Environmental dynamics and land occupation in the Saharan margins of the Holocene Maghreb

Jean-Louis Ballais, Mohamed Tahar Benazzouz, Aïcha Benmohammadi

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1. Introduction

The area considered here runs from the Atlantic Ocean to the Gulf of Gabès. The tightening of the zone and the bio-climatic layering, from the sub-moist layer at the summits to the Saharan layer of the Grands Chotts (below 0) have led to the particularly clear expression of morphogenic nuances, notably during the Lower Holocene and during the optimum climatic period, but also during finer climatic variations and during variations in the modes of occupation of the land during the Upper Holocene.

After local studies (Ballais, 1976), followed by regional studies (Ballais, 1991a; Benazzouz, 2000; Benmohammadi, 2001), it is possible to propose a synthetic view of the environmental dynamics and the occupation of the land of the Saharan margin of the Maghreb during the Holocene period.

The Holocene of the arid margin of the Mediterranean domain of the Maghreb can be divided into four periods: Lower Holocene, Middle Holocene, Prehistoric Upper Holocene and Historic Upper Holocene.

The Holocene periods follows the Late Ice Age during which two moist pulses, contemporaries of the Bölling and the Alleröd, were the forerunners of the high moisture of the Lower and Middle Holocene (Ballais and Benazzouz, 1994; Ballais and Heddouche, 1997). After this optimum period, the climate tends to become more arid until reaching the present level, which was probably reached, for the most part, at the start of the historic period.

2. Lower Holocene (10,000 to approximately 7000 BP): an increase in moisture

2.1. Dune fixation and their colonization by epipaleolithic populations

In the eolian sands which moved and accumulated during the maximum cold of the Upper Pleistocene, prehistoric sites were constituted, featuring strip industries (Ballais and Ben Ouezdou, 1992).

In southern Tunisia, dune fixation actually appears to have begun at the very end of the Upper Pleistocene, during the Younger Dryas. Along the coast of the Gulf of Gabès (*Fig. 1*), in station A [south-facing Capsian (Gragueb, 1983)], just north of el Akarit wadi, two 14C-datings on ostrich egg shells give 10,510 ± 349 and 10,013 ± 281 BP. These dates coincide with an increase in the water supply in the flow basin of the wadi around 10,500 BP (Fontes and Gasse, 1991). Further north, at Kasserine, the arid-to-moist climatic transition also occurred before 10,500–10,000 BP (Medus and Laval, 1997). Likewise, at Tiznit, in western Morocco, early erosion discontinuity can be dated to 10,880 BP (Coudé-Gaussen and Rognon, 1993). The siliceous silt deposit carried by the seasonal winds from the Sahara indicate the moistening of the Canary Islands prior to 9800 ± 140 BP (Coudé-Gaussen and Rognon, 1993). In the valley of el Abiod wadi, southwest of el Hodna Chott (Algeria, *Fig. 1*), the return of moisture is marked by an accumulation of palustral silt covered by a travertine whose summit has been dated using *Helix* shells at 9290 ± 120 BP (Gif-9874) (Benazzouz,

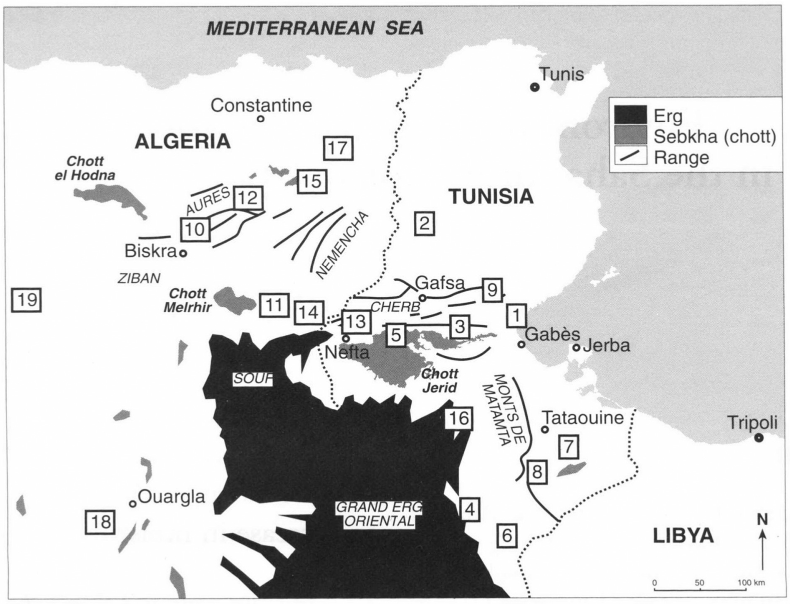

Fig. 1. Location map of Eastern Maghreb.
1. oued el Akarit; 2. Kasserine; 3. Bir Oum Ali; 4. Ez Zobbas; 5. Toumbar, An el Atrouss; 6. oueds Jenan, Makhrerouga et Abdallah, Graret Abdallah; 7. Smila; 8. Oued Bir el Amir; 9. chebket Ouknina; 10. oued Biraz; 11. erg el Oussif; 12. grotte Capéletti; 13. chott Rharsa; 14. chott Aslouch; 15. sebkhet Tarf; 16. Ksar Rhilane; 17. Medracen; 18. Sedrata; 19. Tahert.

2000). Also around 9300 BP, the aquifer of the Great Western Erg was approximately 50 m higher than today (Gasse et al., 1987). The increase in precipitation had started in earnest, but the annual total does not yet appear to have been greater than that of the present, at least in the Algerian–Tunisian pre-Sahara (*Fig. 2*).

Other data argue in favor of prolonged aridity, sometimes up to 8500 BP. Two Capsian sites take hold on the eolian sands of Bir Oum Ali (Ballais and Ben Ouezdou, 1992) (*Fig. 1*), accumulating two snaileries, one 14C–dated to 8260 ± 180 BP using snail shells (Harbi-Riahi, 1989). These Capsians almost exclusively consumed *Leucochroa candidissima*, which is still the main edible species alive today. On the foothills to the north and south of Ben Younès Jebel, to the west of Gafsa (*Fig. 1*), snaileries were also set up on the eolian sands. Although the mobility of these eolian sands cannot be totally excluded, these installations tend to prove that they were more or less set at that time, while they were still moving around 14,000 BP (Ballais and Ben Ouezdou, 1992; Ballais and Heddouche, 1997). In a contradiction with other data from southern Tunisia, the pollens from the Gulf of Gabès indicate prolonged aridity until 8580 ± 330 BP (Brun, 1979). In eastern Morocco, the start of the Lower Holocene appears to have still been arid (Damblon, 1989). This is also the case at Tarfaya, on the Atlantic coast, up until around 6000 BP (Weisrock and Rognon, 1977) and on the northern foothills of the High Atlas Mountains, where the brown eolian silt started to deposit before 8500 BP (Coudé-Gaussen and Rognon, 1993).

2.2. *The reappearance of lakes*

Recently, for the first time, Holocene paleo-lakes were identified in southern Tunisia (Ballais et al., 1995; Burollet et al., 1992; Petit-Maire et al., 1991), notably at Ez Zobbas, near Larich (*Fig. 1*). Here lived *Cerastoderma glaucum* dated to 8230 ± 70 BP.

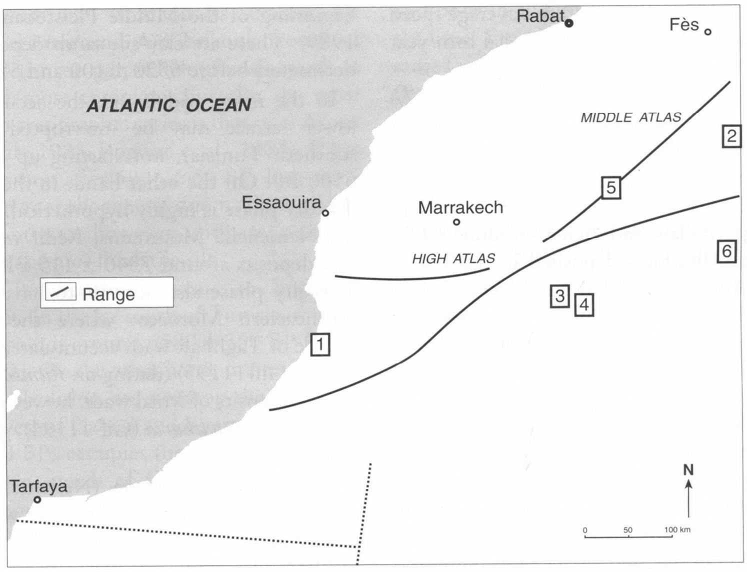

Fig. 2. Location map of Morocco.
1. Tiznit; 2. Ksabi; 3. Oued Taghbalt; 4. oued Mird; 5. Tigelmamine; 6. Sigilmassa.

This discovery fits in with the logic of the appearance and development of the many Holocene lakes containing *Cerastoderma glaucum* in the Sahara, although the lake at Ez Zobbas is about 1000 years younger than the closest lake, 100 km to the south in Libya (Petit-Maire and Delibrias, 1979). This confirms the highly particular situation of the lower Sahara, characterized by the absence of lakes. In the southern area, G. Aumassip (s.d.) long ago pointed out the absence of flooding in the sebbhas of Mya wadi and all research carried out in the Grands Chotts of Algeria and Tunisia have only led to the observation of a return of spring activity proved by the *Melanoïdes* at Toumbar and Aïn el Atrouss, 14C–dated between 9000 and 8500 BP after correction (Zouari, 1988). Recent research in the Souf (Ballais, 2001) confirmed this absence of lakes. These results should confirm that the moist pulse came from the south, from the tropics, and not from the temperate zone. Under this hypothesis, there would be a lag between the replenishing of the deep water tables and local precipitation. In this case, the optimum water period would have preceded the optimum climatic period.

Lakes also appear in central Maghreb, notably at Chergui Chott (Pouget, 1980), which is confirmed by a new date on *Cerastoderma*: 8150 ± 165 BP (Gasse et al., 1987). In eastern Morocco, in the Ksabi basin, they appear around 8500 BP (Lefèvre and Ballouche, 1991).

2.3. Accumulation of the lower terrace and elaboration of the Holocene glacis

Forty years ago, Coque (1962) proposed dating the elaboration of the glacis and the accumulation of the lower terrace in the Lower Holocene period (approximately 8400–7400 BP), in other words contemporary with the Capsians. Recent research has confirmed this attribution, in Tunisia as well as in Algeria and Morocco. At el Akarit wadi, the period between 9100 and 7690 BP is marked by strong water flows enabling the accumulation of the Holocene lower terrace, i.e. formation of Akarit II (Zouari, 1988). In the far south of Tunisia, the upper part of the terrace of Jenain wadi is dated at 7890 ± 90 BP and that of the Makhrerouga and Abdallah wadis at 8010 ± 160 BP In places which currently receive approximately 50 mm of rain a year, aquatic gastropods lived in the lasting puddles of fresh water, notably *Lymnea natalensis* and *Biomphalaria pfeifferi*

(Petit-Maire et al., 1991). This terrace's average speed of accumulation was approximately 1.4 mm/year (Ballais, 1991a).

The Holocene glacis (alias glacis 1 for Coque (1962)) sometimes cuts into the marls and clays of the substratum, but it usually developed in recent eolian deposits. Indeed, it generally cuts into the third generation of these accumulations between Gafsa and the Cherb Range (Ballais and Ben Ouezdou, 1992) and, further south, the loess deposited in the Upper Pleistocene, including in the Matmata Mountains. At Bir Oum Ali, it is punctuated with Capsian snaileries and, in Atra Jebel, many Neolithic sites are found on top of it. At Smila, northeast of Tataouine, it precedes an early Neolithic site (7636 ± 136 BP) (C 3575). Lastly, if we exclude the relief, it corresponds to the upper Saharan layer (precipitation between 150 and 100 mm/year) or to nearly all the Tunisian pre-Sahara.

Globally, therefore, water flows were once again very vigorous, efficient, sometimes as early as before 10,000 BP, notably in the Nemencha Mountains and around Biskra (Ballais and Heddouche, 1997). Although this change can only be interpreted, in relation to the high aridity of the Ice Age, as being due to an increase in local precipitation (*Fig. 2*), this precipitation must have been heavy enough to cause runoff on recently fixed dune sands. The general increase in rainfall is corroborated by palynological analyses (Brun, 1989).

2.4. A dry phase around 7500–7000 BP

In Tunisia, after 7690 BP, water flow in el Akarit wadi dropped off (Zouari, 1988). Notably, the last generation of eolian fossil sands is in place, between Gafsa and the Grand Chotts of Algeria and Tunisia (Ballais and Ben Ouezdou, 1992). It is at most 1 m of highly quartzous sand, with fine to medium grain, well sorted. To the south of these Grand Chotts (El Hamma de Gabès, behind Dahar; the Matmata Mountains), sheets of silty eolian sand, a few decimeters thick, have the same characteristics (Ballais, 1991a). Still farther to the south, this dry phase interrupted the accumulation of the lower terrace (Ballais et al., 1995).

In the Zibans, the sand accumulated on the foothills under the action of effective northwest winds, along a great northwest–southeast sweep from the Hodna basin to the Great Eastern Erg, an eolian flow that has worked during each dry period since at least the beginning of the Middle Pleistocene (Ballais et al., 1989). These are clay-silt sands deposited over a few decimeters before 6320 ± 100 and 5790 ± 140 BP.

In the more arid layers, the accumulation of the lower terrace may be interrupted locally (Ziban, southern Tunisia), not starting up again until after 6500 BP. On the other hand, in the semi-arid layer, this dry phase is highly hypothetical. For example, in the Nemencha Mountains, Rédif wadi accumulated fine deposits around 7340 ± 115 BP (Ballais, 1976). This dry phase also appears to have been absent in southeastern Morocco, where the sand-silt lower terrace of Taghbalt wadi accumulated around 7225 ± 80 BP (Gif-11195) (dating on *Rumina decollata*). The fluvial deposits of Mird wadi, however, dated to 6290 ± 75 BP on *Aspatharia* (Gif-11194), gullied the eolian sandstone.

Higher up in altitude (Nemencha), the alluvial accumulation of gravel and pebbles with intermediate strata of angular blocks marks the return of mechanical fragmentation and, probably, of gelifraction due to the continued low temperatures (Ballais, 1976).

This dry phase also stands out in the moisture layers, for example at Tigelmamine, where the lake presents low levels around 7000 BP (Lamb and van der Kaars, 1995).

3. Middle Holocene (7000–3700 BP?): optimum climatic period?

The Middle Holocene is marked by the end of the accumulation of the lower terrace, the development of pedogenesis and the abundance of the water flow in streams and rivers. It is also the major period of development of Neolithic cultures.

3.1. The end of the accumulation of the lower terrace and the spread of Neolithic cultures

The return of moisture conditions than at present was marked as early as 7026 ± 175 BP in the terrace at Bir el Amir wadi, south of Tataouine, by the appearance of *Eobania vermiculata*, a species that is unknown at this latitude today and which is adapted to greater rainfall than the current low levels (less than 100 mm/year).

Generally, the end of the accumulation of the lower terrace comes after the Capsians and is contemporary with the Neolithics who lived on its summit, for example at Bir el Amir and Aïn Edkouk (south of Tataouine), or in the top part (Hallouf wadi, north of Tataouine). The most complete, but also the most complex, chronostratigraphic series is that of el Akarit wadi (Fontes et al., 1983; Rognon et al., 1983). It has a gypseous crust soon after 5995 ± 50 BP, indicating a phase of eolian morphogenesis due to drying. The accumulation continues, however, until around 3680 ± 160 BP, in the form of fluviatile silt.

Latitudinal differentiation appears to begin to become prevalent. In the far south of Tunisia, the end of the accumulation is around 6580 ± 350 BP (Petit-Maire et al., 1991). On the other hand, in pre-Saharan Tunisia, an epipaleolithic site sits atop the terrace of Seradou wadi (west of Gabès) and a very late Capsian site (6750 ± 130 BP) occupies the summit of that of Ouknina Chebket, north of Gabès (Ballais, 1973). Further to the southeast, a terrace at Mdou wadi is dated to 5195 ± 105 BP (Steinmann and Bartels, 1982). More generally, in the Saharan Atlas of eastern Algeria, the epipaleolithic sites in the lower terrace are often rearranged (Ballais and Roubet, 1981–1982).

In the Feija of southeastern Morocco, at least 50 cm of alluvial silt was deposited after 6645 ± 83 BP (dated on *Rumina decollata*). On the Moroccan coast, near Essaouira, Ksob wadi accumulated sand and brown silt around 4950 ± 120 BP (Weisrock and Rognon, 1977). On the southern foothills of Aurès, Biraz wadi once again accumulated fine sands and clays with a prismatic structure in 5470 ± 180 BP (Williams, 1970).

At the time, water flows were slow and regular, rearranging mainly the fine deposits. They were controlled by a climate that was cooler and more moist than today, especially in summer.

3.2. Stabilization of slopes and development of pedogenesis

Neolithic populations moved into the eolian sands which has progressively stabilized and pedogenesis developed, including inside the Great Eastern Erg, to the west of Nefta.

At Morra Jebel, in the Cherb range (Ballais and Ben Ouezdou, 1992), as well as in the Ziban, in Algeria (Ballais et al., 1989), the soils reach several decimeters in depth, with a structure that is lumpy (probably due to bioturbation by earthworms) to prismatic and rich in Fe_2O_3, $CaCO_3$ (sometimes in the form of nodules) and poor in sulfates. The paleosoils with *Helicella* at el Oussif Erg (*Fig. 1*), a bit further north, present the same features and are poorly dated to 5930 ± 1780 BP (Ballais, 1992b). Quite comparable to the present-day soils in the Ziban (Ballais et al., 1989), they were formed in the arid layer of the Mediterranean climate, while they now occupy the Saharan layer.

The associated Tunisian Neolithic deposits are dated to 5858 ± 66 and 5930 ± 87 BP (Ballais and Ben Ouezdou, 1992). The populations of the day preferred to consume *Helix melanostoma*, which today is found only in the more moist layers.

Further to the south, and on a highly gypseous substratum notably at the summit of the lower terrace, soil developed, now forming hard gypseous crusts, for example along Bir el Amir wadi or along Jenaïn wadi (Petit-Maire et al., 1991). They are typical of the Saharan layer and thus confirm that, during the Middle Holocene, the current zone distinctions existed, but with a shift several ten kilometers to the south, leading to the doubling of the total annual rainfall in the Saharan far south of Tunisia.

Further to the north, at a higher altitude, brown soils were formed on the slopes and vertic soils in poorly drained depressions (Nemencha, Aurès).

Unlike the runoff that created the lower terrace and the glacis, these soils presuppose balanced geosystems, long-term stability of the topographic surface permitting the development of relatively dense vegetation, notably *Cedrus* which has disappeared today (Couvert, 1972). Thus, the seasonal distribution of precipitation was better than during the Lower Holocene and was accompanied by less intensity (*Fig. 2*).

The Helicide fauna in the Ziban (Ballais et al., 1979) and the palynoflora of the Aurasian Neolithic site of Capéletti Cave (Roubet, 1979) confirm that the average annual rainfalls were much heavier than today.

3.3. Proof of greater water flow

The accumulation of the lower terrace is not the result of a simple increase in the solid loads in the wadis. The sedimentology of this terrace shows that the regime in the wadis improved. Hydromorphic traces become more abundant: pseudo-gley and accumulations of MnO_2 (Hallouf wadi) and fine, well-banded aquatic gypsum deposits (Bir el Amir wadi, el Akarit wadi). Locally, swamps may appear, at el Akarit wadi until around 5995 ± 500 BP, and at Bou Zayane wadi, west of Gafsa. More generally, water flow is stronger: for example, flow rates at el Akarit wadi increased after 3910 BP (Zouari, 1988), Jenaïn wadi, blocked today by a dune plug upstream from the Jenain Bordj, flowed all the way to the Great Eastern Erg and Abdallah and Makhrerouga wadis built up a travertine, perhaps around 6970 ± 70 BP (Petit-Maire et al., 1991). In the semi-arid layer of Aurès and Nemencha, many wadi became lasting rivers (Ballais, 1992b).

Lastly, it is highly likely that, at this time, the aïouns (i.e. springs), now fossils in the southern part of Rharsa Chott (*Fig. 1*), were flowing for the last time. Indeed, they are accompanied by pedogenetized sheets of eolian sand and Neolithic industries involving *Leucochroa candidissima* comparable to those of the nearby fixed dunes of the same period.

4. Prehistoric Upper Holocene: progressive drying of the climate

This period remains poorly understood and chronological uncertainties persist, for two reasons. The first is the rarity of deposits or forms between the lower terrace, or Middle Holocene soils, and the very low terrace. The second, partially related to the first, is the almost complete absence of dating for this period, be they isotopic datings or archeological ones, given the non-existence, except for part of Morocco, of the Chalcolithic and Bronze Age (Aumassip, 2001).

The beginning of aridification is traditionally dated towards 4500–4000 BP (Ballais et al., 1979; Simone, 2000). This chronological attribution remains valid in Aurès, where the deposits, paleofauna and paleoflora of Capéletti Cave, make it possible to suggest the dates of 4670 ± 130 or 4340 ± 200 BP (Roubet, 1979), but some 200 km to the east, Chéria-Mezeraa wadi continued accumulating its lower terrace. On the other hand, in the far south of Tunisia, the most recent spreading of *Helicella* sp. at Graret Abdallah stopped early, around 5640 ± 100 BP (Petit-Maire et al., 1991). In the Great Western Erg, approximately 4000–2800 BP, all environmental indicators show very strong and variable fluctuations in the salinity of the ponds, which were shallow, salty and permanent, probably without vegetation (Gasse et al., 1987).

4.1. Cuts in the lower terrace

It appears certain that there was a progressive change in the fluvial morphogenesis: little by little, in all the wadis, the lower terrace was cut into at an average speed of 1.2 mm/year (Ballais, 1991b). Locally, and at a medium altitude, in Nemencha (Chéria-Mezera wadi, Rédif wadi), the major fine deposit was cut open by a channel, later filled in by pebbles which overflow onto the lower terrace (Ballais, 1976). Quite probably, this reversal corresponds to the aridification of the climate (Brun, 1989).

4.2. Return of mechanical fragmentation

Above 1700 m, thin taluses of scree with a brown silty matrix cover the older scree of Aurès and Nemencha. This slight renewal of mechanical breakdown and gross accumulation is mainly due to the thinning of the plant coverage due to the increased drought and, perhaps, deforestation (of which we have no proof) by transhumant shepherds living there since the Neolithic (Ballais, 1992b).

4.3. Development of eolian action

In general, climate aridification is not enough to cause sands to become mobile again under the wind: the considerable aridity of the Ice Age was never reached. And yet, in Tunisia, in the Rharsa and Aslouch Chotts, the bottoms of the sebhas dated to the Middle Holocene are now in inverted relief, 1.5–2 m above the current bottom, due to later eolian deflation and corrasion. At Rharsa Chott, it is hard to determine the two eolian phases of the Upper Holocene because deflation and corrosion are still highly effective today (Ballais, 1992b).

4.4. A moisture phase (around 3300–3000 BP)

In Tunisia, el Akarit wadi still had heavy water flow up until about 3000 BP (Zouari, 1988), which is in agreement with the prolonged buildup of terraces further to the north, in the arid or semi-arid layer (Lubell et al., 1976) (cf. below).

In Algeria, the level of the aquifer of the Great Western Erg was, at least between 9300 and 3000 BP, approximately 50 m higher than it is today (Gasse et al., 1987). Further to the north, in the Zibans, paleosoils were formed, either on eolian sand sheets as at Seifoun Jebel (dated on *Helix*: 3100 ± 55 BP (Gif-

9475), or in the lower terrace of Selga Seghir wadi (dated on charcoal: 3300 ± 70 BP (Gif-10989) (Benazzouz, 2000). These paleosoils can be seen all the way into the semi-arid layer, inter-stratified in the rim of Tarf sebbhet and dated to 3580 ± 80 BP (Benazzouz, 1986). These paleosoils may then have been cut by intense runoff, as at the foot of Ahmar Jebel (M'Doukal region) before 2840 ± 40 BP (Gif-9869 dating on ostrich egg shells).

4.5. A dry phase around 2900–2500 BP

There were hints of this phase in southern Tunisia and in the Zibans (Ballais, 1992b) but, lacking dating, it remained uncertain. It has recently been confirmed in the Zibans (Benazzouz, 2000). Three datings were obtained in the eolian sands: 2840 ± 40 BP on ostrich egg shells (Gif-9869) at Sahbana Jebel, 2790 ± 95 BP on *Helix* at Fozna Jebel (Gif-9876) and 2660 ± 45 BP on ostrich egg shells at Fennd el Baroud (Gif-9872).

5. Historical Upper Holocene

5.1. The moist episode from 2400 to 2200 BP and the Numidian kingdoms

At Ksar Rhilane, southwest of the Matmata Mountains, in the middle of the first barkhanes of the Great Eastern Erg, a few decimeters of sand, silt and clay with fluviatile bands were deposited. Their sedimentological, granulometric and geochemical features (Ballais, 1992a) indicate that they were deposited by floods causing the formation of swamps between the dunes of the Erg. *Helicella*, dated to 2380 ± 155 BP (C 3594), lived in the nearby Graminaceous plants, whereas today they live several ten kilometers further north, under moisture weather conditions.

Another proof of the new abundance of water in the depressions is supplied by the accumulation of gyttja in Rharsa Chott in 2420 ± 155 BP (Scharpenseel et al., 1984).

In the Ziban, the eolian sands deposited during the previous dry period are usually cut into by rolling pebbles recently dated at 2450 ± 40 BP (Gif-9474) on ostrich egg shells on the north side of Foum ez Zgag Jebel and 2290 ± 60 BP (Gif-9871) on *Helix melanostoma* at el Ogla wadi (Benazzouz, 2000).

In the Nemenchas, at medium altitude, the fine upper face of the lower terrace was deposited (Ballais, 1992b). Maximum moisture may have been reached with the development of soil at the summit of the terrace of Regada wadi, around 2590 ± 90 BP and at the summit of the terrace of Chéria-Mezeraa wadi, around 2270 ± 80 BP (Farrand et al., 1982).

This is when the Numidian kingdoms of Algeria developed, one of the most spectacular remains of which is the Medracen, a tomb build in the northern foothills of the Aurès (*Fig. 1*).

5.2. Accumulation of the main very low historical terrace and Roman colonization

The historical terrace is less well developed in southern Tunisia and even in Libya (Ballais, 1991b) than in the center and north of the eastern Maghreb. Quite often, the previous cuts continued to grow in the Lower Holocene terrace, with no letup for backfill, especially along the secondary wadis.

On the other hand, along the larger wadis, a very low terrace fit into or overlapped the first. In this case, the base is often coarse and the summit part is finer, usually sandy. Its historical age is proven by the presence of shards of Roman ceramics (Ballais, 1991c). It disappears in the far south of Algeria and Tunisia.

In some cases, infrequently, the alluvial sheet left its deposits directly on the prehistoric Holocene alluvial sheet, notably along Chéria-Mezeraa wadi, filling in the ancient irrigation channels and dated to 1350 ± 70 BP (Farrand et al., 1982). This gave a few decimeters of rocky silt from a generalized phase of surface reorganization affecting prehistoric Holocene sites and the glacis covering, as well as the surface soil removal during the Roman period, such as that dated to 1730 ± 185 BP.

At el Akarit wadi, the very low main historical terrace dates to 1470 ± 185 BP (Page, 1972).

The "silt of the palm groves" was deposited then, or at least the summit part: that which accumulated on the left bank of Biskra wadi covered the Roman town of Vescera.

The problem of the genesis of this very low historical terrace, quite common around the Mediterranean (Vita-Finzi, 1969) is posed in radically different terms than that of the older forms, as it is necessary to envisage the role of man-caused factors (notably the expansion and modalities of land occupation). This necessity is reinforced by the high average speed at which this terrace accumulated: 7.4 mm/year, i.e. approximately five times faster than the lower terrace (Ballais, 1991b). More precisely, in the eastern Maghreb, and for the first time, all land that was arable using the techniques of the time appears to have been more or less cultivated at the end of the 2nd century and beginning of the 3rd century of our era. In morphogenic terms, this means that the imbalance due to the human influence on the geosystems affects surface areas that had been left untouched until then. Thus, a small fluctuation in the climate could have been enough for the morphogenic system to be knocked off balance as a whole, so that the accumulation of alluvial deposits replaced the gullying of the beds (*Fig. 3*). A small climatic pulse could be imagined in the form of heavier rains which have even more of an effect since farming would have destroyed soil cohesion, thus facilitating rain erosion, notably on slopes (Ballais, 1995). The absence of this terrace in the Saharan layer section which had not undergone Roman agricultural colonization is another argument in favor of this explanation.

5.3. Cuts into the very low terrace

After this episode of accumulation, the generalized vertical cut started backup at the considerable minimum average speed of 3.2 mm/year (Ballais, 1991b) and continues to this day in the most arid layers.

5.4. Accumulation of the very low post-Islamic terrace, the Arab invasions and the sedentary occupation of the northern Sahara

In a few rare cases (mountain valleys, el Akarit wadi), a new terrace may stand out below the previous one. It covers very small surfaces, notably in the convex lobes of meanders, and barely dominates the minor bed by 2 m. Its faces are comparable to those of the main very low terrace. Its age can rarely be determined with precision, except for el Akarit wadi where it is dated to 610 ± 110 BP on collagen (Fontes et al., 1983).

As for the previous terrace, the presence of comparable alluvial deposits all around the Mediterranean (Vita-Finzi, 1969) encourages us to attribute its genesis to a small climatic fluctuation. This attribution is strengthened by the fact that the deposit took place approximately two centuries after the Hilalian invasion which could have caused a contraction of farmed territories, hardly favorable to an increase in rain erosion on cultivated soils (Ballais, 2000). The agricultural re-colonization after this invasion, which is not well understood, does not appear to have been very important. Additional research will be needed to clarify the origin of this terrace.

This period saw the completion of the sedentary occupation of the Algerian lower Sahara with the creation of Sedrata (*Fig. 1*) and the first towns in the Souf. It is also when trans-Sahara trade took off, first to the west from Sigilmassa (*Fig. 2*), then in the east, from Tahert. During this period, after the Arab conquest, date-palm production developed very quickly, at the expense of the old grain crops (Baradez, 1949; Trousset, 1986) and the southern foothills of the eastern Saharan Atlas became a major date-producing region. *Phoenix dactylifera* being a phreatophyte of the arid layer, its development, if not purely socio-cultural in origin, would be the sign of a cooling and/or moistening of the climate.

5.5. Renewed movement of eolian sands, the Little Ice Age, French colonization and independence

Recently, and increasingly, the sand of the dunes and watered slopes has begun to move again with an intensity never seen since the Ice Age. This movement, which in places has been happening for less than 30 years, is certainly related to the later contemporary aridification of the European Little Ice Age. In Tunisia, however, climatologists have been discussing the significance of the increase in the average annual precipitation during the 20th century (Bousnina, 1986). Notably, desertification is progressing from farmed fields, wells and villages, including in places where the average annual precipitation exceeds 100 mm/year (Benazzouz, 2000; Benmohammadi, 2001).

6. Conclusion

It thus appears that the moist phase of the Lower Holocene came early and that aridity tended to disappear in the Late Ice Age. From this point of view, the chronology of the pre-Saharian Maghreb is considerably closer to that used for the tropical Sahara. Along the same lines, the short arid phase around

Isotopic chronology (14C B.P.)	Climate - +	Land use	Morphogenesis
(30) ?	C	DESERTIFICATION	WIND EROSION
			SHIFTING SANDS
		Independences	INCISION
		FRENCH COLONIZATION	
610 +/- 110			Terrace
		ARAB COLONIZATION	
		Byzantine conquest	
1 470 +/- 190		Vandal conquest	Aggradation
1 850 ?			VERY LOW TERRACE
			AGGRADATION
		ROMAN COLONIZATION	
2 270 +/- 80			Pedogenesis
2 380 +/- 155			Floods deposits
2 420 +/- 155			Gyttja
2 450 +/- 40		Numidian Kingdoms	Very low glacis
2 660 +/- 45		Neolithic	Shifting sands
2 790 +/- 95			" "
2 840 +/- 40			" "
3 100+/- 55		Phenician arrival	Pedogenesis
3 300 +/- 70			"
			Deflation - INCISION
3 680 +/- 160			Low terrace aggradation
4 220 +/- 50			" " "
4 340 +/- 200		Neolithic	
4 670 +/- 130		"	
4 950 +/- 120			" " "
5 195 +/- 105			" " "
5 470 +/- 180			" " "
5 640 +/- 100	C ?		Flood deposits
5 858+/- 66		NEOLITHIC	PEDOGENESIS
5 930 +/- 1780		NEOLITHIC	"
			Gypcrete
5 995 +/- 50			Pond
6 290 +/- 75	C		"
6 320 +/- 100			Pedogenesis
6 645 +/- 83			LOW TERRACE
			AGGRADATION
6 750 +/- 130		CAPSIAN	
6 970 +/- 70 ?			Travertine
7 026 +/- 175			LOW TERRACE
			AGGRADATION
7 225 +/- 80	C		"
			SHIFTING SANDS
7 636 +/- 136		Neolithic ?	
			LOW GLACIS
7 890 +/- 90			LOW TERRACE
			AGGRADATION
8 010 +/- 160			"
8 150 +/- 165			LAKES
8 230 +/- 70			"
8 260 +/- 180		CAPSIAN	
	C		"
9 290 +/- 120			Travertine
10 510 +/- 349		CAPSIAN	FIXED DUNES
	CC	BLADELET CULTURES	SHIFTING SANDS

Fig. 3. Morphoclimatic and land use evolution during the Holocene period. Climate: more or less humid than the present day; CC: cold, C: cool.

7500–7000 BP is similar to what has been observed in the Sahel.

On the other hand, concerning the importance of the moist phase after 7000 BP, we must look toward the European Atlantic chronology. Along the same lines, the accumulation of the lower terrace appears for the most part to be contemporary to the "main Holocene fill" of the southern French Alps.

For the Prehistoric Upper Holocene, the tropical Saharan chronology becomes evanescent, due to the increase in aridity. Clues indicating a more moist climate than today have been found, however, for around 2000 and 1500 BP, in different spots in the Sahara, notably around Tibesti and in Sudan. Furthermore, the small amount of evidence currently recognized in the pre-Saharan Maghreb is not yet sufficient for a systematic comparison with the European chronology, although the clues are promising.

Lastly, throughout the Holocene period, the current zone organization appears to have been in place, even if it underwent latitudinal fluctuations: the Saharan layer is characterized by eolian sands and the accumulation of gypsum, the arid layer by accumulation of gypsum, the semi-arid by that of carbonates and the sub-moist layer by leaching and the concentration of iron and even alumina and silica (Ballais, 1993). Lastly, the pre-Saharan Maghreb is a privileged area which should enable us to develop post-Ice Age chronologies for the temperate zone and the tropical zone of the European–African longitudes.

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