Chapter 5
Human Communities in a Drying Landscape: Holocene Climate Change and Cultural Response in the Central Sahara

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5.1 Introduction

Dagge and Hamad (2008) report that Syria is in the midst of an environmental emergency occasioned by a drought that has affected the region since 2006. Massive crop failure with harvests down by a half has produced conditions where famine and even societal collapse might be expected. Fortunately, the Syrian government has been able to ameliorate the problem with imports of food and potable water. In the distant past disasters could not have been avoided in this way, and famine would have resulted in the disaggregation of the community or at least would have forced a drastic change in survival strategies. Episodes similar to those now affecting Syria have caused societal crises throughout prehistory and history, with climate change and human abuse of landscape and natural resources playing crucial roles (Diamond 2005). Of course, local differences need to be understood and treasured. The reaction of the physical environment (the landscape) to stress is not uniform across the globe, regardless of whether we consider climate change, the impact of grazing, or any other human activity.

The present day South Mediterranean arid environments (the subtropical arid belt) offer the opportunity to investigate the human–landscape relationships for the last 10 millennia. During the Holocene, the region experienced a major change in landscape: the shift from desert to savannah and back again. The environmental effects of this cycle are comparable to the ecological change which affected the mid-latitudes at the time of the waning of the Pleistocene glaciers. For instance, in the Saharan region environmental conditions favorable for animal and plant life promoted a high human concentration since the beginning of the Holocene. Consequently, the later aridification affected a densely populated landscape.

The case study analyzed in this chapter deals with the effect of drought on the landscape and human communities in the central Sahara. We report and discuss the environmental changes that occurred in SW Fezzan (Libya; Fig. 5.1), by considering three different physiographic units: the Tadrart Acacus massif and the two adjoining regions lying at the opposite sides of the mountain range, the Erg Uan Kasa, and the fluvial valley of the Wadi Tanezzuft (Fig. 5.2). Furthermore, we will analyze how in the same geographic and hydrologic ecosystems, different geomorphologic units react to climate change. In addition and subsequent to environmental modifications, the human dwellers gave rise to different and complex social dynamics and adaptive strategies.

5.2 Paleoclimate of Central Sahara

From the early to the middle Holocene, the SW Fezzan area enjoyed, as did the entire Saharan region, a period of high rainfall (Cremaschi 1998, 2002; deMenocal et al. 2000; Gasse 2000; Hoelzmann et al. 2004; Mayewski et al. 2004; Wendorf et al. 2007). The latter was driven by the expansion of the summer monsoon from the Gulf of Guinea and the migration of the ITCZ (Intertropical Convergence Zone) to northern positions

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See Plates 2, 3, 4 in the Color Plate Section; also available at: extras.springer.com

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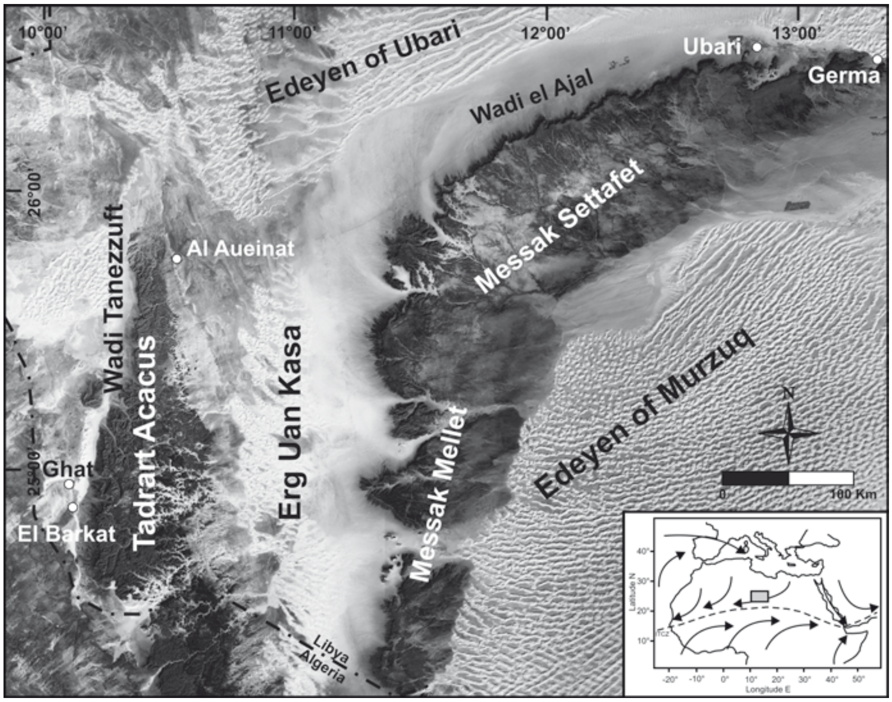

Fig. 5.1 Landsat 7 satellite imagery of the SW Fezzan, indicating the localities mentioned in the text. In the insert the position of the area in a regional context is shown; the present position of the ITCZ (Intertropical Convergence Zone) and the Northern Hemisphere summer atmospheric circulation pattern are also reported (main winds are indicated as *arrows*)

(deMenocal et al. 2000; Gasse 2000). The main effect of this climate change was the recharge of the local aquifers (Cremaschi 1998; Zerboni 2006) and the activation of springs, rivers, and lakes, and the growth of luxuriant vegetation (Mercuri 2008), determining conditions suitable for animal life. Subsequently, the entire area was settled by Epipaleolithic and Mesolithic groups (in this region defined as Early and Late Acacus respectively) and later by Pastoral-Neolithic communities (Cremaschi and di Lernia 1998; di Lernia 2002).

The so-called African Humid Period was interrupted by several transitory dry spells (Mayewski et al. 2004; Kutzback and Liu 2007; Cremaschi et al. 2010) and the termination of the wet phase is dated at ca. 5000 year BP (Cremaschi 2002; Mayewski et al. 2004; Zerboni 2006), due to the abrupt reduction in the intensity of the African monsoon (deMenocal et al. 2000). This event led to the present desert conditions following different modalities as the varying physiographic features responded differently to aridification (Gasse 2000; Kröpelin et al. 2008). 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 (di Lernia 2002; Brooks et al. 2005; Brooks 2006; Kuper and Kröpelin 2006).

The present 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, which is mostly distributed in spring and summer (Fantoli 1937; Walther and Lieth 1960). Occasional rainstorms are recorded also in the winter season (Fantoli 1937).

5.3 Geological and Geomorphologic Background

The Tadrart Acacus and the adjoining erg Uan Kasa and Wadi Tanezzuft are located in SW Libya (Fig. 5.1), in the Fezzan region, well inside the hyperarid belt of the Sahara desert, between 26° and 24° latitude N. Geologically, this region belongs to the western fringe of the wide geosyncline of the Murzuq Basin (Goudarzi 1970; Kalefa El-Gahali 2005), whose base, mainly composed of Paleozoic sandstone and marls, lies upon the intrusive formation of the Tassili massif, located in Algeria. The Paleozoic formations are covered by the Mesozoic sandstone and shale of the Messak Settafet ridge and Murzuq Basin (Kalefa El-Gahali 2005). The main geologic structural pattern consists of a monocline characterized by an E–NE tilted cuesta in

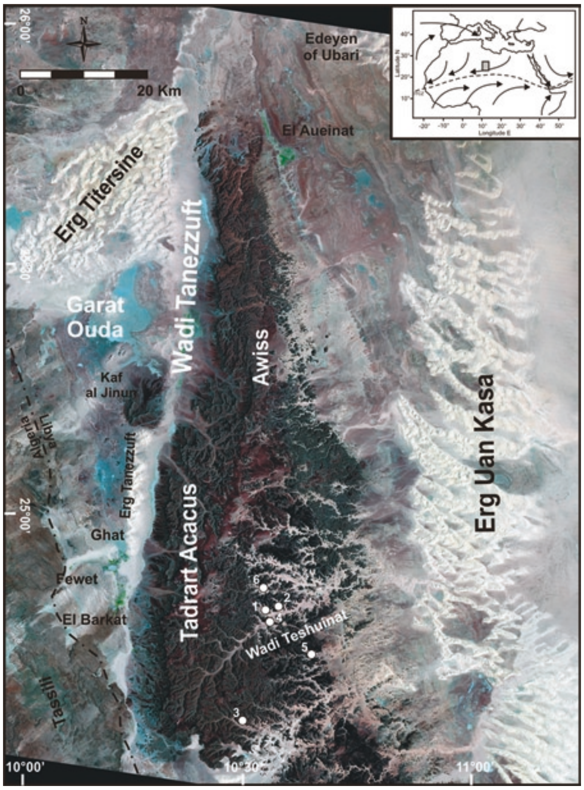

Fig. 5.2 Landsat 7 satellite imagery of the investigated area, indicating the localities mentioned in the text; *dots* represent the main archaeological sites in the Tadrart Acacus area: *1* Uan Afuda; *2* Uan Tabu; *3* Wadi Afar; *4* Uan Muhuggiag; *5* Uan Telocat; *6* Wadi Sennadar

the Tassili and Tadrart Acacus areas (Goudarzi 1970; Cremaschi 1998), and flat landscape in the Erg Uan Kasa. The Wadi Tanezzuft valley is oriented according the direction of the rock strata and is bounded by the Tassili mountain to the west and the cliff of the Acacus massif to the east. The wadi is underlain by the almost impermeable Tanezzuft Formation composed of shales and thin-bedded sandstones. On the western side of the valley, along the geological contact between the highly permeable Tassili sandstone and the Tanezzuft Formation suitable conditions exist for development of numerous springs that made this area rich in water and palm groves (Desio 1937).

The Tadrart Acacus massif covers an area of 4800 km^2 with a maximum elevation of 1100 m asl in the western part and is composed of Paleozoic sedimentary rocks (Goudarzi 1970; Kalefa El-Gahali 2005). It is dissected by a fossil drainage network whose NE–SW, E–W, and N–S trending pattern is controlled by the tectonic structure (Galeĉiĉ 1984; Cremaschi 1998). A scarp delimits the massif towards the west, whereas to the east it grades through a pediment to the dune-field of the Erg Uan Kasa. The mountains consist of lower-middle Silurian shales (the Tanezzuft Formation), outcropping at the western fringe along the Tanezzuft valley, apparently conformably overlying upper Silurian and lower Devonian sandstones (Acacus and Tadrart formations). These formations display different hydrological behaviour: the Tanezzuft Fm. has a very low hydraulic conductivity and transmissivity and acts as an aquiclude, whereas the Acacus and Tadrart formations are highly permeable also being highly fractured. Numerous fossil springs identifiable by the presence of calcareous tufa had developed in the past along the contact between these formations. At present few springs are still active in the inner part of the massif, feeding small pools locally called 'gheltas'.

The Erg Uan Kasa is a 200 km long, 20–35 km wide, N–S oriented sand sea; it is located between the eastern fringe of the Tadrart Acacus massif and the western escarpment of the Messak Settafet plateau. It consists of parallel, NW–SE trending alignments of complex linear sand dunes, more than 100 m in height, and separated by flat, wide interdune corridors (Cremaschi 1998). Its substrate consists of Devonian and Carboniferous shales (Wadi Ubarracat Fm.) and Carboniferous-Permian thin bedded limestone (Wadi Tesalatin Fm.) that deeps about 10° toward the northeast (Kalefa El-Gahali 2005).

The Wadi Tanezzuft is a 200 km long, N–S oriented valley with an ephemeral stream (Fantoli 1937). The catchment basin is delimited to the west by the Tassili and to the east by the Tadrart Acacus massifs. From a geomorphologic point of view, the Wadi Tanezzuft flows along the geological homocline constituted by the Tassili sandstones to the west, the Acacus sandstone to the east, and the Tanezzuft shale in the center. The shape of the valley is asymmetrical being steeper to the east and for that reason the widest part of the catchment basin lies in the Tassili region. The source of the river is located in the Takarkori area (southern Tadrart Acacus), and its northern reach has been recently identified in a wide endorheic depression at the western fringe of the Edeyen of Ubari (Perego et al. 2007). The main course of the wadi is surrounded by lowlands with inselberg/pediment type relief, playas, and sand seas.

The Tadrart Acacus massif, the Erg Uan Kasa, and the Wadi Tanezzuft are different neighboring physiographic units interconnected by the fact that the former constitutes the hydrographical catchment of the latter.

5.4 The Wet Holocene: Landscapes and Strategies

The onset of wet conditions at the beginning of the Holocene led to the systematic occupation of the central Sahara, with variations of human settlement patterns and adaptive strategies depending on the characteristics of each region. During subsequent millennia the strategies were modified, with climate as one of the driving factors.

5.4.1 Inside the Mountain Range of the Tadrart Acacus

5.4.1.1 Configuration and Paleoclimate of the Tadrart Acacus at the Beginning of the Holocene

The morphology of the Tadrart Acacus massif is rather similar to that described for the Navajo Sandstone in the Arizona and Utah deserts: the scarp of the valley shows slick-rock slopes and slab walls. The valleys and canyons dissecting the mountains are the relicts of a landscape that has been shaped mostly under a Tertiary equatorial climate (Busche and Erbe 1987). The present morphology of the mountain is the result of several processes the most important having been fluvial and pseudo-karst actions on siliceous rocks (Busche and Hagedorn 1980).

The original width of the valleys has been enlarged by backwasting of scarps and by progressive undersapping processes (Busche and Hagedorn 1980; Busche and Erbe 1987). Typical features developed such as bluffs, rock arches, and stacks. Wide and deep rockshelters were also formed in massive sandstone units by undersapping along bedding planes at the contact between the sandstones beds and the shales; alcove-shaped shelters occur at the head of the wadis. Today the formation of the rockshelters is inactive. In fact, the parts which can be reached by rain water or surface runoff display black desert varnish, but the accumulation of unvarnished blocks in front of them indicates that some roof collapses have recently occurred. Furthermore, the retreating of the valley slopes exposes relict tunnels of various caves that developed during the Tertiary. The caves were an effect of the silica karst processes acting at that time in response to the equatorial climate existing in the area. Therefore the walls flanking the wadis and the steep slopes of the canyon are pinpointed by a variety of rockshelters and caves that were systematically occupied by the communities living in the Tadrart Acacus since the Late Pleistocene. Moreover, the caves preserved the most reliable anthropogenic characteristics and natural proxies as archives to reconstruct the environmental changes of the region.

The most reliable proxy indicating the arrival of the monsoon pattern of rainfall in the Tadrart Acacus during the Holocene consists of calcareous tufa discovered, and recently re-dated, near former springs and pseudo-karst cavities (Carrara et al. 1998; Zerboni 2006; Cremaschi et al. 2010). Generally speaking, the formation of calcareous tufa requires a continuous soil cover, high metabolic soil activity induced by plants, and high, constant water supply; furthermore, in the present case, a saturation of the Tadrart Acacus aquifer up to the upper reaches of the mountain system would be required, which could only be sustained by high rainfall. U/Th dating indicates that conditions suitable for tufa formation began at ca. 9600 year BP and were mostly interrupted at ca. 8200 year BP (Cremaschi et al. 2010), coinciding with the well known, cold-dry event of North Atlantic origin (Fig. 5.3; Alley et al. 1997). Tufa did not form later, indicating that during

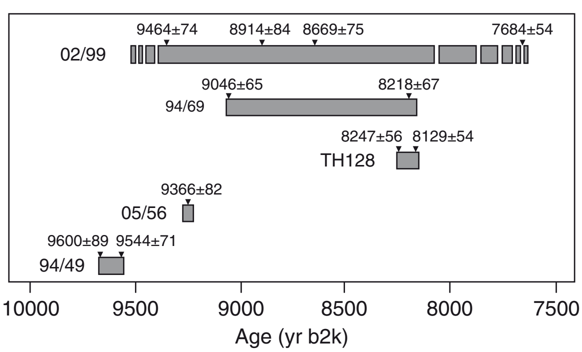

Fig. 5.3 U-series dating indicates that spring tufa sedimentation in the Tadrart Acacus took place between ca. 9600 and 8200 year BP, as consequence of the northward shift of the SW African Monsoon (*Bars* indicate the duration of the tufa deposition in each locality; obtained dates are also reported). (After Cremaschi et al. 2010)

the middle Holocene the water supply and the intensity of the monsoons did not reach again the intensity they had during the very early Holocene.

5.4.1.2 Living in Caves and Rockshelters

The most important stratigraphic sequences recently explored in the caves from the Tadrart Acacus massif (Cremaschi and di Lernia 1998) permit the delineation of the past environmental conditions of the area, their modifications, and the consequences on human communities. The evidence derives from the analysis of the natural and anthropogenic deposits of the Uan Afuda Cave (di Lernia 1999a), and the rockshelters of Uan Tabu (Garcea 2001), Uan Muhuggiag (Pasa and Pasa Durante 1962; Cremaschi and di Lernia 1998), Uan Telocat, Wadi Sennadar (Cremaschi and di Lernia 1998). The importance of these sites both for the archaeology of the central Sahara and for the environmental history of the Holocene has been long known, since pioneering multidisciplinary researches were introduced in the late 1950s (Pasa and Pasa Durante 1962), and a geoarchaeological approach was established at the beginning of the 1990s (Cremaschi and di Lernia 1998). Many radiocarbon dates are available (Fig. 5.4).

The basal parts of the most complete stratigraphic sequences show evidence for a dry Upper Pleistocene phase: at that time the so-called Ogolian desert was at its apogee (Rognon 1989). Reddish aeolian sand has been described at the base of the sections excavated in the Uan Afuda cave (Fig. 5.5) and in the Uan Tabu rockshelter. These units are correlated with the remains of fossil dunes deposited in the area, and have been used as evidence of a general desert expansion during the Late Pleistocene. The discovery at the base of the rubified dune in the Uan Afuda cave of Middle Paleolithic artefacts attributed to the Aterian cultural phase (di Lernia 1999a), and the TL and OSL dating of sand (90,000–69,000 year BP; Martini et al. 1998) allow the correlation of the last Pleistocene expansion of the desert with the MIS 4 isotopic stage.

The onset of wet conditions at the beginning of the Holocene is marked in the Uan Afuda sequence by the weathering of the dune (Fig. 5.5) through rubification and clay translocation; both processes require high water availability and seasonality in precipitation. The organic unit dated at ca. 9800 year BP that overlaps the weathered dune represents a limit *ante quem* for the development of pedogenesis (Cremaschi 1998; Cremaschi and Trombino 1999). This date accords with the recharge of the water system as indicated by the deposition of calcareous tufa.

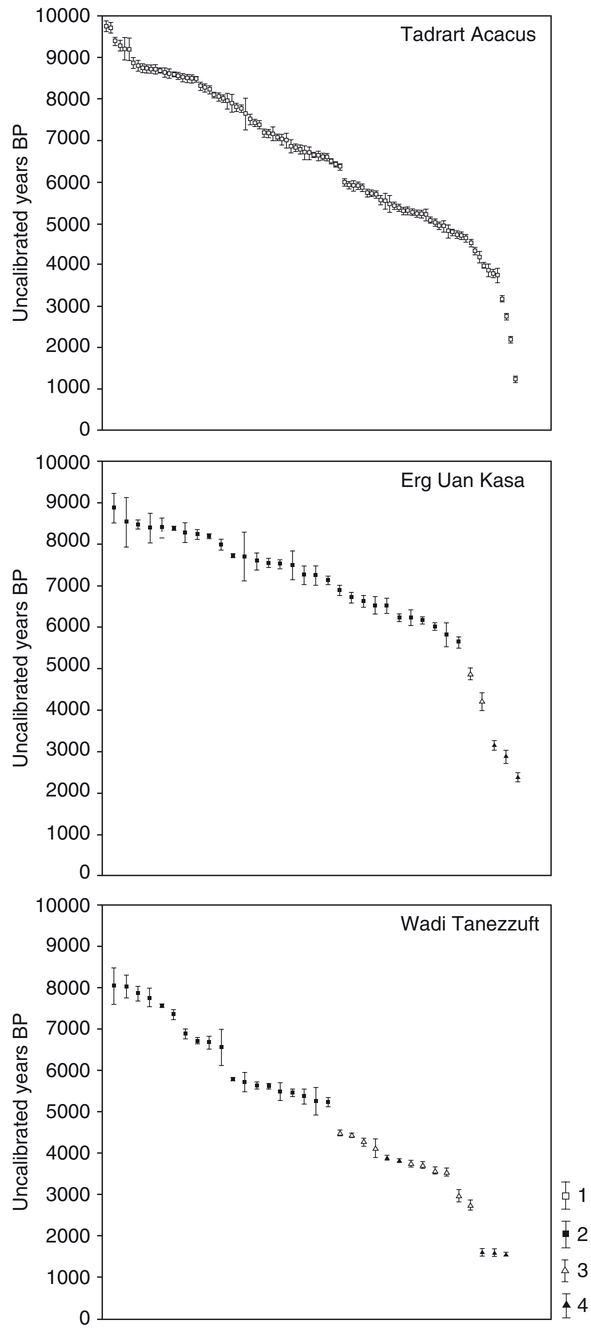

Fig. 5.4 Uncalibrated conventional and AMS ^{14}C dates for the Tadrart Acacus, Erg Uan Kasa, and Wadi Tanezzuft. (*1* anthropogenic deposit; *2* lake deposits; *3* fluvial deposits; *4* other: sebkha deposits, organic sediments, sub-fossil wood)

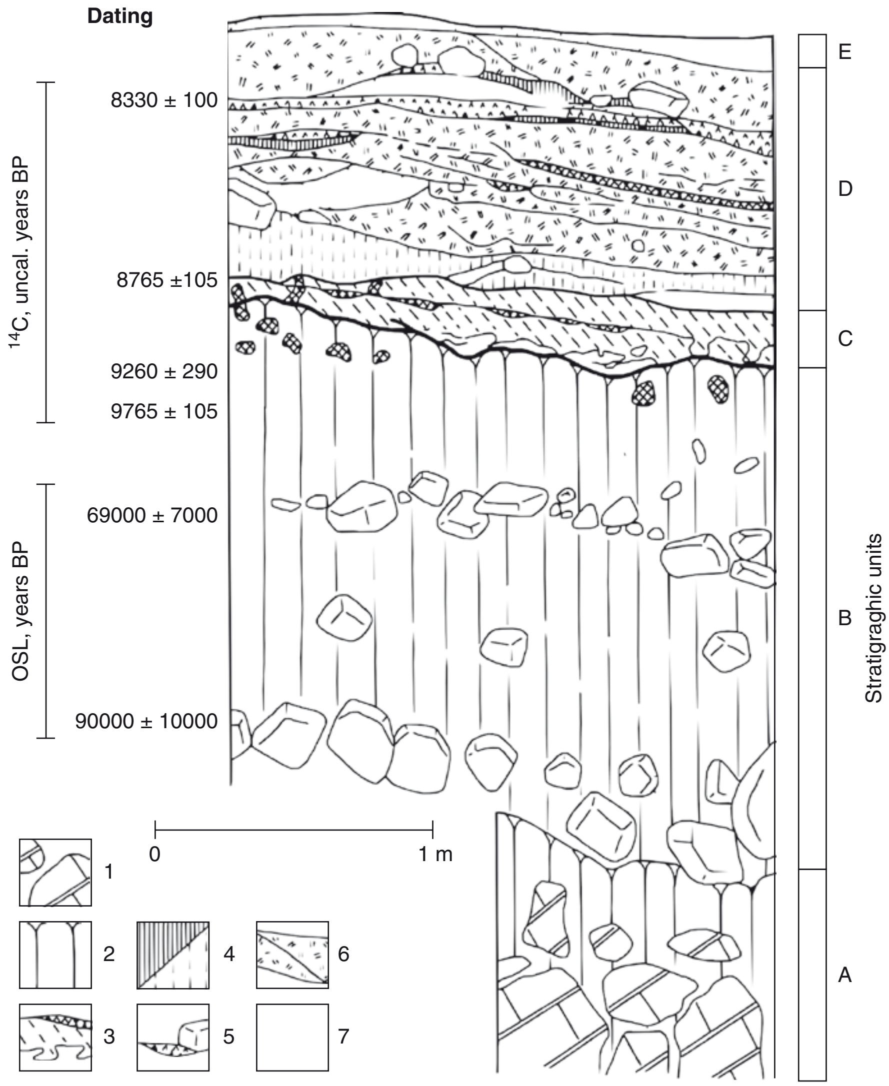

Fig. 5.5 The stratigraphic sequence of the Uan Afuda Cave (After Cremaschi and di Lernia 1998; di Lernia 1999a). (Units: *A* paleosol; *B* Pleistocene aeolian sand, weathered at the top; *C* colluvial sand; *D* organic matter, hearths, and loose sand; *E* modern aeolian sand. Key: *1* collapsed blocks; *2* aeolian sand; *3* colluvial sand and gypsum concretions; *4* loose sand with charcoal, humified organics; *5* hearth with stones and ash lenses; *6* undecomposed vegetal remains; *7* loose sand)

The beginning of a human presence in the study area dating to the Holocene is marked by anthropogenic sedimentation above the rubified dune. The deposits in question have survived wind erosion and can be regarded as lithostratigraphic units typical of the Holocene. Deposits consist of plant fragments, coprolites, finely subdivided organic matter in different stages of humification, ash, charcoal, chemical precipitations, and aeolian sand (Cremaschi 1998). Artificial accumulation of fodder, mainly grass and vegetal fragments, and its transformation through trampling, fire, and addition of organic material related to the penning practice at the site and to human dwelling, are the main processes responsible for the sedimentation inside the rockshelters.

The Holocene basal layers of the deposits in Uan Afuda Cave are of colluvial origin (gray brown laminated sand, including gypsum nodules). Toward their top the organics are progressively better preserved (massive dark brown organic sand, including lenses of preserved plant remains with gypsum concretions), indicating increasing aridity. An interruption in sedimentation is recorded in caves by an erosional surface dated between ca. 8000 and 7500 year BP, thanks to a humified dung layer. The pollen diagrams obtained from the fill of rockshelters (Mercuri 2008) suggest the same scenario of higher water availability. Reconstruction of the landscape between 9800 and 8000 year BP from these data suggests a patchwork of savannah and wooded grassland. The diversified flora indicated includes plants requiring permanent freshwater sources (*Typha, Potamogeton, Lemna, Scirpus*), thus confirming the occurrence of spring pools sustained by constant water supply by precipitation.

Evidence of an Epipaleolithic human presence in the mountain range is not as strong as in the lowlands surrounding the Tadrart Acacus (see following sections and Fig. 5.6). It is dated to the 10th millennium BP

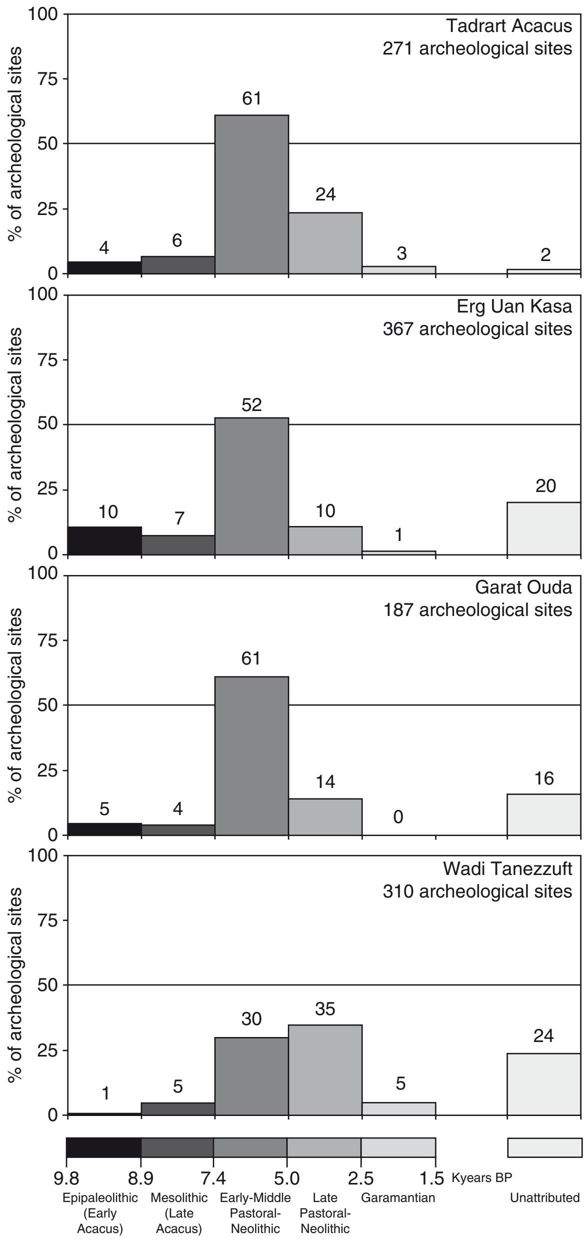

Fig. 5.6 Chronological distribution of the archaeological sites in the investigated areas (Tadrart Acacus, Erg Uan Kasa, Garat Ouda playa, and Wadi Tanezzuft)

(Cremaschi and di Lernia 1998). Stone structures, shallow hearths, lithics (including backed points), and less commonly grinding implements are found at the base of the sequence of Uan Afuda (di Lernia 1999c). No seeds of wild cereals were found in the layers belonging to this phase. The few faunal remains are mostly of *Ammotragus lervia* (the Barbary sheep, a wild capriovid) indicating selective hunting. Even if rare and poor in findings, Epipaleolithic sites inside the massif may be interpreted as base camps for nomadic hunter groups.

In the Uan Afuda and Uan Tabu sites the layers consisting of poorly decomposed organic matter enclose archaeological materials dating back to the Mesolithic phase. This period is marked by the introduction of pottery, displaying dotted wavy line and packed zigzag decorations; at Uan Afuda and Uan Tabu pottery production is documented since the first half of the 9th millennium BP (Cremaschi and di Lernia 1998; di Lernia 1999c; Garcea 2001). Mesolithic sites are also rich in grinding equipment and lithics, including backed tools and geometrics (lunates and triangles). The main difference from the previous phase is seen in a change in economic strategies from an economy of specialized hunting of *Ammotragus* to hunting diversified to include small and large mammals, fish, and birds (Cremaschi and di Lernia 1998). The most important event however, was the introduction of the exploitation of wild cereals (di Lernia 1999; Cremaschi and di Lernia 1999), testified in caves and rockshelters by large concentrations of straw and wild cereals seeds, either complete or at different stages of processing (Mercuri 2008). Recently, we found a good evidence of the use of wild plants in the Wadi Afar Cave, where entire layers of the cave fill are made of straw, grass fragments, and cereal seeds displaying different stages of processing. Moreover potholes served as silos were found; some are empty because of recent erosion, but a few, closed by large, flat stones, preserve a large amount of wild cereals (Fig. 5.7). In one pothole, seeds were found in a basket that was radiocarbon dated to ca. 8400 year BP.

Soil micromorphology of the Mesolithic anthropogenic sediments provides revealing information (Cremaschi and Trombino 1999, 2001). The stratigraphic units are mainly composed of a large quantity of poorly degraded, vegetal fragments (mainly grass), lenses of ash and charcoal from hearths, and small concentrations of sand with a lesser content of organics. The large quantity of straw (and phytolithes) and a general sub-horizontal lamination in thin section

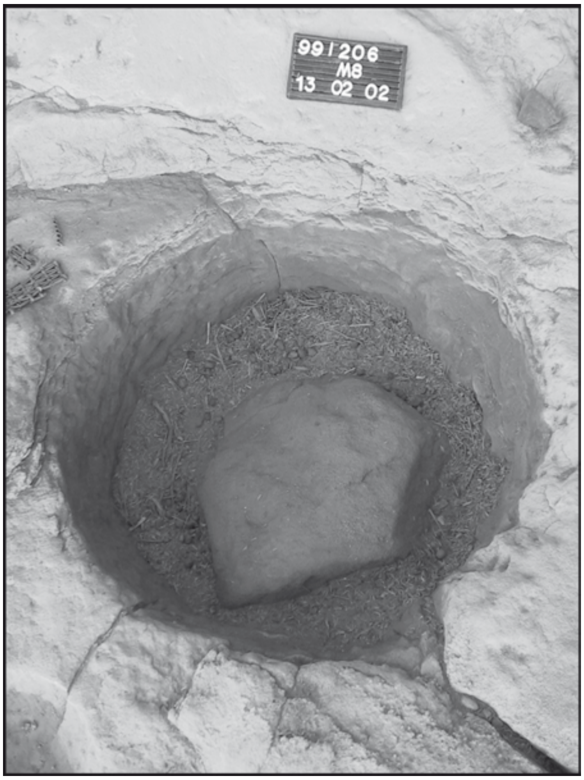

Fig. 5.7 The Wadi Afar Cave: a pothole served as silo, still preserving a large quantity of wild cereals

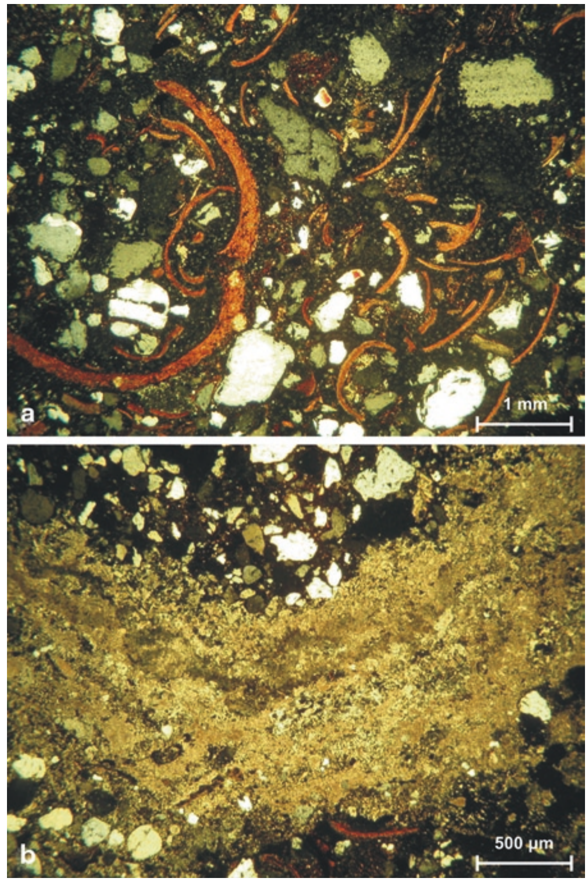

Fig. 5.8 Microphotographs of the sedimentary sequence of the Uan Afuda Cave. **a** Undecomposed straw (cross polarized light). **b** Crystallitic fabric of calcite, corresponding to ash lenses (cross polarized light)

(Fig. 5.8) indicate both anthropic accumulation of fodder and a continuous trampling; furthermore, the presence of almost entire caprovids coprolite (*Ammotragus*) and accumulation of fecal spherulites indicate the presence of these animals inside the rockshelters.

Considering the evidence from the wadis Afar and Uan Afuda, the intentional accumulation of straw and the presence of seeds remains in the deposits and inside the potholes (Fig. 5.6), can be interpreted to indicate that the rockshelter was a place used for processing and storage of wild cereals. Moreover, at Uan Afuda the occurrence of the pedofeatures related to trampling, the massive presence of coprolites and dung in the internal part of the cave, and the abundant presence of straw and other vegetal remains interpreted as fodder, may indicate forced enclosure of Barbary sheep and forms of taming (Cremaschi and di Lernia 1998; di Lernia 1999a, c).

In the Acacus area the preservation of natural resources (wild cereals and *Ammotragus*) is recorded between 8500 and 8000 year BP (the last part of the Mesolithic presence in the area), and it constitutes an attempt at conservation of the food for special periods (Cremaschi and di Lernia 1998, 1999; di Lernia 1999a, b). This evidences the complexity of subsistence strategies adopted by the Mesolithic groups (di Lernia 1999a). The reasons for the storage of food (cereals in natural silos and *Ammotragus* penning inside the rockshelters) are not completely understood. In addition to cultural implication, it could indicate a change in environmental conditions and a reduction in natural resources. One of the possible driving factors might be the dry phase with progressive reduction in water-availability dated here at ca. 8000 year BP (Zerboni 2006).

Changes in the exploitation of the landscape may also be investigated by deciphering the perception that people had of their environment, as displayed in rock art. The earliest expressions of the central Saharan rock art are mainly of mythological representations, including fantasy animals, but in some cases it is possible to identify realistic figures, which may be compared with the geoarchaeological evidence for ecological significance (Cremaschi et al. 2008). Large animals typical of the savannah environment (Large Wild Fauna style) are the most representative figures of the beginning of the Holocene. They indicate the interest in wild game of the Epipaleolithic and Mesolithic hunters. *Ammotragus* is depicted in the so-called Round Heads style. The 8000 year BP climatic deterioration appears to be supported by the representation of *Orix dammah*, a large antelope adapted to arid environments, in several rockshelters of the Tadrart Acacus. The early Holocene dry event could be expected to have facilitated the migration of the *Orix* inside the massif from the sandy lowlands, where they were confined earlier (Cremaschi et al. 2008).

Following the early Holocene dry spell, recharge of the water resources and the restoration of environmental conditions more suitable for life date from 7500 to 5000 year BP (Cremaschi and di Lernia 1998, 1999). The human population living in the area dramatically changed its adaptive strategy. The archaeological sequence of the Uan Muhuggiag rockshelter (Fig. 5.9) was generated through the occupation of Pastoral-Neolithic groups and is sufficiently well preserved to serve as a reference stratigraphic section (Pasa and Pasa Durante 1962; Cremaschi and di Lernia 1998). The older units of the deposit consist of gray sand that has suffered strong humification of the organic fraction with movement of solutes that indicates water percolation. Pollen content documents a savannah plant cover (Mercuri 2008). In the upper part of the sequence hearths are common, and organic matter of unrecompensed plant and grass fragments is progressively better preserved toward the top. A trend towards aridity is indicated by a peak in the concentration of *Panicum* pollen.

The Early Pastoral-Neolithic occupation of the Tadrart Acacus is mainly documented in the inner part of the massif. This probably indicates a sort of continuity with the settlement pattern adopted by the Mesolithic groups, as well as the existence of peculiar environmental conditions such as higher water availability. Food production has been confirmed for this phase (Cremaschi and di Lernia 1999), but processing of wild cereals and hunting continued to be practiced (Mercuri 2008). In the site of Uan Muhuggiag, as in other sites along the Wadi Teshuinat, archaeological deposits dating to the Middle Pastoral-Neolithic phase consist of alternating lenses of hearths, undecomposed vegetal remains, and coprolites. A seasonal occupation of the rockshelters by shepherds moving with their ovicaprines flocks is indicated (Cremaschi and di Lernia 1998). Micromorphology can help in better understanding the configuration of the settlements. Coprolites, spherulites, wood charcoals, bones, plant fragments, and phytolithes occur at different frequencies in each level, which may be interpreted as evi-

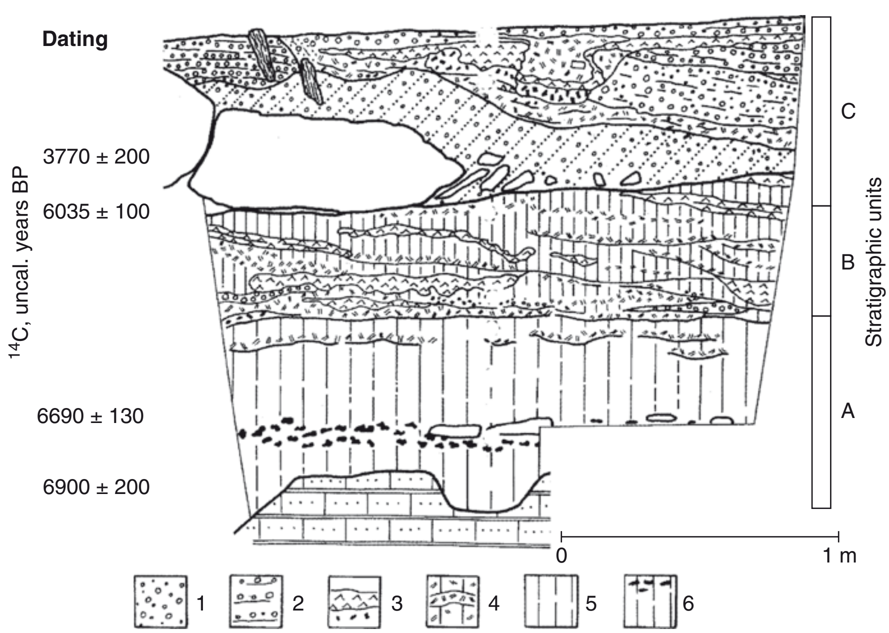

Fig. 5.9 The stratigraphic sequence of the Uan Muhuggiag rockshelter (After Cremaschi and di Lernia 1998). (Units: *A* humified sand; *B* straw and ash lenses; *C* organic sand. Key: *1* loose sand and coprolites; *2* dung; *3* ash lenses; *4* organic deposits, undecomposed vegetal remains; *5* humified organic deposits; *6* humified organic deposits with gypsum and carbonate concretions)

dence for differing uses of the rockshelter (Fig. 5.10). Charcoal, bones, and hearths indicate human dwelling inside caves, the occurrence of coprolites and their strong increase at the top, where charcoal and bone fragments decrease and disappear, shows that although penning is present from the base, it becomes dominant in the last phase of occupation when the rockshelters became stables. Changes in economic strategies show a parallel trend with the climatic variations inferred from the anthropogenic deposits. All this underlines the increase of aridity at the transition from the 6th to the 5th millennium BP (Cremaschi and di Lernia 1998).

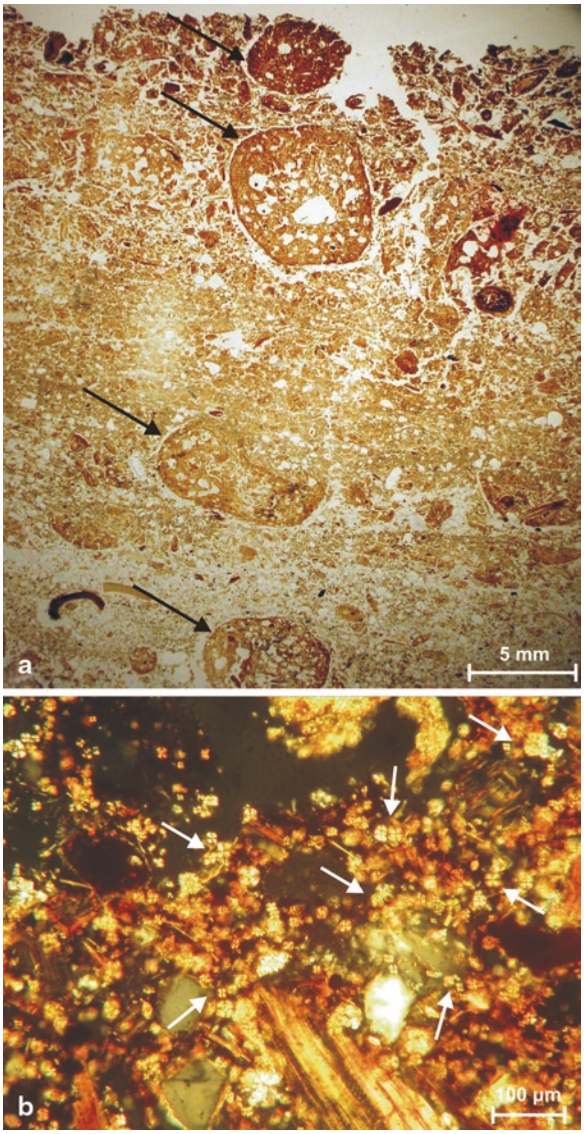

Fig. 5.10 Microphotographs of the sedimentary sequence of the Uan Muhuggiag rockshelter. **a** Undecomposed ovicaprines coprolites (indicated by *arrows*); the groundmass displays evidence of trampling (plane polarized light). **b** Arrows indicate clusters of spherulites (cross polarized light)

In the Middle Pastoral-Neolithic phase goats were not the only component of flocks. Cattle were also present—large herds are represented on the walls of many caves used as stables by Pastoral-Neolithic shepherds. In addition to rock art representations, the landscape of the Tadrart Acacus still preserves signs of its pastoral exploitation, such as tracks on the rocky slopes of the massif left by the continuous trampling of herds during their migrations. The tracks are ancient and a Middle Holocene age is confirmed by a dark rock varnish that was deposited in the central Sahara starting around 5000 year BP (Zerboni 2008).

5.4.2 The Erg Uan Kasa

During the wet Holocene, the main effect of the enhanced water supply to the central Sahara was the rise of the water table and the formation of lakes and ponds. This has been particularly noticed in the lowlands at the eastern fringe of the Tadrart Acacus, occupied by the dunes of the Erg Uan Kasa. This region represents the discharge area of the main wadis dissecting the massif.

5.4.2.1 Geomorphology and Sediments

In the area of the Erg Uan Kasa, Holocene lake deposits and hydromorphic soils were found associated with archaeological sites. The sedimentary record here is heavily affected by wind erosion and represents only a small part of the former lakes (Cremaschi 2002).

A thick hydromorphic horizon, consisting of bleached and mottled sand and friable weathered sandstone (saprolite), systematically occurs at the base of the dunes and in the bedrock in the whole area covered by the erg. This phenomenon is the result of water-logging below the water table for a long period. Enhanced rainfall would explain the high water table. Because of the higher reflectance of the bleached sand, the hydromorphic horizon is visible on Landsat satellite imagery. The prevalence and extent of water-saturation would have been due to the ability conferred on the dunes by a high porosity, which made them potentially large reservoirs.

The availability of water promoted weathering along the dune slopes and formation of inceptisols. At the base of the dunes, springs gave rise, in suitable topographic and geomorphologic conditions, to small and shallow lakes or ponds (Cremaschi 1998, 2002). Lacustrine deposits are located in the interdune corridors, mainly at the fringes of the dunes, where they are protected from wind erosion. The sedimentary facies identified in the field (Fig. 5.11) consist of bioturbated organic sand with vegetal remains indicating shallow water; dark organic silt representing the shore facies; and biochemical calcareous silt, including a rich molluscan fauna composed of few species. Characteristic species are *Lymnaea natalensis, Valvata nilotica, Biomphalaria pfeifferi*, and *Afrogyrus oasiensis*, typical of permanent fresh or hypohaline waters (Girod 2005), and indicative of full lacustrine sedimentation. In the Erg Uan Kasa the thickness of the lacustrine sediments is generally low in comparison with the Holocene sequence found in the Edeyen of Murzuq where they consist of carbonatic mud up to 2 m thick (Zerboni 2006). Radiocarbon dates obtained from organic layers at the base of the sequence and from littoral facies indicate that in the erg the water table was rising from ca. 8900 year BP (almost coincident with the beginning of spring activity inside the Tadrart Acacus) (Fig. 5.4). The Uan Kasa lakes and those of the Edeyen of Murzuq (150 km east from the Erg Uan Kasa) reached their highest stand during the 8th and 7th millennia BP (Cremaschi 1998, 2002; Zerboni 2006). However, evidence of the negative fluctuation recorded in the Edeyen of Murzuq in coincidence with the 8200 year BP event is lacking in the Uan Kasa area (Cremaschi 1998; Zerboni 2006).

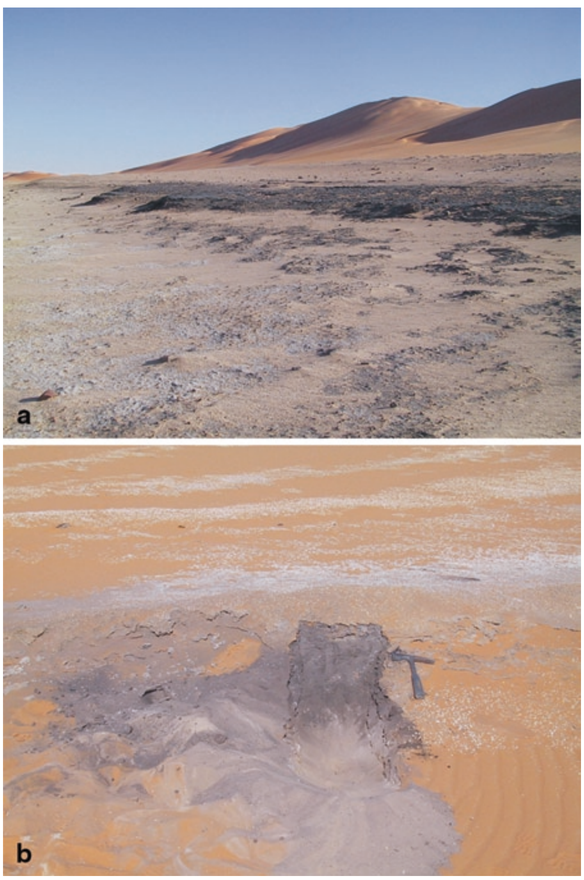

Fig. 5.11 Erg Uan Kasa. **a** Organic sand deposit at the base of the dune, corresponding to shore facies. **b** Discontinuously laminated, organic sand at the center of the basin, covered by calcareous silt, containing mollusc shells

The typical configuration of a lake deposit in the Erg Uan Kasa (Cremaschi 1998) consists of a basin up to 5 km long and 2 km wide, with sedimentary sequences on weathered bedrock ranging from 1 to 2 m thick. Marginal facies consist of organic and bioturbated silty sand, grading toward the center of the basin, into organic sand discontinuously laminated and superposed on a thin, hydromorphic, massive sand. At the center of the basin these deposits are covered by discontinuously laminated, calcareous silt containing molluscs (Fig. 5.11). The calcareous sediments are concentrated in the middle of the basin and they may indicate a phase of strong biological activity in the lake connected to a high water level. The organic deposits at the upper part of the sequence are interpreted as progression of the marginal facies toward the center of the basin as the lake level progressively dropped. The sequences are sometimes capped by a thick gypsum carbonate crust that marks the transformation of the lakes into sabkas.

5.4.2.2 Settlements in the Erg Uan Kasa

The archaeological sites are generally located close to former standing water bodies. More than 350 sites

(Fig. 5.6), ranging from the Early Acacus up to the Late Pastoral-Neolithic phase, have been identified mostly at the base of the dunes in correspondence to paleolake shores, marsh deposits, and paleosols. The environmental constraint for this was the hydrological behaviour of sand dunes under conditions of water saturation. This resulted in the formation of ecological niches at the fringe of the dunes rich in vegetation, suitable for animal life, and therefore attractive to prehistoric communities.

The Epipaleolithic sites consist of clusters of 'débitage', micro-blade cores, and formal tools such as backed tools, points, lunates, and particularly pedunculated Ounan points (Fig. 5.13; Cremaschi and di Lernia 1998). No primary archaeological structures or faunal remains are associated with these sites. Nevertheless, the occurrence of some specialized tools (hooks) may suggest fishing activities. The Epipaleolithic sites are not actually located along the shores of former lakes that are along the dune fringes, but rather they are buried within the organic deposits at the base of the lacustrine sequences. They are therefore related to the very beginning of lacustrine sedimentation in the area. No direct radiometric dates are available for the Epipaleolithic sites, but the ^{14}C age obtained from the organic sediments covering them should be considered as a limit *ante quem* for the human frequentation. These dates range from ca. 8700 to 8500 year BP, placing them at the very beginning of the wet phase in the area. During this phase the raw material employed in the lithic industry is largely represented by local lithotypes, such as very fine quartzarenite commonly outcropping in the Messak Settafet and Tadrart Acacus regions, and silcrete that outcrops inside the erg. The assemblage also includes Jurassic to Cretaceous flint obtained from remote areas (likely from northern regions). This indicates a high mobility of the hunter-gatherer groups promoted by the extension of a green corridor to the entire central Sahara (Hoelzmann et al. 2004).

Mesolithic sites are rare in the erg (Fig. 5.6) and can be distinguished in the field from Epipaleolithic ones because of the configuration and occurrence of specific archaeological materials (Cremaschi and di Lernia 1996). They are associated with microlithic equipment and pottery fragments decorated with a dotted wavy line, found together with large grinding equipment and clusters of poorly preserved fireplaces (Cremaschi and di Lernia 1996). These features suggest, for the 8th millennium BP, a change in exploitation of resources toward the introduction of wild plant processing, as also documented in the Tadrart Acacus (di Lernia 1999a; Mercuri 2008).

The Early and Middle Pastoral-Neolithic sites date back to the 7th and 6th millennia BP and represent 50% of the archaeological evidences identified in the area (Fig. 5.6). Their large number indicates the apogee of the Pastoral-Neolithic cattle herders and their good adaptation to the wet environment. Generally speaking, the sites are regularly related to the geomorphologic features of a high standing water level and the objects they are composed of (such as lithics, pottery, bone fragments, stones) are systematically scattered for hundreds of meters (sometimes up to few kilometers) in continuity along the former shores of the interdune lakes and on the slope above (Fig. 5.12).

Fig. 5.12 Erg Uan Kasa. **a** Configuration of a Pastoral-Neolithic archaeological site laying on the dune slope; the surface is dotted by artifacts. **b** Faunal remains and a complete Middle Pastoral-Neolithic pot residual of differential wind erosion

Fig.5.13 Erg Uan Kasa. **a** Epipaleolithic stone tools. **b** Some examples of Middle Pastoral-Neolithic pottery

The spatial configuration of the archaeological features is well preserved and consists of clusters of several tens to hundreds of fireplaces, pits containing cattle bones, entire vessels, and grinding stones. Entire pots and grinding equipment were found semi-buried among fireplaces and probably represent hiding places (Fig. 5.12). By contrast, pits filled with animal bones are much more commonly located outside the perimeter of the sites.

The large size of the sites is interpreted to indicate a dense population, probably with recurrent occupation of the same places along the lake shores (Cremaschi and di Lernia 1998; di Lernia 1999b; Biagetti and di Lernia 2003). Support for this view is also provided by the permanent siting of heavy duty tools and large vessels, difficult to transport, and ready for reuse during subsequent visits. The sites of the lakes are therefore interpreted a terminus in the transhumance route connecting the lakes in the Erg Uan Kasa to the mountain ranges of Tadrart Acacus (Cremaschi and di Lernia 1998; di Lernia 1999a, b; Biagetti and di Lernia 2003). This strict connection is further demonstrated by the provenance of the raw material employed for lithics (quarzarenite) and grinding equipment (quartzarenite and sandstone), that derive from the Acacus area. However occurrence of grinding equipment obtained from granite and micaschist also indicates that transhumance may have extended at least to the western slopes of the Algerian Tassili (250 km to the west) or/and to the westernmost outcrops of the Tibesti granite (350 km to the east).

5.4.3 The Wadi Tanezzuft and the Garat Ouda Paleolake

5.4.3.1 Physiography

During the wet Holocene the Wadi Tanezzuft was a large river, fed by several influents from the Tassili and from the upper Tadrart Acacus. At its maximum extension, it was about 200 km long and ended in a large interdune lake close to the Edeyen of Ubari at about 60 km north of the Tadrart Acacus massif. In this region three main physiographic features still preserve paleoenvironmental records of the alluvial plain of the Tanezzuft valley (early to late Holocene), the interdune basins of the ErgTanezzuft (early Holocene), and the playas fed by lateral branches of the main river (early and middle Holocene).

The fluvial sedimentation inside the main valley was already active by the 7th millennium BP, but the deposits of this age are deeply buried in the middle of the wadi and outcrop only locally at its margins. In the early to middle Holocene (ca. 8000–6000 year BP) the discharge of the Wadi Tanezzuft was large enough to carry coarse sediments deposited as longitudinal gravel bars (Fig. 5.14) in a braided river system, turning downstream into large meanders (Perego et al. 2007), which architecture appears well preserved in satellite images. After 5000 year BP, 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. The overbank deposits belonging to the last aggradation phase are constituted by upward fining cycles of cross laminated sand, sandy silt, and sandy clay, often weathered into inceptisols or entisols. The deposition of silty sediments is dated between 4000 and 3000 year BP by the presence of several archaeological sites with fireplaces entombed within the alluvial deposits (Cremaschi and di Lernia 2001).

In the middle part of the wadi, a few kilometers north from the village of Ghat, the course of the river bordered the Erg Tanezzuft. Although the erg is not very wide, it is similar to the larger Erg Uan Kasa. It is composed of linear and star dunes separated by interdune corridors. Lacustrine deposits occur along the corridors at the base of the dune slopes, which consist of hydromorphic horizons and organic sand deposited during the early and middle Holocene.

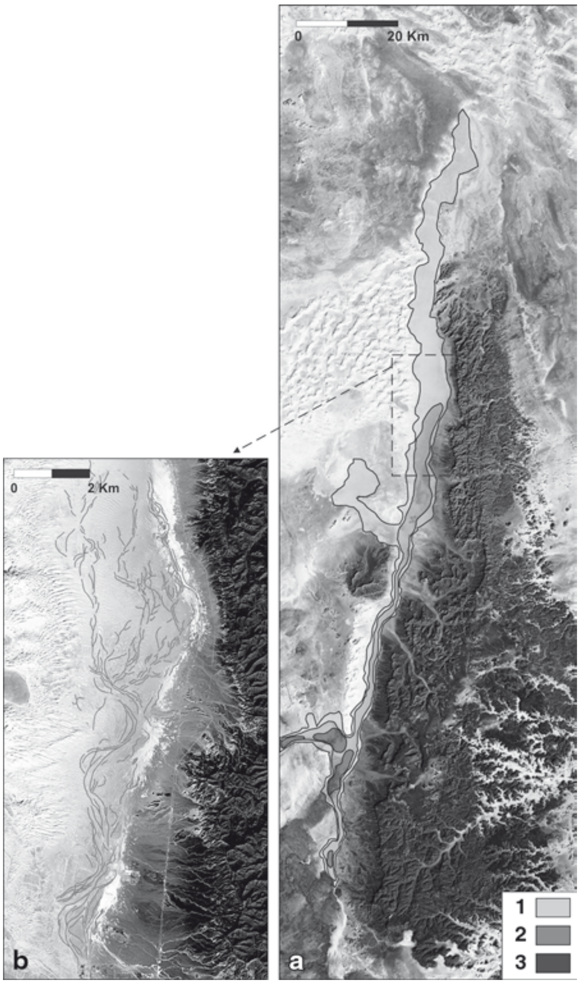

Fig. 5.14 The Wadi Tanezzuft as from Landsat 7 satellite imagery **a** On the left **b** a detail of the meander bars dating to the early-middle Holocene. The progressive contraction of the oasis is indicated in **a**. (Key: *1* extent of the late 6th millennium BP oasis; *2* extent of the 4th–3rd millennium BP oasis; *3* extent of the 2nd millennium BP oasis)

During the early Holocene the water supply from the Wadi Tanezzuft was very large and several minor channels branched out from the main stream into the lowlands and depressions of the floodplain (Cremaschi 2001; Cremaschi et al. 2005). A similar phenomenon is reported in northern Egypt where at the beginning of the Holocene the Nile bed silted up high enough to let the river overflow into the Fayum depression, feeding the ancient lake Moeris (Hassan 1986).

The Garat Ouda playa is the widest basin of the area. It hosted a lake some 80 km^2 wide in a depression dammed to the north and to the west by the south-eastern fringes of the Erg Titersine, and to the east and the south by Inselberg-type reliefs and flat-irons. Close to the dune, shore deposits are still preserved and consist of black organic sand some tens of centimeters thick intercalated with bleached sand. Fish bones and vegetal remains have been found in the organic horizons. On Landsat satellite images, the bright reflectance of the area of Garat Ouda is produced by light gray to white silt that fill the depression. The flat area covered by the silt corresponds to the alluvial plain formed during the early to mid-Holocene by the lateral branch of the Wadi Tanezzuft. In the southern part of the basin there is a system of meandering paleochannels that become the distributaries of a delta toward the middle of the alluvial plain. These channels are not evident on Landsat images but their shape is very clear in Ikonos images (Fig. 5.15). Furthermore, channel deposits (consisting of pink silty sand) are evident in the field, as is the fact that differential aeolian erosion has lowered the surface of the alluvial plain by more than 50 cm. On satellite images the architecture of the middle Holocene lower fluvial reaches and delta appear well preserved, and through the superimposition of the channels, a progressive migration of the main course towards the east can be discerned (Cremaschi et al. 2005).

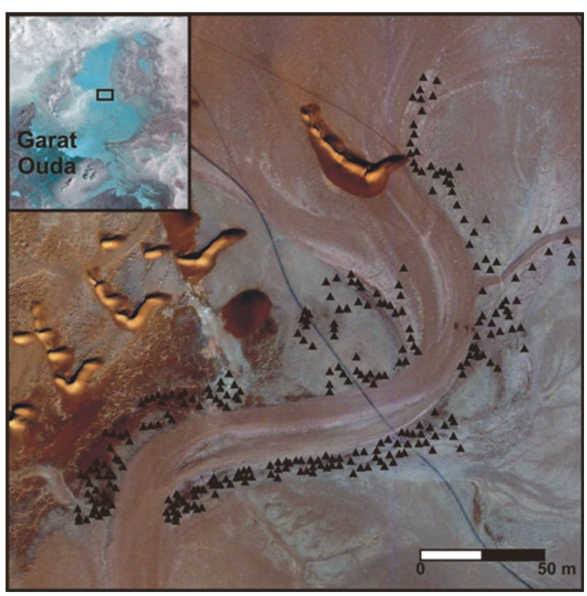

Fig. 5.15 A detail of the meandering paleochannel of the terminal reach of the left branch of the Wadi Tanezzuft in the area of Garat Ouda (Ikonos satellite imagery): the black triangles represent single middle Pastoral-Neolithic fireplaces, dotting the perimeter of the paleochannel. Insert: the location of the paleochannel in the Garat Ouda area

5.4.3.2 Settlements

A few Epipaleolithic and Mesolithic sites have been discovered at the margin of the early Holocene Tanezzuft river, mostly in the northern part of the valley. They consist of clusters of lithics eventually associated with fireplaces, large grinding equipment and pottery with dotted wavy line decoration. Commonly, Mesolithic sites are buried in the silt of the alluvial plain, indicating that the settlements were located close to the former bank of the Wadi Tanezzuft. The Early and Middle Pastoral-Neolithic sites occur in large number along the main wadi course and inside the small ergs surrounding it. The sites display similar features to contemporary sites in the Erg Uan Kasa (Cremaschi and di Lernia 2001). The Pastoral-Neolithic sites were mostly located in the vicinity of river banks or close to former lakes, especially in the central and northern part of the valley, whereas evidence dating to these phases are almost lacking south of the Erg Tanezzuft.

The distribution of sites in the Erg Tanezzuft is similar to that described for the Erg Uan Kasa and is related to the geological evidence of former standing water. Sites date almost to the Early and Middle Pastoral-Neolithic periods. At a site (97/180) located in an interdune corridor of the Erg Tanezzuft there is a catenary sequence of soils and sediments at the base of the dune slope, which may be regarded as representative for settlement in this area (Cremaschi and di Lernia 2001). On the floor of the corridor, lacustrine sediments occur consisting of black sand with mollusc shells. Upwards, along the slope, these sediments grade into hydromorphic soil with root casts, superposed on hydromorphic sand. Above these, there is red weathered sand, covered in turn by the mobile part of the dune. Around the fringe of the inner part of the corridor, which roughly corresponds to the shore of a former lake, there is a middle Pastoral-Neolithic semi-permanent camp. Radiocarbon dating indicates that the site was contemporaneous with the lacustrine sedimentation.

The archaeological record is particularly rich and well preserved in the area of the Garat Ouda playa, and indicates adaptation to a fluvial-lacustrine transitional environment. The Epipaleolithic sites are located along the former shore of the lake in the northern part of the area. The sites of the Pastoral-Neolithic periods are dominant and consist of more than 2500 fireplaces and grinding equipment distributed as a continuous belt along the lower fluvial reaches near the deltaic areas (Cremaschi et al. 2005). The main concentrations of archaeological features form small mounds up to 1 m high. This is a post-depositional effect of wind erosion, which lowered the area surrounding the sites but not the sites themselves protected by the concentration of stones and artefacts. The strong relationship between the former channels and the distribution of sites is clearly visible on Ikonos satellite imagery of a meander of the lowermost fluvial reaches feeding a delta located in the center of the Garat Ouda area (Fig. 5.15). Fireplaces systematically dot the two banks of the channel and some occur nearby (up to 30 m) on the surrounding alluvial plain. Several pits containing charred faunal remains have also been observed. Faunal remains are of fish, crocodile, and hippopotamus, and of cattle (as in the Erg Uan Kasa) better preserved along the paleochannel. Bones belonging to large animals are mainly found scattered throughout the archaeological sites, and fish bones are concentrated in small mounds that are the remains of garbage pits or fireplaces partially removed by wind erosion. This suggests a specific exploitation of the area of Garat Ouda through hunting and especially fishing integrating the Pastoral-Neolithic practice of herding.

5.5 Drought at 5000 Years BP

The main climate change toward aridity in the Sahara (termination of the African Humid Period) is dated at ca. 5000 year BP (deMenocal et al. 2000; Kröpelin et al. 2008). Dry conditions did not affect the whole region simultaneously, and effects on the landscape differed depending on geographical position and geomorphologic conditions. In SW Fezzan the desiccation of the lakes, together with other environmental evidence (such as rivers activity, pollen data, dendroclimatological studies), indicates that this occurred during the middle Holocene, and correlates with the weakening of the monsoon rainfall and its retreat to southern regions (Cremaschi 1998, 2002; Zerboni 2006, 2008). This dry event is well represented in the dendroclimatic record of the *Cupressus dupreziana* by two strongly negative spells in the tree-ring sequence, which dates it at ca. 5040–4850 cal year BP (Cremaschi et al. 2006). The influence of the termination of the monsoon rainfall on the Tadrart Acacus massif, the Erg Uan Kasa, and the Wadi Tanezzuft is described in the following sections.

5.5.1 Inside the Acacus

The transition to different environmental conditions at ca. 5000 year BP is evident in many caves of the Tadrart Acacus, and is marked by erosion and a change in the sedimentation pattern. Depositional trends that indicate aridity consist of erosional surfaces at the top of the Middle Pastoral-Neolithic layers, deposition of lenses of aeolian sand inside the caves capped by extensive dung layers, and collapse of the roofs of many rockshelters. Micromorphologically the dung layers are characterized by a platy discontinuous microstructure with few voids, including deformed coprolites and elongated plant fragments; this is interpreted as due to trampling and is indicative of a stable deposit (Fig. 5.10). In some cases sand lenses alternate with the organic strata, indicating a formation in a dry environment with marked seasonality. Dung deposits are dated from 5200 to 3770 year BP. In the sequence of Uan Muhuggiag, for instance, a discontinuity related to wind erosion is covered by a layer of dung consisting of unaltered plant and straw remains cemented by animal excrement. The fact that this material did not suffer significant bacterial degradation is attributed to a semi-arid, dry environment (Cremaschi 1998). Pollen analyzes from the Uan Muhuggiag site confirm the general paleoenvironmental trend of the sedimentary sequence with Poaceae, Capparaceae, *Acacia*, and *Artemisia* at the top indicating dry steppe (Mercuri 2008). The same sedimentary pattern has been described in several other rockshelters, such as in the case of the Uan Telocat sequence, where a thick layer of preserved leaves alternate with sandy layers.

The Late Pastoral-Neolithic sites increased in number from the end of the 6th millennium BP up to the beginning of the 4th millennium BP (Fig. 5.6). This increase is both related to the archaeological visibility (the mountains archaeological sites are better preserved) and to a different settlement pattern that implied a seasonal occupation of rockshelters, used for penning activity. The main characteristic of this phase are the diversified use of rockshelters, the introduction of undecorated pottery, and the exclusive use of ovicaprines (Cremaschi and di Lernia 1998).

After the Late Pastoral-Neolithic phase and during the Garamantian period (5th century BC to 5th century AD), the caves and rockshelters of the Tadrart Acacus are still attended, although the sites are very limited in number. The exploitation of the mountain is mainly based on herding of flocks, and the sites in the massif were connected to the main settlements of the time (Liverani 2005), located in the oasis and corresponding to the main centers of the network of the Garamantian kingdom (a tribal people in the Fezzan, descended from Berbers and Saharan pastoralists).

Considering the rock art as an indication of the perception of landscape, a main discontinuity with the Pastoral-Neolithic phase is evident. During the wet early and middle Holocene, the representations were strictly related to the landscape and its exploitation (paintings and engravings of animals close to former water points, hunting scene, shepherd with flocks, and so on), whereas in this and later periods rock art became a tool to mark the territory (Cremaschi et al. 2008). The late Holocene dwellers of the massif left a few representations of humans and animals to indicate the seasonal availability of water, to signpost the main paths and passes crossing the mountain, and to mark their presence in specific areas. The main routes were marked by representation of four-horse chariots. Furthermore, they decorated with inscriptions in Tifinagh (a Berber alphabetic script) the most relevant localities leaving us a complex system of landmarks not yet completely understood.

The exploitation of the Tadrart Acacus valleys is at present limited to a few Tuareg groups (the so-called kel Tadrart), whose life is regulated by the availability of natural resources (water and grass); till the late 1970s they used to move on the massif, looking for water, and building their base camps close to active ‘gheltas’. Today, notwithstanding the harsh climatic conditions, their style of life is becoming more sedentary, as the excavation of deep wells at the month of the main wadis of the massif guarantees the availability of water for man and goats throughout the year.

5.5.2 Drying and Abandonment of the Erg Uan Kasa

Lacustrine sedimentation is no longer recorded in the Erg Uan Kasa after ca. 5500–5200 year BP (Fig. 5.4) indicating that shortly after this period the lakes dried out (Cremaschi 1998, 2002; Zerboni 2006). Interruption of the monsoon precipitation radically changed the environmental conditions of the dune corridors in the Erg Uan Kasa. Water availability rapidly decreased and the water stored in sand was drawn to the topographic surface by capillary uprise. Then it evaporated and salts precipitated. Most of the lacustrine basins, located in the northern and central parts of the erg were sealed by gypsum and alkali crusts. The effects of incoming drought were slightly different in the southern part of the Erg Uan Kasa where the interdune corridors correspond to the downstream direction of the main valleys cutting the Tadrart Acacus massif. In this area the run off of water from the massif lasted for several centuries and the result was that the early to mid-Holocene lacustrine deposits were buried by fluvial silty sediments, as an effect of enhanced slope degradation in the mountain range (Fig. 5.16). A subsequent single, very short, wet episode in the southern part of the erg dates at ca. 2400 year BP (Cremaschi 1998). It is probably related to a limited resumption of the monsoon. However, the dominant process soon became wind erosion and this removed most of the deposits and soils formed during the wet Holocene (Cremaschi 2002, 2003).

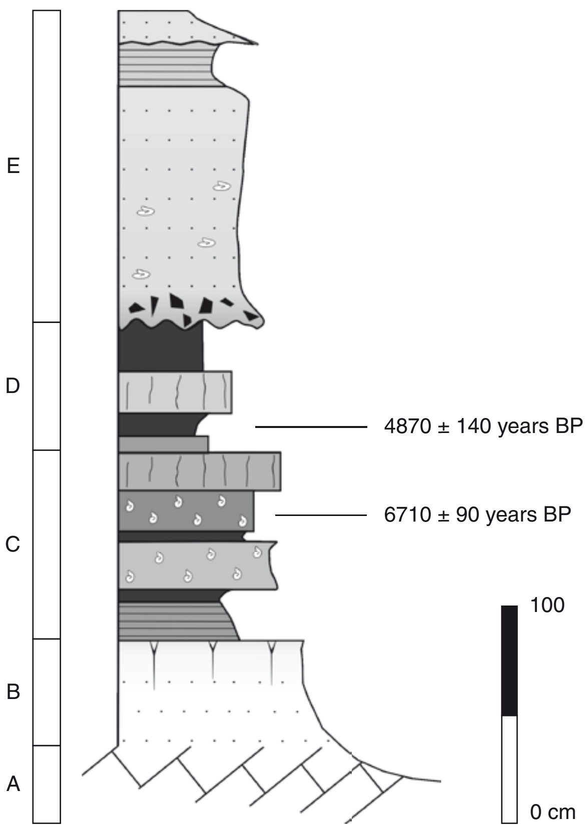

Fig. 5.16 Stratigraphic sequence from a southern interdune corridor of the Erg Uan Kasa (site 03/508); it is representative for the transition from a lacustrine to fluvial sedimentary environment. Uncalibrated radiocarbon dates are reported (*A* bedrock (sandstone); *B* hydromorphic horizon; *C* organic deposit and carbonatic mud containing molluscs (shallow lake facies); *D* silt intercalated by organic mud (alluvial plain); *E* silty to sandy deposits (channel bars))

The Pastoral-Neolithic occupation which followed the desiccation of the Erg Uan Kasa was dramatically reduced. The transition from Middle to Late Pastoral-Neolithic phases recorded not only a decrease in site concentration, but also a major change in the configuration of the settlements. The Middle Pastoral-Neolithic sites were large and included organized settlement structures and facilities, whereas those of the later phase appeared to be quite small, almost lacking any complex archaeological feature, except for a few scattered fireplaces, small concentrations of tethering stones, and scarce artefacts (Cremaschi and di Lernia 1998). The Late Pastoral-Neolithic groups left the margin of the dunes where the shores of the desiccated lakes were located, and moved towards the center of the interdune corridors. The sites of this phase lie on erosional surfaces. In any case, clusters of fireplaces could indicate that the erg was never completely abandoned even under very dry conditions and may have been marginally exploited by nomads for hunting and pastoralism (Kuper and Kröpelin 2006). Later, it was crossed by the early historical caravan routes, as testified by the Garamantian fortified sites at the western margin of the erg.

5.5.3 *Origin and Decline of the Tanezzuft Oasis*

During the middle Holocene, after the surrounding areas had already dried out, the activity of the Wadi Tanezzuft persisted for millennia (Fig. 5.4), although the river became shorter and endorheic, no longer reaching the terminal lake located close the sand sea of Ubari. Its fringe was located at the northern end of the Tadrart Acacus massif.

As an effect of the reduced discharge, the grain size of the sediment also changed. Gravel was replaced by sand and mud, and an alluvial plain developed along the main branches of the river over gravel bars and burying archaeological sites. The deposits belonging to the alluvial plain have been radiocarbon dated from ca. 4200 to 2900 year BP (Cremaschi 2001). Sandy-loamy sediments are interlayered with thin soils with hydromorphic features and crossed by root casts. Both are evidence of a greater groundwater availability and plant cover on the alluvial plain.

The subsequent increase in dryness reduced the flow along the Wadi Tanezzuft such that water supply to the Garat Ouda delta-lake system ended between 5200 and 4800 year BP and the lake dries up (Cremaschi 2001; Cremaschi et al. 2005). Abruptness of the change allowed for good preservation of geomorphologic features, also because no reactivation occurred afterwards.

During the mid-late Holocene drying phase, the Wadi Tanezzuft became an oasis (Cremaschi 2001, 2003). In this context the term oasis should be understood as an isolated physiographic unit within the mosaic of the desert physiographic features of the Saharan-Arabic arid belt. It consists of an area of vegetation, typically surrounding a water source that occurs where groundwater lies close to the desert surface, and where plant roots and wells can reach it. The oasis attracted and concentrated the Late Pastoral-Neolithic communities pushed out from the surrounding territories by drought. Moreover, the onset of new environmental conditions led to adaptive strategies to aridity that, starting from a simple exploitation of the land resources (such as agricultural activity), became more sophisticated after several centuries combining local land resource exploitation with long distance trade through the caravan routes (Liverani 2004).

It is not surprising, therefore, that the Wadi Tanezzuft was also densely inhabited during the Late Pastoral-Neolithic period (Fig. 5.6), when occupation in surrounding areas was considerably reduced and limited to specific movements related to nomadism. Configuration and distribution patterns of the sites dating from this period and found inside the perimeter of the oasis may suggest an interest in exploitation of the soil in a context of rising sedentarism. Individual sites are basically composed of fireplaces and storage pits, with vessels and faunal remains, but they include also a large number of grinding equipments, together with lithic hoes and gouges—possible indications of land management and crops processing.

In the central part of the alluvial plain of the Wadi Tanezzuft some phytogenic dunes related to tamarisk bushes are concentrated along the most depressed part of the alluvium. The dunes date from medieval times (ca. 600 year BP; Fig. 5.17), and they blanketed the alluvial plain in which Late Pastoral-Neolithic archaeological sites are buried (Cremaschi 2001). These sites were located close to the water resource despite the possibility of flooding. Micromorphology of a buried inceptisol developed at the top of the alluvium and connected to a Late Pastoral-Neolithic site shows strong bioturbation (root cast), fragmentation of the structure, and occurrence of coarse coatings associated with charcoal and phytolithes (Fig. 5.17). Micropedological evidence suggests some kind of soil management, including ploughing and the slashing and burning of the vegetal cover.

Clusters of tethering stones have been found in the alluvial plain at the northern end of the Tadrart Acacus massif (Fig. 5.18). They are distributed across the width of the valley, in the northern part of the Wadi Tanezzuft (Fig. 5.18). The significance of tethering stones in the Saharan archaeology is still under dis-

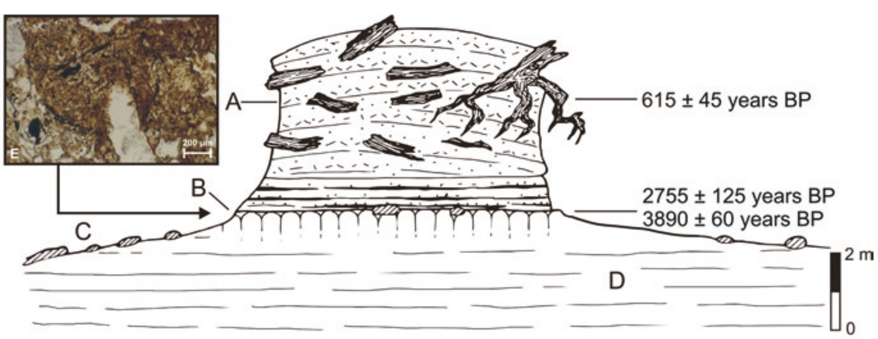

Fig. 5.17 Stratigraphy of a phytogenic dune (*A*) that covers a soil (*B*) developed at the top of the middle Holocene alluvium (*D*). A Late Pastoral-Neolithic site (*C*) is buried under the soil (site 96/267); uncalibrated radiocarbon dates are also indicated (After Cremaschi 2001). The insert (*E*) is a microphotograph of a thin section (plane polarized light) of the soil showing strong bioturbation, fragmentation of the structure, coarse coatings, small charcoal, and phytolithes

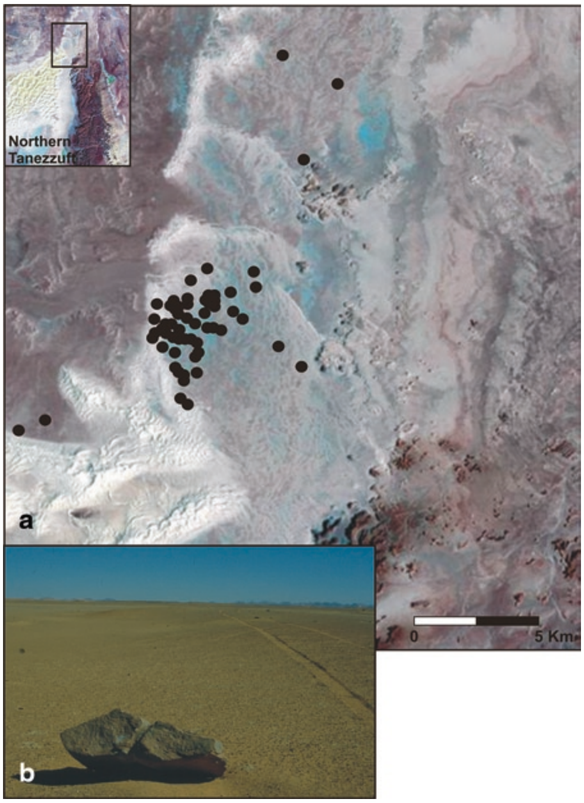

Fig. 5.18 **a** Distribution of the tethering stones at the northern fringe of the mid-Holocene Tanezzuft oasis (location in the insert). **b** A tethering stone from the northern Wadi Tanezzuft

cussion: even if a use in management of livestock cannot be excluded, the evidence of rock art suggests that they were certainly connected to hunting activity and used as a component of traps for wild animals (Pachur 1992; Cremaschi 2001; di Lernia et al. 2008). In this case the distribution of tethering stones corresponds with the extreme reach of the Wadi Tanezzuft, and therefore with the limits of the oasis in the late 5th millennium BP, as reconstructed on the basis of the geological evidence. Here the main concentrations of tethering stones, occurring at the interface between the oasis and the desert, would indicate the most probable access of wild game to the water in the oasis, and an intense exploitation of the marginal areas by hunters.

Radiocarbon dates indicate that the boundaries of the Tanezzuft oasis were stable in the 4th and 3rd millennia BP, but during the 2nd millennium BP the oasis contracted significantly (Fig. 5.14; Cremaschi 2003). At this time, archaeological evidence shows that the Tanezzuft oasis became the southern border of the Garamantian kingdom, and acted as a node on caravan routes connecting the central Sahara to sub-Saharan Africa (Liverani 2004). The climatic conditions at the beginning of the 2nd millennium BP and its effects on the Garamantian civilization are still under discussion. However, during their whole history the Garamantes tried to adjust to increasing aridity, for instance with water management (irrigation) for intensive agriculture within the oasis (Liverani 2005). For example, the foggara system (a traditional systems of water catchments and horizontal underground shafts that drain water and convey it by gravity) was used in the Germa (formerly Garama, capital of the Garamantian kingdom) oasis until medieval times (Mattingly 2003). In the southern Wadi Tanezzuft, where the main Garamantian settlements were located, there is no evidence of complex irrigation strategies apart from a few small canals now largely buried by sand dunes. It is likely that in the area of Ghat, El Barkat, and Fewet agriculture was sustained by shallow wells.

In the Tanezzuft valley the Garamantian settlement mainly consists of fortified villages and compounds located as a protection of the fringes of the oasis (Liverani 2005; Biagetti and di Lernia 2008). Information about actual land use is poor although archaeobotanical data confirm intensive agriculture (Mercuri et al. 2005). Several minor sites of this age, composed of clusters of fireplaces and scatterings of pottery, have been found buried by alluvial deposits (Cremaschi 2005). They indicate that the oasis was larger than today, and was probably sustained by the wet conditions evidenced by the presence of *Cupressus dupreziana,* which occurred between 2800 and 2200 years BP (Cremaschi et al. 2006). At that time Wadi Tanezzuft was still active and was a source of water for cultivation.

It is impossible to separate climate change and socio-political factors in explaining the collapse of the Garamantian kingdom. However, it was coincident with the onset of very dry conditions in the region and with the disaggregation of the boundary of Roman Empire in North Africa, and the consequent interruption of the commercial routes to the south (Liverani 2005). In any case the Garamantian occupation in the oasis ended about 1600 years BP. This coincides with the onset of very dry conditions, as indicated by the progradation of sand dunes into the oasis and by a sharp decrease of the tree-ring size in the dendroclimatic record of *Cupressus dupreziana* at 1573 year BP (Cremaschi 2005; Cremaschi et al. 2006).

The configuration of the oasis of the Wadi Tanezzuft at the end of the Garamantian kingdom was preserved by the exploitation of the residual water resource by means of shallow wells up to the beginning of the last century. These conditions lasted until a few decades ago, when the oasis slightly expanded again to a maximum extent in the 1980s thanks to the excavation of deep wells that exploited the fossil hydrological reserve. Today overexploitation of such waters is exhausting the reserve, and Ikonos satellite imagery shows recent plantations abandoned and obliterated by sand.

5.6 Conclusions

From the climatic history and cultural dynamics of the central Sahara a few conclusions can be reached.

a. A comparison of the geoarchaeological development throughout the Holocene of the Tadrart Acacus, Erg Uan Kasa, and Wadi Tanezzuft, strongly suggests that water availability was the main factor shaping the landscape and driving the evolution of settlement and the cultural dynamics of the population living there. For example, the early Holocene dry event (8.2 kiloyear BP event), though short, had a disruptive effect on the landscape. The most sensitive environment was the mountain where a discontinuity in anthropogenic sedimentation in caves and rockshelters marks a strong reduction in resources, likely followed by a change in survival strategies.
b. The modern period of hyperaridity began with the mid-late Holocene transition. The withdrawal of the African monsoon and the progressive fall in water resource mark the turning point of environmental conditions at ca. 5000 year BP. The response of fresh water systems seems to be instantaneous, while terrestrial environments have gradually adapted to increasing aridity. Finally, the water resources contracted to the oasis. The Pastoral-Neolithic communities which had settled all the landscape units were forced into the limits of the oasis, where they developed different subsistence strategies. The oases promoted a new, revolutionary model of territorial management, giving rise to different subsistence strategies evolving towards complex social systems.
c. The oases did not constitute stable geomorphologic system. They experienced a reduction in size following the decrease in the water resource. They could not halt the encroaching aridification, and crisis and collapse of societies such as the Garamantian was a common outcome. Moreover, the recent history of the Tanezzuft oasis shows that in a marginal environment the anthropic impact, even if very limited in time, would have quickened natural changes (as the recent lowering of the deep aquifers testifies), and thus accelerated desertification.
d. However, even after aridification, dry lands (as the Erg Uan Kasa and the northern part of the Wadi Tanezzuft) were never completely abandoned, and were subjected to reduced human exploitation. These areas, apparently remote and abandoned, were in reality frequented by nomads, hunters, and shepherds who exploited their scarce resources. These are fragile environments and the seemingly marginal but protracted human pressure may have ultimately contributed to accelerate landscape degradation. Large scale devastation may have resulted from the human-induced intensification of such interconnected processes as aeolian erosion, soil stripping, and the extreme reduction of vegetal cover. Marginal pastoralism might have enhanced the soil erosion and consequently the spread of desertification. Furthermore, the use of specific hunting artefacts in the desert areas, such as tethering stones in the Sahara region, or desert-kites in the Middle East (Helms and Bettis 1987), might have a long term effect on the local environment.
e. The steps toward aridity and the reduction in size of the oases appear to be connected to local conditions. In this sense, the present work should be intended as a confirmation of recent hypotheses concerning a differentiated Saharan mid-Holocene aridification and a slow rate of desertification in specific areas (Kröpelin et al. 2008). Care should be taken to avoid any regional generalization and future detailed studies should be encouraged in selected areas to better understand the effects on the landscape of the termination of the African Humid Period.
f. Although data archives of high resolution proxies (isotopes, tree-rings, CO_2, CH_4, as so on) give an idea of the intensity of climate change, a reliable interpretation of what happened in the physical

environment is offered only by combining geomorphologic evidence with the archaeological record into an integrated geoarchaeological approach. Holocene paleoenvironmental reconstructions in arid lands should be coupled with the study of the settlement pattern revealed by archaeology. The geoarchaeological approach to climate change offers an opportunity to understand the past and provides a key to solve present and future issues.

g. Finally, in the context of Quaternary changes, the modern Sahara seems to show anomalous behaviour. The dismantling of the Alpine glaciers, even at mid-latitudes, could be considered typical of an interglacial, but the modern expansion of the desert may correspond to environmental conditions more consistent with a glacial period. It is possible that desertification may have been intensified by human exploitation of the Sahara since the mid-late Holocene. This may be taken as one more case where humankind has significantly affected decrease in the size of a water reserve and a reduction of the sequestration of CO_2 in soils and sediments since early times. This would conform to the ideas proposed by Ruddiman (2003) concerning the early anthropogenic overprints on climate.

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