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## Morphosedimentological record and human settlements as indicators of West-African Late Holocene climate variations in the littoral zone of the Iwik peninsula (Banc d'Arguin – Mauritania)

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*Key-words.* – Late Holocene, Climate changes, Beach ridges, Sand flats, Banc d'Arguin, Mauritania

*Abstract.* – The geomorphological, sedimentological and archaeological studies of coastal features in the Iwik-Aouatil area show two categories of coastal sedimentary units: very extensive sand flats and linear relief features covered by a thin veneer of anthropogenic *Anadara senilis* shell-middens. These units provide an opportunity to discuss the return to arid conditions in western Sahara during the Late Holocene, when climate changes induced the alternating occurrence of more or less dry episodes, from around 5 ka until today.

These constructions reflect the global climate change within the general framework known for the region. Two different processes occurred: (1) constant deposition of wide sand-flats and (2) construction of sedimentary ridges at specific moments. These processes demonstrate the existence of (1) constant sand discharge during the whole period as sand availability is not a limiting factor and (2) a substantially increased sand influx during the 4.2-3.2 ka episode. Because of sea-level stability in the Banc d'Arguin area during the Late Holocene, the variability of morphogenetic agents is considered to be the likely cause of fluctuations, influencing sand input rate and implying that either sand was delivered in greater abundance (aridity crisis and stronger winds) or littoral drift was more powerful (stronger waves and more frequent storms in the northern part of the Atlantic ocean), or both simultaneously. The action of these two driving forces in the depositional processes observed in the Iwik-Aouatil coastal plain is evaluated with respect to the occurrence of episodes of rapid climate changes (RCCs) and North Atlantic Oscillation (NAO) changes. A climate pattern combining episodes of RCC and NAO positive (NAO+) index during the 4.5-3.2 ka period is convenient for both sand supply, which accelerates the southwestward migration of barchan's lines, and sand transportation, which improves the efficiency of the littoral drift.

### Enregistrements morphosédimentologiques et occupations humaines dans la zone littorale d'Iwik (Banc d'Arguin-Mauritanie), témoins des variations climatiques en Afrique de l'Ouest au cours de l'Holocène terminal

*Mots-clés.* – Holocène terminal, Changements climatiques, Cordons littoraux, Estrans sableux intertidaux, Banc d'Arguin, Mauritanie

*Résumé.* – L'étude géomorphologique, sédimentologique et archéologique de la zone littorale de la région d'Iwik-Aouatil (Banc d'Arguin – Mauritanie) permet de caractériser deux types d'unités sédimentaires : des estrans sableux intertidaux très étendus et des cordons linéaires couverts par un placage mince d'amas coquilliers anthropiques à *Anadara senilis*. La disposition et la chronologie de mise en place de ces unités permettent de discuter le retour des conditions arides au Sahara occidental alors que les changements climatiques opposent des épisodes plus ou moins secs pendant l'Holocène terminal, de 5 ka environ jusqu'à nos jours.

L'édification de ces unités sédimentaires s'insère dans le cadre général des changements climatiques globaux connus pour le secteur. Deux processus sont prédominants (1) dépôt de larges sand-flats et (2) construction de cordons sédimentaires à des moments spécifiques. La construction de ces différentes unités traduit (1) l'existence d'un apport constant de sable pendant toute la période, car la disponibilité en matériel n'est pas un facteur limitant et (2) l'occurrence d'un apport plus important pendant l'épisode allant de 4,2 à 3,2 ka. Dans ce dernier cas, en raison de la stabilité du niveau de la mer dans le secteur d'Arguin pendant le fini-Holocène, la variabilité des agents morphogénétiques paraît être la cause probable des fluctuations influençant le taux d'apport sédimentaire. Cela implique que le sable a été fourni en plus grande abondance (crise d'aridité et vents plus forts) ou que la dérive littorale était plus puissante (vagues plus énergiques et tempêtes plus fréquentes dans l'Atlantique nord), ou les deux simultanément. L'intervention de ces deux facteurs est mise en corrélation avec la survenue des épisodes de changements climatiques rapides (RCC) et des variations du NAO index. Un modèle climatique combinant des épisodes de RCC et de NAO+, pendant la période de 4,5-3,2 ka, convient bien pour la fourniture du sable en accélérant la migration vers le sud-ouest des lignes de barkhanes mais aussi pour son transport en augmentant l'efficacité de la dérive littorale.

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## INTRODUCTION

Over the last decade, many palaeoclimate studies highlighted the extremely fluctuating conditions during the last glacial-interglacial cycle [Partridge *et al.*, 1997; Ganopolski *et al.*, 1998; Claussen *et al.*, 1999; Gasse, 2000; Renssen *et al.*, 2003]. In Northwest Africa, for the past 25 ka, three major phases were identified [Lancaster *et al.*, 2002]:

- the Pleistocene hyper-arid phase, around the Late Glacial Maximum;

- the extensively documented African Humid Period during the early to middle Holocene, with an early-Holocene arid interval around 8 ka [Alley *et al.*, 1997; deMenocal *et al.*, 2000b; Wagner *et al.*, 2002] and a second Holocene wet phase, fully established by 6.5 ka, continuing up to 5.5 ka [Claussen and Gayler, 1997; Ganopolski *et al.*, 1998; Claussen *et al.*, 1999];

- the Late Holocene return to arid conditions, coincident with the onset of the generally dry conditions that prevail until today in the northern subtropics and the Mediterranean belt [Claussen *et al.*, 1999; Regard *et al.*, 2006].

Comparisons made on a globally distributed array of palaeoclimate proxy records emphasized that the Holocene climate was also under the influence of a dynamic fluctuating regime, showing a number of rapid climate changes (RCCs). These studies also concluded that a more precise examination of the timing of RCC intervals and teleconnections is still required [Mayewski *et al.*, 2004]. The Sahara desert –the largest warm desert on Earth– provided numerous records of global climate restructuring, hence an opportunity for such studies [Kocurek *et al.*, 1991; Lancaster *et al.*, 2002; Gasse, 2000; Haslett and Smart, 2006]. In the Sahara region, detailed Holocene climate changes with wet and dry alternating episodes were described through a multidisciplinary methodology [Street-Perrott and Perrott, 1993; Gasse, 2000; Lezine *et al.*, 2007]. They generally emphasized the role of wind-system

organization in the terrestrial domain and water mass distribution in the marine area. The occurrences of aridity phases were largely inferred from the aeolian activity signal within the aeolian, fluvial, and lacustrine deposits [Swezey, 2001; Lancaster *et al.*, 2002]. In addition, the marine sedimentary record was extensively used for a number of studies investigating climate variations and ocean response during the Late Quaternary in Northwest Africa [Haslett and Smart, 2006]. Moreover, from another perspective, reconstruction of the links between changing climate and environments is being documented in countless archaeological remains and occupation sites [Brooks *et al.*, 2003; Brooks, 2006; Kuper and Kröpelin, 2006; Vernet, 2007; Barusseau *et al.*, 2007].

This body of data shows that the climate episodes during the Holocene do not always begin simultaneously at all the locations [Alley *et al.*, 1997; Gasse and Van Campo, 1994; Street-Perrott *et al.*, 2000; Brooks, 2006] and their course is also highly variable [Salzmann and Hoelzmann, 2005]. Reference was made to two short episodes of drought observed around 8.5-8 ka and 7-6.5 ka, while general aridity prevailed in the whole desert only after 4.5-4 ka, with the strengthening of the northern trade-winds at around 4 ka and the correlated weakness of monsoonal episodes [Gasse and Van Campo, 1994]. A wet spell was still noted in some places [Maley, 1997; Barusseau *et al.*, 1995; Vernet, 1998; Vernet and Ould Mohamed Naffé, 2003; Vernet and Tous, 2004], and Swezey [2001] pointed out some evidence of a brief, but widespread phase of fluvial-lacustrine deposition and aeolian-sediment stabilization at approximately 3 ka-2 ka cal. B.P. This complex alternation of humidity and drought with abrupt transitions is not yet clearly explained. According to Street-Perrott *et al.* [2000], the main reason is that observations are too few and palaeoclimate data for the last few millennia are too sparse, resulting in discrepancies in the timing of desiccation episodes [Brooks *et al.*, 2003], in spite of the fact that a gross homogeneity in the palaeoclimate records is observed on multi-millennial timescales [Petit-Maire *et al.*, 1997].

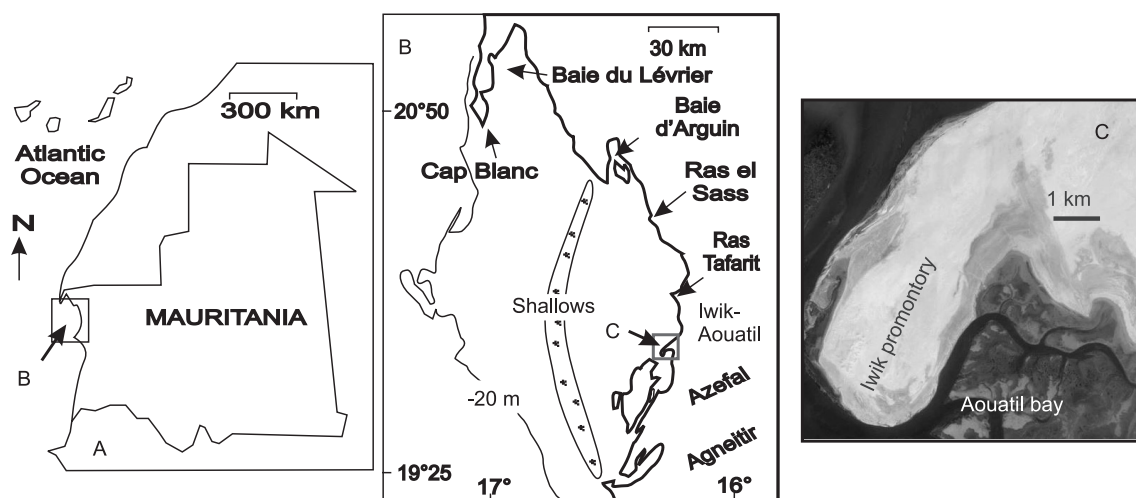


FIG. 1. – Location of the study area. The study area is delineated by a square on sketch B. The heavy line in sketch B delineates the present shoreline. Shallows are underwater rocky banks separating the inner part of the Banc d'Arguin from the open outer ones. Depths are as low as  $-5$  m at the top of the shallows. Sketch C is provided by Google Earth imagery.

FIG. 1. – Situation de la zone étudiée. La zone étudiée est entourée par un cadre sur le schéma B. Le trait épais du schéma B correspond à la ligne de rivage actuelle. Les hauts-fonds sont des bancs rocheux sous-marins séparant la partie intérieure du Banc d'Arguin de la partie externe. Les profondeurs au sommet y sont de l'ordre de  $-5$  m. L'image C provient de Google Earth.

Little is known about the possibility of centennial and millennial-scale climate variability at lower latitudes [deMenocal *et al.*, 2000a], particularly in the Atlantic Sahara.

In the region of Iwik (Banc d'Arguin, fig. 1), the coastal sedimentary units formed after completion of the post-glacial transgression show a wide variety of forms and illustrate a history closely linked to the construction of the coastal zone itself (Barusseau *et al.*, submitted). Hence, given the identification, timing of construction of these units and implemented sedimentary volumes, this paper focuses on the Holocene climate changes likely to generate sequential coastal units. These units are the result of factors involving both coastal marine dynamics, including the wave action, and wind dynamics – providers of sandy material. The Banc d'Arguin area offers a unique opportunity to measure the impact of climate changes affecting these two factors through their consequences on coastal morphodynamics.

## STUDIED AREA

The Iwik peninsula region forms a part of the gulf of Arguin in northwestern Mauritania (fig. 1). In this region, three main morphological units can be identified (fig. 2): low rocky elevations at the east and northeast boundaries, a rocky cape (Ras Iwik) to the southwest and, in between, sandy beaches and mud or sand tidal flats. Both rocky formations bear witness to the Tafariitian Formation [Hébrard, 1978; Elouard, 1975], initially considered a marine one, but later found to be a continental, alluvial lakeside or sebkha formation of mid-Quaternary age [Giresse *et al.*, 1989]. Some of these Tafariitian elevations formed islands when the sea reached its current level (around 5.5 ka). Sandy beaches and tidal flats are the result of the Late Holocene sedimentary evolution [Barusseau *et al.*, 2007].

The region is now subject to the effects of tides and waves. The observed tide is semi-diurnal and microtidal, with a range between 0.8 and 2 m [Koopmann *et al.*, 1979; Mahé, 1985]. At low tide, large coastal flats are exposed due to the relatively flat bathymetry of the Banc d'Arguin where the inter-tidal area can reach 600 km<sup>2</sup> [Mahé, 1985]. The swell is attenuated by Cap Blanc and the shallow bathymetry of the Banc (minimum depths on the shallows around 5 m; fig. 1). In this area, the dominant long-shore drift runs south, as confirmed by the numerous south-easterly-oriented sand spits [Barusseau, 1985]. Aeolian processes account for the SSW onshore movement of barchan lines, feeding on the vast sand reservoir formed in the continental domain during the glacial low level and post-glacial transgression periods [Deynoux *et al.*, 1991].

Irregularly distributed Neolithic shell-middens are often found, capping available local elevations in the Iwik area as in the entire coastal region of the Banc d'Arguin. The archaeological content of some of the middens has already been accurately described [Vernet, 1998; Vernet and Ould Mohamed Naffé, 2003; Vernet and Tous, 2004]. A set of 47 <sup>14</sup>C ages, collected by Vernet [2007] attests continuous or regular human occupation or passage during that period.

Data on climate evolution in the Banc d'Arguin zone revealed variability during the Holocene period, very similar to the one described for the West African area. According to

Vernet [2007], the transitional period following the Early to Middle Holocene African Humid Period was characterized by an unstable climate regime in the area. At the beginning of that transitional period (7.5-7 ka), wet conditions prevailed followed by a more contrasted regime between, on the one hand, the littoral zone and the inland part and, on the other, between North and South. Around 6 ka, a two-season regime (wet-monsoon and strong upwelling with trade winds episodes) became prevalent, particularly in the Cap Blanc area. During the following millennium, climate conditions were wetter with enhanced monsoonal regime. Numerous palaeosols formed up to 4.25 ka and rivers were still active up to 5 ka (Khatt Ataoui, Ogol, oued ech Chibka). However, from 4.2 to 4 ka, an aridity crisis terminated the former favorable conditions.

## METHODOLOGY

Identification, mapping and determination of mutual relations of sedimentary units, are a prerequisite to understand their development in terms of environment dynamics and climate changes. The following operations were conducted in order to determine the various phases of sedimentary construction.

– Defining the location of the irregularly delineated shoreline at the end of the post-glacial transgression corresponding to the maximum flooding surface *ca.* 6-5.5 ka, by using Tafariitian outcrops, field observations, GPS measurements, and photo analysis.

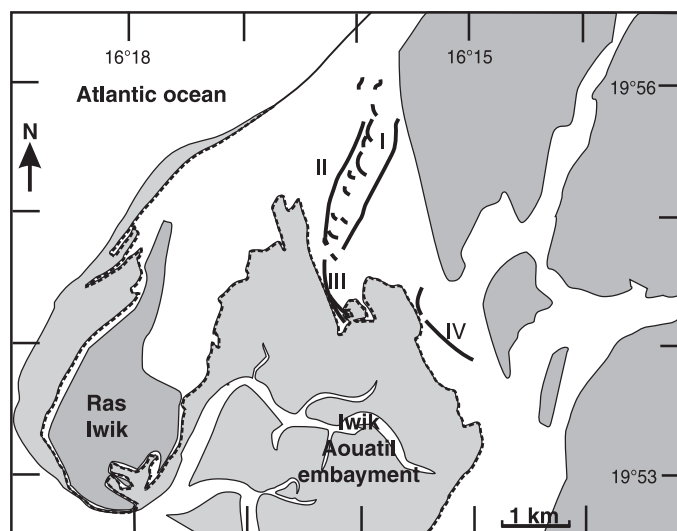


FIG. 2. – Geomorphological sketch of the Iwik-Aouatil embayment. Tafariitian outcrops uncovered by the Holocene deposits (maximum Holocene flooding surface) in dark gray; no morphological features are shown on this very low part of the continental domain. Present inter-tidal zone in light gray with low-tide shoreline (thin line) and exceptional high-tide shoreline (dashed line). Heavy black lines I, II, III, and IV corresponding to the successive sand ridges and dune complex (I : 4.2-3.8 ka; II : 3.8-3.4 ka; III and IV : 3.4-3.2 ka).

FIG. 2. – Croquis géomorphologique de la baie d'Iwik-Aouatil. La limite des affleurements tafariitiens en gris foncé, non recouverts par les dépôts holocènes correspond à la surface d'inondation maximum à l'Holocène; aucune morphologie n'est représentée dans cette région très plate. La zone intertidale actuelle est en gris clair (avec la limite de BM en trait fin et la limite de HM exceptionnelle en tiretés). Les traits épais I, II, III et IV correspondent aux cordons successifs et aux zones dunaires (I : 4,2-3,8 ka; II : 3,8-3,4 ka; III et IV : 3,4-3,2 ka).

– Identifying the two different types of coastal sedimentary units occurring in the Iwik-Aouatil zone: sand flats and ridges (fig. 2).

– Surveying two topographic profiles with a total station so as to establish an altimetric benchmark for sandy surfaces and the recognized palaeo-shorelines, in comparison with the present mean sea level.

– Determining the chronological framework of the sedimentary unit development by (1) using the archaeological approach, giving proxy data based on the well-known typology of ceramic shards [Vernet, 1998; Vernet and Ould Mohamed Naffé, 2003; Vernet *et al.*, 2004; Vernet, 2007; Barusseau *et al.*, 2007], and (2)  $^{14}\text{C}$  dating of shell samples recovered in sediments and shell-middens. The coastal zone being sheltered from the upwelling influence, the correction for reservoir effect suggested by Saliège *et al.* [2005] was not taken into consideration.

The morphological context and morphodynamical history of the Iwik embayment, already published separately (Barusseau *et al.*, submitted), are presented hereafter before discussing their paleoclimate implications.

## RESULTS

Between the shoreline formed by the Tafarien substratum *ca* 6-5.5 ka and the present one, two types of coastal sedimentary units were evidenced by geomorphology and sedimentology methods: the very extensive sand flats and the linear relief features covered by a thin veneer of anthropogenic *Anadara senilis* shell-middens (fig. 2).

During the above-mentioned period, sand flats developed at variable rates. They form vast expanses of very flat areas, close to the present average sea level, hence still included in the tidal range as reflected by the topometric

profiles. They are bordered, towards the sea, by rarely flooded salt marshes, and by large emerging strands (fig. 2).

The linear relief features formed four sets of beach ridges and coastal dunes (I-IV; fig. 2). Because Neolithic populations who created shell-middens on top of sand ridges are known to have settled very shortly after the sand-ridge formation, as observed in other parts of the Banc d'Arguin area [Barusseau *et al.*, 2007], dating the superimposed shell middens can give a fair idea of the approximate age of the formation of the underlying beach ridges. Unit I is a complex unit made of beach ridges, sand spits, and dunes. Wave action was responsible for the development of the often hook-ended coastal sand ridges, showing a dominant N-S littoral drift (fig. 3). Two additional  $^{14}\text{C}$  dates give an uncalibrated age of  $4070\pm 50$  (Pa 2409) and  $3875\pm 50$  years B.P. (Pa 2412). The linear extension of the system reaching 3 km towards the SSW sheltered the formation of inter-tidal strands. However, between 3.8 and 3.4 ka, the elongation of the system stopped and only sand flats continued to develop. During this time interval, a low berm (unit II) formed after the construction of unit I and before the profound morphogenetic changes accompanying the formation of units III and IV. It is clearly visible on satellite pictures, marking the coastline stabilization within a limited area (II in fig. 2). Unit III ( $3360\pm 35$  years B.P. – Pa 2407) shows a marked curvature at its distal end, from N-S to north to WNW-ESE (III in figs 2 and 4), interpreted as a drastic change in the direction of incoming waves (Barusseau *et al.*, submitted), also responsible for the pattern displayed by unit IV ( $3335\pm 30$  years B.P. – Pa 2410).

That change is explained by the closure of the shallow strait separating the inland region from the Iwik island due to increasing progradation of sand flats (fig. 5). As a result of the closure, the wave-refraction pattern was dramatically modified before the beach ridge formation period, skirting round the Iwik island, instead of directly propagating across the strait (fig. 6). However, the present small beach barrier bordering the shore does not prevent the occasional storm swell between lines 1 and 2, as shown in figure 5.

## DISCUSSION

Two combined driving forces are involved in the depositional processes observed in the Iwik-Aouatil coastal plain: the littoral drift and aeolian processes. The question is how did these processes vary during the Late Holocene? Wind force variability is influenced by the instability of atmospheric systems, whilst littoral drift variability related to swell is influenced by storm-intensity fluctuations. In this instance, climate variations on the scale of the Late Holocene period are determining factors as shown by the literature review in introduction.

### Holocene aeolian processes

Wind-induced sand inputs are flagged by two types of signals: formation of littoral dune accumulations and increased arenitic index value in the sedimentary records. On the northern Banc d'Arguin coast, sand is brought directly to the sea by the barchan train progression through the borderland of the Banc providing a third type of signal, not taken into account to date: sand ridges themselves.

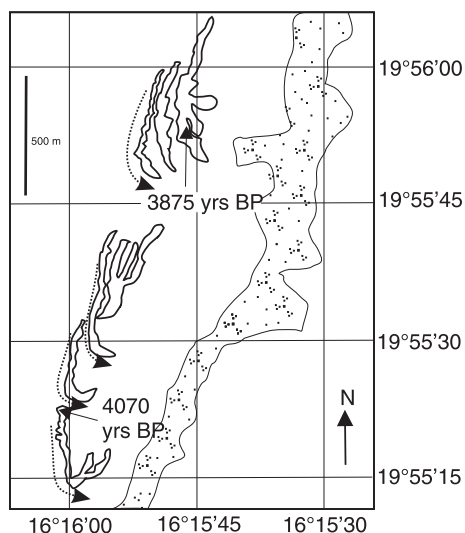


FIG. 3. – Sedimentary unit I. The dotted surface represents the extension of the coastal dunes during the period of hooked-spit formation. The dashed arrows correspond to the morphodynamic scheme of spit generation combining littoral drift and wave refraction at the spit end, and provoking the progressive curvature of the hooks.

FIG. 3. – Unité sédimentaire I. La zone en pointillés correspond à l'extension des dunes côtières pendant la période de formation des flèches à crochets. Les flèches en pointillés indiquent les tendances morphodynamiques combinant la dérive littorale et l'effet de la réfraction des houles à l'extrémité des cordons sédimentaires provoquant la courbure des crochets.

As the literature shows, these signals reflect climate changes at various periods of the Holocene, and reveal an overwhelming presence of sand and dust transport and deposition in the whole of western Africa.

An abrupt increase in aeolian-sediment mobilization around 5.5 cal. ka B.P. confirms a strengthening of northern trade-winds associated with a rapid reduction of rainfall and vegetation cover in the dust-source areas [deMenocal *et al.*, 2000b], correlated with colder climate conditions in the northern hemisphere [Swezey, 2001]. These arid episodes of terrigenous production are also documented by the studies of ODP hole 658C [Haslett and Davies, 2006].

In northeastern Nigeria, peaks of desert-dust concentrations were observed in a dry lake of the Kajemarum Oasis at 4.6, 3.8, and 3.5 cal. ka B.P., and at 4.1 ka in Bal Lake, aeolian sand layers interrupted the mid-Holocene organic silt accumulation [Holmes *et al.*, 1999]. The major environmental change during 3.9-3.5 ka corresponds to a pronounced shift in atmospheric circulation and climate, and parallels a significant arid episode in Tibet and Northwest India [Street-Perrott *et al.*, 2000]. Similarly, an adjustment from wet to dry forest in East Africa, a considerable drop in lake levels in Ethiopia, eastern and Central Sahara (but not west of the 0° Greenwich meridian), Ghana, and lake Chad confirms the regional extension of the climate change.

In western Mauritania, the dune record [Lancaster *et al.*, 2002] closely matches the dust record observed by deMenocal *et al.* [2000a]. The authors plotted the age cluster of aeolian activity by OSL dating into three groups, one of them included in the Holocene period, after 5 ka.

Therefore, in West Africa (but there are strong correlations with similar observations elsewhere in the world), over-activation of sand occurrences was generally observed after 5 ka, particularly in the 4.6-3.5 ka interval. This increase runs in parallel with wind reinforcement coupled with the intensification of the Azores anticyclone.

In the Iwik area, the oldest beach ridge/dune complex developed within a relatively short period (0.4 ka) and the dune-like constructions are oriented in a N020E direction (fig. 3). Lancaster *et al.* [2002] looked into the origins of a similar configuration in the close vicinity. They tried to reconstruct post-wind situations by simulating the most likely combination of winds able to produce dunes aligned in a certain direction. They calculated that a north-northeast direction (similar to that of the Iwik dune-like system) implies a wind regime with two dominant components: from the east and from the northwest. Easterly winds would then mean sand input, while northwest winds were likely to signify stronger occurrence of wave activity on the coast. This situation, in view of the net strengthening of the NW component during the coastal dune formation, is clearly different from the present one, the barchan lines having a N005E-N010E orientation in the area.

#### Holocene littoral drift and storm-reinforcement episodes

In relation to sand input in the coastal zone, the second factor is to be found in the changes in the longshore drift. One of those changes is the longshore wave breaker/shoreline incidence angle [Blivi *et al.*, 2002], but the chief one is the frequency and force variability of the storms. A noteworthy feature testifying to littoral drift activity is the formation of

spits, requiring an abundant supply of sediments [Gonzalez Bonorino *et al.*, 1999], combined with a stable sea level [Roy *et al.*, 1994].

Very few data are available in the literature on sand drift and storm-activity variations during the Late Holocene. Weiler [1998], analyzing littoral deposits in the Anegada Bay (Argentina), describes strong episodes of marine events (exceptionally high tides and exceptional storm wave events), causing massive sediment pulses and changes in the direction of the littoral drift.

In Europe, sand invasion and dune drift are known to have occurred during the cooler period of the Little Ice Age, and a climate-driven mechanism was suggested for their onset [Clarke *et al.*, 2002]. This assumption is based on an increased thermal gradient between 50°N and 65°N, and an increase in the frequency of severe storms [Lamb and Frydendahl, 1991] in the North Atlantic. More generally, records of sand drifts are also documented elsewhere in Europe in the Late Holocene. Three periods of sand drift are dated by IRSL techniques: phase I: 4-3 ka ago, phase II: 1.3-0.9 ka ago, and phase III: 0.55-0.2 ka ago. The older one is also corroborated in Scotland: 3.3-3.8 ka; Netherlands: after 3.5 ka; Southwest England: 2.7-3.5 ka. Clemmensen *et al.* [2001] studied the Holocene aeolian stratigraphy at the inner margin of the Vejers dunefields of Jutland and concluded that sand movements apparently happened at the time of the climate swing towards more stormy conditions. The sequence observed for more intense inland sand transport (6 ka, 4.3 ka, 2.6 ka, and 1.65-1.45 ka B.P.) suggests that it may be linked to a millennial-scale cycle in the North-Atlantic Holocene climate. Zazo *et al.* [1994] showed that small amplitude, non-eustatic variations of sea level, together with changes in wave-regime conditions, induced by a number of different mechanisms, can play a favorable role in spit-bar development. Beach ridges tend to build up during events of comparatively higher mean relative sea level, analogous to centennial spring tides, coupled with rough-weather conditions. One out of the four generations of spit bars described, corresponding to intense

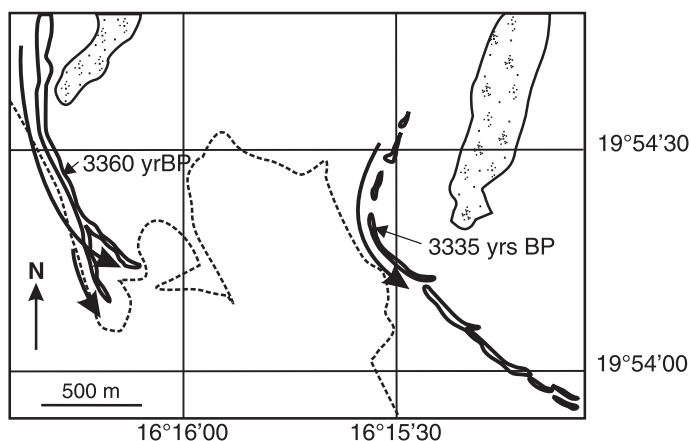


FIG. 4. – Sedimentary units III and IV. Two generations of beach ridges showing the progressive directional change of the crest as a result of the closure of the strait separating Iwik island from the terrestrial domain. Dotted surfaces correspond to the dune field in the coastal zone.

FIG. 4. – Unités sédimentaires III et IV. Deux générations de cordons montrent le changement progressif de direction de la crête en raison de la fermeture de la passe séparant l'île d'Iwik de la terre ferme. Les dunes côtières de l'époque sont en pointillés.

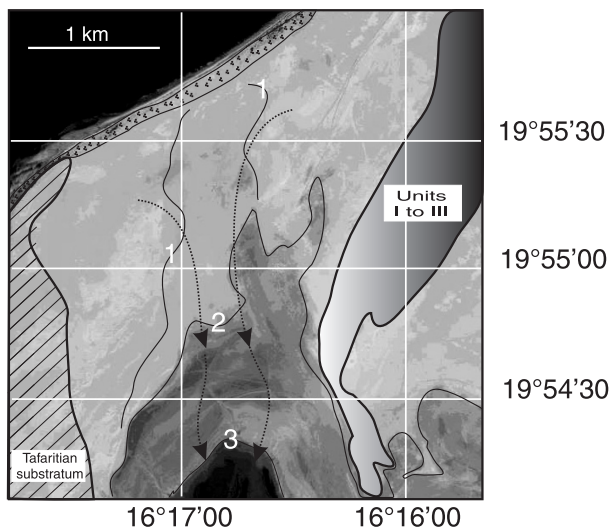


FIG. 5. – Morphological sketch of the Iwik strait evolution. The successive steps of the strait closure (1, 2, and 3) between Iwik island and the mainland. No dates are known for these steps. Closure is over just before 3,300 years B.P., but recent changes are exhibited by the submersion lines between 1 and 2, 2 and 3. Dashed arrows illustrate the development trends of the sand-flat progradation. The dotted surface alongshore corresponds to the present beach barrier.

FIG. 5. – Croquis morphologique de l'évolution de la passe d'Iwik. Étapes successives non datées de la fermeture de la passe d'Iwik (1, 2 et 3). La fermeture est effective juste avant 3,300 ans B.P. et les changements postérieurs sont matérialisés entre les lignes 1 et 2 puis 2 et 3. Les flèches en pointillés figurent les directions de la progradation des zones intertidales sableuses. Le cordon littoral actuel est en pointillés.

progradational phases, occurred during the 4-2.5 ka interval.

Consequently, in terms of creation of littoral units, such as ridges and sand spits/bars, there is a set of indicators all pointing in the direction of one favorable moment in time between 4.3 and 2.5 ka B.P., notwithstanding local disparities. Thus, in the coastal plain of Iwik, observations carried out show that, on two occasions, littoral drift action induced a change in the volume and type of deposits. The first beach ridges formed towards 4 ka B.P., seem to evidence the major role of easterly winds fueling sand supply as well as the part played by northwest winds generating storm conditions, amplifying the littoral drift. In addition, the latest beach ridges, circa 3.3-3.2 ka B.P., also demonstrate the essential role of the swell.

### The climate background

Based on all the above, it clearly appears that the variations of two sets of factors play a crucial role: wind (supplier of material) and drift (transporting mechanism), the combination of both resulting in the construction of sedimentary units, provided a number of favourable conditions are met. Can relatively new approaches like NAO and RCC help us define them?

Within the last decade, the NAO became increasingly important to explain changes in westerly storm track location and intensity [Clarke and Rendell, 2006] across the Atlantic and also in Europe [Dawson *et al.*, 2002]. This approach is sometimes extended to changes in the littoral drift and its causes. In the instance of Portugal (A.D.

1750-1900), Clarke and Rendell [2006] established a correlation between the southward deflection of Atlantic storm tracks due to a negative winter NAO index and an increased sand supply to the littoral drift, coupled with strong onshore winds leading to sand invasion and dune building.

In contrast, an NAO<sup>+</sup> index is altogether propitious to sand influxes on the Iwik coastal zone. It corresponds to (1) the northeastward deflection of Atlantic storms circulating between 40°N and 50°N, enhancing energetic waves on the Northwest African coasts as observed, in Atlantic Morocco, by Aït Laamel *et al.* [2003] and Idrissi [2006] and (2) a strengthening of the Azores anticyclone inducing, in turn, a trade-wind enhancement evidenced by a decrease in sea surface temperature (SST), as described around 4 ka B.P. by Gasse and Van Campo [1994].

RCC can also be used to explain Holocene climate variability as there seem to be chronologically correlated data in palaeoclimate archives [deMenocal *et al.*, 2000a]. During the period from 8 to 1 ka, as a rule, cool poles and dry tropics occurred simultaneously. These events spread over a number of centuries and were characterized by extreme temperatures [Mayewski *et al.*, 2004]. During the last climate phase of the Holocene, four of them were recorded at 6-5, 4.2-3.8, 3.5-2.5, and 1.2-1 ka B.P. These cooling events reported for the North Atlantic by Bond *et al.* [1997] were synchronous with the arid episodes, monsoon weakening and SST drop in the northern hemisphere at low/mid latitudes [deMenocal *et al.*, 2000a; Fleitmann *et al.* 2003; Brooks, 2006].

Hence, a climate pattern combining episodes of RCC and NAO<sup>+</sup> index is conducive to both sand supply, as it accelerates the southwestward migration of barchan's lines, and sand transportation, as it improves the efficiency of the littoral drift. In the Iwik coastal plain, three episodes of sand-spit construction fall into the time interval of recognized RCC occurrences (4.2-3.8 ka; 3.5-2.5 ka) and NAO<sup>+</sup> induced over active swell around 4 ka B.P.

### CONCLUSION

After the arrival of the transgressive sea, the change from the open configuration of the coast in the Iwik area around 6-5.5 ka B.P., to the current one, is marked by the dual formation, in several stages, of sand flats and four sets of linear sedimentary structures. The sand flats developed through lateral accretion leading to an extended infilling of

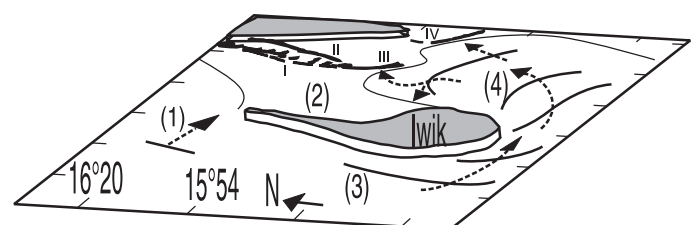


FIG. 6. – Palaeo-oceanographic wave pattern ca 3.4-3.2 ka B.P. (1): hypothesized direction of the wave; (2): Iwik strait; (3): waves fronts (heavy lines); (4): orthogonals (dashed lines); I, II, III, IV: sedimentary units described in the text.

FIG. 6. – Schéma du paléo-plan de vagues vers 3,4-3,2 ka B.P. (1) : houle incidente présumée ; (2) : passe d'Iwik ; (3) : fronts de houles (traits épais) ; (4) : orthogonales (lignes en tiretés) ; I, II, III, IV : unités sédimentaires décrites dans le texte.

the quietest sheltered zones. The linear structures are represented by a set of beach ridges and bars similar to littoral spits, displaying notably different orientations.

These constructions reflect the global climate change within the general framework known for that area. They provide local evidence of the aridity crisis *ca* 4.5-3.2 ka [Salzmann and Hoelzmann, 2005; Street-Perrott *et al.*, 2000] and emphasize more precisely the two episodes of

over-abundant sand supply around  $4\pm 0.2$  ka and 3.3-3.2 ka, respectively. These constructions also echo, to a certain extent, the RCC in these intervals and situations of NAO<sup>+</sup> generating more frequent and active wave episodes, thus inducing more efficient littoral drift on the Banc shorelines.

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## References

- AÏT LAAMEL M., BOUKSIM H., IDRISSE M., CHAGDALI M. & HOURIMECHE A. (2003). – Etude des houles exceptionnelles sur la côte atlantique marocaine. – 3èmes Journ. marocaines Sc. Mer, unpublished report, Rabat.
- ALLEY R. B., MAYEWSKI P. A., SOWERS T., STUIVER M., TAYLOR K. C. & CLARK P. U. (1997). – Holocene climate instability; a prominent, widespread event 8,200 yr ago. – *Geology*, **25**, 6, 483-486.
- BARUSSEAU J.-P. (1985). – Evolution de la ligne de rivage en république islamique de Mauritanie. – Unesco, Division des Sciences de la Mer, unpublished report, Contract Sc 217.614.4, 104 p.
- BARUSSEAU J.-P., BA M., DESCAMPS C., DIOP E.H.S., GIRESSE P. & SAOS J.L. (1995). – Coastal evolution in Senegal and Mauritania at  $10^3$ ,  $10^2$  and  $10^1$  year scales. Natural and human records. – *Quatern. Internat.*, **29/30**, 61-73.
- BARUSSEAU J.-P., VERNET R., SALIÈGE J.-F. & DESCAMPS C. (2007). – Late Holocene sedimentary forcing and human settlements in the Jerf el Oustani – Ras el Sass region (Banc d'Arguin – Mauritania). – *Géomorphologie, relief, processus, environnement*, **7**, 7-18.
- BARUSSEAU J.-P., CERTAIN R., VERNET R. & SALIÈGE J.-F. (2009). – Late Holocene formation of the littoral zone in the Iwik peninsula area (Banc d'Arguin – Mauritania). – *Geomorphology* (submitted).
- BLIVI A., ANTHONY E. & OYEDE L.M. (2002). – Sand barrier development in the Bight of Benin, West Africa. – *Ocean and Coastal Management*, **45**, 2-3, 185-200.
- BOND G., SHOWER W., CHESEBY M., LOTTI R., ALMASI P., DEMENOCAL P., PRIORE P., CULLEN H., HAJDAS I. & BONANI G. (1997). – A Pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. – *Science*, **278**, 5341, 1257-1266.
- BROOKS N. (2006). – Cultural responses to aridity in the Middle Holocene and increased social complexity. – *Quatern. Internat.*, **151**, 29-49.
- BROOKS N., DI LERNIA S., DRAKE N., RAFFIN M. & SAVAGE T. (2003). – The geoarchaeology of western Sahara. Preliminary results of the first Anglo-Italian expedition in the free zone. – *Sahara*, **14**, 63-80.
- CLARKE M. L., RENDEL H., TASTET J.-P., CLAVÉ B. & MASSÉ L. (2002). – Late-Holocene sand invasion and North Atlantic storminess along the Aquitaine coast, southwest France. – *The Holocene*, **12**, 2, 231-238.
- CLARKE M.L. & RENDELL H.M. (2006). – Effects of storminess, sand supply and the North Atlantic oscillation on sand invasion and coastal dune accretion in western Portugal. – *The Holocene*, **16**, 3, 341-355.
- CLAUSSEN M & GAYLER V. (1997). – The greening of Sahara during the mid-Holocene: results of an interactive atmosphere-biome model. – *Global Ecol. and Biogeography Letter*, **6**, 369-377.
- CLAUSSEN M., KUBATSKI C., BROVKIN V., GANOPOLSKI A., HOELZMANN P. & PACHUR H.-J. (1999). – Simulation of an abrupt change in Saharan vegetation in the mid-Holocene. – *Geophys. Res. Lett.*, **26**, 14, 2037-2040.
- CLEMMENSEN L.B., ANDREASEN F., HEINEMEIER J. & MURRAY A. (2001). – A Holocene coastal aeolian system, Vejers, Denmark: landscape evolution and sequence stratigraphy. – *Terra Nova*, **13**, 2, 129-134.
- DAWSON A.G., HICKEY T., HOLT T., ELLIOT L., DAWSON S., FOSTER I.D.L., WADHAMS P., JONSDOTTIR I., WILKINSON, J., MCKENNA J., DAVIS N.R. & SMITH D.E. (2002). – Complex North Atlantic Oscillation (NAO) Index signal of historic North Atlantic storm-track changes. – *The Holocene*, **12**, 363-369.
- DEMENOCAL P., ORTIZ J., GUILDERTON T. & SARNTHEIN M. (2000a). – Coherent high- and low-latitude climate variability during the Holocene warm period. – *Science*, **288**, 2198-2202.
- DEMENOCAL P., ORTIZ J., GUILDERTON T., ATKINS J., SARNTHEIN M., BAKER L. & YARUSINSKI M. (2000b). – Abrupt onset and termination of African humid period: Rapid climate response to gradual insolation forcing. – *Quat. Sci. Rev.*, **19**, 347-361.
- DEYNOUX M., PROUST J.-N. & SIMON B. (1991). – Relations entre géométrie, association de faciès, discontinuité et variation du niveau de base dans la zone de transition entre domaines marin et continental. – *J. African Earth Sci.*, **12**, 181-198.
- FLEITMANN D., BURNS S.J., MUELSESE M., NEFF U., KRAMERS J., MANGINI A. & MATTER A. (2003). – Holocene ITCZ migration recorded in stalagmites from Oman (southern Arabia). – *Eos. Trans. AGU*, **84** (46), Fall Meet. suppl., Abstract PP21A-05.
- ELOUARD P. (1975). – Formations sédimentaires de Mauritanie atlantique. In: Monographies géologiques régionales. – *Notice explicative de la carte géologique au 1/1 000 000 de la Mauritanie*, BRGM, Paris, 171-254.
- GANOPOLSKI A., KUBATZKI C. CLAUSSEN M., BROVKIN V. & PETOUKHOV V. (1998). – The influence of vegetation-atmosphere-ocean interaction on climate during the Mid-Holocene. – *Science*, **280**, 1916-1919.
- GASSE F. (2000). – Hydrological changes in the African tropics since the Last Glacial Maximum. – *Quatern. Sci. Rev.*, **19**, 189-211.
- GASSE F. & VAN CAMPO E. (1994). – Abrupt post-glacial climate events in West Asia and North Africa monsoon domains. – *Earth Planet. Sci. Lett.*, **126**, 435-456.
- GIRESSE P., BARUSSEAU J.-P., GASSE F. & HOANG C.-T. (1989). – Paléoenvironnements pléistocènes du littoral de Mauritanie d'après l'étude de la coupe du Cap Tafarit: proposition de suppression de la notion de Tafariten, « étage marin ». – *C. R. Acad. Sci.*, Paris, **309**, II, 1377-1382.
- GONZÁLEZ BONORINO G., BUJALESKY G., COLOMBO F. & FERRERO M. (1999). – Holocene coastal paleoenvironments in Atlantic Patagonia, Argentina. – *J. South Am. Earth Sci.*, **12**, 3, 325-331.
- HASLETT S.K. & DAVIES C.F.C. (2006). – Late Quaternary climate-ocean changes in western North Africa: offshore geochemical evidence. – *Trans. Inst. Br. Geogr.*, NS, **31**, 34-52.
- HASLETT S.K. & SMART C.W. (2006). – Late Quaternary upwelling off tropical NW Africa: new micropalaeontological evidence from ODP Hole 658C. – *J. Quatern. Sci.*, **21**, 3, 259-269.
- HÉBRARD L. (1978). – Contribution à l'étude géologique du Quaternaire du littoral mauritanien entre Nouakchott et Nouadhibou, 18°-21° latitude nord. Participation à l'étude des désertifications du Sahara. – *Docum. Lab. Géol. Fac. Sci. Lyon*, **71**, 210 p., 59 fig.



- HOLMES J.A., STREET-PERROTT F.A., PERROTT R.A., STOKES S., WALLER M.P., HUANG Y., EGLINGTON G. & IVANOVICH M. (1999). – Environmental changes, lake and groundwater in the Sahel of northern Nigeria. Part 2. Holocene landscape evolution of the Manga grasslands. Evidence from palaeolimnology and dune chronology. – *J. Geol. Soc.*, London, 155, 357-358.
- IDRISSI M. (2006). – Evolution du littoral de Casablanca-Mohammedia (Maroc): étude de la dynamique sédimentaire et des impacts anthropiques. – Unpublished thesis, Toulon, 188 p.
- KOCUREK G., HAVHOLM K.G., DEYNOUX M. & BLAKEY R.C. (1991). – Amalgamated accumulations resulting from climate and eustatic changes, Akchar Erg, Mauritania. – *Sedimentology*, **38**, 751-772.
- KOOPMANN B.J., LEES A., PIESSENS P. & SARNTHEIN M. (1979). – Skeletal carbonate sands and wind-derived silty marls off the Saharan coast: Baie du Lévrier, Arguin Platform, Mauritania. – “*Meteor*” *Forschung Ergebnisse*, C, **30**, 15-57.
- KUPER R. & KRÖPELIN S. (2006). – Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution. – *Science*, **313**, 803-807.
- LAMB H.H. & FRYDENDAHL K. (1991). – Historic storms of the North Sea, British Isles and northwest Europe. – Cambridge University Press, 216 p.
- LANCASTER N., KOCUREK G., SINGHVI A., PANDEY V., DEYNOUX M., GHIENNE J.F. & LÔ K. (2002). – Late Pleistocene and Holocene dune activity and wind regimes in the western Sahara desert of Mauritania. – *Geology*, **30**, 11, 991-994.
- LEZINE A.-M., TIERCELIN J.-J., ROBERT C., SALIÈGE J.-F., CLEUZIQU S., INZAN M.L. & BRAEMER F. (2007). – Centennial to millennial-scale variability of the Indian monsoon during the early Holocene from a sediment, pollen and isotope record from the desert of Yemen. – *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **243**, 3-4, 235-249.
- MAHÉ E. (1985). – Contribution à l'étude scientifique de la région du Banc d'Arguin (littoral mauritanien: 21°20' – 19°20' lat. N). – Unpublished thesis, Sciences, Montpellier, I, 576 p.
- MALEY J. (1997). – Middle to Late Holocene changes in tropical Africa and other continents: paleomonsoon and sea surface variations. *In*: H. NÜZHET DALFES, G. KUKLA and H. WEISS, Eds., Third millennium B.C. climate change and Old World collapse. – Springer Verlag, *NATO ASI Series*, 1, **49**, 611-640.
- MAYEWSKI P.A., ROHLING E.E., STAGER J.C., KARLÉN W., MAASCH K.A., MEEKER L. D., MEYERSON E. A., GASSE F., VAN KREVELD S., HOLMGREN K., LEE-THORP J., ROSQVIST G., RACK F., STAUBWASSER M., SCHNEIDER R.R. & STEIG E.J. (2004). – Holocene climate variability. – *Quatern. Res.*, **62**, 243-255.
- PARTRIDGE T.C., DEMENOCAL P., LORENTZ S.A., PAIKER M.J. & VOGEL J.C. (1997). – Orbital forcing over South Africa: a 200 000-year rainfall record from the Pretoria saltpan. – *Quatern. Sci. Rev.*, **16**, 1-9.
- PETIT-MAIRE N., BEAUFORT L. & PAGE N. (1997). – Holocene climate changes and man in the present day Sahara desert. *In*: H. NÜZHET DALFES, G. KUKLA and H. WEISS, Eds., Third millennium B.C. climate change and Old World collapse. – Springer Verlag, Heidelberg, 297-308.
- REGARD V., BELLIER O., BRAUCHER R., GASSE F., BOURLÈS D., MERCIER J., THOMAS J.-C., ABBASSI M.R. SHABANIAN E. & SOLEIMANI S. (2006). – <sup>10</sup>Be dating of alluvial deposits from southeastern Iran (the Hormoz strait area). – *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **242**, 1-2, 36-53.
- RENSSEN H., BROVKIN V., FICHEFET T. & GOOSSE H. (2003). – Holocene climate instability during the termination of the African Humid Period. – *Geophys. Res. Letters*, **30**, 1184.
- ROY P.S., COWELL P.J., FERLAND M.A. & THOM B.G. (1994). – Wave-dominated coasts. *In*: R.W.G. CARTER and C.D. WOODROFFE, Eds., Coastal evolution. – Cambridge University Press, Cambridge, 121-186.
- SALIÈGE J.-F., LEZINE A.-M. & CLEUZIQU S. (2005). – Estimation de l'effet réservoir en mer d'Arabie. – *Paléorient*, 31/1, 64-69.
- SALZMANN U. & HOLZMANN P. (2005). – The Dahomey gap: an abrupt climatically induced rain forest fragmentation in West Africa during the Late Holocene. – *The Holocene*, **15**, 2, 190-199.
- STREET-PERROTT F.A., HOLMES J.A., WALLER M.P., ALLEN M.J., BARBER N.G.H., FOTHERGILL P.A., HARKNESS D.D., IVANOVITCH M., KRON D. & PERROTT R.A. (2000). – Drought and dust deposition in the West African Sahel: a 5500-year record from Kajamarum Oasis, northeastern Nigeria. – *The Holocene*, **10**, 3, 293-302.
- STREET-PERROTT F.A. & PERROTT R.A. (1993). – Holocene vegetation, lake levels and climate of Africa. *In*: H.E. WRIGHT JR., J.E. KUTZBACH, T. WEBB, W.F. RUDDIMAN, F.A. STREET-PERROTT and P.J. BARTLEIN, Eds., Global climates since the Last Glacial Maximum. – Univ. Minnesota Press, Minneapolis, 318-356.
- SWEZEY C. (2001). – Eolian sediment response to Late Quaternary climate changes: Temporal and spatial patterns in the Sahara. – *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **167**, 119-155.
- VERNET R. (1998). – Le littoral du Sahara atlantique mauritanien au Néolithique. – *Sahara*, **10**, 21-30.
- VERNET R. (2007). – Le golfe d'Arguin: de la Préhistoire à l'Histoire: littoral et plaines intérieures. – *Collection PNBA*, Nouakchott, **3**, 203 p.
- VERNET R. & OULD MOHAMED NAFFÉ D. (2003). – Dictionnaire archéologique de la Mauritanie. – CRIAA – LERHI, université de Nouakchott, 164 p.
- VERNET R. & TOUS P. (2004). – Les amas coquilliers de Mauritanie occidentale et leur contexte paléoenvironnemental (VIIe-IIe millénaires B.P.). – *Préhistoire et Anthropologie Méditerranéennes*, **13**, 1-15.
- WAGNER F., AABY B. & VISSCHER H. (2002). – Rapid atmospheric CO<sub>2</sub> changes associated with the 8,200-years B.P. cooling event. – *Proc. Nat. Acad. Sci.*, **99**, 19, 12011-12014.
- WEILER N.E. (1998). – Holocene sea levels in Anegada Bay, Argentine Republic. – *J. Coast. Res.*, **14** (3), 1034-1043.
- ZAZO C., GOY J.-L., SOMOZA L., DABRIO C.-J., BELLUOMINI G., IMPROTA S., LARIO J., BARDAJI T. & SILVA P.-G. (1994). – Holocene sequence of sea-level fluctuations in relation to climate trends in the Atlantic-Mediterranean linkage coast. – *J. Coast. Res.*, **10** (4), 933-945.