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HOLOCENE DEPOSITS IN THE LOWER SECTION OF THE ASSAKA WADI, SOUTH MOROCCO: PRELIMINARY RESULTS

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ABSTRACT

At the southern side of the Anti-Atlas mountains, the lower section of the Assaka wadi valley joins the Atlantic ocean by crossing an Appalachian basin and range area. Holocene deposits of the lower section of the Assaka wadi show two main sedimentary formations: the upper sheet-fans and the lower terraces. The upper sheet-fans are probably from the lower Rharbian (Holocene) age, they are located above the Soltanian (Würmian) formations at the outlets of tributaries. They consist of accumulations with silts, aeolian quartz and high palygorskite contents. After this period, a trench cut through the older formations took place between 8 000 years BP and 4 200 years BP. The lower river terraces, 5 to 11 metres thick, are inset in the trench cut through the Soltanian formations and show four superimposed and fining upwards (from pebble to silt) cross-bedded units. This study shows many geodynamic and palaeoclimatic conditions. Lower Rharbian fans indicate that the climate was sufficiently arid to denude the slopes, where, during big storms, gullies and run-off supplied the Assaka wadi with silts and sands. Torrential floods cut the Soltanian formations and then created the Middle Rharbian low terrace. Finally, the Historic terrace, superimposed onto the Middle Rharbian one, shows that important flood events took place during the XVII^e and XVIII^e centuries, but nevertheless with low frequency. However, this sequence indicates wetter conditions during an arid episode. The ¹⁴C age is contemporary with the "cold winters" in Western Europe ; this fact proves that the synoptic conditions in South Morocco were the same at 280±30 years B.P. as at present.

Key-words: Arid zone, Morocco, Holocene, alluvial terraces, fluvial geodynamic, stratigraphy, palaeoclimatology.

RÉSUMÉ

LES DÉPÔTS HOLOCÈNES DE LA BASSE VALLÉE DE L'OUED ASSAKA, SUD-MAROC : RÉSULTATS PRÉLIMINAIRES

L'oued Assaka, exutoire d'un vaste bassin versant (7 000 km²) rejoint l'océan Atlantique sur le versant sud de l'Anti-Atlas en recoupant une zone de relief appalachien. Des cônes attribuables au Pléistocène supérieur ou au Rharbien ancien (Holocène ancien) surmontent les formations alluviales et colluviales soltaniennes (Würm), avant que celles-ci soient entaillées sur 20 à 25 mètres ; ils sont circonscrits aux débouchés des fousms que déterminent les affluents de l'oued Assaka. Ils sont constitués de limons sableux riches en grains de quartz éolisés et par des teneurs en palygorskite qui s'accroissent de la base vers le sommet. Aux environs de 8 000 BP, une phase d'incision linéaire importante entailla les dépôts plus anciens sur une épaisseur de 20 mètres. De basses terrasses sont emboîtées dans les dépôts soltaniens. D'une épaisseur variant de 5 à 11 mètres, elles sont constituées de séquences granoclassées qui mettent en évidence des géodynamiques et des ambiances climatiques contrastées. Le Rharbien ancien reflète une sécheresse suffisante pour dénuder en partie les versants, qui lors d'orages probablement assez localisés, alimentent les affluents de l'oued principal en limons sableux. Les crues torrentielles (charriant des blocs surdimensionnés) ont incisé les formations soltaniennes -essentiellement limoneuses- et ont mis en place les basses terrasses du Rharbien moyen. Enfin, la terrasse historique étagée sur celle du Rharbien moyen montre la permanence de crues importantes durant les XVII^e et XVIII^e siècles avec une fréquence cependant moins élevée. En outre, cette séquence indique l'existence de conditions humides durant un épisode aride sous cette latitude contemporaines des "hivers froids" de l'Europe de l'Ouest ; ce qui prouve que les situations synoptiques dans le Sud du Maroc étaient les mêmes à 280±30 ans BP qu'aujourd'hui.

Mots-clés : Régions arides, Maroc, Holocène, terrasses alluviales, géodynamique fluviale, stratigraphie, paléoclimatologie.

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INTRODUCTION

The Assaka wadi or Noun wadi, 250 km to the South of Agadir, is the main river of a 7 000 km² watershed which enters the Atlantic ocean by crossing the Georgian and Acadian basin and range area, on the southern side of the Anti-Atlas mountains (Pique, 1994). The lower section extends from the "feija" (= longitudinal depression of structural origin developed into an appalachian relief) of Goulimine to the Atlantic Ocean. In this region, gorges alternate with small basins (fig. 1). Thick Pleistocene and Holocene superficial formations (Wengler *et al.*, 2002), mainly from colluvial and alluvial origins, are well recorded despite the significant and present erosion. Five sites were studied to characterize the Holocene deposits (from upstream to downstream): the cote 102, the cote 65, the cote 23 at Sidi Messaoud and Fom Assaka (fig. 1). They represent the basis for the first observations of the Holocene formations of the Assaka wadi and will be compared to the Holocene data of the arid and semi-arid Morocco and Maghreb.

The terraces were analysed by using different methods. At first, stratigraphic sections were made at each site, in keeping with the International stratigraphic Guide (Hedberg, 1976). Units were delimited and divided into many series according to structure, texture, colour, transition between the layers (discordance or progressive transition) and palaeontologic contents of the sediments. Then for each series, 200 g of sediment was taken with the aim of doing sedimentological analyses. During the sampling, charcoal fragments were searched to date the formation by ¹⁴C. Laboratory analysis of the sediment samples included detecting the grain-size distribution of each sample with a Laser Particle Sizer and observing the sediments with a mineragraphic microscope to complete their description (structure, texture, mineral contents etc.), and to analyse the quartz facies to detect pedogenesis features, marks of aeolian activity or even of fluvial activity. These methods allowed us to differentiate the different terraces in the lower section of the Assaka wadi.

1 - PRESENT BIOCLIMATIC CONDITIONS

A - CLIMATIC AND HYDROLOGIC CONDITIONS

The lower section of the Assaka wadi is under the influence of an arid climate on the Northern margin of the Sahara. The average annual rainfall is about 100 mm with significant irregularity in the distribution. Effectively, there is a maximum in December, followed by a secondary maximum in March. These two maxima coincide with a decrease in the upwelling system, which is nevertheless strong in this southern area and on a decrease in the Azores High and the Canary Islands anticyclones. Generally, meridian polar air incursions are common in March in the temperate latitudes over the Atlantic Ocean and western European coasts. In Maghreb, they generate unsettled weather with frequent and sometimes heavy rainfall events. They are able to regenerate the Canary Islands depression and to provoke rainfall in Southern Morocco. Moreover, oceanic influence is felt in the lower valley, especially in summer, and is characterized by the

arrival of maritime air advections. Fog and stratus are often observed. They are concentrated above an altitude of 400 metres. A cooling down of the air mass coming from the Azores anticyclone develops these two types of cloud. Effectively, in contact with the cold coastal Moroccan waters or by humidification of banks of clouds, the condensation point is quickly reached, lower stage clouds appear and are blown towards the continent by a West-Northwest maritime breeze.

The occult rainfall, a consequence of these frequent maritime influences, is essential to the vegetal cover of this arid zone. Indeed, plants benefit from a complementary water supply.

The hydrologic conditions do not reflect this lack of rainfall. In effect, the Assaka wadi is perennial most of the year thanks to karstic exurgences coming from the deep karst system developed in the Georgian limestones and the Acadian schists of the Goulimine feija (Dijon, 1966; Oliva, 1978). The phenomenon fills gueltas (marshes) between which the flow is limited during the drier season (from spring to winter). However, in winter, when rainfall exceeds 10 mm per day, floods occur. This rainfall is often very localized and often corresponds to storms. The floods are also concentrated in the main tributaries that furnish the main part of the Assaka wadi flows. Nevertheless, when rainfall extends over the entire watershed, all the channels are in spate and longitudinal floods dominate.

B - THE FLORA

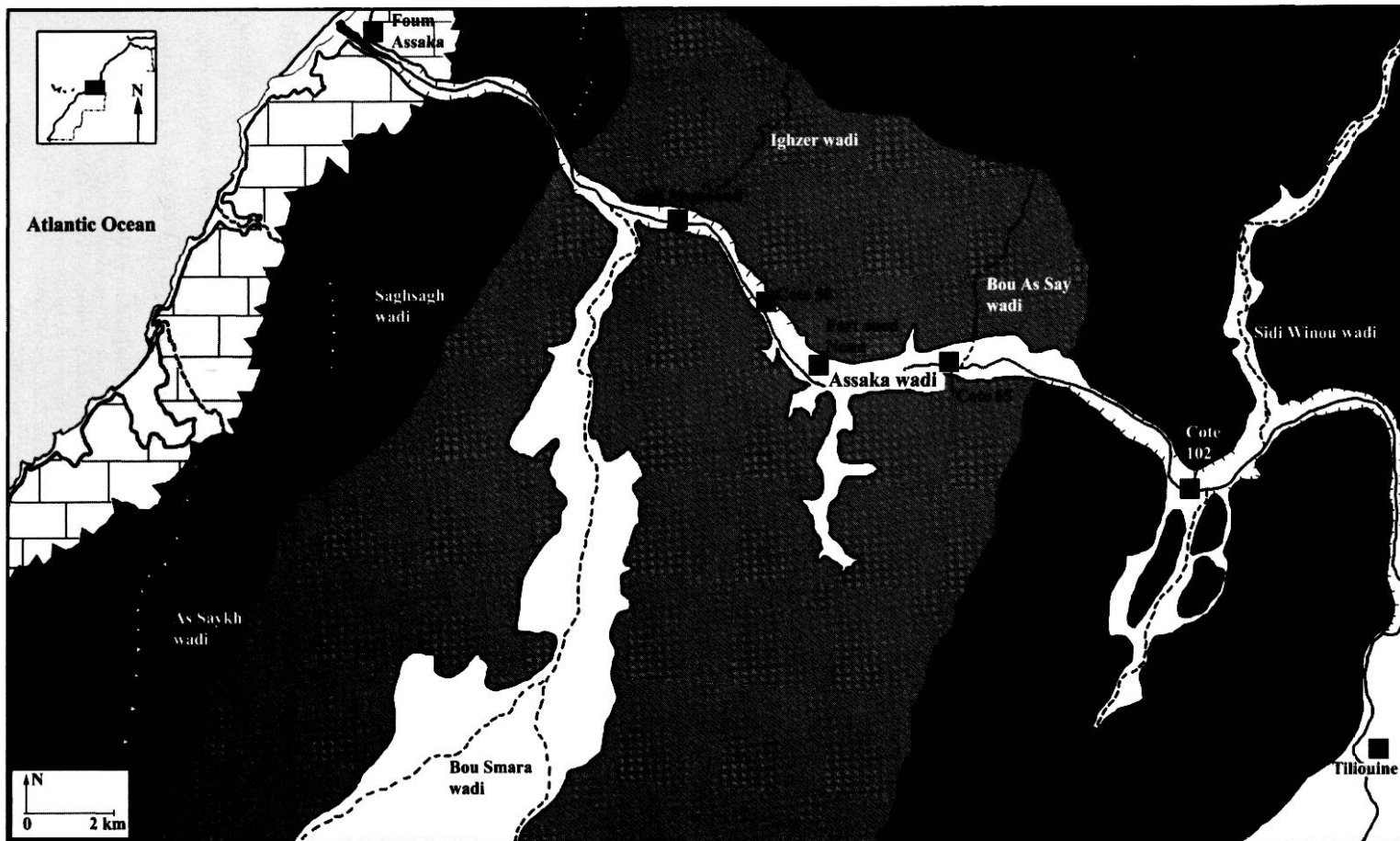
Climatic conditions, and especially summer fog, favour the development of a semi-arid Euphorbiaceous steppe along the lower section of the Assaka wadi, dominated by *Euphorbia echinus*, *Euphorbia Regis jubae* and *Senecio Anteuphorbium* (Peltier, 1982). This steppe is the degraded form of the "Argania clear forest", which has been cut by Man since historic times (TARRIER and Benzyane, in press). In the present mean-water bed of the Assaka wadi and its main tributaries, or sometimes close to the gueltas, a well-developed riparian forest with *Tamarix*, *Nerium oleander*, *Acacia gummifera*, *Argana spinosa* and *Nicotiana glauca*, takes advantage of the perennial flows of the karstic exurgences to grow.

C - MICRO-MAMMAL FAUNA

Present micro-mammal fauna was partly studied on the left bank of the channel of the Assaka wadi at Sidi Messaoud and, near the cote 65 (fig. 1), at the top of the Soltanian terrace. Five species were identified : three rodents, respectively *Gerbillus cf. campestris*, *Meriones sp.* and *Eliomys quercinus*, a macroscelideous species, *Elephantus rozeti* and an insectivorous species, *Crocidura sp.* This association confirms the climatic and biogeographic conditions described above : a mineral and arid environment.

2 - HOLOCENE FORMATIONS OF THE ASSAKA WADI

Holocene deposits occupy two different morphological situations. At first, the older overlies the Soltanian (=Würmian) terrace (fig. 2). Then, the inner terrace of the



1. Lithology :

- Middle Cambrian (Acadian) : Schist and sandstone of the feijas.
- Lower Cambrian (Georgian) : Schist and breccian and dolomitic limestone.

2. Land forms :

- ▲ Hogback.
- ▲ Fault-controlled scarp and fault scarp.
- ▬ Gorge.

3. Plio-Pleistocene and Pleistocene formations :

- alluvial and colluvial deposits.
- ▲ Moghrebian abandoned cliff.
- ▬ Moghrebian rasa.
- ▬ Present shore cliff.

4. Hydrography :

- Perennial wadi.
- Ephemeral and tributary wadi.

5. Sites :

- Studied site.

Fig. 1: Geological map and location of the main studied sites of the lower section of the Assaka wadi.
Fig. 1 : Carte géologique et localisation des principaux sites étudiés dans la basse vallée de l'oued Assaka.

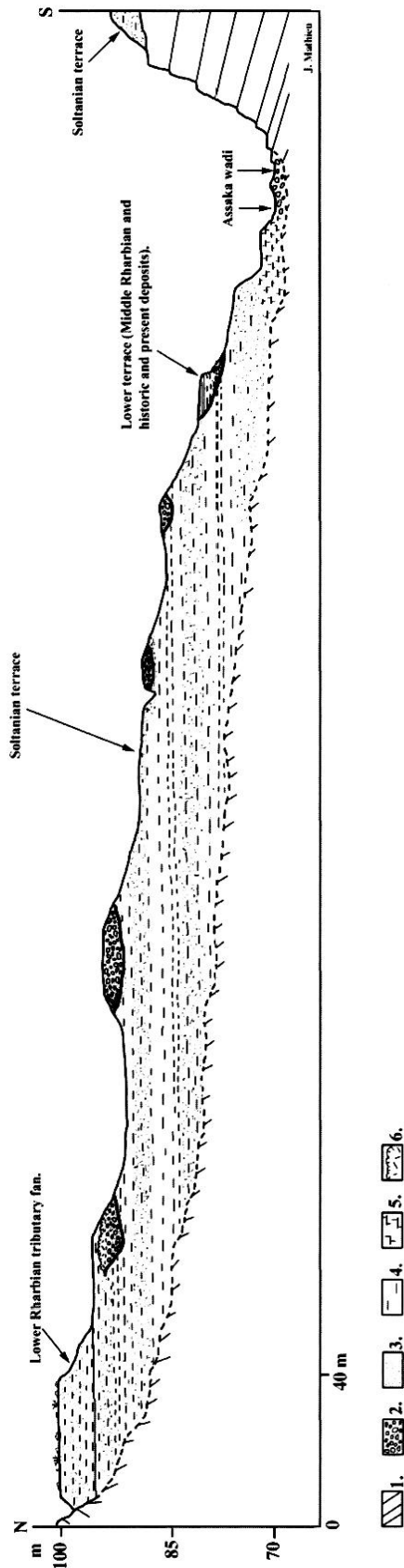


Fig. 2: Situation of the different Holocene formations in the lower section of the Assaka wadi upstream cote 65. 1. Acadian schists, 2. Pebble sheet, 3. Sand, 4. Silt, 5. Carbonated silt, 6. Travertine.
Fig. 2 : Situation des différentes formations holocènes de la basse vallée de l'oued Assaka à l'amont de la cote 65. 1. Schistes acadiens, 2. Nappe de galets, 3. Sable, 4. Limon, 5. Limon carbonaté, 6. Travertin.

Holocene is inset in the trench cut through the Soltanian formations, one metre above the present mean-water bed of the Assaka wadi. Finally, present and historic deposits are superimposed on the top of the inner terrace. The deposits comprise two main forms in the present valley : adjacent fans at the top of the Soltanian terrace and inner lower terraces above the present channel of the Assaka wadi.

At the top of the Soltanian terrace, near the valley slopes on both sides of the Assaka wadi tributaries, three to four metres thick fans are well-developed in the landscape. They are today eroded by gullies and run-off and form badlands. They are localized at the confluence of the Assaka wadi and its main tributaries. This fact proves that they result from dominant lateral flows coming from the affluents. We have not observed discordant transition between the Soltanian deposits and this unit (fig. 3). Furthermore, the tributary fans are made of sub-horizontal beds as in the older fluvial formations. Sometimes, alluvial or marshy deposits, situated at the same altitude, are probably contemporary with these adjacent fans and have been preserved from erosion (fig. 4). They are perhaps their lateral equivalents. This is the situation at the cote 102 (fig. 4) where they are stepped on channel and bench facies (fig. 4).

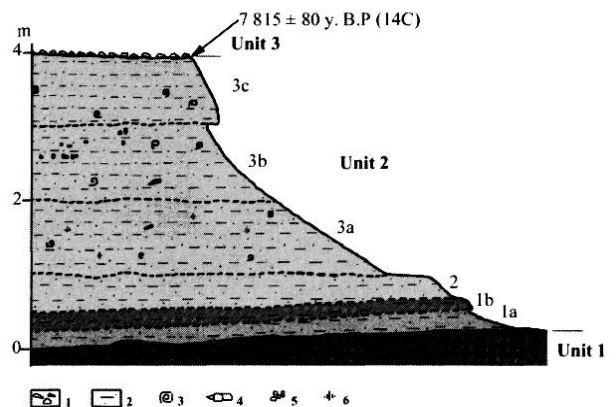


Fig. 3: Stratigraphic section of the cote 65 fan.

1. angular schist stones, 2. sandy silts, 3. *Otala* sp., 4. *Rumina decollata*, 5. calcareous nodules, 6. carbonated marks.

Unit 1: Soltanian (Würmian) terrace, Unit 2: Lower Rharbian (Holocene)- tributary fan.

1a: 30 cm thick medium sandy silt strong brown (7,5 YR 5/8),

1b: 20 cm thick medium silt reddish yellow (7,5 YR 6/8),

2: 50 cm thick medium sandy silt yellow red (5 YR 5/8), sandy beds alternated with silty sand beds,

3a: 1 m thick sandy silt reddish yellow (5 YR 5/6), with calcareous nodules gypsum, and terrestrial gastropods,

3b: 1 m thick sandy silt strong brown (7,5 YR 5/6), including calcareous nodules and terrestrial gastropods,

3c: 1 m thick sandy silt strong brown (7,5 YR 5/6), with big *Otala* sp.,

Unit 3: present and subactual pediment slope deposit.

Fig. 3 : Coupe stratigraphique du cône de la cote 65.

1. débris anguleux de schiste, 2. limons sableux, 3. *Otala* sp., 4. *Rumina decollata*, 5. nodules calcaires, 6. taches carbonatées.

Unité 1 : Terrasse du Soltanien (Würmien), Unité 2 : Cône-terrace du Rharbien inférieur (Holocène).

1a : limon sableux, 30 cm, brun (7,5 YR 5/8),

1b : limon moyen, 20 cm, rouge jaune (7,5 YR 6/8),

2 : limon sableux moyen, 50 cm, jaune rouge (5 YR 5/8), lits sableux alternant avec des lits limono-sableux,

3a : sable limoneux, 1 m, rouge jaune (5 YR 5/6), à nodules calcaires, gypse et gastéropodes terrestres,

3b : sable limoneux, 1 m, brun sombre (7,5 YR 5/6), à nodules calcaires et gastéropodes terrestres,

3c : sable limoneux, 1 m, brun sombre (7,5 YR 5/6), à gros *Otala* sp.,

Unité 3 : Dépôts de versant actuels et subactuels.

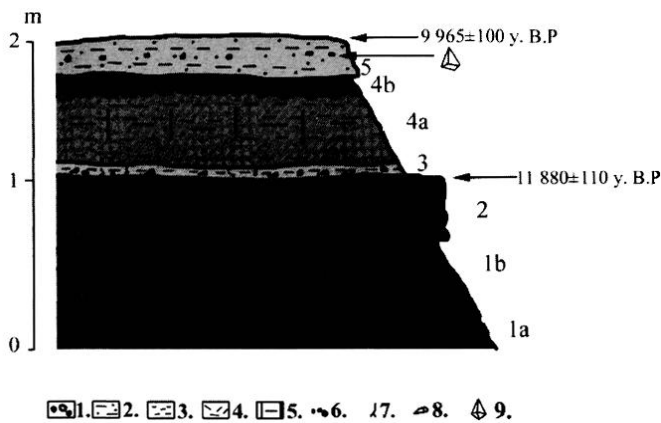


Fig. 4: Stratigraphic section of the Lower Rharbian alluvial deposits at cote 102.

1. gravels, 2. sandy silts, 3. clay, 4. reworked travertine, 5. polyedric structure, 6. carbonated nodules, 7. root marks, 8. *Melanopsis*, 9. Epipalaeolithic implements.

Lithology: 1a. silty clay with polyedric structure, 1b. silty clay containing gravels, 2. sandy silt with reworked travertine, 3. sandy silt comprising gastropod shells and roots marks, 4a. sandy silt, 4b. sandy silt with gastropod shells, calcareous nodules and gypsum, 5. sandy silt containing gypsum, calcareous nodules and gastropod shells.

Fig. 4: Coupe stratigraphique des dépôts alluviaux du Rharbien ancien à la cote 102.

1. graviers, 2. limons sableux, 3. argile, 4. travertin remanié, 5. structure polyédrique, 6. nodules carbonatés, 7. racines, 8. *Melanopsis*, 9. Artefacts épipaléolithiques.

Lithologie : 1a. limon argileux à structure polyédrique, 1b. limon argileux à graviers, 2. limon sableux à travertin remanié, 3. limon sableux à coquilles de gastéropodes et racines, 4a. limon sableux, 4b. limon sableux à coquilles de gastéropodes, nodules calcaires et gypse, 5. limon sableux à gypse, nodules calcaires et coquilles de gastéropodes.

Inner terraces of the Assaka wadi are inset in a 25 to 30 meter deep trench cut through the Soltanian terrace. On their top, they are covered by piedmont slope or by historic and present sequences (fig. 5 and 6). Erosion has sometimes destroyed this terrace so that this formation is not present on the two banks of the present mean-water channel. Thus, from upstream to downstream, we only find it on the left bank at the cote 102 and the cote 65 and on the right one at the cote 50 and at the cote 23. It is only on both banks at Fom Assaka as the main wadi joins the Ocean. The thickness of these accumulations decreases downstream from 11 metres to 3 metres. In most of the cases, the last metres of these formations are of historic ages, as the ^{14}C dating at Sidi Messaoud (cote 23) leads us to believe. Finally, between cote 65 and the Fort Oued Noun (fig. 1), recent floods have built gravelly and sandy benches on the margin of the present mean-water channel as in the Tagus river (Benito *et al.*, 1998). These inner terraces are the result of longitudinal floods probably coming from the entire Assaka wadi watershed, unlike the upper fans, which were built by the main tributaries.

The geomorphologic position and the first dating of these sequences show that they were deposited at different stages of the Moroccan Rharbian (=Holocene) chronology. Effectively, the Upper Soltanian sequences, overlaid by the fans, have been dated by U/Th (on a travertine formation) to 21 600 years BP and the equivalent alluvial sequences of the adjacent fans by ^{14}C between 11 800 to 9 900 years BP (two datings). Therefore, the tributaries adjacent fans are from the Upper Soltanian or the Lower

Rharbian. The inner terraces have been dated by ^{14}C from 4 250 \pm 70 years BP (Gif. 101065) (one dating at Fort oued Noun) and are from the Middle Rharbian. Finally, one dating of historic and present sequences at the cote 23 (Sidi Messaoud) by ^{14}C gives an age of 280 \pm 30 years BP (Gif. 11522).

3 - THE UPPER PLEISTOCENE OR THE LOWER RHARBIAN : THE UPPER FANS AND THEIR LATERAL EQUIVALENTS

At cote 65 (fig. 2 and 3), the adjacent fan consists of brown to red sandy silts and silts with a high content of terrestrial gastropods : *Otala sp.* and *Rumina decollata*. Sedimentological studies show high palygorskite and aeolian quartz contents. Much of the quartz, with pedogenesis features, comes certainly from Mediterranean fersiallitic soils. These analyses demonstrate that these fans have been built from the reworking of both older drier environment formations with aeolian quartz and palygorskite contents (Callen, 1984) and wetter environment formations with the reworking of red Mediterranean soils.

Alluvial equivalents of these fans are conserved at cote 102 (fig. 4). They overlay the top of the Soltanian terrace and consist of small channel infillings of red to brown silty clays and silts with, in the middle part of the section, fine gravels capped by a carbonated bed rich in reworked travertine fragments. At the base of the carbonated layer, *Melanopsis sp.* have been dated by ^{14}C from 11 880 \pm 110 years BP (Gif. 11022). At the top of the unit, fragments of ostrich eggs have been dated by ^{14}C from 9 965 \pm 100 years BP (Gif. 11023). These data show that these deposits were built at the end of the Upper Pleistocene or at the beginning of the Lower Rharbian period. Future datings will aim to confirm this hypothesis. Furthermore, we often found Epipalaeolithic implement and pieces of pottery at the top of these formations (fig. 3). These artefacts show that these deposits are contemporary or close to the Upper Palaeolithic occupation. At this time, before 10 000 years BP, the Assaka wadi had not yet entrenched, or only slightly, the Lower Holocene and the Upper Soltanian accumulations.

In arid and semi-arid Morocco, previous workers and authors (tab. 1) have rarely described Lower Rharbian deposits superimposed or stepped on older formations. Generally, they have studied inner terraces inset in the Soltanian accumulations and succeeding to an erosional phase. Only the Tamdroust wadi comprises a similar organisation, with Lower Rharbian deposits stepped on the top of the Soltanian terrace (Ouammou, 1993; Weisrock *et al.*, 1994). These deposits and their situations at the top of the Soltanian terrace display the uniqueness of the lower valley of the Assaka wadi. Thus, in the valleys of the Tamri and Tamghart wadis, Rohdenburg (1977) shows that a 10-metre-thick accumulation set up before 7 380 \pm 120 years BP and even before 5 875 \pm 175 years BP into a trench cut through Soltanian formations. Weisrock *et al.* (1991) note that, in the valley of the El Ouarr wadi, silty formations were deposited at 8 430 \pm 130 years BP, while the deep channel incision period had already started. In eastern Morocco, in the

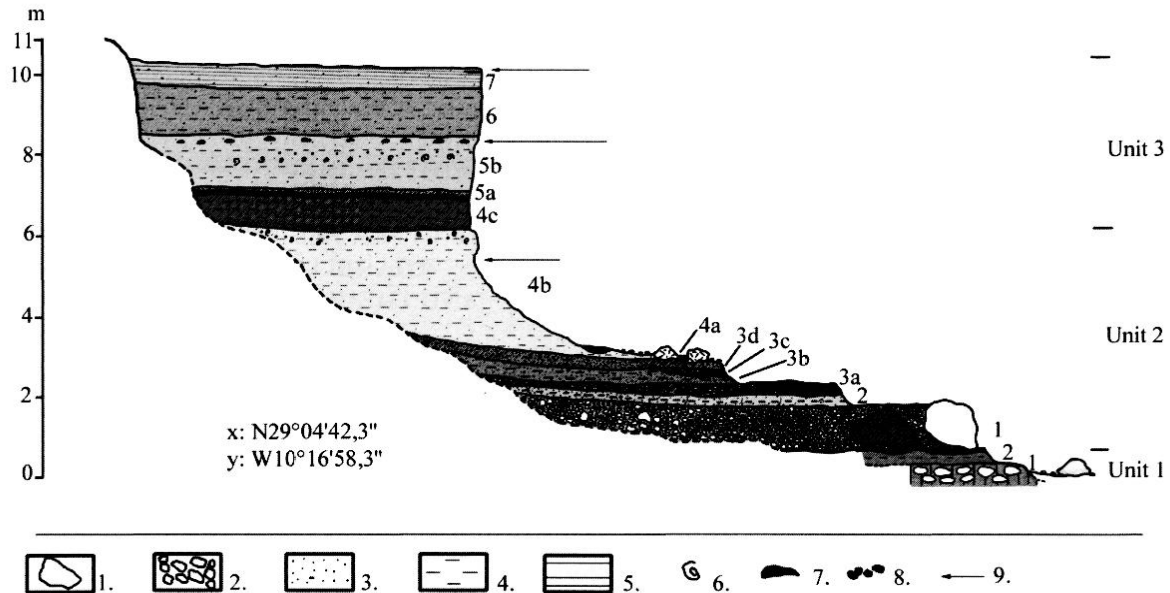


Fig. 5: Stratigraphic section of the lower terrace at cote 102.

1. block, 2. pebbles, 3. sand, 4. silt, 5. lamellar structure, 6. *Otala sp.*, 7. *Unio sp.*, 8. carbonated nodules, 9. future ^{14}C datings.

Unit 1: basement of the Soltanian (Würmian) formations:

1- Pebbles mixed into a carbonated matrix 2- Consolidated silt.

Unit 2: Lower Rharbian deposits:

1: Pebble sheet including metric blocks into a gravelly matrix. 2: Consolidated sandy silt (10 YR 8/4), containing mainly root marks, gastropods shells, travertine fragments and carbonated marks. 3a: consolidated pink (7,5 YR 7/4) gravelly sand including *Melanopsis*, *Rumina decollata* and *Unio sp.* shells and travertine fragments. 3b: Pink (7,5 YR 7/4) silt including schist gravels, gastropods fragments and root marks. 3c: Heterometric pebble sheet. 3d: Pink (7,5 YR 7/4) coarse sand with *Unio* and *Melanopsis* shells. 4a: Pebble sheet with travertine bloks. 4b: Brown (7,5 YR 6/4) silt with charcoals fragments, schist gravels and at the top *Otala sp.* Shells. 4c: Brown (7,5 YR 6/4) silt with many root marks and charcoals fragments.

Unit 3: Historic and modern deposits: 5a: gravel beds, 5b: Pink (7,5 YR 7/4) silt with root marks, charcoal beds, calcareous nodules, *Otala sp.*, shells and near the top *Unio sp.* shells.

6: Pink (7,5 YR 7/4) silt, 7: Reddish yellow (5 YR 7/6) silt with lamellar structure, root marks, charcoal fragments and schist gravels.

Fig. 5 : Coupe stratigraphique de la basse terrasse à la cote 102.

1. bloc, 2. galets, 3. sable, 4. limon, 5. structure lamellaire, 6. *Otala sp.*, 7. *Unio sp.*, 8. nodules carbonatés, 9. datations ^{14}C en cours de réalisation.

Unité 1 : base de la terrasse Soltanienne.

1. Galets emballés dans une matrice carbonatée. 2- Silt consolidé.

Unité 2 : Dépôts du Rharbien inférieur :

1 : Nappe de galets à blocs métriques dans matrice graveleuse. 2 : Sable limoneux consolidé (10 YR 8/4), à traces de racines, coquilles de gastéropodes, fragments de travertin et taches carbonatées. 3a : Sable graveleux consolidé rose (7,5 YR 7/4) à *Melanopsis*, *Rumina decollata* et *Unio* et fragments de travertin. 3b : Limon rose (7,5 YR 7/4) à graviers schisteux, fragments de gastéropodes et traces de racines. 3c : Nappe de galets hétérométriques. 3d : Sable grossier rose (7,5 YR 7/4) à *Unio* et *Melanopsis*. 4a : Nappe de graviers à blocs de travertin. 4b : Limon brun (7,5 YR 6/4) à charbon de bois, gravier de schiste et, au sommet, coquilles d'*Otala sp.* 4c : Limon brun (7,5 YR 6/4) avec traces de racines et charbons.

Unité 3 : Dépôts historiques et modernes : 5a : lits de gravier, 5b : Limon rose (7,5 YR 7/4) à traces de racines, lits de charbon, nodules calcaires, *Otala sp.*, et près du sommet, coquilles d'*Unio*.

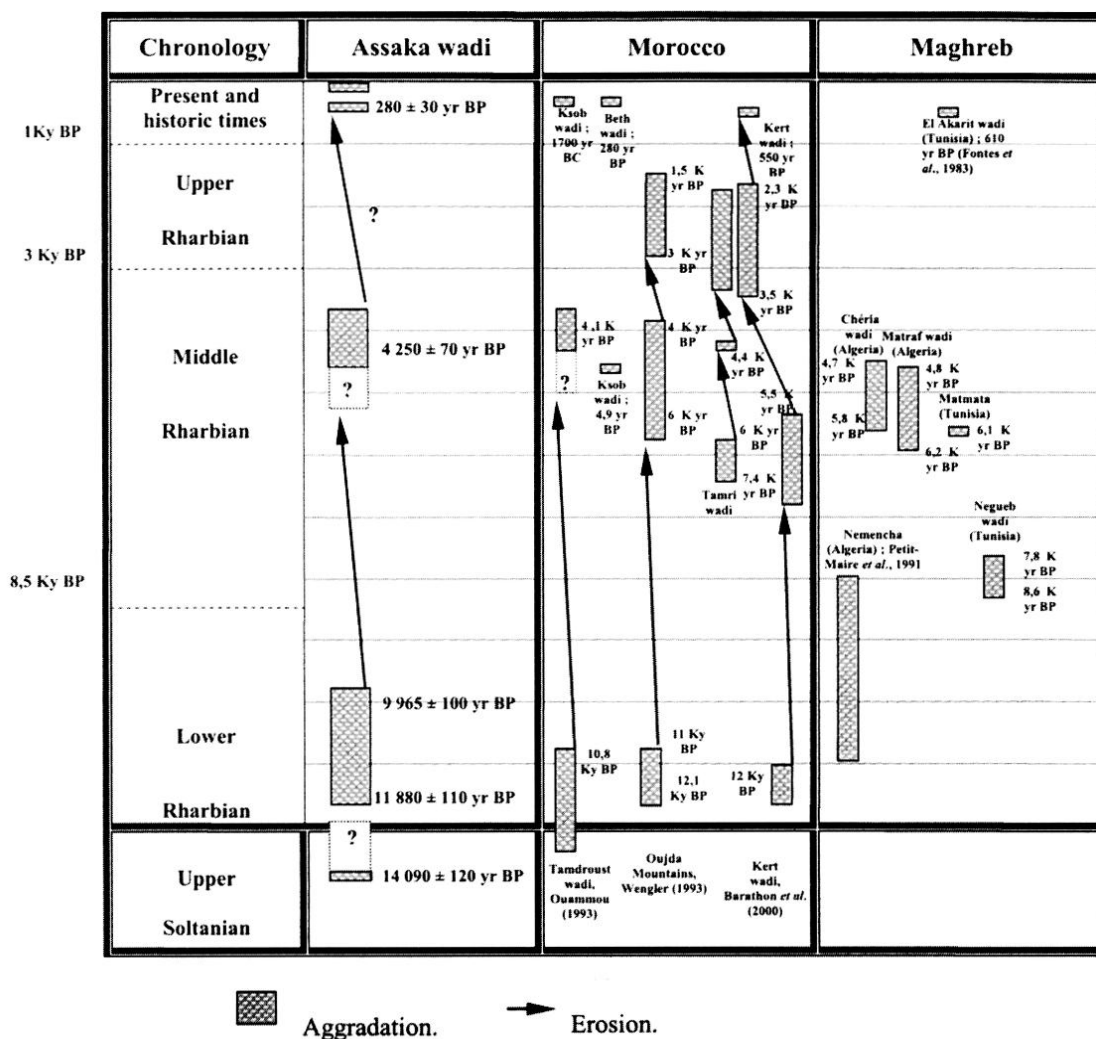
6 : Limon rose (7,5 YR 7/4), 7 : Limon rouge jaune (5 YR 7/6) à structure lamellaire, traces de racines, charbons et graviers schisteux.

Oujda mountains, in the Charef, Ouyyane and Al-Gazmir wadis watersheds, Wengler (1993) analysed discordant deposits on Upper Soltanian formations set up between $11\,290 \pm$ years BP and $12\,120 \pm 170$ years BP, inset in a 4 to 6 metres deep trench cut. The same situation has been demonstrated by Barathon *et al.* (2000) in the Kert wadi valley, where an organic sequence has been dated to $12\,039 \pm 221$ years BP. This formation constitutes the substratum of the Upper Rharbian terrace of the Kert wadi valley. On the Atlantic coast, 100 km to the North of the Assaka wadi, Ouammou (1993) and Weisrock *et al.* (1994) noted a carbonate silty level dated by ^{14}C to $10\,880 \pm 140$ years BP, at the top of the Soltanian accumulations and prior to the channel incision period.

These different works show that the Lower Rharbian deposits are rare in arid and semi-arid Morocco. This period often corresponds to a channel incision phase or to the sedimentation of an inner terrace. However, on both sides of the Anti-Atlas Mountains, in the Assaka wadi and in the Tamdroust wadi (Ouammou, 1993; Weisrock *et al.*, 1994), the Lower Rharbian formations are superim-

posed on the Upper Soltanian terrace. This situation indicates that the geodynamic context was different during the Lower Rharbian in Southern Morocco: adjacent fans represent a period during which the discharges of the tributaries were dominant in the area.

However, the comparison to other Moroccan sites shows the uniqueness of the Upper Pleistocene or Lower Rharbian deposits of the Assaka wadi that are mainly associated with tributary sediments and correspond to adjacent fans. Andres (1977), in the Jbel Bani, near the studied area, described the formation of red soils between 13 000 and 7 000 years BP, which were eroded and transported by wadis and gullies to form alluvial fans. We can suppose that similar processes could be applied to the upper fans of the Assaka wadi: red soil formation during a wetter period and a phase of aridity at the transition Pleistocene-Holocene (Rognon, 1980 and 1987; Nicholson and Flohn, 1980) would produce denudation of the slopes and erosion of red soil by gullies and run-off and finally the main tributaries built the adjacent fans during the return of wetter conditions.



Tab. 1: Holocene sedimentation and channel incision phases in the lower section of the Assaka wadi valley, in semi-arid and arid Morocco and in Maghreb.

Tab. 1 : Phases de sédimentation et d'incision holocènes dans la basse vallée de l'oued Assaka, au Maroc semi-aride et aride et au Maghreb.

These results show that there were wetter conditions in South Morocco during the transition Upper Pleistocene-Holocene associated with red soil development and probably with more regular discharges than at present. However, the climate became drier during the Lower Holocene, sufficiently to denude the slopes, where during big storms, gullies and run-off supplied the tributaries of the Assaka wadi with sandy silts and developed adjacent fans. Ballais (1991) and Ballais and Benazzouz (1994) have reached the same conclusion in Southern Tunisia and in Eastern Algeria. Thus in the Nemencha, the Lower Holocene reflects wetter conditions about 10 000 years BP. Petit-Maire *et al.* (1991) have noted that there was a development of the lakes in Southern Tunisia at 8 000 years BP.

In the lower valley of the Assaka wadi, during the Lower Rharbian, the development of adjacent fans probably modified the hydrologic conditions. Effectively, fans certainly dammed the Assaka wadi channel and bounded the floods coming essentially from the tributary watersheds. This situation has already been noted by Estorges *et al.* (1969) in Libya. Near the present city of Tiliouine, upstream to the Assaka gorges (fig. 1), a lake developed behind an alluvial dam, probably correspon-

ding to an adjacent fan like those that overlay the Soltanian terrace. Organic matter contained at the top of the accumulation have been dated by ^{14}C to 14 090 ± 120 years BP (Gif. 11209).

4 - A DEEP CHANNEL INCISION PERIOD BETWEEN THE LOWER RHARBIAN AND THE MIDDLE RHARBIAN

The generalized channel incision period that cut the Lower Rharbian fans and the Soltanian terrace is still not well dated (fig. 2 and 4). The depth cut is about 20 to 30 metres. It seems that this erosion phase took place after 9 965 ± 100 years BP, according to the ^{14}C age of ostrich eggs found at the top of the stratigraphic section of cote 102 (fig. 4) and even after 7 815 ± 80 years (Gif. 11643), according to the ^{14}C age of charcoal fragments extracted from an Epipalaeolithic site occupying the top of piedmont slope deposits superimposed and eroding the top of the Soltanian terrace. So between 10 000 and 8 000 years BP, run-off on slopes was still active and the erosion phase had still not started. We hope that future ^{14}C datings at cote 102 (fig. 5) will give us more precision about the age of the channel incision period.

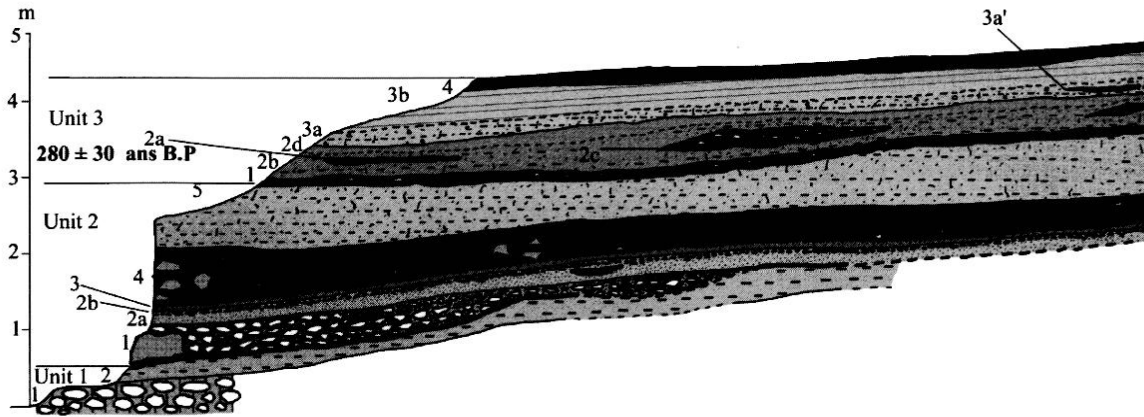


Fig. 6: Stratigraphic section of the lower terrace at Sidi Messaoud. See fig. 5 caption.

Unit 1: basement of the Soltanian formations: 1. Pebble mixed into a carbonated matrix, 2. Consolidated silt.

Unit 2: Middle Rharbian: 1. Decimetric pebbles and blocks (major discordance), 2a. reddish yellow (5 YR 7/6) gravelly sand with *Melanopsis* shells, 2b. bed of schist gravels, 3. Pink (5 YR 7/4) fine sand with reddish yellow (7,5 YR 6/8) hydromorphic marks, 4. Gravels and stones beds alternating with sand and including blocks and gastropods shells, 5. Reddish yellow sandy silt (5 YR 6/6) with many root marks and gastropod shells.

Unit 3: Historic and modern deposits: 1. Angular stones mixed into a silty sand matrix (major discordance), 2a. hearth, 2b. yellowish red silty sand with many roots marks, gastropod shells and travertine fragments, 2c. stones and gravels, 2d. reddish yellow (5 YR 7/6) clayey silt with lamellar structure, many roots marks and *Otala* sp. shells, 3a. reddish yellow (5 YR 7/6) silty sand sequence with lamellar structure, 3a'. Hearth with charcoal, 3b. lamellar silt (7,5 YR 6/5) with roots marks, floated charcoal and *Otala* sp. shells, 4. Yellowish red (5 YR 5,5/6) silt with root marks and *Otala* sp. shells.

Fig. 6 : Coupe stratigraphique de la basse terrasse à Sidi Messaoud. Voir légende fig. 5.

Unité 1 : Base de la terrasse Soltanienne : 1. Galets dans matrice carbonatée, 2. Limon consolidé.

Unité 2 : Rharbien moyen : 1. Blocs et galets décimétriques (discordance majeure), 2a. Sable graveleux rouge jaune (5 YR 7/6) à coquilles de *Melanopsis*, 2b. Lit de graviers schisteux, 3. Sable fin rose (5 YR 7/4) à traces d'hydromorphie rouge jaune (7,5 YR 6/8), 4. Lit de graviers alternant avec des sables et incluant des blocs et des coquilles de gastéropodes, 5. Limon sableux rouge jaune (5 YR 6/6) avec nombreuses traces de racines et coquilles de gastéropodes.

Unité 3 : Dépôts historiques et modernes : 1. Blocs dans matrice limono-sableuse (discordance majeure), 2a. "foyer", 2b. Sable limoneux rouge à traces de racines, coquilles de gastéropodes et fragments de travertin, 2c. Pierres anguleuses et graviers, 2d. Limon argileux rouge jaune (5 YR 7/6) à structure lamellaire, traces de racines et coquilles d'*Otala* sp., 3a. Sable limoneux rouge jaune (5 YR 7/6) à structure lamellaire, 3a'. "foyer riche en fragments de charbon de bois", 3b. Limon à structure lamellaire (7,5 YR 6/5) à traces de racines, charbons flottés et coquilles d'*Otala* sp., 4. Limon rouge jaune (5 YR 5,5/6) à traces de racines et coquilles d'*Otala* sp.

Many authors in Morocco or in the Maghreb seem to agree with the presence of a generalized channel incision period between the Lower Rharbian and the Middle Rharbian (tab.1). In eastern Morocco, Wengler (1993 and 1995) and Wengler *et al.* (1994) have shown for the Charef, El Haÿ and Al-Gazmir wadis that this phase took place after 11 300 and 12 000 years BP. At Makhfame on the Northern High-Atlas piedmont, near Marrakech, the channel incision period was after 11 300 years BP (Weisrock and Miskovsky, 1988). To the South, near the Assaka Wadi watershed, in the Tamdroust wadi, this phase took place after 11 000 years BP (Ouammou, 1993; Weisrock *et al.*, 1994). At Tnine Rharbia, close to Safi, Weisrock *et al.* (1985) situate this period after 10 000 years BP.

In Tunisia, Coudé-Gaussen *et al.* (1983) describe a similar channel incision phase of the loess-like deposits of the Matmata Plateau after 10 000 years BP and before the settling of an inner silty terrace, about 8 000 years BP. In the North-western Sahara, the Saoura wadi cut the "Saourian" terrace between 14 500 and 8 950 years BP (Alimen, 1976).

This generalized cutting phase put an end to a long period of a continuous aggradation since approximately the Middle Soltanian (since the MIS 5). This change could have many explanations. First, neotectonic activity may have an influence on the base level of the Assaka wadi. But, such evidence is lacking. Eustatic change has generally an impact on the base level and leads to channel erosion. But at 8 000 years BP and after, the Mel-

lahian transgression occurred and a small number of eustatic Middle Holocene terraces were known on the Atlantic coast of Morocco (Beaudet and Maurer, 1960; Weisrock, 1980). So eustatic change could not have a notable influence there. In the Assaka wadi watershed, it seems that Man has a minor impact on the environment during the Lower Holocene. There were only small groups of hunter-gatherers. Finally, morphodynamic processes and climatic conditions are probably the best explanatory factors for this generalized channel incision period after a long aggradation phase since the Soltanian. This quick incision may have taken place with torrential floods during a transitional arid/humid episode, before the wetter Middle Rharbian.

5 - THE LOWER INSET AND SUPERIMPOSED RIVER TERRACES

Two examples of the lower inset and superimposed river terraces of the Assaka wadi are studied in this article : cote 102 and the Sidi Messaoud (cote 23) stratigraphic sections (fig. 5 and 6).

A - THE MIDDLE RHARBIAN LOWER TERRACE (fig. 5 and 6)

The morphology and the characteristic position of the Middle Rharbian terrace of the Assaka wadi valley are the same as those described by many authors in Morocco: Rohdenburg (1977), Sabelberg (1978), Weisrock (1980), Weisrock and Rognon (1977), Weisrock and Miskovsky

(1988), Weisrock *et al.* (1991), Ballouche *et al.* (1985), Wengler (1993 and 1995), Wengler *et al.* (1994), Barathon *et al.* (2000) and in Maghreb: Ballais (1991), Ballais and Benazzouz (1994), Coudé-Gaussen *et al.* (1983) and Alimen (1976). Only one of the lower terraces of the Assaka has been dated. Effectively, at Fort Oued Noun, fragments of ostrich eggs found in the upper metres of the terrace have been dated by ^{14}C to $4\,250 \pm 70$ years BP (Gif. 101065). Thus, we can believe that this formation is of Middle Rharbian age.

This fluvial formation corresponds to the unit 2 of figure 5. It is inset in the base of the Soltanian terrace, unit 1 (fig. 5). Unit 3 (fig. 5 and 6) corresponds to historic and present deposits which are discordant on its top and are superimposed on the stigmata of an erosional phase succeeding the sedimentation of unit 2, the inner terrace of the Middle Rharbian. The Middle Rharbian terrace always starts with a rounded pebble sheet including blocks (fig. 5). Then, this sequence is capped by reddish yellow to red sandy silts with numerous fluvial gastropods and molluscs like *Melanopsis sp.* and *Unio sp.*, present in modern habitats. Diffuse calcium carbonate spots are linked to roots and/or to the phreatic sheet. These basal layers were built by sudden and strong floods carrying blocks, while sandy silts and silts correspond to the end of the flooding. The palaeoclimate was wetter than during the Lower Rharbian. The rainfall was certainly still irregular and corresponded to strong storms succeeding more or less long dry periods during which vegetation was developed and dominated by herbaceous flora close to the gueltas where gastropods and molluscs were living.

In arid and semi-arid Morocco, similar terraces are thicker. They start also with a basal pebble sheet covered by sandy silts and silts, including sometimes coarser layers. Thus, in the lower valley of the Tamdroust wadi (tab. 1), *Helix sp.*, found in the middle of a comparable river terrace, have been dated by ^{14}C to $4\,130 \pm 50$ years BP (Ouammou, 1993; Weisrock *et al.*, 1994). To the North, a similar terrace, in the lower valley of the Ksob wadi (tab. 1) has been dated to $4\,950 \pm 120$ years BP (Weisrock, 1980). In the same area, in the valley of the Tamri wadi (tab. 1), this accumulation takes place at $4\,375 \pm 145$ years BP (Rohdenburg, 1977). In eastern Morocco, Wengler (1993) shows that this terrace was deposited between 6 000 and 4 000 years BP in all the valleys of the El Haÿ and Isly wadis watersheds (tab. 1).

In Tunisia, to the North of the Matmata Plateau (tab. 1), the top of a silty river terrace, inset in the trench cut through the Pleistocene loess-like deposits, has been dated by ^{14}C to $6\,130 \pm 180$ years BP (Coudé-Gaussen *et al.*, 1983). To the Southeast in the Negueb wadi (tab. 1), the terrace was built between $8\,600 \pm 150$ and $7\,775 \pm 340$ years BP (Coudé-Gaussen *et al.*, 1983). In Algeria in the Ziban Mountains, an aggradation phase of the Matraf wadi, contemporary to the Middle Rharbian one (tab. 1), takes place between $6\,230 \pm 100$ and $4\,830 \pm 120$ years BP (Ballais *et al.*, 1979); in the Nemencha, in Eastern Algeria, the main terrace of the Chéria wadi contains gastropods that have been dated by ^{14}C to $5\,830 \pm 95$ years BP and $4\,685 \pm 95$ years BP (tab. 1). But this chrono-

nology obtained by dating of gastropods might reflect more recent shells that have fixed older carbon particles; so they have to be considered with caution (Bard, 2002).

Finally, the Middle Holocene terrace was deposited, in many valleys of Morocco and Maghreb, between 6 000 and 4 000 years BP (tab. 1). In most of the cases, this terrace is inset in a trench cut through older formations, for example through the Soltanian terrace in Morocco. This formation corresponds to the Holocene climatic optimum, confirmed by Lamb *et al.* (1999) in the Middle-Atlas Mountains, in the Aguelmann Sidi Ali Lake, close to the transition between the Mediterranean and Saharan climatic zones. Effectively, these authors show with a six-metre-thick core that between 6 000 and 5 000 years BP, the environmental conditions were wetter. Thus, the water level was rising and cedar, oak and aquatic macrophytes were in expansion.

B - THE UPPER RHARBIAN LOWER TERRACE

Usually well developed in the valley of the Moroccan wadis (tab. 1), it has not been noticed in the lower section of the Assaka wadi. It is probable that the Upper Rharbian correspond to an erosion phase. The results of ^{14}C datings might prove the contrary.

The main sites studied in arid and semi-arid Morocco are generally characterized by the deposits of a new terrace inset in the trench cut through older formations. In Atlantic Morocco, this terrace has been dated by ^{14}C between $3\,365 \pm 110$ and $2\,240 \pm 85$ years BP (Rohdenburg, 1977). The same chronology is evident in the valley of the El Ouair wadi (Weisrock *et al.*, 1991) and in the Souss wadi floodplain (Weisrock *et al.*, 2002). In Eastern Morocco, the Upper Holocene terrace occurred at the same time: $3\,540 \pm 60$ years BP (Boudad *et al.*, in press), $3\,500$ to $2\,300$ years BP in the lower valley of the wadi Kert (Barathon *et al.*, 2000) or slightly later between 3 000 and 1 500 years BP (Wengler, 1993 and 1994). The environments described by the authors is wetter than today, with more regular rainfall.

C - HISTORIC AND PRESENT DEPOSITS

Corresponding to unit 3 at Sidi Messaoud and to cote 102 (fig. 5 and 6), historic and present deposits start with a pebble sheet sometimes associated with reshaped travertine blocks or with coarse layers of colluvial angular schist stones and gravels. Then laminated sandy silts and silts rich in hearths complete and cap the recorded sedimentary sequence. Charcoals extracted from one of these hearths (unit 3, sequence 2a, fig. 6) have been dated by ^{14}C to 280 ± 30 years BP (Gif. 11522). This historic series is contemporary with the "cold winters" of the XVII^e and XVIII^e centuries in Western Europe and more generally with the Little Ice Age. These fragments of charcoals have been identified by an anthracologist. Three species growing nowadays in the region have been recognized: *Argania spinosa*, *Tamarix* and *Zygophyllum sp.*, indicating semi-arid conditions (Weisrock, 1980; Peltier, 1982). These observations indicate that the climate at 280 ± 30 years BP was wetter than today. Effectively, nowadays, rainfall is very scarce with a significant annual irregularity and comes from two main systems of atmospheric

depressions. During the XVII^o and the XVIII^o centuries, anticyclones above Western Europe were stronger and diverted depressions towards Southwest Morocco. Thus, rainfall was certainly more significant and more regular in the studied area. This fact is confirmed by many travelers like Chénier (1787) or Le Chatelier (1891). Moreover, these witnesses have related that the Assaka wadi area had an important settlement with a great impact on the environment. Effectively, cultivating and deforesting increase erosion factors and furnish materials for the floods. Finally, increases in rainfall and in Man's impact on the environment provoked the sedimentation of historic and present deposits superimposed on the top of the Middle Rharbian terrace.

Similar deposits have been identified in Morocco and in Maghreb (tab. 1). They have been interpreted as the witnesses of the Little Ice Age. Thus, these deposits indicate an increase in the rainfall contemporary with the cold winters in Europe. There, strong anticyclones were diverting depressions by a North-South flux towards Morocco and more generally towards Maghreb. In the Lower valley of the Ksob wadi, near Essaouira, a sequence starting with sands and calcrete fragments capped by brown silts with *Helix sp.* and charcoals has been dated by ¹⁴C to 1 700 ± 80 years BC (Weisrock and Rognon, 1977). This dating is contemporary with the end of the activity of the saadian sugar manufactory set up in the neighbouring area. This activity, which requires important quantities of water, confirms that during the XVII^o and the XVIII^o centuries, the discharges of the Ksob wadi were more regular than today and that the climatic conditions were wetter. To the North, in the Beth wadi valley, the boundary between the "tirs" (soils rich in organic matter), indicating a wetter climate, and the grey soils, is dated by ¹⁴C to 280 ± 60 years BP (Gigout, 1959). In North-Eastern Morocco, near Tafersite, colluvial and alluvial deposits are mentioned by Barathon *et al.* (2000) and dated by ¹⁴C to 550 ± 138 years BP. In southern Tunisia, Ballais (1991) has studied a lower terrace in the El Akarit wadi where Fontes *et al.* (1983) have dated historic deposits by ¹⁴C to 610 ± 110 years BP.

Finally, previous authors, when they have studied and dated historic formations, have admitted that they were linked to the European Little Ice Age. However, they rarely linked this fact to the atmospheric conditions. We think that this increase in rainfall in the South Morocco is linked to strong anticyclones localized off Western Europe that have diverted the West flux towards Morocco. Moreover at the same time, around the Mediterranean Sea, historic terraces were deposited: in Greece (Vita-Finzi, 1969; Dufaure, 1985), in Italy (Neboit, 1983 and 1985) and in the Eastern Mediterranean Morocco (Wengler, 1995). It proves that during the Little Ice Age the Mediterranean basin and North Africa received more rainfall.

The last recorded sequences in the stratigraphic sections (fig. 5 and 6) are characterized by laminated silts incorporating pebbles, schist gravels and terrestrial gastropods like *Otala sp.* and *Rumina decollata*. These accumulations were probably deposited during the XIX^o and the XX^o centuries and are the results of strong floods.

These episodes have overflowed the inner terrace of the Assaka wadi and imply an important water sheet able to reach the top of the lower terrace, 5 to 11 metres above the present channel.

Degradation of the environment by Man and drier climatic conditions are probably responsible for these recent events. Thus, Man has increased erosion factors by deforesting the "Argania clear forest" and the Euphorbiaceous steppe (Tarrier and Benzyane, in press). This negative impact is the consequence of the development of many tribes in the lower valley of the Assaka wadi, described by Le Chatelier (1891). The degradation of the vegetation cover destabilized slopes and alluvial formations whose silty sequences were reworked by irregular but strong flood events. Moreover, the valley, between 1912 and 1956, was the boundary between French and Spanish territories. Respective armies built two wide fortified places accommodating many soldiers and amplifying environmental degradation.

CONCLUSIONS (tab. 1)

1. The Holocene deposits of the lower section of the Assaka wadi consist first of Upper Pleistocene or Lower Rharbian adjacent fans, coming from the dominant activity of the main tributaries, superimposed on the Soltanian deposits. They indicate irregular climatic conditions at the transition Rharbian-Soltanian, with big storms eroding red soils on the slopes and supplying gullies and run-off with fine materials, forming tributary fans.

2. After that, a deep channel incision period put an end to a long phase of aggradation started since the Soltanian. This incision took place between 10 000 and 5 000 years BP. The climate was drier, the vegetation could not fix the sediments, which were carried by strong floods coming from localized storms.

3. During the Middle Rharbian, a lower terrace was built in the trench cut. Its basal layers associating pebble sheets and blocks indicate powerful floods. They are progressively capped by silty sequences which are the result of more regular floods and of wetter conditions before 4 200 years BP. During this time, the Assaka wadi was perennial thanks to karstic exurgences; gueltas, where gastropods and molluscs were living, were occupying the mean-water channel. After this episode, a new channel incision phase took place. It left an upstanding terrace, the terrace of the Middle Rharbian.

4. Sequences of the Upper Rharbian have not yet been recognized. We hope that ¹⁴C datings, especially at cote 102, could delimit these formations. However, it is possible that the Upper Rharbian of the Assaka wadi valley corresponds to a channel incision phase that created the Middle Rharbian terrace.

5. Finally, historic and present deposits, superimposed on the Middle Rharbian terrace, dated by ¹⁴C to 280 ± 30 years BP, are contemporary with the "cold winters" of the Little Ice Age of Western Europe during the XVII^o and XVIII^o. At this time, above Europe, strong anticyclones diverted depressions coming from the North-Atlantic towards the Maghreb and South-western Morocco. We think that this episode provoked an increase in flooding

and in sedimentation. Local history witnesses this strong flood event. Effectively, at the end of the XVII^e century, the regional capital, Tagaost, near the present Goulimine, was destroyed by a sheet flood of the Assaka wadi (Gandini, 2001).

The accumulations of the two most recent centuries (XIX^e and XX^e centuries) were superimposed on the top of the historic deposits and were deposited by strong floods. These historic and present accumulations depend on climatic conditions and on human impact on environment, which amplifies the erosion factors by deforesting and cultivating.

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