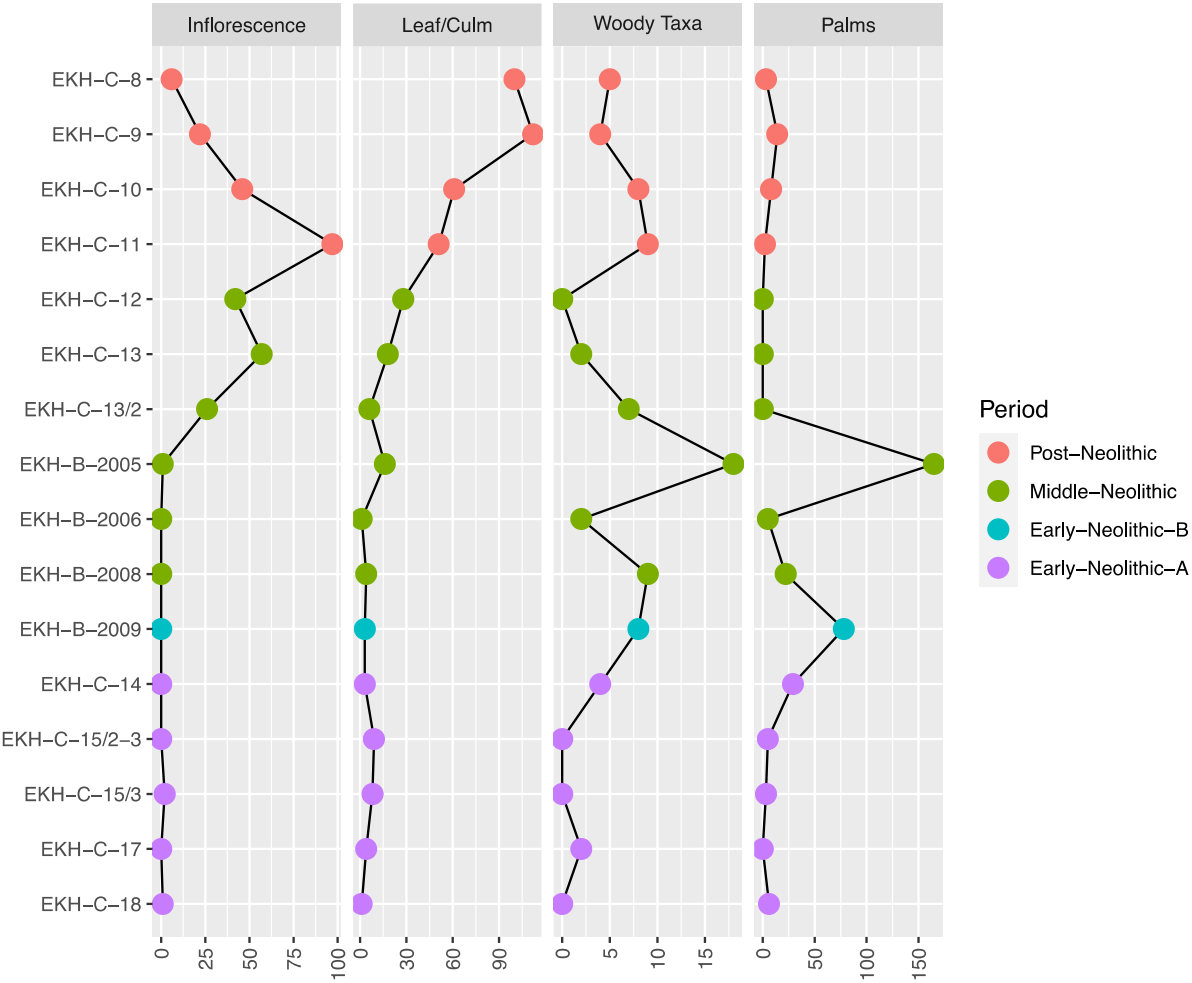
658
659 Figure 8. Khil: chronological variation of the main categories of phytoliths observed in the samples from *grotte* B and
660 *grotte* C. Note that the scales are different as woody taxa produce fewer phytoliths than the other categories.
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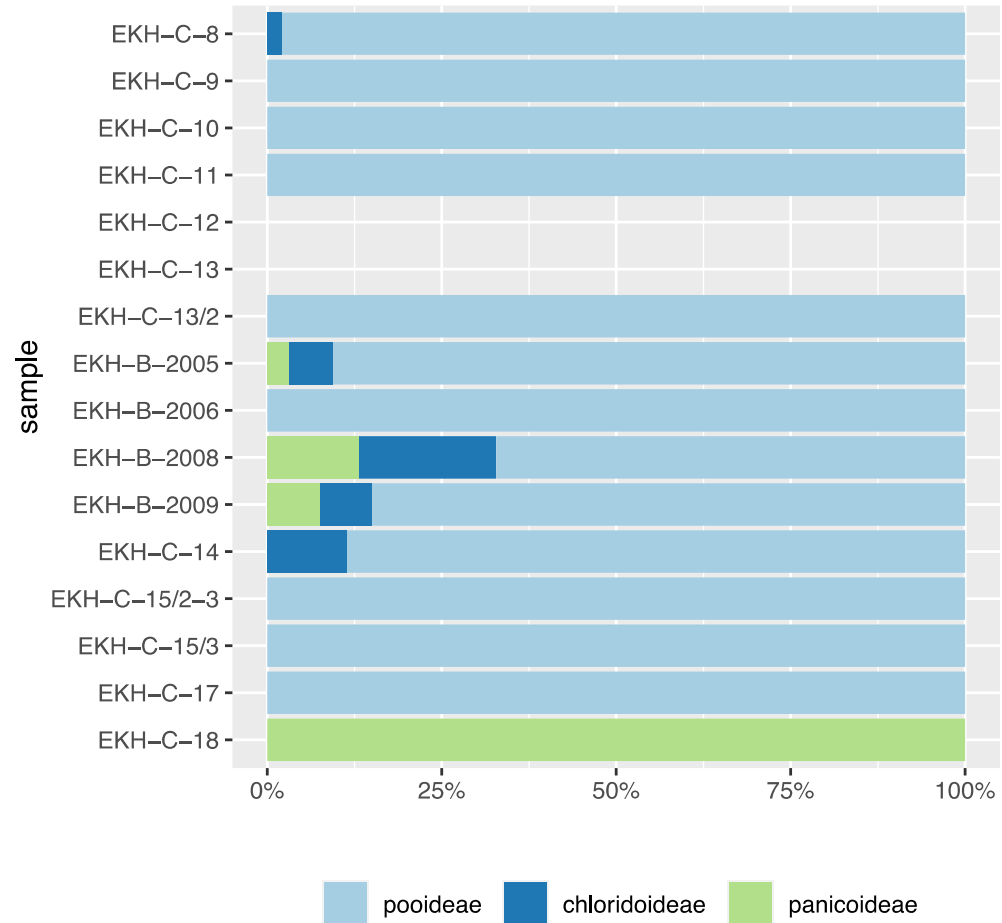
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664 Figure 9. Khil: chronological variation of the grass subfamilies identified at the site.
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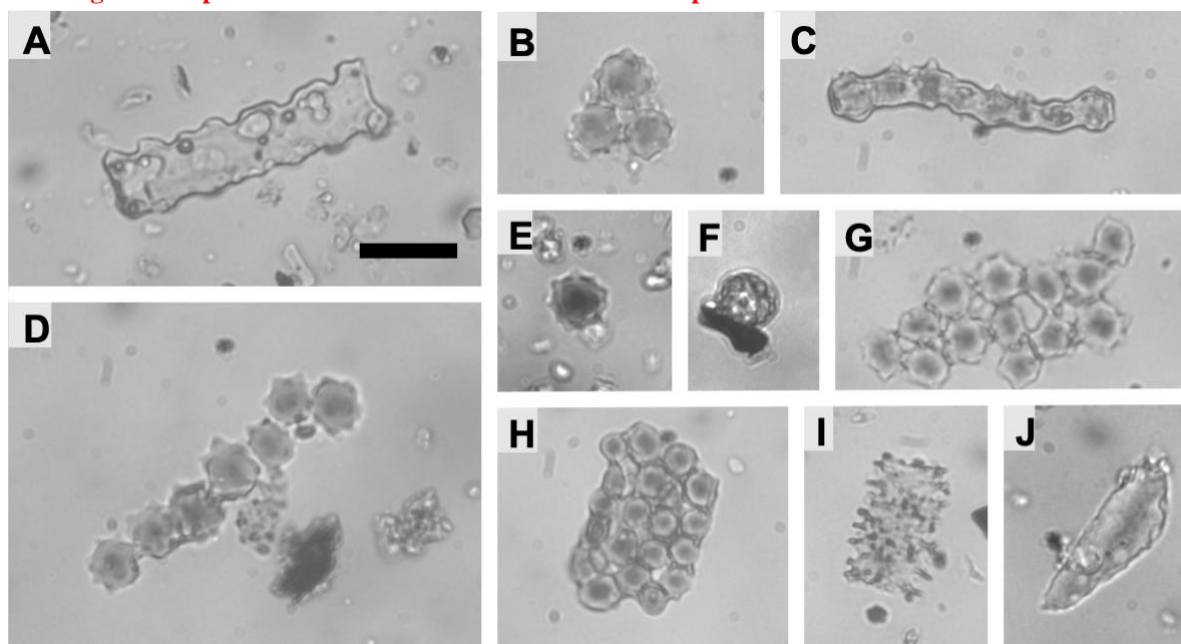
671
672 Figure 10. Kaf Taht el-Ghar: microphotographs of meaningful morphotypes. A) Elongate sinuate with signs of chemical
673 dissolution; B) Silica skeleton of 3 globular echinates; C) Semi-melted long line of globular echinates in anatomical
674 connection; D) Line of globular echinates in anatomical connection; E) Single cell globular echinate; F) Globular
675 granulate; G) Several globular echinates in anatomical connection; H) Silica skeleton of globular echinates; I)
676 Dendriform; J) Trichome with signs of chemical dissolution. Scalebar in A = 20µm (valid for all photographs).
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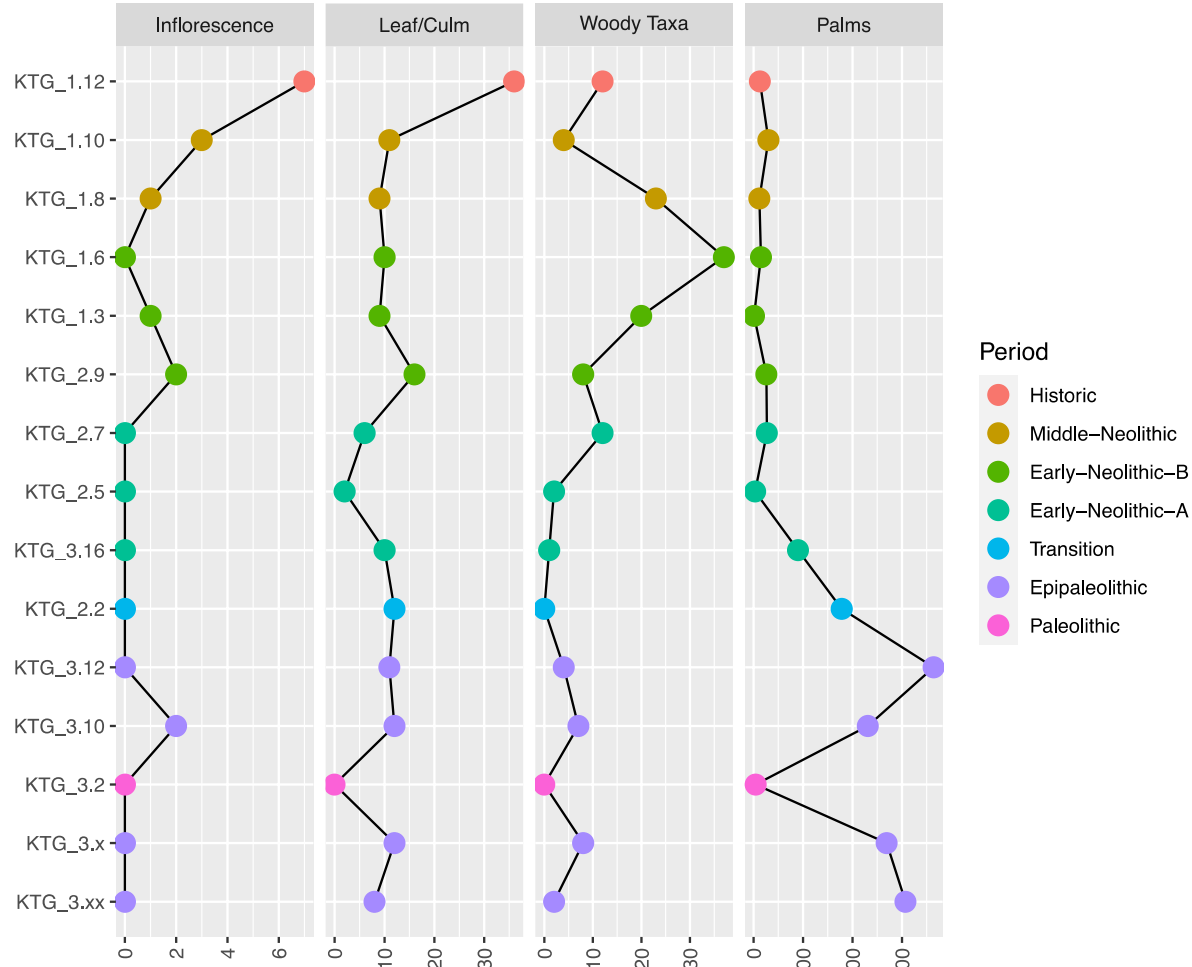
679
680 Figure 11. Kaf Taht el-Ghar: chronological variation of the main categories of phytoliths observed. Note the difference
681 in scale between the categories showing how palm phytoliths are much more abundant than any of the others. The two
682 Epipaleolithic fireplaces have been kept separate as they represent a different, specialised context. However, it is
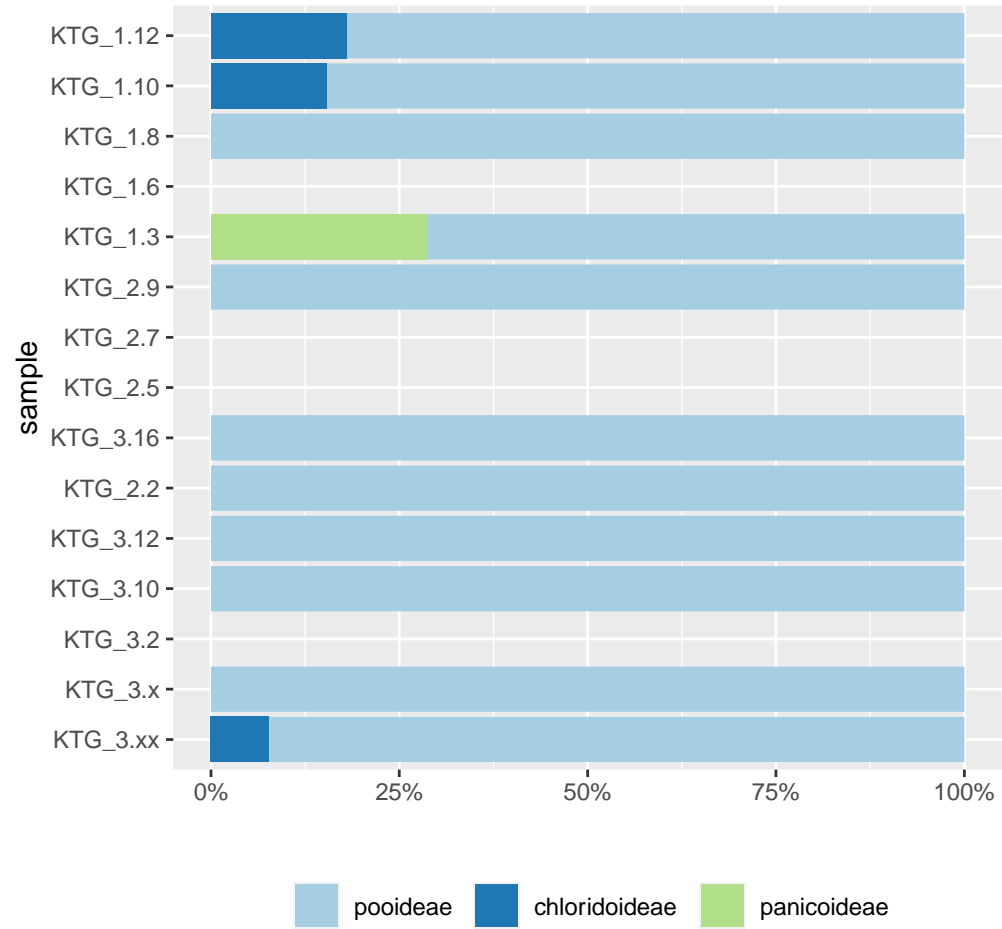683 evident their values are in line with those of the other Epipaleolithic samples.
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687 Figure 12. Kaf Taht el -Ghar: chronological variation of the grass subfamilies identified at the site of Kaf That el Gar.
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710 *Table 1. Periods and phases of the two caves at El Khil, their stratigraphic correlation as defined*
711 *during excavation (from Peña-Chocarro et al. 2012, Martínez-Sánchez et al 2018a) and description*
712 *of the contexts sampled. In bold the stratigraphic units analysed for this work. Radiocarbon dates*
713 *from Martínez-Sánchez et al. 2018a and Morales et al. 2016.*
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	Period	Phase	*grotte* B	*grotte* C	
		1		Sterile layers with evidence of bioturbation (s.u. 1, 2)	Sub-actual
		2		Post Medieval, scarce evidence of occupation; high bioturbation (s.u. 3)	Historic
		3		Islamic Medieval occupation, marine resource exploitation (s.u. 4, 5)	
		4		Scarce or no human presence (s.u. 6-**8**)	
		5		Late Roman occupation with ceramic dated to the IV- V centuries AD (s.u. **9**)	
Abandonment	1	6		Transition between prehistoric and historic periods (s.u. **10**)	Abandonment
Late prehistory	2	7	Protohistoric occupation (s.u 2001, 2002)	Recent prehistory, sporadic use, possible funerary use (s.u. **11**)	Late Prehistory
Neolithic	3	8	Post-depositional erosion processes (s.u. 2003). Intense occupation with Ashakar ware and abundant marine resources (s.u. 2004, **2005**, **2006**, 2007, **2008**) 5490±40 (Beta 316505); 5420±40 (Beta 316506)	Frequent occupation with characteristic Neolithic material (both lithic and ceramic) and remains of domesticated crops and animals (s.u. **12**,**13**,**14**) 5450±40 (Beta 316507); 5470±40 (Beta 316508)	Middle Neolithic

Early Neolithic B	4	9	Beginning of the occupation of *grotte* B, with non Cardial impressions and with evident signs of marine resources exploitation (s.u. **2009**, 2010) 5790±30 (Beta 331845)		Early Neolithic
Early Neolithic A	4	10		Cardial impressions and channelled ware (s.u. **15**, **16**, **17**, **18**) 6180 ± 50 BP (Beta-295780)	
Natural layer				Alteration of the natural rock by biological agents and weathering. S.u. 19 contains large quantity of fossil malacofauna and lays on sterile sand u.s 20	Geologic

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Table 2. Periods and phases of the excavated trenches at Kef That el Ghar, their stratigraphic correlation and dating as defined during excavation, and description of the contexts sampled (from Martínez- Sacnhéz et al. 2021 and references therein). In bold the stratigraphic units analysed for this work.

	Phase	*26AB / 26AB ext*	*26G*	26HI / 26JK
Historic	1	Long phase that contains Medieval wheel-made pottery alongside some later prehistory potsherds.		
		s.u. **1100**, 1100 hearth, 1101-1, 1101-2		s.u.1201
Middle Neolithic	2	The most recent of the prehistoric sequences, shows a less intense occupation and is dated c. 4200 cal. BC. Identified plant remains include naked wheat (*Triticum aestivum/durum*), legumes (*Lathyrus/Vicia*) and fruits (*Pistacia lentiscus* and *Vitis vinifera*).		
		1101-3, **1102**		1201-1, **1202-2**, 1203
Early Neolithic	3	The richest phase in terms of material culture and plant and animal remains, dated between 5500 and 5100 cal. BC. Identified plant remains include cereals (*Triticum diccocum, T. aestivum/durom, Hordeum vulgare*), legumes (*Lathyrus/Vicia* sspp.) and fruits (*Vitis vinifera* and *Myrtus communis*).		
		1103-1, **1103-2**	**1003-1**	**1204-1**, **1204-2**
Transition	4	Period of abandonment or very low frequentation of the cave, dated between 6200 and 5500 cal. BC.		
		s.u. 1104	s.u.1003 Crust	s.u.1205
Epipaleolithic	5	This phase consists of repeated occupations presenting at least 4 hearths, one floor level and a possible post hole and is dated between 10900 and 6200 cal. BC. It yielded abundant microlithic industry, but no pottery and no domestic plant or animal remains.		
		s.u.1104 concretion, 1105	s.u. 1003-2, **1003 Hearth**, 1003 Under Hearth, 1003-3, 1003-4, 1003-5, 1003-6, 1003-7, **1004**, **1005** 1019, 1006-1, 1006-2, **1006 Hearth**, 1006 Pit, 1006-3, 1006 Ash, 1006-4, 1007 Interfacies, 1006 Basis	s.u. 1208, 1209-1, **1209-2**, 1209-3

Paleolithic	6		Long phase that spans from the Middle Pleistocene to the Upper Palaeolithic subdivided into 2 periods (s.u. **1024**, **1025**). Evident frequentation with bone remains and lithic artefacts	

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Table 3. Khil: summary of the samples analysed and the results of the analysis.

		Concentration		Morphotypes n.		Inflorescence		Leaf/culm		Woody taxa		Palms	
Period	Sample	Value	mean	Value	mean	Value	mean	Value	mean	Value	mean	Value	mean
Post Neolithic	EKH-C-8	819,799	568,508	14	11	42	31.5	28	17	5	6.5	3	6.75
	EKH-C-9	1,174,836		9		57		18		4		14	
	EKH-C-10	275,039		11		26		6		8		8	
	EKH-C-11	4,359		10		1		16		9		2	
Middle Neolithic	EKH-C-12	542	115,463	2	9	0	10.6	1	40.6	0	6.6	0	38.6
	EKH-C-13	1,561		2		0		4		2		0	
	EKH-C-13/2	2,101		4		0		3		7		0	
	EKH-B-2005	322,565		15		6		100		18		165	
	EKH-C-14	37,050		8		0		3		2		5	
	EKH-B-2006	201,985		17		22		112		9		22	
	EKH-B-2008	242,436		15		46		61		8		78	
Early Neolithic B	EKH-B-2009	1,084,783		13		97		51		4	0	29	29
Early Neolithic A	EKH-C-15/2-3	16,881	7,215	7	6.75	0	0.75	9	0.75	0	0.5	5	3.5
	EKH-C-15/3	2,624		8		2		8		0		3	
	EKH-C-17	1,661		6		0		4		2		0	
	EKH-C-18	7,694		6		1		1		0		6	

Table 4. Kaf Taht el-Ghar: summary of the samples analysed and the results of the analysis. The two fireplace samples are dated to the Epipalaeolithic period but have been kept separate from the others as they represent a different type of deposit and their formation correspond to different depositional processes than those of the other samples.

		Concentration		Morphotypes n.		Inflorescence		Leaf/culm		Woody taxa		Palms	
Period	Sample	Value	mean	Value	mean	Value	mean	Value	mean	Value	mean	Value	mean
Historic	KTG 1.12	2,416,331		11		7		36		12		13	
Middle Neolithic	KTG 1.10	589,063	713,566	11	11	3	2	11	10	4	13.5	30	21
	KTG 1.8	838,068		11		1		9		23		12	
Early Neolithic B	KTG 1.6	505,049	482,145	8	10.7	0	1	10	11.7	37	21.7	15	14
	KTG 1.3	445,668		12		1		9		20		1	
	KTG 2.9	495,179		12		2		16		8		26	
Early Neolithic A	KTG 2.7	33,483	421,636	8	6.3	0	0	6	6	12	5	27	40
	KTG 2.5	59,128		5		0		2		2		3	
	KTG 3.16	1,172,298		6		0		10		1		90	
Transition	KTG 2.2	946,340		4		0		12		0		178	
Epipalaeolithic	KTG 3.12	1,659,625	7,034,134	9	9	0	1	11	11.5	4	5.5	364	297.5
	KTG 3.10	12,408,643		9		2		12		7		231	
Palaeolithic	KTG 3.4	5,386	5,451	2	1.5	0	0	0	0	0	0	0	2
	KTG 3.2	5,561		1		0		0		0		4	

| Fireplaces (Epipaleolithic) | KTG 3.x | 7,690,415 | 14,283,901 | 11 | 10 | 0 | 0 | 12 | 10 | 8 | 5 | 269 | 288 |
| | KTG 3.xx | 20,877,386 | | 9 | | 0 | | 8 | | 2 | | 307 | |

Supplementary Material SM1 - Protocol for Phytolith Extraction

Sample preparation

Soil was dried in the dry cabinet until no loss of weight was measured then 4 to 5 grams of material were separated from the rest and put into a 100 millilitres beaker. A series of steps was then performed to eliminate the unwanted mineral fractions, i.e. carbonates and clay and the organic matter. The entire procedure is summarised in the following tables.

Table 1.1. Phytolith extraction from soil

Procedure	Effect
1. Pour c. 25 ml of HCl (5%) into the beakers	Eliminate the carbonates
2. Put the beakers, immersed in sand, on a hot plate	
3. Leave until the reaction has stopped (never more than 3-4 hours)	
4. Label and weight 50 ml centrifuge tubes	
5. Transfer the samples into the tubes and fill with distilled water	Wash the HCl away from samples
6. Centrifuge for 3 minutes at 1500 rpm	
7. Discard the supernatant, fill with water	
8. Repeat steps 6 and 7 three times (4 centrifuges in total)	
9. Discard the supernatant	
10. Add up to 50 ml of NaPO6	Deflocculate clays
11. Shake well and leave overnight or for a minimum of 8 hours	
12. Repeat steps 6, 7, 8 and 9	Wash the NaP06 away from samples
13. Add up to 25 ml of H2O2	Digest organic matter
14. Shake well and re-open the tubes	
15. Put tubes into oven at 35ºC until the reaction has stopped (never more than 8 hours)	
16. Repeat steps 6, 7, 8 and 9	Wash the H2O2 away from samples

After these steps are completed, the samples are left to dry until no weight loss occurs. The content of the tubes represents the Acid Insoluble Fraction (AIF), which is weighted and then used to calculate phytoliths concentration in the samples.

Phytoliths extraction

Phytoliths were extracted from the AIF by adding up to 25 ml of sodium polytungstate (SPT) at a specific gravity of 2.35 g/ml. Phytoliths are lighter than the SPT therefore float at the top of the solution. They are then recovered with a Pasteur pipette and transferred in new 50 ml centrifuge tubes. Here the density is lowered again by adding distilled water so that the phytoliths are deposited at the bottom. Once the sodium is washed away by means of centrifuging, discarding the supernatant and adding water, the remaining residue is transferred into sealed glass vials and left to dry.

Table 1.2. Extraction of phytoliths from AIF through gravity separation with sodium polytungstate.

Procedure	Effect
1. Prepare new 50 ml centrifuge tubes	
2. Add c.25 ml of SPT to the AIF	Phytoliths are suspended
3. Centrifuge at 1500 rpm per 3 minutes	
4. Recover phytoliths with a Pasteur pipette and transfer them in the new tube	
5. Repeat steps 3 and 4	
6. Add water to the new tubes up to 50 ml at the bottom of the tube	Pellet the phytoliths
7. Centrifuge at 1500 rpm per 5 minutes	
8. Discard the supernatant and fill with water	
9. Repeat steps 6, 7 and 8 three times (four centrifuges in total)	

10. Label and weight 7 ml glass vials	
11. Transfer the phytoliths into sealed vials and leave to dry	

The residue in the vials is then weighted again to determine the total weight of silicates, a data that is also used to calculate phytoliths concentrations. After the residue is dried temporary or permanent slides can be mounted.