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Early to Middle Holocene landscape exploitation in a drying environment: Two case studies compared from the central Sahara (SW Fezzan, Libya)

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Abstract

The erg Uan Kasa and the wadi Tanezzuft (Libyan Sahara) reacted in different ways to Holocene climatic changes. Consequently, the human groups settled there responded with different ways of adaptation to the drying environment. In the erg Uan Kasa, shallow lakes were formed from the Early to the Mid-Holocene, and their shores were densely inhabited from the Epipalaeolithic to the Pastoral-Neolithic periods. The erg dried out at c. 5000 years BP, but the area was not completely abandoned, as indicated by minor Late Pastoral-Neolithic sites composed of scattered fireplaces. During the wet Holocene, the wadi Tanezzuft was a large meandering river, and its banks were densely settled. At c. 5000 years BP, the stream was not completely dried out, but it changed its pattern, originating an alluvial plain. A large oasis was formed between c. 4000 and 2000 years BP, exploited by Late Pastoral-Neolithic pastoral communities, and later by Garamantians, which introduced soil management and agricultural practices. The Tanezzuft oasis suffered a drastic reduction in size during the first centuries AD, at the time of the abandonment of the Garamantian settlements. ***To cite this article: M. Cremaschi, A. Zerboni, C. R. Geoscience 341 (2009).***

Résumé

Exploitation du paysage au cours d'un assèchement de l'environnement entre l'Holocène inférieur et l'Holocène moyen : comparaison de deux études de cas au Sahara central (SW Fezzan, Libye). L'erg Uan Kasa et l'oued Tanezzuft (Sahara libyen) ont réagi de différentes façons aux changements climatiques de l'Holocène ; par conséquent, les groupes humains installés dans ces contrées se sont adaptés différemment au milieu aride. Dans l'erg Uan Kasa, des lacs peu profonds se sont formés entre l'Holocène antique et moyen et leurs rives étaient densément habitées de l'Épipaléolithique au Néolithique-pastoral. L'erg s'assécha aux alentours de 5000 ans BP, mais la région ne fut pas complètement abandonnée, comme l'indiquent les foyers dispersés du Néolithique-pastoral tardif, à la fois associés à des pierres d'entrave. L'oued Tanezzuft pendant l'Holocène humide était un large fleuve à méandres et ses berges étaient densément peuplées. Vers 5000 ans BP, le cours d'eau ne fut pas totalement tari par la sécheresse, mais son débit changea, créant ainsi une plaine alluviale. Une importante oasis s'est formée entre 4000 et 2000 ans BP ; elle a été exploitée par les communautés pastorales du Néolithique-pastoral tardif et plus tard par les Garamantes, qui ont introduit la gestion des sols et les pratiques agricoles. L'oasis Tanezzuft a subi une réduction de taille drastique au cours des premiers siècles de

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notre ère, alors qu'au même moment, les installations des Garamantes furent abandonnées. ***Pour citer cet article : M. Cremaschi, A. Zerboni, C. R. Geoscience 341 (2009).***

Keywords: Climate change; African monsoon; Landscape exploitation; Subsistence strategies; Aridity; Holocene; Central Sahara; Garamantians

Mots clés : Changements climatiques ; Mousson africaine ; Exploitation du paysage ; Stratégie de subsistance ; Aridité ; Holocène ; Sahara central ; Garamantes

1. Introduction

From the Early to Middle Holocene, the SW Fezzan (Libyan Sahara) enjoyed, as did the entire Saharan region (e.g. [19,31–34,40,45,54,62,64]), a period of high rainfall [5,8–10,27,68,69], the driving cause of which was the northward expansion from the Guinea gulf of the summer monsoon and the migration of the intertropical convergence zone (ITCZ [19,32–34,40,54,59]). The main effect of this climate change was the recharge of the local aquifers [8,68] and the consequent activation of springs, rivers, and lakes, and the growth of luxuriant vegetation [56,57], determining conditions suitable for animal life. Subsequently, the entire area was settled by Epipalaeolithic and Mesolithic groups (Early and Late Acacus) and later by Pastoral-Neolithic communities [13–16,23].

The North-African Holocene climatic Optimum (*sensu* [67]) was interrupted by several transitory dry spells [38,47,54], and the termination of the wet phase is dated at c. 5000 years BP [10,54,68], due to the abrupt reduction in the intensity of the African monsoon [19]. This event has led to the present desert conditions [32,45] along different paths, as the varying physiographic features provided local responses to aridification [47]. For much the same reason, the human communities living in the region reacted in different ways to face the constraint of a landscape advancing toward aridity [4,5,10,23,24,46].

Even if the withdrawal of the Atlantic and Indian monsoon systems was regulated by global events due to an orbital change in summer insolation, new researches in the Sahara and in other deserts demonstrate that the steps toward aridity appear to be connected to local hydrological and geomorphological conditions: the response of fresh water systems seems to be instantaneous, while terrestrial environments have gradually adapted to increasing aridity [48]. Furthermore, an example of local variability and a slow rate aridification in the Mid-Holocene desertification has been recently described for the eastern Sahara [45], contrasting with the largely accepted model of a synchronous drought at the termination of the African Humid Period [19].

Although data archives of high resolution proxies give an idea of the intensity of climate change, a reliable interpretation of the response of the terrestrial and fresh water environments (i.e. the landscape) is offered by combining geomorphologic evidence with the archaeological record, into an integrated geoarchaeological approach. This statement is discussed in the present article through the comparison of the geoarchaeological events in the erg Uan Kasa and wadi Tanezzuft (Fig. 1), two adjoining regions lying at the opposite sides of the Tadrart Acacus mountains, whose responses to Mid-Holocene reduction in rainfall show great variability.

2. Geographic and climatic background

The erg Uan Kasa and the wadi Tanezzuft are both located in SW Libya, in the Fezzan region, well inside the hyperarid belt of the Sahara desert, between 26° and 24° latitude N (Fig. 1). The SW Fezzan is part of the broad geosyncline of the Murzuq basin [20,37,42], mainly composed of Palaeozoic to Mesozoic sandstone and shale [30,41,42].

The erg Uan Kasa is a 200 km long, north-south-oriented sand sea, located at the eastern fringe of the Acacus massif. It consists of parallel alignments of linear sand dunes, more than 100 m in height, separated by flat, wide interdune corridors [8,52]. The wadi Tanezzuft is a 150 km long, north-south-oriented fluvial valley, only occasionally still active today [28]. Its catchment's basin is delimited to the west by the Tassili and to the east by the Acacus massif. The origin of the river is located in the Takarkori area (southern Acacus), while it's northern reach has been recently identified in a wide endorheic depression at the western fringe of the edeyen of Ubari [61]. The main course of the wadi is surrounded by lowlands with Inselberg/pediment type relief, playas, and sand seas.

Today, the climate of the SW Fezzan is hyperarid. The mean annual temperature is 30 °C and the mean annual rainfall is between 0 and 20 mm, mostly distributed in spring and summer [28,66]. Occasional rainstorms are recorded also in the winter season [28].

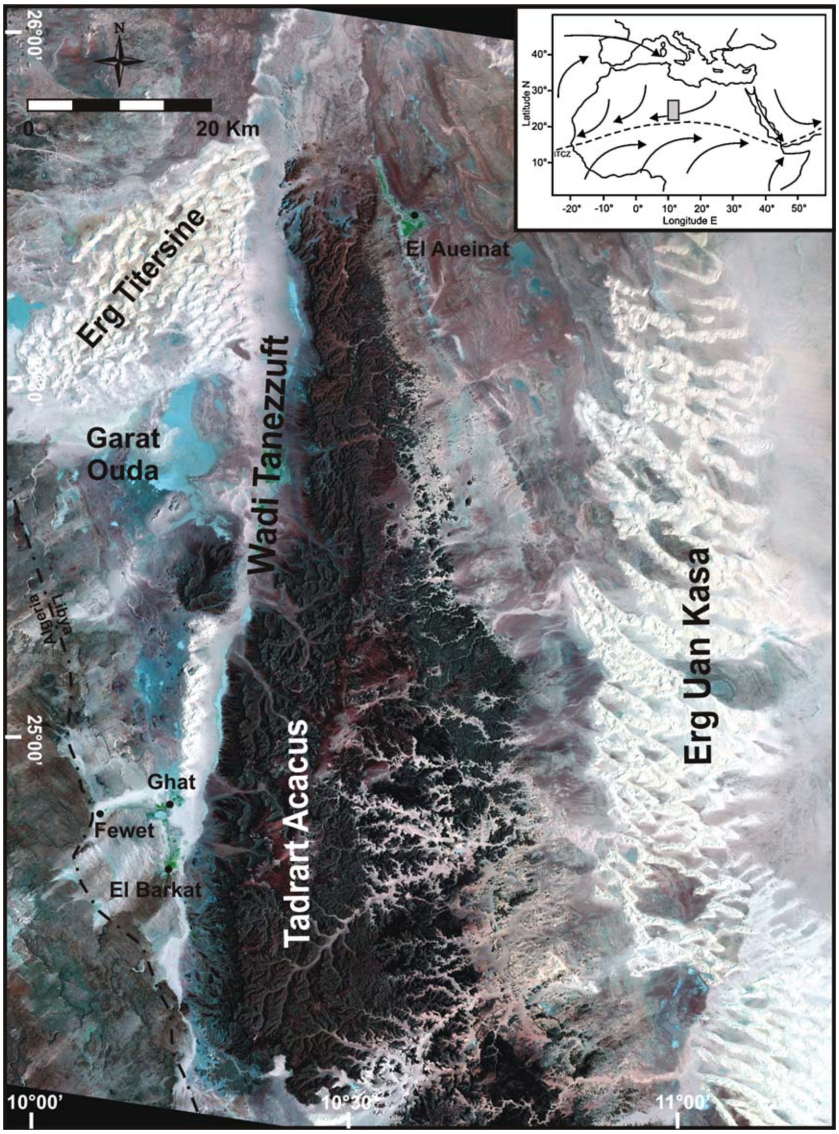

Fig. 1. Landsat 7 satellite imagery of the investigated area, indicating the localities cited in the text. In the upper corner is shown the position of the area in a regional context; the present position of the ITCZ (intertropical convergence zone) and the Northern Hemisphere summer atmospheric circulation pattern are also reported (main winds are indicated as arrows).

Fig. 1. Imagerie satellitaire Landsat 7 de la zone étudiée indiquant les localités citées dans le texte. La position de la zone dans un contexte régional est figurée dans le coin supérieur ; la position présente de la zone de convergence intertropicale (ITCZ) et le schéma de la circulation atmosphérique en été dans l'hémisphère nord sont aussi figurés (les vents principaux sont indiqués par des flèches).

3. Methods

In this article, we present the results of the geoarchaeological survey conducted in the area from 1996 to 2005. The archaeological sites, identified in the field, were mapped by GPS in their geomorphologic context evidenced in satellite images. Key sedimentary sequences and soil profiles both in in-site and off-site positions were described and sampled for age determination and laboratory analyses.

The chronological framework here discussed is based upon a number of conventional and accelerator mass spectrometry (AMS) radiocarbon dates obtained from organic soils and sediments, and charcoal from hearths of archaeological sites [8–11]. The dates were calibrated, with a precision of 2σ, using the INTCAL04 calibration curve [63]. The archaeological sites were classified according to the cultural phases of the Holocene Prehistory in the Sahara as discussed in [13–15,21], and for the Garamantian period reference is given to [51,53].

4. The beginning of the wet Holocene in the area

The most reliable proxy indicating the arrival of the monsoon rainfall in the area studied consists of the calcareous tufa [7] discovered and recently re-dated [68] in the Tadrart Acacus massif, which supplied water to the erg Uan Kasa. Together with the Tassili, the Tadrart Acacus massif belongs to the catchment's basin of the wadi Tanezzuft. The tufa were formed in correspondence with springs whose activity required the over-saturation of the local aquifers. On the basis of U/Th dating [68], the conditions suitable for tufa formation began at c. 9600 years BP, and were mostly interrupted at c. 8200 years BP in coincidence with the well-known cold–dry event of North Atlantic origin [1,43,54,68,69]. Calcareous tufa did not form after that, indicating that precipitation no longer reached the intensity displayed in the very Early Holocene.

The same scenario of higher availability of water is confirmed by the pollen diagrams obtained from the fill of caves and shelters in the Tadrart Acacus mountains [55,56]. The landscape suggested by these data consists of a patchwork of savannah and wooden grassland (during the first part of the Early Holocene, c. 11,000–9200 cal. years BP), with a diversified flora, including plants requiring permanent freshwater sources (*Typha, Potamogeton, Lemna*, *Scirpus*), and thus confirming the occurrence of spring pools, whose constant water supply was sustained by precipitation.

5. The erg Uan Kasa

A thick hydromorphic horizon, consisting of bleached and mottled sand (also defined as etiolated sand [39]) and friable weathered sandstone (saprolite) systematically occurs at the base of the dunes and deep inside the

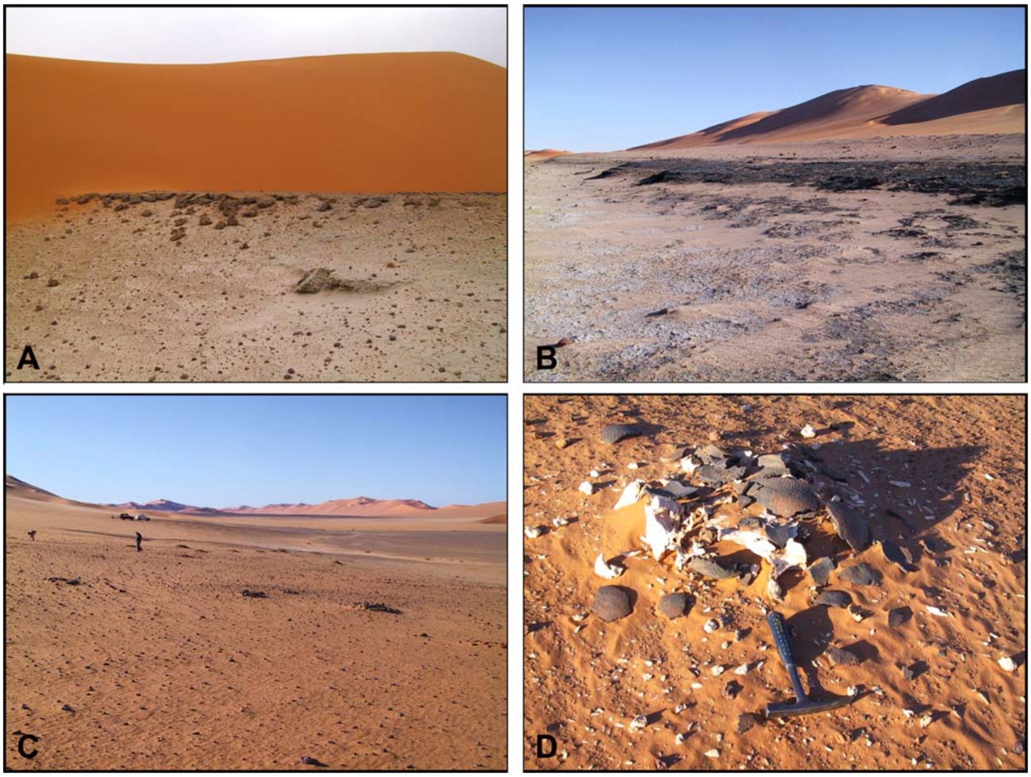

Fig. 2. The erg Uan Kasa. (A) The hydromorphic horizon of bleached sand at the base of the dune. (B) Organic sand deposit at the base of the dune corresponding to the shore of an extinct lake. (C) Configuration of a Pastoral-Neolithic archaeological site. (D) A pit (resulting by differential erosion) containing faunal remains and a complete Middle Pastoral-Neolithic pot.

Fig. 2. Erg Uan Kasa. (A) Horizon hydromorphe de sable blanchi à la base de la dune. (B) Dépôt sableux organique à la base de la dune, correspondant au rivage d'un lac disparu. (C) Configuration d'un site archéologique du Néolithique-pastoral. (D) Fosse (résultant d'une érosion différentielle) contenant des restes animaux et un pot complet du Néolithique-pastoral moyen.

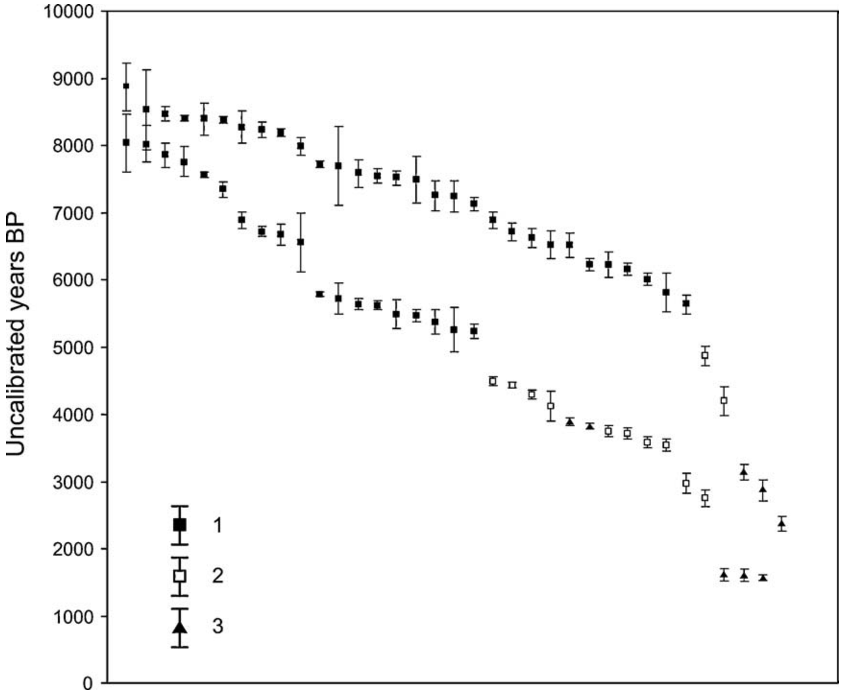

Fig. 3. Uncalibrated conventional and AMS ^{14}C dates for the erg Uan Kasa (above) and the wadi Tanezzuft (below); 1: lake deposits; 2: lacustrine deposits; 3: others.

Fig. 3. Datations ^{14}C conventionnelles non calibrées et AMS pour l'erg Uan Kasa (en haut) et le wadi Tanezzuft (en bas) ; 1 : dépôts lacustres ; 2 : dépôts fluvatiles ; 3 : autres.

bedrock in the whole area covered by the erg (Fig. 2). This phenomenon is the result of hydromorphic conditions generated by the generalized rise of the water table, as a consequence of an enhanced water supply. Furthermore, the dunes acted as immense water reservoirs as the rain was stored inside the intergranular porosity of the sand. The availability of water promoted weathering along the dune slopes, and deep soils were formed.

Downslope, and at the base of the dunes, the outcrop of aquifers gave rise, in suitable geomorphologic conditions, to small and shallow lakes or ponds [8,9]. The deposits therein consist of biochemical calcareous silt, including a rich mollusc fauna composed of few species (*Lymnaea natalensis, Valvata nilotica, Biomphalaria pfeifferi,* and *Afrogyrus oasiensis)* typical of fresh or hypohaline waters [35,36]. The radiocarbon dates obtained (Fig. 3) from peat layers at the base of the sequence, and from the organic silty mud of shore facies (Fig. 2), indicate that the water level of the lakes in the erg was rising at 8870 radiocarbon years BP, at the same time of the beginning of the tufa formation inside the mountain range. The erg Uan Kasa lakes reached their highest stand during the VIII and VII millennia BP [8,10,68], but present knowledge does not perceive evidence in them of the negative fluctuation recorded in the corresponding deposits of the edeyen of Murzuq, coinciding with the 8200 years BP dry event [8,69].

More than 350 archaeological sites (Fig. 4), ranging from the Epipalaeolithic up to the Late Pastoral-Neolithic phase, have been identified, mostly at the base of the dunes, in correspondence with former palaeolake shores, marsh deposits, and palaeosols.

The Epipalaeolithic sites [14] consist of clusters of *débitage*, microlamellar cores, and formal tools such as backed points, lunates, and particularly, peduncolate Ounan points (comparable, in many ways, to the North African and Arabic Epipalaeolithic). No fauna remains are associated with these sites. The occurrence of some specialized tool equipments (e.g. hooks) may suggest fishing activities in proximity of the water bodies.

The Epipalaeolithic sites are not distributed in relation with the shores which are observed along the palaeolake fringes, but are buried inside the organic deposits at the base of the lacustrine sequences, and therefore are related to the beginning of the lacustrine sedimentation of the area, when the lakes were still rising. To confirm this statement, the radiocarbon age for the sediments covering the Epipalaeolithic sites ranges from c. 8700 to 8500 years BP (c. 11,000–9500 cal. years BP), situating them at the very beginning of the wet phase in the area.

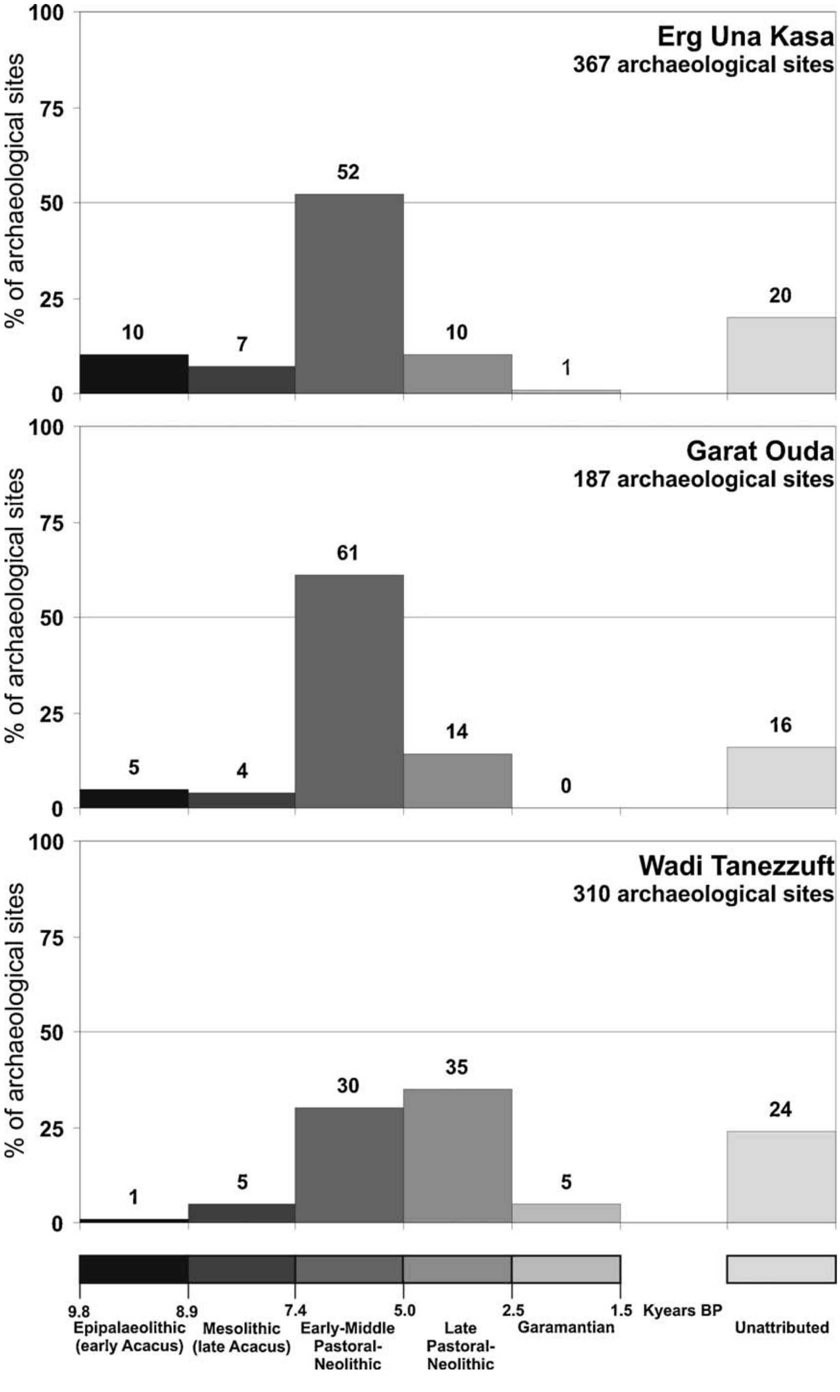

Fig. 4. Chronological distribution of the archaeological sites in the investigated areas (erg Uan Kasa, Garat Ouda playa, and wadi Tanezzuft).

Fig. 4. Distribution chronologique des sites archéologiques dans les zones étudiées (erg Uan Kasa, Garat Ouda playa et wadi Tanezzuft).

The raw materials employed in the lithic industry are largely represented by local lithotypes, such as very fine quartzarenite. Aside from this, the assemblage also includes Jurassic and Cretaceous flint obtained from remote source-areas, suggesting that the hunter-gatherer groups were significantly mobile. Easy accessibility to the natural resources was promoted by a propitious environment [32,33,40,67] reaching across the whole central Sahara, dominated by a savannah landscape.

Mesolithic sites (Fig. 4) are rare in the area of the erg [14,15,23]. They can be distinguished in the field from the Epipalaeolithic sites on the basis of appearance, and of the presence of microlithic equipment and Early Holocene pottery [14,15,21,23], together with large grinding equipment and clusters of fireplaces. These features, for the VIII millennium BP, point to a shift in resource exploitation towards the processing of wild plants (as documented also in caves from the Acacus massif, [21,56,57]), and more stable settlements [23].

The Early and Middle Pastoral-Neolithic sites date back to the VII and VI millennia BP (Fig. 4). Their impressive number indicates the apogee of the Pastoral-Neolithic cattle herders and their perfect adaptation to the wet environment. The sites systematically correspond to the geomorphologic evidence of a high standing water level, and the objects they are composed of (lithics, pottery, bone fragments, stones) are continuously distributed for hundreds of metres (sometimes up to a few kilometres) along the former shores of the interdune lakes, and on the slopes above them (Fig. 2). The spatial configuration of the archaeological features is well-preserved and consists of clusters of several tens to hundreds of fireplaces, entire vessels, grinding stones, and pits containing cattle bones (Fig. 2).

Several human burials were also found within the sites, according to a practice spread among the Pastoral-Neolithic groups of the Saharan region [44,65].

The large size of the sites can be interpreted in terms of high population density, but also of recurrent frequentation of the same places along the lake shores [2,22], which is further supported by the permanence of heavy-duty tools and large vessels, difficult to transport, and ready to be reused again during succeeding visits. The lake sites therefore are to be interpreted as a pole in the transhumance itineraries connecting the erg Uan Kasa lakes to the mountain ranges of the Acacus and the Messak, where the Pastoral-Neolithic sites are located mainly in caves and rock shelters [2,14,21,23]. This strict connection is further demonstrated by the provenience from the Tadrart Acacus of part of the raw materials employed for lithics (quartzarenite) and grinding equipment (quartzarenite and sandstone) in the lakes. Furthermore, the occurrence of grinding equipment obtained from granite and micashists indicates that the transhumant itineraries were extended at least to the western slopes of the Tassili, where these rocks are present [30].

6. The wadi Tanezzuft

During the wet Holocene the wadi Tanezzuft was a large river, fed by several influents from the Tassili and from the upper Acacus (Fig. 5). At its maximum extension, it was about 150 km long and ended in a large lake about 60 km north of the northern fringe of the Tadrart Acacus massif. At this time, the discharge was large enough to carry, all along the bed of the wadi [61], coarse sediments deposited as longitudinal gravel bars in a braided river system, turning downstream to large meanders (Fig. 5). The water supply was significant enough to exceed the carrying capacities of the river bed. From the main stream, several minor courses branched out to the lowlands and basins bordering the course of river [9,18]. The largest of these basins was the Garat Ouda playa, which hosted a lake some 80 km^2 wide [9]. In satellite images (Fig. 6), the architecture of the Middle Holocene delta appears well-preserved. The distributary channels are easily perceived in the field as well, because their sedimentary fill, loam-clayey in texture, was made evident by later selective aeolian erosion [18].

A few Epipalaeolithic and Mesolithic sites have been discovered at the margin of the Early Holocene Tanezzuft river, mostly in the northern part of the valley. These consist of clusters of lithics, possibly associated with fireplaces, and grinding equipment and Sudanese style pottery. A considerable number of Early and Middle Pastoral-Neolithic sites occur along the main wadi course and inside the small ergs surrounding it, displaying features similar to the contemporary sites in the erg Uan Kasa [14,16].

The archaeological record is particularly rich and well-preserved in the area of the Garat Ouda playa (Fig. 4), constituting a specific case of adaptation to a fluvial-lacustrine transitional environment. In the northern part of the area, the Epipalaeolithic sites were located along the former shore of the lake. The sites of the Pastoral-Neolithic period are dominant, consisting of thousands of fireplaces and grinding equipment distributed as a continuous belt over kilometres along the delta channel margins (Fig. 6). The main concentrations of archaeological features originate small mounds, rising about one metre above the topographic surface. We can see these as a postdepositional effect of the wind erosion which lowered the area surrounding the sites, but not the sites themselves, protected by the concentration of stones and artefacts. Several pits, including burnt faunal remains, have also been observed. Faunal remains are not represented only by cattle (as in the erg Uan Kasa), better preserved in the proximal part of the delta upstream, but mainly by fish, crocodile, and hippopotamus. This suggests specific exploitation of the delta environment in the area of Garat Ouda: hunting and

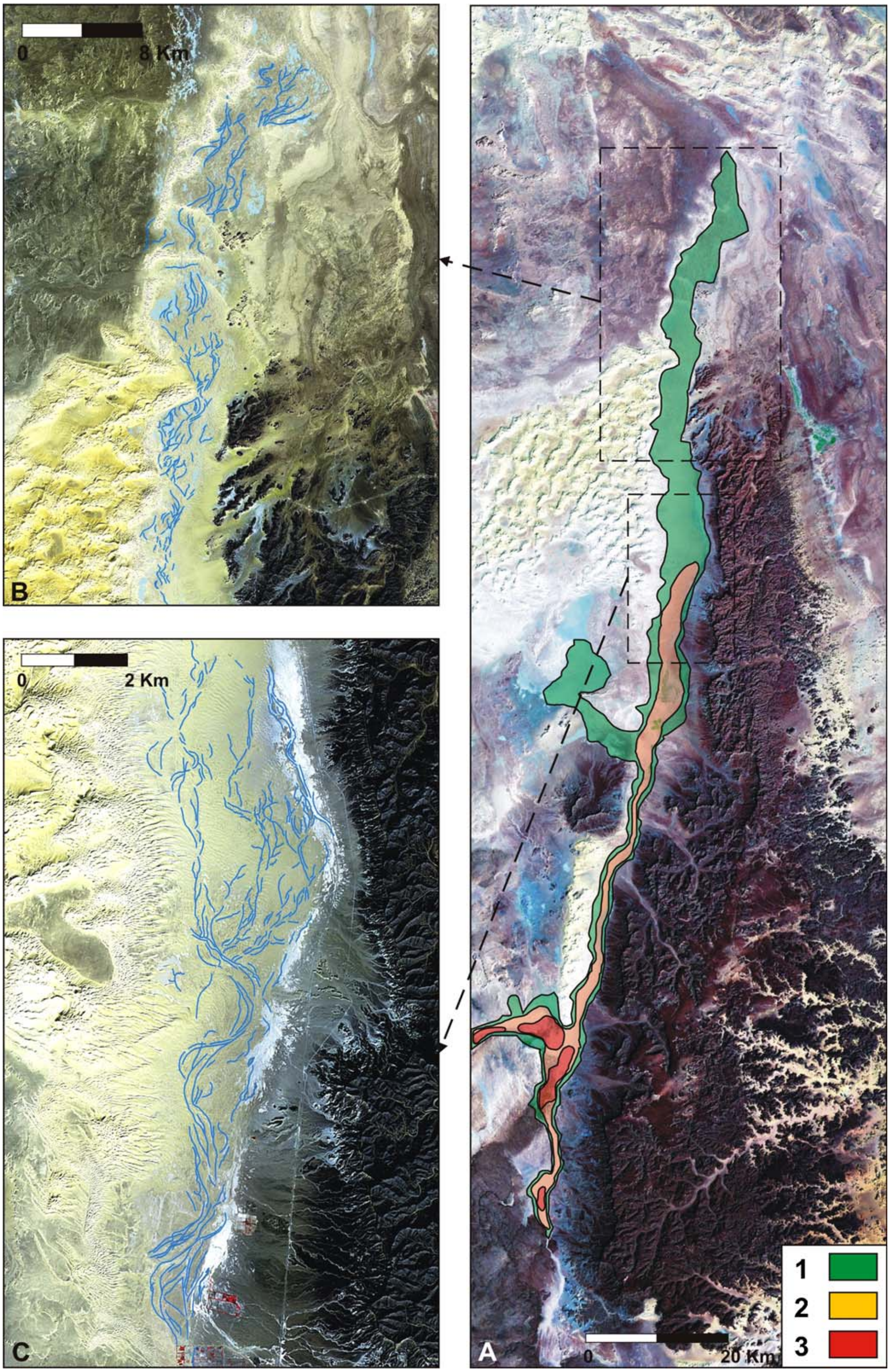

Fig. 5. The wadi Tanezzuft as from Landsat 7 satellite imagery (A). On the left (B, C) some details of the meander bars dating to the Early-Middle Holocene. The progressive contraction of the oasis is indicated in (A); 1: extent of the late VI millennium BP oasis; 2: extent of the IV–III millennium BP oasis; 3: extent of the II millennium BP oasis.

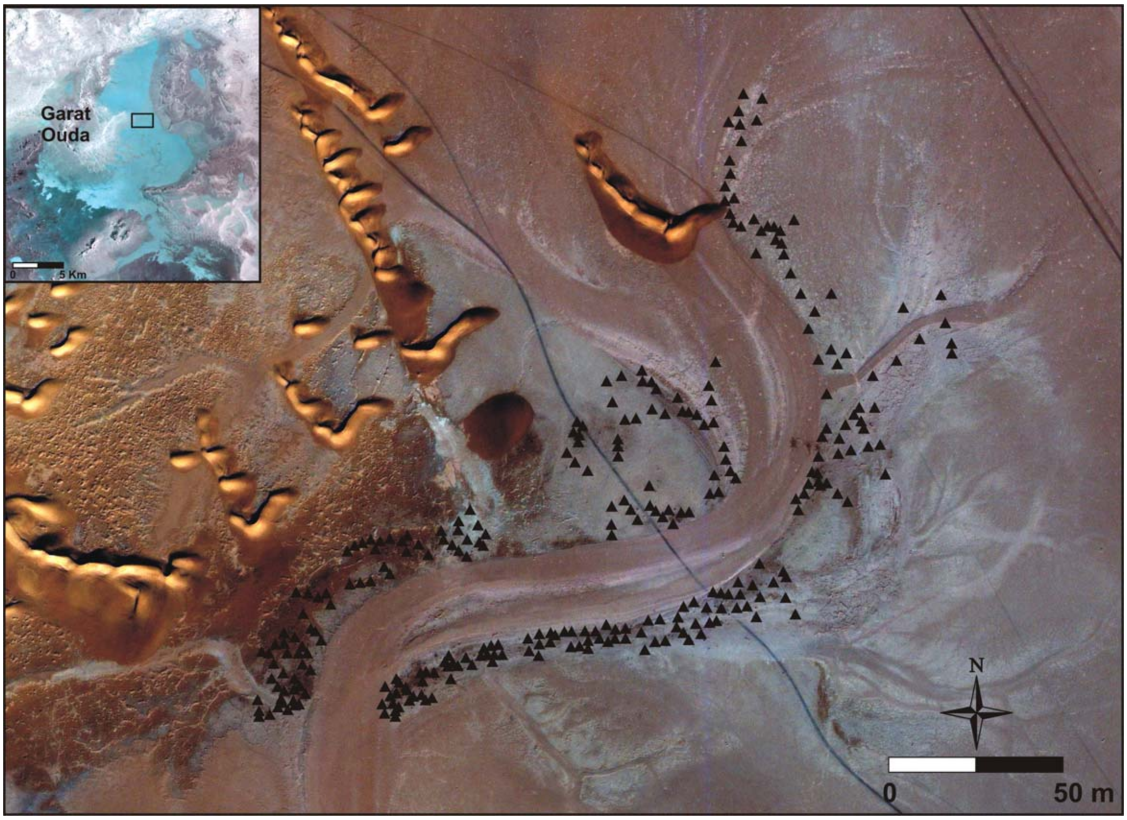

Fig. 6. A detail of the meandering palaeochannels of the Garat Ouda delta (Ikonos satellite imagery): the black triangles represent single Middle Pastoral-Neolithic fireplaces dotting the perimeter of the palaeochannel.

Fig. 6. Détail de paléochenaux méandriformes du delta de Garat Ouda (imagerie satellitaire Ikonos) ; les triangles noirs représentent des foyers du Néolithique-pastoral moyen individuels ponctuant le périmètre du paléochenal.

fishing were integrated with the Pastoral-Neolithic herding activities.

7. Desiccation at 5000 years BP: origin and decline of the oasis

No lacustrine sedimentation is recorded in the erg Uan Kasa and adjoining sand seas (edeyen of Ubari and edeyen of Murzuq) after c. 5500–5200 years BP [6,8,10,68], indicating that shortly after this age, the lakes dried out (Fig. 3). Desiccation of the lakes, together with many other proxies of the region [10,68,69] indicate that this date was a turning point of the Middle Holocene climate, and it may be correlated with the retreat of the monsoon rainfall toward southerly positions. This dry event is well-represented in the dendroclimatic record of the *Cupressus dupreziana* by two strongly negative picks in the tree ring sequence, and it can be more accurately dated at c. 5040–4850 cal. years BP [17].

The interruption of the monsoon precipitation radically changed the environmental conditions of the dune corridors in the erg Uan Kasa. Most of the lacustrine basins were sealed by gypsum crust, due to the prevalence of evapotranspiration over precipitation. In the southern part of the erg, where the corridors correspond to the downstream of the main valleys cutting the Tadrart Acacus massif, the Early to Mid-Holocene lacustrine deposits were buried by silty fluvial sediments (Fig. 7). These are up to several metres thick, as an effect of enhanced slope degradation in the mountain range [35,36]. However, the dominant process

Fig. 5. Le wadi Tanezzuft vu par imagerie satellitaire Landsat 7. (A) Sur la gauche (B, C), quelques détails des bancs de méandre datant de l'Holocène inférieur moyen. La contraction progressive de l'oasis est indiquée en (A) ; 1 : extension de l'oasis à la fin du 6^{e} millénaire BP ; 2 : extension de l'oasis aux 3^{e}–4^{e} millénaires BP ; 3 : extension de l'oasis au 2^{e} millénaire BP.

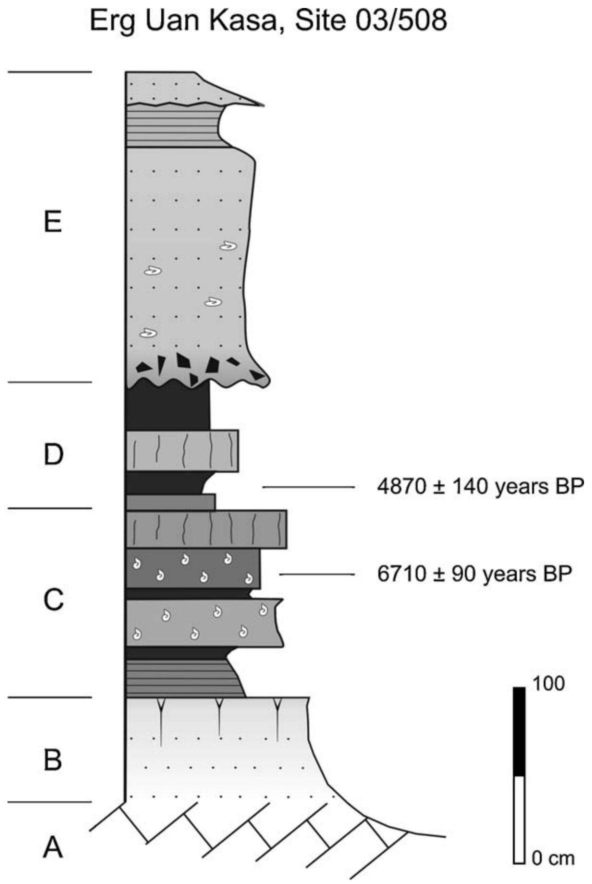

Fig. 7. Schematic stratigraphic sequence from a southern interdune corridor of the erg Uan Kasa (site 03/508); it is representative for the transition form a lacustrine to fluvial sedimentary environment. Uncalibrated radiocarbon dates are reported. (A) Bedrock (sandstone). (B) Hydromorphic horizon. (C) Organic deposit and carbonatic mud containing molluscs (shallow lake facies). (D) Silt intercalated by organic mud (alluvial plain). (E) Silty to sandy deposits containing *Melanoides tubercolata* (channel bars).

Fig. 7. Séquence stratigraphique schématisée à partir d'un corridor méridional interdune de l'erg Uan Kasa (site 03/508) ; elle est représentative de la transition entre un environnement lacustre et fluvial. Les âges radiocarbone non calibrés sont figurés. (A) Roche mère (grès). (B) Horizon hydromorphe. (C) Dépôt organique et boue carbonatée contenant des mollusques (lac peu profond). (D) Boue organique en intercalation dans le silt (plaine alluviale). (E) Dépôts silteux à sableux contenant *Melanoides tubercolata* (facies fluviatile).

soon became wind erosion [10,11,69], which removed most of the deposit and the soil formed during the wet Holocene.

The Late Pastoral-Neolithic occupation that followed desiccation was dramatically reduced (Fig. 4). The sites of this period are quite small in size, consisting of few scattered fireplaces, small concentrations of tethering stones, and scarce archaeological material. Moving away from the margin of the dunes, where the shores of the desiccated lakes were located, they lie upon erosional surfaces close to the centre of the corridors. This indicates, nonetheless, that the erg was never completely abandoned, even in very dry conditions, and was marginally exploited for hunting [29] by crossing desert groups (*sensu* [46]), and later crossed by the caravan itineraries.

The water supply of the Garat Ouda delta-lake system ended between 5200 and 4800 years BP [9,18], as a consequence of the reduction of the discharge of the wadi Tanezzuft and the abrupt interruption of its lateral branch, allowing for the perfect preservation of the geomorphologic features.

During the Middle Holocene, after the surrounding areas had already dried out, the activity of the wadi Tanezzuft persisted for millennia. However, the river became shorter and endorheic, no longer reaching its terminal lake, and its fringe was located at the northern end of the Tadrart Acacus massif (Fig. 5).

As an effect of the reduced discharge, the grain size of the sediment transported also changed, as the gravel load was replaced by sand and mud, and an alluvial plain deposited along the main branches of the river. These deposits have been radiocarbon dated from c. 4200 to 2900 years BP [9]. Sandy-loamy sediments are interlayered with thin soils displaying hydromorphic features, and crossed by root casts. Both are evidence of larger ground water availability and plant cover on the alluvial plain.

In this period, the valley of wadi Tanezzuft became an oasis (Fig. 5), as did many other places in the deserts in which local geological conditions permitted persistence of water availability [9,11]. The birth of the oasis is to be regarded as a geomorphologic event, typical of the Late Mid-Holocene of the Sahara and Arabic deserts [11]. It had a major consequence on cultural dynamics as the oases attracted, and concentrated, the Late Pastoral-Neolithic communities expelled from the surrounding territories by drought. This led to adaptive strategies to aridity that combined local land resource exploitation with long distance trade through the caravan routes [49,50].

It is not surprising, therefore, that the wadi Tanezzuft was densely inhabited also during the Late Pastoral-Neolithic period, when occupation in surrounding areas was considerably reduced (Fig. 4). Configuration and distribution patterns of the sites dating to this period may suggest an interest in soil exploitation in a context of rising sedentarism. Individual sites are basically composed of fireplaces and storage pits, but they include a large amount of grinding equipment, together

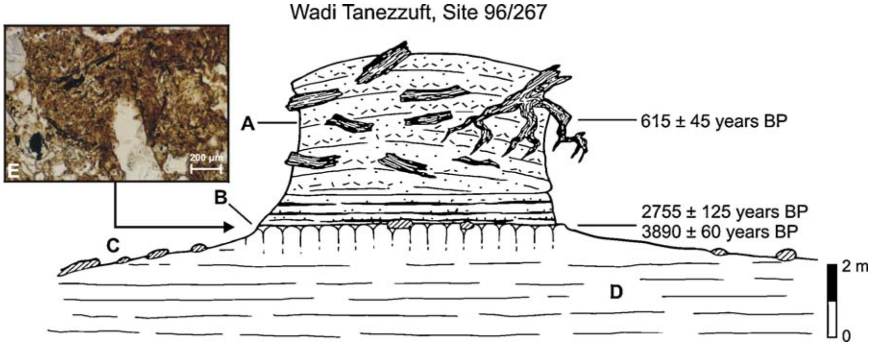

Fig. 8. Stratigraphy of a phytogenic dune (A) that covers a soil (B) developed at the top of the Middle Holocene alluvium (D). A Late Pastoral-Neolithic site (C) is entombed under the soil (site 96/267); uncalibrated radiocarbon dates are also indicated (modified, from [9]). In thin section (plane polarized light) the soil (E) shows strong bioturbation, fragmentation of the structure, coarse coatings, small charcoal, and phytoliths.

Fig. 8. Stratigraphie d'une dune phytogénique (A) qui recouvre un sol (B) développé au sommet des alluvions de l'Holocène moyen (D). Un site du Néolithique-pastoral tardif (C) est enfoui sous le sol (site 96/627) ; les âges radiocarbone non calibrés sont aussi indiqués (modifié selon Cremaschi [9]). En lame mince (lumière polarisée plane), le sol (E) montre une bioturbation intense, une fragmentation de la structure, des revêtements grossiers, une petite quantité de charbon de bois et des phytolithes.

with lithic hoes and gouges, which may be associated to land management and crop processing.

Micromorphology of a buried soil connected to a Late Pastoral-Neolithic site, in the alluvial plain of the Tanezzuft, shows strong bioturbation, fragmentation of structure and occurrence of coarse coatings, associated with charcoal and phytolithes (Fig. 8). These features do not prove that the horizon was ploughed, but they are indicative of a surface subjected to disruption and burning of the vegetal cover and, in any case, of some kind of soil management.

Several sites have been found buried inside the alluvial deposits, indicating that the areas selected for dwelling were located close to the water resource, despite the possibility of flooding. The funerary structures of this age (tumuli and monuments) were built at the fringe of the oasis [25], but outside the fertile land, which therefore deserved special interest.

Clusters of tethering stones have been found in correspondence with the limits of the oasis in the late V millennium BP, reconstructed on the basis of the geological evidence [9]. Even if a use in management of livestock cannot be excluded, on the basis of rock art evidence tethering stones appear to be often connected to hunting practice, and to be used as a component of traps for wild animals [9,26,60]. The main concentrations of tethering stones, occurring at the fringe of the alluvial plain, at the interface between the oasis and the desert, indicate the most probable access of the wild stocks to the water resources persistent in the oasis.

According to the distribution of the radiocarbon dates (Fig. 3), the boundaries of the Tanezzuft oasis were stable in the IV and III millennia BP [11], but during the II millennium BP, they contracted significantly (Fig. 5). At this time, the Tanezzuft oasis became the southern border of the Garamantian kingdom [49,50], and acted as a node on the caravan routes which connected the central Sahara to sub-Saharan Africa [49]. The state of the climate at the beginning of the II millennium BP, and its consequences on the Garamantian civilisation, are still under discussion. However, the Garamantes, during their whole history, tried to react against increasing aridity, by, for instance, implementing water management inside the oasis for intensive irrigated agriculture [51], as evident in the Germa oasis (e.g. the Old Garama [53]).

In the Tanezzuft valley, the Garamantian settlement mainly consisted of fortified villages and compounds [51], located as a protection of the fringes of the oasis [3,49,51], but poor information exists about the actual land use, even if archaeobotanical data confirm intensive agriculture [58]. Several minor sites of this age, composed of clusters of fireplaces and scatters of pottery, have been found buried inside the alluvial deposits [12]. They suggest that the oasis, at the time, was larger than the present one (Fig. 5), probably sustained by the wet conditions occurring between 2800 and 2200 years BP, as indicated in the *Cupressus dupreziana* record [17], and by the rise of the water table in the erg Uan Kasa [11]. In that period, wadi Tanezzuft was still active, and was the main source of water for the cultivated land.

It is impossible to say if climate change had a role in the collapse of the Garamantian empire, most probably determined mainly by historical processes [51]. And yet, on a local scale, the Garamantian occupation ended at around 1600 years BP [11,12], coinciding with the onset of very dry conditions. This is indicated by the progradation of sand dunes beyond the boundaries of the oasis, and by a sharp decrease of the tree-ring size in the dendroclimatic curve of *Cupressus dupreziana* at 1573 years BP [17]. These conditions have persisted until today, when the oasis has expanded again, thanks to deep wells exploiting the fossil hydrological reservoirs.

8. Conclusion

Comparing the geoarchaeological development throughout the Holocene of the erg Uan Kasa and the wadi Tanezzuft, water availability appears to be the obvious factor driving the evolution of the settlement patterns and cultural dynamic of the population living in the region. In the framework of a progressive drop in water resources starting from the Early Holocene, the turning point of the onset of desert conditions dates back at c. 5000 years BP, coinciding with the withdrawal to the south of the summer monsoon (Fig. 3). Since this event, the landscape development contrasted with the previous period, as most of the area dried out, and the water resources, while in progressive reduction, were concentrated in the oases. According to the drop and the change in location of water resources, the Pastoral-Neolithic communities which settled all the landscape units of the area were forced into the oases, giving rise to different subsistence strategies evolving towards complex social systems.

All notwithstanding, these units were never abandoned and were subjected to human exploitation and marginal pastoralism, which may have enhanced the soil erosion and consequently, the spread of desertification. Furthermore, the oases were not a stable geomorphologic entity, and were subject to reduction in size according to the drop in water resources.

Yet again, the steps toward aridity and a reduction of the oases appear to be strictly connected to local conditions. In this sense, the present article should be intended as a confirmation of recent hypotheses regarding a differentiated Saharan Mid-Holocene aridification and a slow rate of desertification in specific areas [45,48]. We should be careful to avoid any regional generalization, while encouraging much more detailed studies in selected areas.

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