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Late glacial–postglacial North African landscape and forest management: Palynological and anthracological studies in the caves of Kaf Taht el-Ghar and El Khil (Tingitana Peninsula, Morocco)

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A B S T R A C T

This work presents the anthracological and archeopalynological results obtained within the project AGRIWESTMED (ERC AdG 230561), which has involved a comprehensive retrieval of archeobiological remains based on a systematic sampling strategy, beyond the recovery of the usual archeological materials. These surveys were conducted on three sites located in the North of Morocco: the cave of Kaf Taht-el-Ghar, 8 km southeast from Tetuan, and two caves within the El Khil complex, close to Tanger. Both plant micro- and macro-remains (charred wood) were studied through palynological and anthracological analyses, respectively.

Our goal was to assess the vegetation composition of the area as well as the impact of human activities on the landscape. In Kaf Taht-el-Ghar the dynamics of vegetation and land use is recorded over the Paleolithic, Epipaleolithic, Neolithic and Historic times. Clear changes such as the demise of ancient Paleolithic pine and juniper woods during the Epipaleolithic and the subsequent spread of grasslands are shown. Other conifers like *Abies pinsapo*, *Cedrus atlantica* and *Taxus baccata* also disappeared from the pollen and charred wood records. In the palynological study, cereal and broad beans (*Vicia faba*) are already detected in the Early Neolithic, as well as a lowering of grazing pressure. Both cereal and broad beans, along with the development of grazing activities are also documented around El Khil caves since the Early Neolithic. Throughout the whole pollen and anthracological sequences a progressive retreat of the tree cover and an extensive spread of grasslands could be set as the main features of the vegetation dynamics in this area.

1. Introduction

North-eastern Morocco first traces of human land-use were detected in inlander North eastern Morocco (Linstädter et al., 2018; Cheddadi et al., 2019) during the Epipaleolithic, but the impact of these settlers on the landscape was fairly slight. The onset of the Early Neolithic in coastal areas of Northern Morocco brought the earliest evidences of livestock farming and cereal agriculture (Zapata et al., 2013; Morales Mateos et al., 2016; Linstädter et al., 2018; Martínez Sánchez et al., 2021), but also a major impact on vegetation, revealing the transition from natural to cultural landscapes (Roberts, 2014; Rick et al., 2020). In this sense, these archeological surveys conducted in Southern Iberia and Northern Morocco attest the onset of agriculture during the second half of the 8th millennium cal yr BP. However, vegetation changes driven by human impact has attracted less interest, despite some works regarding this issue in the north of Morocco (e.g. Ballouche, 1986; Ballouche and Marinval, 2003; Zapata et al., 2013). Paleoecological studies are a reliable tool to assess the dynamics of land use as well as the establishment of cultural landscapes (Birks, 2019; Mercuri et al., 2019). Among this diverse group of interdisciplinary studies, pollen and non-pollen palynomorphs analyses as well the analyses of charred wood stand out, as they can provide a wider scope of the changes on land use and vegetation dynamics (Zapata et al., 2013).

The Tingitana Peninsula is considered a key region to study the onset of Neolithic processes, due to its strategic location next to the Strait of Gibraltar, a passage between the North of Africa and the South of

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Europe (Linstädter et al., 2018; Martínez Sánchez et al., 2021). In the western area of this region, the caves of Kaft That el-Gahr (KTG) and El Khil (Fig. 1) have been explored since mid-20th century by a number of researchers (e.g. Tarradell, 1955; Gilman, 1975; Daugas et al., 2008). A more recent survey (Peña-Chocarro et al., 2013; Martínez Sánchez et al., 2021) has provided a wide range of archeobotanical remains ranging from Paleolithic to historical times, some of which have been published elsewhere (Morales Mateos et al., 2016; Martínez Sánchez et al., 2018; Lancelotti et al., 2021).

In this work we analyze palynological and anthracological data coming from this latter sequence. We want contribute to a better knowledge of the vegetation and the management of forest resources in prehistoric times, focusing on Neolithic chronologies. More specifically, the aims concerning the palynological study are related to vegetation dynamics in the area and the impact of human activities on the landscape, with special attention to pollen grains from cultivated species, as well as non-pollen palynomorphs linked to livestock grazing, fire events and arid phases. On the other hand, regarding the anthracological analysis, our goal focuses on the quantification of the preserved charred-wood remains and, subsequently, the assessment of the composition of the local vegetation, in order to better acknowledge the exploitation patterns of forest resources by the settlers of KTG and El Khil caves, as well as the uses of timber.

2. Physical and archeological setting

The cave of Kaf Taht el-Ghar (KTG; 35°30′34,75"N; 5°19′48,68"W) is located in the province of Tétouan (Fig. 1), near the Mediterranean coast. It is a karstic complex cavern, resulting from the dissolution of Triassic and Lower Jurassic limestones (Domínguez Bella and Maate, 2008). This cave was first excavated by Miguel Tarradell in 1955 (Tarradell, 1955) and was explored again between 1984 and 1987 and between 1989 and 1994 (Daugas et al., 2008; El Idrissi, 2012; Martínez Sánchez et al., 2021). These works attested for the first time post-Neolithic and historical occupations. The last survey was performed in 2012, within the scope of the project AGRIWESTMED (ERC AdG 230561). Four stratigraphic pits were excavated in the main chamber with the aim of establishing a high-resolution chronological framework and solving some issues found in previous campaigns. Four profiles were sampled for archeobotanical remains from the 47 stratigraphic units identified (Fig. 2) which encompass six different phases from the Paleolithic to the Historical Period (Martínez Sánchez et al., 2021).

The El Khil caves (35°45′44,74"N; 5°56′10,81"W) are located in the province of Tangier (Fig. 1), below a cliff along the Atlantic coast. They are also a karstic complex with numerous cavities, the largest identified as A, B, C, and D. They are developed over Neogene calcarenites, comprising several caves occupied since the Early Neolithic (Morales Mateos et al., 2016; Martínez Sánchez et al., 2018). First interventions were reported by Hugh Henken in 1947 (Gilman, 1975). Later, they were again explored in 1958 (Jodin, 1958-1959) and 1980 (Daugas et al., 2008) with the aim of collecting pollen samples in cave C. Additionally, their eastern profile (Cave C) was also sampled in 2000 (Otte et al., 2004). The samples for our study were collected (Peña-Chocarro et al., 2012) in an intact sector of cave B, corresponding to Early Neolithic B and Middle Neolithic phases, as well as in a remaining baulk of cave C (Fig. 2) comprising phases from Early Neolithic A to Historical Period (Martínez Sánchez et al., 2018).

At both sites the climate is of Mediterranean type, with a significant oceanic influence. Autumn and mainly winter precipitations contrast with a hot and dry summer season. Mean annual rainfall varies from 600 mm in low areas and more than 2000 in nearby mountains. Mean annual temperatures range between 10 and 20 °C (Ajbilou et al., 2003). Current vegetation is highly disturbed but still dominated by the maquia-forest type composed of oaks (*Quercus ilex, Q. suber, Q. faginea*), wild olives (*Olea europaea*), pines (*Pinus halepensis*) or araar (*Tetraclinis articulata*) according to altitude (Charco, 1999).

3. Palynological and anthracological methods

3.1. Pollen sampling and analyses

KTG samples were collected from several sedimentary columns (Fig. 2), 16 samples from 26G, 10 samples from 26HI/26JK and, finally,

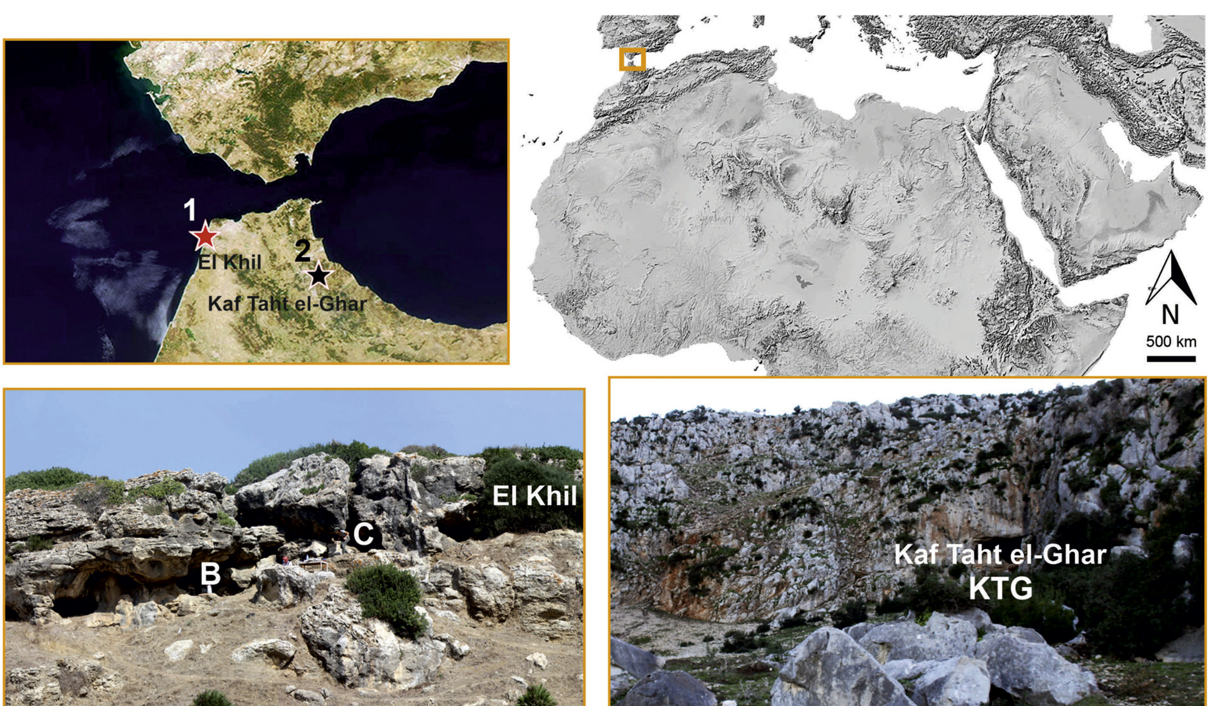

Fig. 1. Location of the archeological sites. 1: El Khil; 2: Kaf Taht el-Ghar.

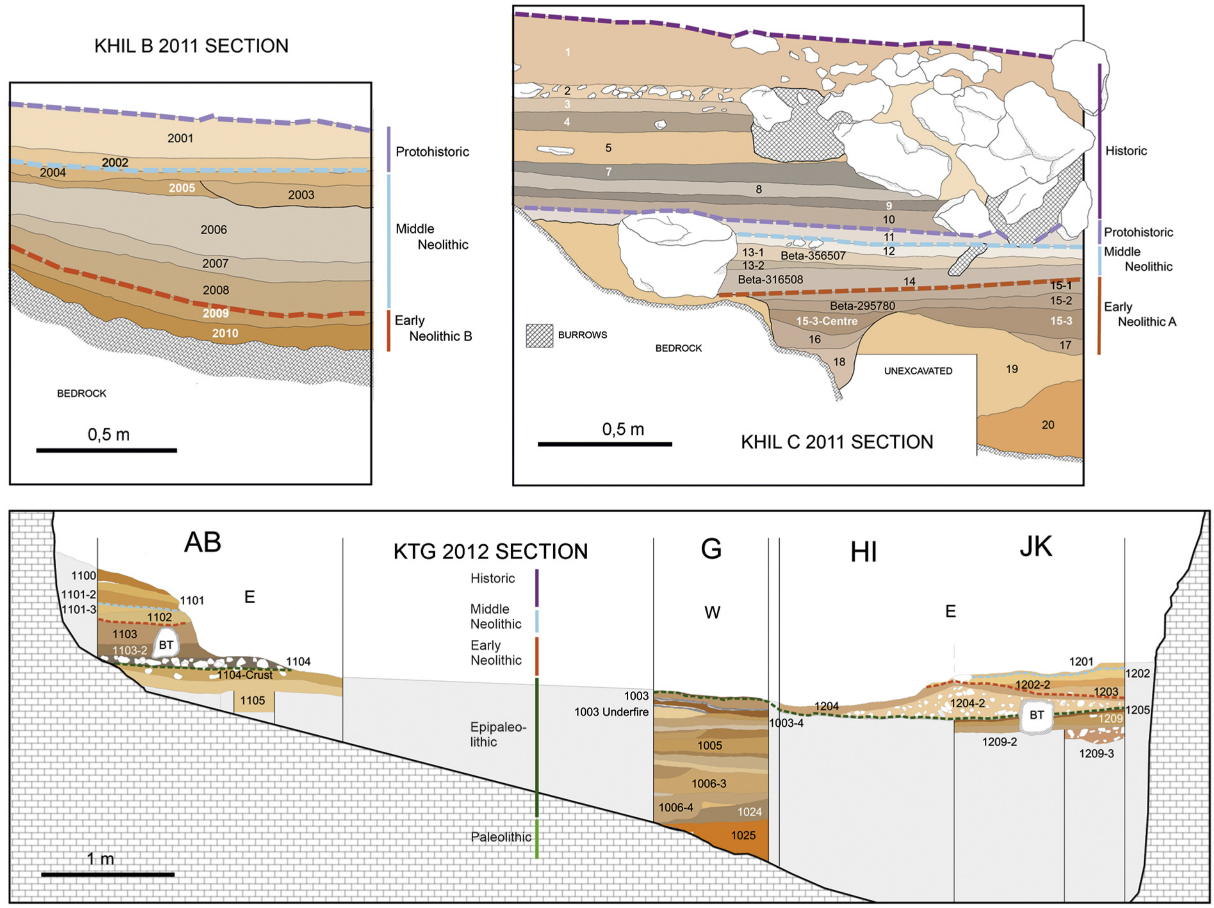

Fig. 2. Stratigraphy of El Khil B and C (top) and Kaf Taht el-Ghar (bottom).

12 samples from 26A/B. On the other hand, 4 samples were collected from El Khil B, and 9 samples from El Khil C (Fig. 2). All of them followed the usual vertical or stratigraphic way of sampling (Burjachs et al., 2003). Later, they were packed, labeled and cold stored before chemical analysis. This treatment was carried out using the method proposed by Faegri and Iversen (1989) including densiometric removal of palynomorphs (Goeury and de Beaulieu, 1979). Pollen types and non-pollen palynomorphs (NPPs) were identified with the help of different atlases and keys (e.g. Reille, 1999; van Geel, 2001), following the nomenclature of Miola (2012). The pollen sum records a minimum of 200 grains, excluding those belonging to Cichorieae, Cardueae or *Aster* type because of their anthropozoogenic nature (Zapata et al., 2013; Florenzano et al., 2015). Graphics were built with Tilia software (Grimm, 2004).

3.2. Anthracological sampling and analyses

The studies regarding charred wood were performed on samples retrieved through flotation. The whole sediment was floated in both sites, so that even little plant macrorremains were recovered providing a wider scope of these materials.

A total volume of 581,5 l was processed for KTG samples, while 269 l were studied for El Khil. Results are all related to wood exclusively preserved by charring. Samples from El Khil, 15 from cave B and 7 from cave C, show the results obtained for prehistoric chronology, while in KTG results come from a selection of 57 samples.

Wood remains collected and used in KTG were preserved because of their contact with fire. As previously mentioned, from the 135 processed samples only 57 were analyzed in this study. Some of them were discarded as they seemed to correspond to removals such as burrow debris. A new subsampling was conducted among the remaining ones, searching for a similar number of data for the different chronological stages, avoiding the overrepresentation of some of them due to their uneven volume within the stratigraphy. Additionally, at least one sample from each Stratigraphic Unit was analyzed. Thus, charred-wood fragments were identified in 14 samples from Paleolithic levels, 18 from the Epipaleolithic, 1 from the transition to the Early Neolithic, 6 from the Early Neolithic, 12 from the Middle Neolithic and, finally, 6 from the Historical period. Fragments > 2 mm have been considered reliable for identification.

Wood remains have been also preserved by charring El Khil B and C. From the 38 recovered samples, 22 have been analyzed in this study, as the remaining ones do not correspond to Prehistoric chronologies. Likewise, charred wood fragments > 2 mm have been studied.

An incident-light microscope Leica DM 4000 M (50×/100×/200×/500×) was used for the anatomical analysis of wood charcoal, where transversal and longitudinal radial and tangential sections of the specimens have been observed. A reference collection and different atlases (e.g. Schweingruber, 1990; Hather, 2000; Vernet et al., 2001) were also used for the identification and comparison of the anatomical features.

4. Results

Recent archeological research (Martínez Sánchez et al., 2021) identified 6 phases in the sequence of KTG (Fig. 2). It begins with a Pleistocene package and a level with Iberomaurisian materials (Phase 6). The following ones, corresponding to the Epipaleolithic (Phase 5) and the

Early Neolithic (Phase 3: 5450–5100 cal BC) are the richest in levels and archeological material, including a hiatus phase (Phase 4) which marks the transition between them. The Middle Neolithic (Phase 2) is also well represented as well as some levels corresponding to Late Prehistory (Phase 1). Likewise, Martínez Sánchez et al. (2018) noted two phases in El Khil B, corresponding to the Early (4700–4500 cal BC) and Middle Neolithic (4500–4000 cal BC), respectively. The Early Neolithic (5200–5000 cal BC) and the recent Historical period are also well represented in the sequence of El Khil C (Fig. 2).

4.1. Pollen analysis

4.1.1. KTG (Figs. 3, 4 and 5)

Some samples were sterile in the three sedimentary columns. Most of them (13) were located in KTG 26G, whereas 2 were in KTG 26HI/26JK and only one in KTG 26A7B.

The Paleolithic is only reported in KTG 26G (Fig. 3). These samples show the dominance of pine forests (*Pinus halepensis*: 50%), with a significant presence of other conifers like *Juniperus*/*Tetraclinis* (15%), *Abies pinsapo* (10%) and *Cedrus atlantica* (3%) in the deepest one. The sample from UE 1024 display a more noticeable presence of shrubs like *Genista* (7%) and a major one of herbaceous taxa like Apiaceae (12%), Fabaceae (11%), Poaceae (10%) or Brassicaceae (9%). Anthropogenic taxa also show also a significant occurrence, especially Cichorieae, but also *Aster* and Cardueae, coinciding with a simultaneous remarkable one of *Pleospora* sp. (HdV 3B) which is considered as an indicator of arid phases (van Geel, 2001).

The Epipaleolithic (10,900/9700–6200 cal BC) is described in KTG 26HI/26JK (Fig. 4), showing an open landscape dominated by grasslands, with high percentages of Poaceae (38–27%), Fabaceae (16–17%) and Brassicaceae (2–5%). The tree cover is characterized by oak forests of *Quercus ilex* (4–14%), *Q. faginea* (4–7%) and *Q. suber* (5%) with a significant presence of *Genista* (4%). Medium values of anthropogenic taxa as well as low levels of coprophilous fungi like *Sordaria* sp. and spores related to fires like *Chaetomium* sp. are also detected.

In the Early Neolithic (5450–5100 cal BC), reported in the three sedimentary columns (Figs. 3, 4 and 5), pinewoods and the rest of conifers have virtually disappeared, giving rise to an open landscape, dominated by grasslands with Poaceae, Fabaceae and Brassicaceae, with moderate values of anthropogenic taxa. Tree cover is represented by oak forests with *Quercus ilex*, *Q. suber* and *Q. faginea*, as well as *Juniperus*/*Tetraclinis*, with a relatively wide development of shrubs like *Genista*. Crops of Cerealia and *Vicia faba* should also be stressed, as well as the absence of coprophilous fungi.

The Middle Neolithic (4200 cal BC) is recorded in KTG 26HI/JK (Fig. 4) and 26A/B (Fig. 5).

Tree cover (35%) shows a significant presence, led by oak forests and *Juniperus*/*Tetraclinis*, but grasslands (50%) dominate the landscape with Poaceae, Fabaceae and Brassicaceae as main elements. Maximum values of anthropogenic taxa, the sporadic presence of Cerealia and *Vicia faba* and the absence of coprophilous fungi are also noteworthy.

Finally, the samples corresponding to the Historical period, located in KTG 26A/B (Fig. 5), show a minor representation of woody vegetation with low percentages of oak forests (ca. 12%) and a significant presence of heathlands (*Erica*: 8%) and *Cistus* (6%). Maximum values of herbaceous taxa (58%) confirm the dominance of grasslands, with the new and noteworthy presence of *Asphodelus albus* related to fire events. Anthropogenic taxa display medium levels, Cerealia appears sporadically and coprophilous fungi (*Podospora* sp.) show low ones.

4.1.2. El Khil B and C (Figs. 6 and 7)

No samples were sterile. The ones from El Khil C depict the Early Neolithic A (5200–5000 cal BC), the Middle Neolithic (4200 cal BC) and Historical Period, while in el Khil B only the Early Neolithic B (4700–4500 cal BC) and theMiddle Neolithic (4200 cal BC) are shown.

The Early Neolithic A (5200–5000 cal BC) reveals *Tamarix* (40%) and *Juniperus* (10%) as main elements, as well as *Quercus suber* (4%) and *Genista* (5%). Herbs (ca. 20%) show a limited extension with a low presence of *Plantago* and *Rumex acetosa*, and occasional occurrences of Cerealia and *Vicia faba*. Nitrophilous taxa display relatively high values. Coprophilous fungi (*Sordaria* sp.) are also moderately abundant, just like *Coniochaeta ligniaria*, linked to deforestation processes (Van Geel, 2001). The presence of *Pleospora* sp. related to arid phases should also be noted.

During the Early Neolithic B, vegetation in this coastal enclave is mainly composed of *Tamarix* (24%) and *Juniperus* (13%) with a significant presence of *Quercus suber* (2%). There was also a significant extension of termophilous shrubland, mostly *Buxus*, *Ephedra* and *Genista*. Among the herbaceous species, Poaceae (25%) reach medium percentages. In addition, there is a low but significant percentage of antropozoogenous taxa like *Plantago* and *Urtica*, as well as crops such as Cerealia and *Vicia faba*. Nitrophilous plants like *Aster*, Cichorieae and Cardueae show relatively high values, just like coprophilous fungi (*Gelasinospora* sp., *Sordaria* sp., *Podospora* sp.), which could indicate the in-situ presence of livestock.

During the Middle Neolithic (4200 cal BC) the tree cover is low (10%), especially *Juniperus* (3%), against a noticeable one of shrubland, led by *Tamarix* (45%) and, to a lesser extent, *Genista* (5%), with the sporadic occurrence of *Olea europaea*. Among the herbs, Fabaceae (11%) and Poaceae (7%) show a relatively moderate presence with constant levels of Brassicaceae and Apiaceae. Nitrophilous taxa are also present with low values of *Plantago* and *Urtica*. Among crops, only *Vicia faba* appears. Levels of coprophilous fungi are relatively low.

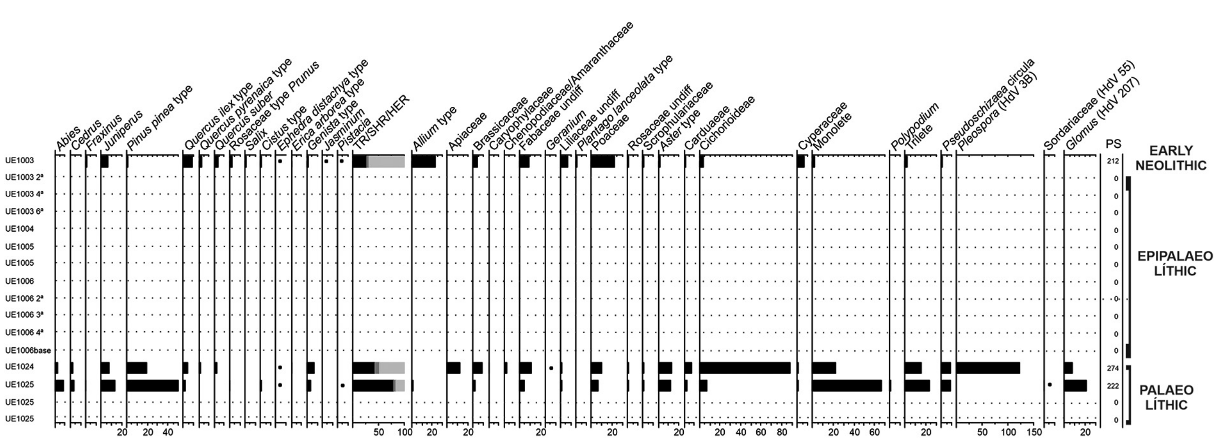

Fig. 3. Pollen diagram of Kaf Taht el-Ghar. KTG26G.

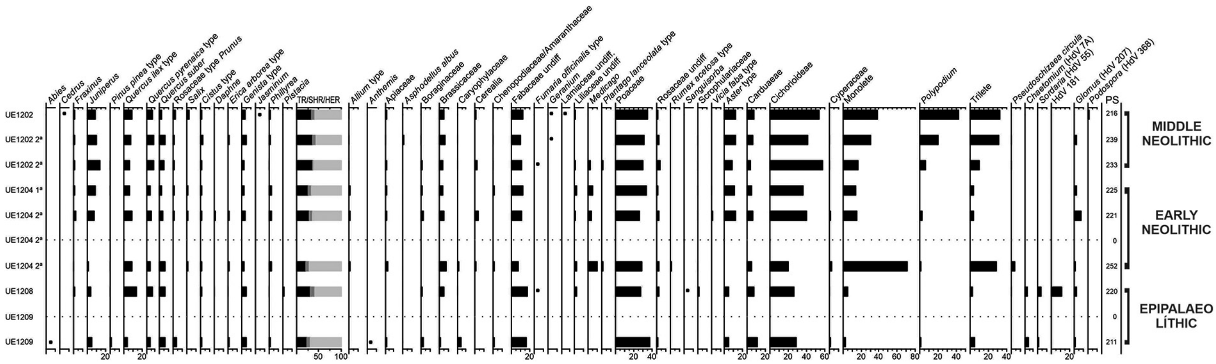

Fig. 4. Pollen diagram of Kaf Taht el-Ghar. KTG26HI/JK.

Samples encompassing the Historical Period show a significant presence of the tree cover (8–15%), led by *Juniperus* and *Quercus suber*, as well as the prevalence of *Tamarix* (46%). Both shrubs and herbs display relatively low percentages, just like nitrophilous taxa, while coprophilous fungi and *Vicia faba* are absent.

4.2. Anthracological analysis

4.2.1. KTG (Fig. 8; Tables 1 and 2)

A total sum of 3469 fragments were analyzed, from which 3275 were identified. Absolute and relative results are shown in Tables 1 and 2, as well in Fig. 8. Wood identified in KTG corresponds to a minimum of 14 taxa. Among the conifers, *Juniperus* sp., *Pinus* sp. and *Taxus baccata* have been identified. In addition, *Acer* sp., *Arbutus*, *Fraxinus*, Fabaceae, *Olea*, *Pistacia*, deciduous and evergreen *Quercus*, Rosaceae (e.g. *Prunus*) and Rhamnaceae, among broad-leaved species, are also present. The non-identified 188 fragments correspond to charred wood with a very altered anatomy, so that their diagnostic characters could not be observed. It can be related to green wood, bark or knots.

Once the percentage information was processed, samples were chronologically joined and the anthracological diagram was built. Three main phases can be observed in relation to wood selection.

The first one is a level of Paleolithic chronology (n = 168) where the most represented wood corresponds to conifers like *Taxus* (30,4%), *Pinus* (28%) and *Juniperus* (25,6%), with sporadic occurrences of *Quercus*, *Prunus*, Leguminosae, *Acer*, *Olea* and *Fraxinus*.

The second phase corresponds to the Epipalaeolithic, where a very high number of fragments were identified (n = 1709). *Fraxinus* (>50%) is the most represented wood, even in remains belonging to a hearth (n = 200). *Olea* is the second most used wood, mainly in the hearth (ca. 30%), together with Leguminosae, *Juniperus*, evergreen *Quercus* and Monocotiledoneae. *Pinus* (11,1%) was also important in the Epipaleolithic level, although in the hearth is almost absent. The rest of the taxa show very low percentages. In the level identified as transitional (n = 100), marked by a stalagmitic crust, ash wood (*Fraxinus*: 42%) keeps the highest percentages, followed by both *Quercus* and Rosaceae (ca. 11% each). In addition, a rise in the use of *Pistacia* and *Juniperus* is detected, as well as a minimal presence of the remaining taxa and the absence of *Olea* and *Pinus* charcoal.

Finally, the third phase (n = 1298) includes the last three chronological stages of the diagram (Neolithic and Historical). The scenario changes again in the first level, from the Early Neolithic (n = 600), with very low levels of wood from *Fraxinus* (2,2%) against the major presence of *Olea* (ca. 42%) and, to a lesser extent, of Leguminosae, deciduous *Quercus* as well as Rhamnaceae. Taxa like Rosaceae, *Pistacia*, cf. *Arbutus*, *Juniperus*, *Prunus* and evergreen *Quercus* remain under 4%. During the Middle Neolithic (n = 633), *Olea* (43%) is still the most represented taxon, followed by Leguminosae (22,3%) and *Juniperus* (17,5%). Moreover, a lower presence of Rhamnaceae (4,5%), *Pistacia* (2,7%), deciduous *Quercus* (2,7%), Rosaceae (1,9%), *Fraxinus* (1,9%), evergreen *Quercus* (1,6%) and *Prunus* (1,6%) is attested. The Historical period (n = 65) shows the main presence of *Juniperus* (23%) and Rosaceae (22%) wood, along with Leguminosae and *Olea* (both with 20%), *Pistacia* and *Fraxinus* (both with 6,2%) as well as Rhamnaceae (ca. 3%).

4.2.2. El Khil (caves B and C) (Tables 3 and 4)

Despite the efforts made, only 60 charred wood fragments have been recovered, and 32 out of them have been identified. Five taxa are observed, *Juniperus*, Ericaceae, Fabaceae, *Olea* and evergreen *Quercus* as well as other undetermined taxa among the Angiosperms. The 28 non-identified remaining taxa also correspond to charred wood with a very altered anatomy.

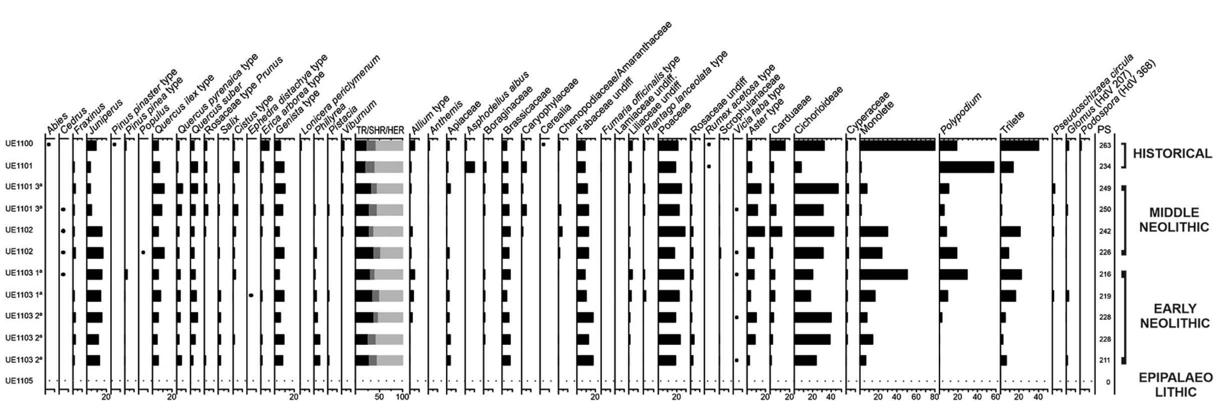

Fig. 5. Pollen diagram of Kaf Taht el-Ghar. KTG26A/B.

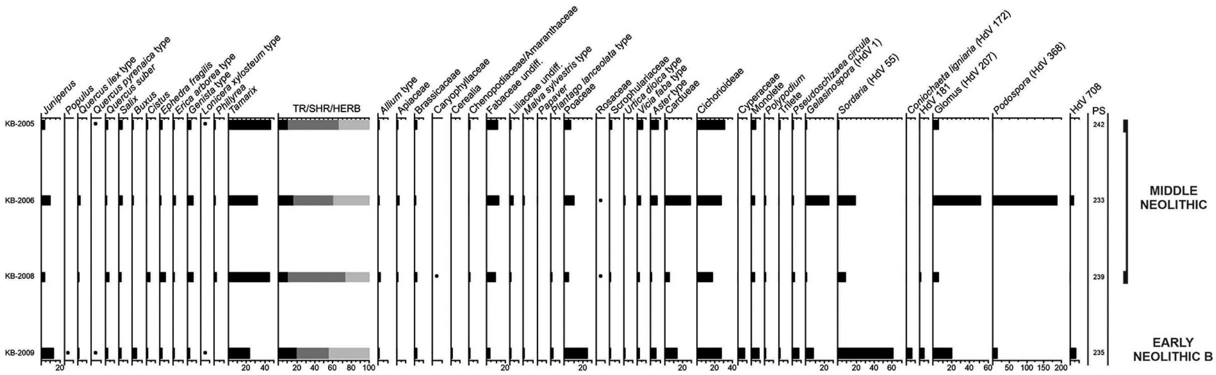

Fig. 6. Pollen diagram of El Khil B.

Despite the low number of identified fragments, the most represented wood is that of *Olea* (n = 13) and *Quercus* (n = 8).

5. Discussion

Both pollen and anthracological analysis have constraints to inform landscape dynamics, especially when they come from archeological sites, which are biased by humans who selected specific plant species for particular purposes. Archeobotanical studies provide essential data to better understand the archeological site, the ways of life of its inhabitants and the environment, similarly approaching the selection of plant resources. In addition, the combination of these proxies provides invaluable information, improving the interpretation of vegetation dynamics from a very local to regional scale (Mercuri, 2008; Zapata et al., 2013; Roberts, 2014; Fyfe et al., 2018).

Previous pollen and anthracological research is very limited in this area (López Sáez and López Merino, 2008). In KTG only four samples, spanning the Neolithic, were previously analyzed (Ballouche and Marinval, 2003), confirming cereal cultivation and the clearing of forests as well as the spread of grasslands during this period. On the other hand, El Khil caves were also studied (Ballouche, 1986), but only a marked increase of anthropogenous herbs (Cichorieae, Brassicaceae), was reported during the last stages of the Neolithic period. Eastward, Zapata et al. (2013) show a detailed description of vegetation dynamics through the palynological and anthracological analysis in Ifri Oudadane, during the transition from Epipaleolithic to Early Neolithic.

Inland, other analyses conducted at Ifri el Baroud (Carrión Marco et al., 2021) and Taforalt (Barton et al., 2016; Carrión Marco, 2020) also provided information on plant landscape and land use since ca. 23 ka cal BP.

Additionally, other studies in the same sites have focused in other proxies such as pottery, seed or phytoliths (Morales Mateos et al., 2016; Martínez Sánchez et al., 2018, 2021; Lancelotti et al., 2021), which conclusions will be considered along this discussion.

5.1. Paleolithic and Epipaleolithic

Our study reveals that the main landscape feature throughout the Paleolithic period is the presence of a forest cover (Fig. 3) dominated by conifers like *Pinus halepensis*, *Juniperus/Tetraclinis* and a significant presence of *Cedrus atlantica*, *Abies pinsapo* and *Taxus baccata*. Both pollen and charred wood (Fig. 8; Tables 1 and 2) evidence this vegetation pattern, as well as the subsequent spread of thermophilous shrubland and, especially, of grasslands. The relatively high percentages of both *Abies pinsapo* and *Cedrus atlantica* point to their significant extent in lowland areas before the beginning of the Holocene, when they are considered to have been steadily moving up to higher elevations due to climate changes (Cheddadi et al., 2017; Abel-Schaad et al., 2018). These data are the oldest evidence of their presence at low elevations in Northern Morocco so far. On the other hand, the high presence of *Taxus* among charred wood is probably related to both the manufacture of tools, due to its hardness and elasticity, and its use as fuel, due to its high calorific value and long duration (Cortés et al., 2000; Abella, 2009). The selection of *Pinus* and *Juniperus* wood may also be due to the fact that they provide hard and compact wood, widely used for construction and fuel. The rest of the wood species such as *Quercus*, *Olea*, *Fraxinus* among others, appear in very reduced numbers (between 1 and 5 fragments).

The occurrence of coprophilous fungi, such as *Sordaria* (HdV 55) in this period is likely related to the use of the cave by wild herbivores.

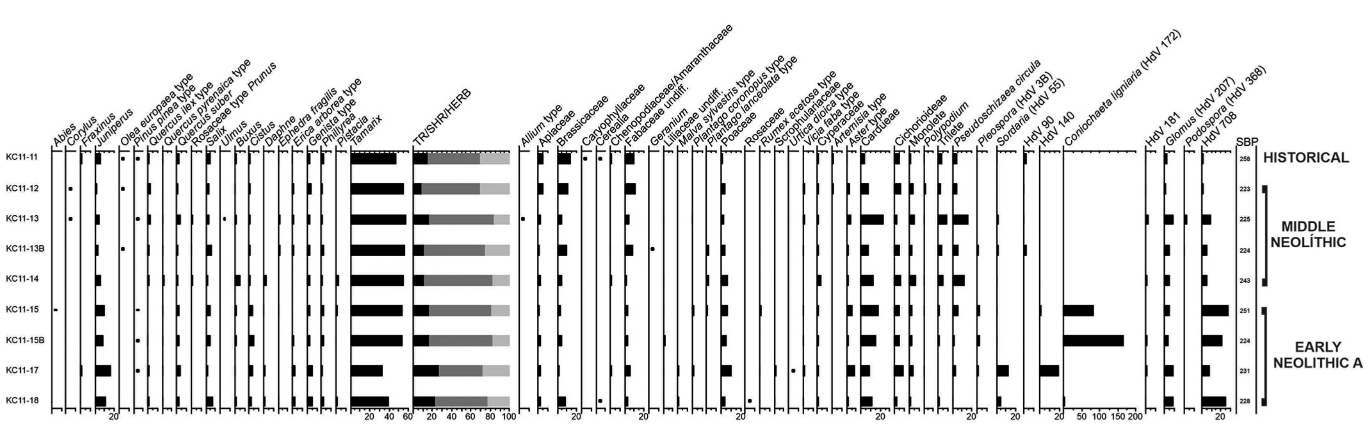

Fig. 7. Pollen diagram of El Khil C.

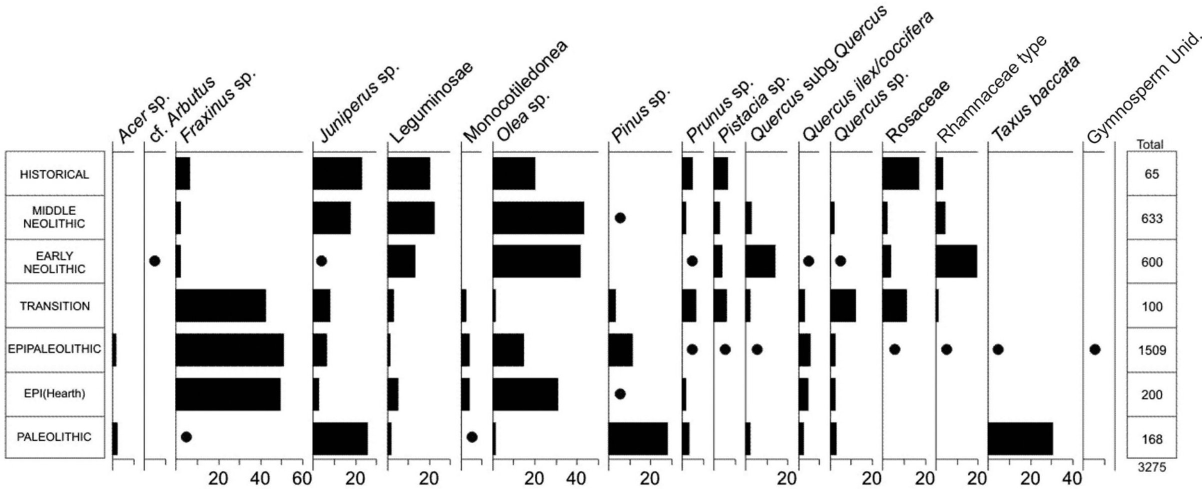

Fig. 8. Percentage histogram of the total identified charred wood from Kaf Taht el-Ghar (n = 3275). Points indicate percentages <1%.

Likewise, *Sordaria* spores appear in the Epipaleolithic, as well as *Chaetomium* (HdV 7A), more linked to fire events (Kuhry, 1985). Human pressure seems to be moderate, as pointed by the values of grasslands and nitrophilous herbs such as Cichorieae, Apiaceae, Fabaceae and Brassicaceae.

The striking appearance of *Pleospora* sp. seems to indicate the onset of an arid phase (Van Geel, 2001) within a broadly cool climate, which would have favored the prevalence of conifers.

As shown by our palynological study, pine forests finally disappear during the Epipaleolithic period (Fig. 4), although in the anthracological record a total of 11% is detected, pointing to the use of pine wood also in this period. The forest cover became composed of oaks, especially holm oaks (*Quercus ilex*), but also cork (*Q. suber*) and kermes oaks (*Q. coccifera*), leading the wide expansion of thermophilous shrubland, with a significant contribution of broom communities (*Genista* sp.). In any case, grasslands are still the main component in this open landscape. On the other hand, ash became the most important charred wood during this period, despite displaying low percentages in the pollen record, pointing to the selection of this timber for different purposes as, for instance, the manufacturing of tools due to its hardness and elasticity, serving its surpluses for use as firewood. Also, *Olea* wood is detected, with values even higher in the Epipaleolithic hearth (Fig. 8, Tables 1 and 2).

Since the wood located in a fireplace represents the last fire (Chabal, 1988, 1992), hearths have its own characteristics which affect interpretation. On the other side, scattered charcoal could represent several fires, different hearth cleanings, being a longer process, contributing with data that can be interpreted in terms of the composition and evolution of the surrounding vegetation (Badal, 1992; Chabal, 1988, 1997; Badal et al., 2003; Carrión Marco, 2005; Théry Parisot et al., 2010). Despite this fact, both the Epipaleolithic level and the hearth show similar values in the rest of the taxa, but with some exceptions. Here is where the highest values of Aceraceae are detected among the phytoliths (Lancelotti et al., 2021), probably reflecting that its leaves were used as fuel, although this family is absent from both the wood remains and the pollen record.

Research carried out at the eastern Rif site of Ifri Oudadane (Zapata et al., 2013) shows a similar picture of conifer forests retreat, with its own particular geographical features, close to a wadi-river. Vegetation also seems to be still scarcely disturbed by human activities. A wider extension of the tree cover with evergreen *Quercus* and thermophilous shrubland, as well as a well-preserved riparian wood, allow the authors

Table 1
Absolute anthracological data from KTG retrieved through flotation and grouped by chronological stages.

	HIS	MN	EN	TRANS	EPI	EPI (Hearth)	PAL
Acer sp.					19		3
cf *Arbutus*							
Fraxinus sp.	4	12	13	42	765	98	1
Juniperus sp.	15	111	4	8	98	5	43
Leguminosae	13	141	80	3	23	10	3
Monocotiledoneae				2	57	8	1
Olea sp.	13	272	248	1	221	61	2
Pinus sp.		3		3	168	1	47
Prunus sp.	3	10	4	6	7	3	5
Pistacia sp.	4	17	21	6	2		
QsQ		17	84	2	4		3
Q. i/c			3	3	82	9	4
Quercus sp.		10	1	12	34	5	5
Rosaceae	11	12	22	11	14		
Rhamnaceae type	2	28	115	1	11		
Taxus baccata					2		51
Gymnosperm Unid.					2		
TOTAL	**65**	**633**	**600**	**100**	**1509**	**200**	**168**
Unid	26	62	35	9	49	6	7

Table 2
Percentage anthracological data from KTG retrieved through flotation and grouped by chronological stages.

	HIS	MN	EN	TRANS	EPI	EPI (Hearth)	PAL
Acer sp.					1,3		1,8
cf *Arbutus*			0,8				
Fraxinus sp.	6,2	1,9	2,2	42	50,7	49	0,6
Juniperus sp.	23,1	17,5	0,7	8	6,5	2,5	25,6
Leguminosae	20	22,3	13,3	3	1,5	5	1,8
Monocotiledoneae				2	3,8	4	0,6
Olea sp.	20	43	41,3	1	14,6	30,5	1,2
Pinus sp.		0,5		3	11,1	0,5	28
Prunus sp.	4,6	1,6	0,7	6	0,5	1,5	3
Pistacia sp.	6,2	2,7	3,5	6	0,1		
QsQ		2,7	14	2	0,3		1,8
Q. i/c			0,5	3	5,4	4,5	2,4
Quercus sp.		1,6	0,2	12	2,3	2,5	3
Rosaceae	16,9	1,9	3,7	11	0,9		
Rhamnaceae type	3,1	4,4	19,2	1	0,7		
Taxus baccata					0,1		30,4
Gymnosperm Unid.					0,1		
	65	**633**	**600**	**100**	**1509**	**200**	**168**

Table 3
Absolute anthracological results from El Khil B.

SU	TABLE	cf. Ericaea	*Juniperus* sp.	cf. Legum..	*Olea*	cf. *Olea*	*Quercus* sp.	Angiosp unid.	Unid.
2003	B	1							
2004	D								1
2004	B					2		3	
2005	C		1						2
2005 (2)	B (2)								4
2006	C								4
2007	B				1		1		1
2007	C								3
2008	D							2	
2008	C					3			1
2008	B			1			1		
2009	D				1				3
2009	C					1	1		
2009	B					2	1		1
2010	B								1

of the study to suggest a warm and humid climate for this period, also pinpointed by other researchers (Lüning and Vahrenholt, 2019).

5.2. Early Neolithic

The transition to the Early Neolithic is considered the period when cultural landscapes started to develop in North eastern Morocco (Zapata et al., 2013). The first significant expansion of human population, mainly in lowland sites (Linstädter et al., 2018; Cheddadi et al., 2019) is attested within a climatic framework of warmer temperatures and increasing aridification (Yanes et al., 2018; Lüning and Vahrenholt, 2019).

The main feature of this period (Figs. 3–5) in our study is the relevant percentages of Cerealia, already detected in previous works (Ballouche and Marinval, 2003; Morales Mateos et al., 2016) together with the presence of pollen from *Vicia faba*. Likewise, both cereal and *Vicia faba* are sporadically observed in El Khil (Figs. 6 and 7), against the phytoliths analysis, where the presence of C3 taxa (wheat and barley) and C4 (millet type) is detected (Lancelotti et al., 2021). Our pollen record suggests that vegetation around KTG appears to be dominated by grasslands, with a high rate of Poaceae, Fabaceae and Brassicaceae, whereas the limited tree cover consisted of oaks and juniper trees and a scarce extent of thermophilous shrubland. These changes on the plant landscape are reflected in the low percentages of the tree cover. In our anthracological study, *Olea* and leguminous shrubs become the main charred wood identified, with few occurrences of Rhamnaceae and *Quercus*. The importance of *Olea* among the wood remains throughout the Neolithic period has no correlation with our pollen analysis. This circumstance may point to the selection of this species and its transfer from other environments, probably not very distant, where *Olea* was represented within more thermophilic faciations of the potential vegetation at that time. Despite the advance of a disturbed landscape, neither antropozoogenous taxa levels nor coprophilous fungi values were high in our pollen record, showing a very low relevance of grazing activities. By contrast, fungi related to livestock became relatively important in El Khil during this period, especially in the top samples, pointing likely to the use of the caves for animal shelter (Ballouche, 1986). The same trend is reflected in the phytolith analysis with the detection of leaves and grass stalks, probably used as animal fodder or bedding material (Lancelotti et al., 2021). Our analyses suggest that riparian and thermophilous shrubland covered the surrounding area of El Khil caves, with *Tamarix* along the river and broom communities a little further. Scattered juniper (*Juniperus phoenicea*) and cork oak (*Quercus suber*) stands, as well as grasslands patches would shape this landscape. In the case of the use of wood, results show a noteworthy change in relation with the Epipaleolithic levels, since *Fraxinus* is not used, and *Olea* and, to a lesser extent, evergreen *Quercus*, Leguminosae and Rhamnaceae type are the most identified charred wood all along the anthracological record (Fig. 8; Tables 1–4). The latter also points to the selection of these species for firewood during the whole Neolithic period.

Other studies illustrate a similar picture. The site of Ifri Oudadane shows a more intense disturbance of vegetation attributed to a more severe human pressure on this eastern area, but also to an increasing climate-induced aridification (Zapata et al., 2013). Eastward, the site of Ifri n'Etsedda (Linstädter et al., 2016) also displays a higher relevance of grazing activities.

5.3. Middle Neolithic

During Middle Neolithic period the most outstanding feature pointed by our analyses is the persistence of vegetation (Figs. 4–7). Both previous levels of the tree cover and thermophilous shrubland stay around KTG, with grasslands remaining as the main component of the landscape. Likewise, in the surroundings of El Khil, both *Tamarix* and thermophilous shrubland show similar percentages as before, whereas the tree cover, and mainly *Juniperus phoenicea*, display lower ones. Grasslands remain unchanged. On the other hand, human

Table 4
Absolute anthracological results from El Khil C.

SU	TABLE	BOOST	DATE	cf. Ericaceae	*Juniperus* sp.	cf. *Olea*	*Quercus* sp.	*Quercus ilex/coccifera*	Unid.
11			17/09/2011		1				
12			17/09/2011						3
13		2ª		1		2	1	2	1
13						1			1
14					1				1
15		2ª Sur							1
N.	**LEVEL**	**FLOT. VOL.**	**OBS**						
5	C3-base	90 ml	Seed level					1	

pressure seem to decrease during this period, as indicated by the sporadic occurrences of cereal and *Vicia faba* in KTG (Figs. 4 and 5), as well as the disappearance of Cerealia and the low levels of coprophilous fungi in El Khil (Figs. 6 and 7). In the case of the wood remains, *Olea* and *Quercus* are the most represented taxa, but the low number of retrieved pieces (Tables 3 and 4) must be considered. In the case of KTG, among charred assemblage, *Olea* is still the most used fuel with Leguminosae. *Juniperus* becomes relevant, perhaps related to its recovery also observed in the palynological record (Fig. 8; Tables 1 and 2). Its further retreat shown by the pollen diagram could also be linked to its selection for different purposes in the cave.

5.4. Historical period

Only two samples from KTG are attributed to the Historical period (Fig. 5), marked by low values of the tree cover in favour of thermophilous shrubland, possibly because of the use of fire, as the significant presence of *Asphodelus albus* percentages seems to indicate. In any case, grasslands maintain their extent on landscape. Rosaceae wood becomes important, along with *Juniperus*, while the use of Fraxinus wood rised among charred wood (Fig. 8; Tables 1 and 2). The use of *Olea* and Leguminosae becomes less important, pointing to its selection likely for fire wood. Regarding human influence, cereals appear only sporadically, while grazing activities gain a higher relevance as shown by the novel presence of *Podospora* sp. By contrast, *Juniperus phoenicea* and *Quercus suber* show noticeable values in the tree cover in the only sample from El Khil corresponding to this period (Fig. 7). Both thermophilous shrubland and grasslands remain without major changes. No indicators of grazing activities are found, whereas Cerealia displays a new occurrence as the only crop detected. Hence, human pressure seems to be rather low during this phase.

6. Concluding remarks

The palynological and anthracological data obtained from KTG and El Khil sites provide relevant information about the environment and its management from Paleolithic to Neolithic periods in the Northwestern region of Morocco. Pine and juniper woods dominate the vegetation during the Paleolithic, and progressively retreated against grasslands and thermophilous shrubland. The significant percentages of pollen from *Abies pinsapo an*d *Cedrus atlantica* at this time can be considered the first evidence of a pre-Holocene wider extent of these taxa in lowland areas of Northern Morocco. Also noticeable is the relevant presence of *Taxus baccata am*ong the charred wood. Throughout the Epipaleolithic, these forests virtually disappeared, within an open landscape where grasslands prevailed with scattered oak stands. Human influence seems to be still very scarce. The main vegetation change occurred in the transition to the Early Neolithic, considered as the period when cultural landscape started to be shaped. Crops like cereals and broad beans (*Vicia faba*) *a*re detected in the pollen record, not only in KTG, but also in El Khil. From this date onwards, the tree cover shows a progressive retreat, whereas thermophilous shrubland and, especially, grasslands reach their maximum extent. The existence of a wadi-river by El Khil caves allow the persistence of *Tamarix* communities.

Human pressure, represented by agriculture and grazing activities, seems to drop during Middle Neolithic in North western Morocco. In KTG, crops seem to have a greater relevance than in El Khil, where grazing is more significant. During Historical period cereals become the only crop, while livestock grazing undergoes a noticeable increase, parallel to the development of thermophilous shrubland and grasslands in the area.

All these changes revealed by the pollen record are also reported in the anthracological analysis, although conditioned by the origin and supply of the wood as well as by the use of the harvested wood for different purposes. In KTG, the conifers are selected mainly during the Paleolithic (*Juniperus*, *Pinus*, *Taxus*) and *Fraxinus*, together with *Olea* during the Epipaleolithic. The transition to the Neolithic is marked by the use of *Olea* and leguminous shrubs, although both are present, with low values, from the beginning of the sequence in the Paleolithic. At El Khil, the Neolithic is also defined by the use of *Olea*, but charred wood remains of evergreen oaks also appear.

This study highlights the utility and relevance of pollen and charred wood analyses to depict environmental and land-use changes from archeological sites, in this geographically key area of Northern Morocco.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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