Late-middle Pleistocene, late Pleistocene and Holocene palaeo-sea-level records at Agadir and the Atlantic Atlas coastal reach, Morocco: an updated overview

Enregistrements des paléorivages du Pléistocène moyen-supérieur, Pléistocène supérieur et Holocène à Agadir et sur la côte de l’Atlas atlantique, Maroc : une vue d’ensemble actualisée

André Weisrock
LATE-MIDDLE PLEISTOCENE, LATE PLEISTOCENE AND HOLOCENE PALAEO-SEA-LEVEL RECORDS AT AGADIR AND THE ATLANTIC ATLAS COASTAL REACH, MOROCCO: AN UPDATED OVERVIEW

André L.-E. WEISROCK

ABSTRACT

Out of the Late Holocene sea-level highstand at ca. 2.7 ka, seven Late Pleistocene and Late-Middle Pleistocene palaeo-sea-levels (PSL) are today recorded along the coast of the Atlantic Atlas of Morocco: 1) as near-shore dunes (NSD) deposits, records of two MIS 2 and MIS 3 PSL near 0 m a.s.l. or just below, at 28 and ca. 40 ka; 2) records of three MIS 5a, 5c and 5e PSL between zero and +8 m a.s.l.; 3) records of two MIS 7 and MIS 9 PSL above +10 m a.s.l. and near +20 m a.s.l. All datable records are placed in their morpho-lithostratigraphic units (UMS) and discussed with regard to their location, palaeo-environmental and tectonic implications.

Keywords: morpho-lithostratigraphic units (UMS), palaeo-sea-levels (PSL), near-shore dunes (NSD), malacofaunas, U/Th dates, aminochronology, MIS 2-3-4, 5, 7, 9, palaeo-environments, tectonic

1 - INTRODUCTION

"The Atlantic littoral of Morocco... clearly provides one of the most complete Pleistocene successions of the world" (Howell, 1962, in Stearns, 1978), and this is especially true along the coast of the Atlantic Atlas, between Agadir and Essaouira. Nevertheless, on the Moroccan Meseta, associated human bones and artifacts found in marine-aeolian calcarenites of Casablanca and Rabat induced the strongest interest in its chronology, which was here, earlier and more completely studied, and established as a model (Biberson, 1958; Texier et al., 1985; Lefèvre, 2000; Texier et al., 2002; Plaziat et al., 2008).

At the same time, the southernmost Atlantic Atlas coastal reach (fig. 1), with uplifted Pleistocene marine deposits, was first studied by Lecointre (1952), Ambroggi (1963), Weisrock (1980) and more recently with U/Th datings, aminochronology and tectonic analysis (Weisrock, 1981; Weisrock et al., 1999; Meghraoui et al., 1998). Before the undertaking of new OSL/IRSL and TIMS measurements, and more detailed microtectonic investigations, this paper attempts an updating of the present knowledge about the Late Pleistocene and Late-Middle Pleistocene palaeo-sea-level records in this area.
2 - MORPHOLOGICAL SETTING OF THE ATLANTIC ATLAS COASTAL REACH

2.1 - COASTAL MORPHOLOGY: MOROCCAN ATLANTIC “OULJA” AND RAISED TERRACES

Along the well-regularized Atlantic coast of Morocco, a morphological feature prevails, which is called the “oulja” or “oulja morphogenic system” (Guilcher & Joly, 1954; Weisrock & Fontugne, 1991). It consists of three well-developed morphological elements (fig. 2): the coastline, an inland dead cliff and, between them, a longitudinal depression which is the oulja s.s. Along the uplifted Atlantic Atlas coast, marine erosion generally prevails and, very often, only the inland part of the oulja system remains at the foot of the dead cliff. This truncated oulja and even the basal part of the dead cliff are covered by cemented dunes and/or colluvial calcruited deposits over the basal palaeo-shorelines. Due to the continuous uplift since the Neogene (Ambroggi, 1963; Weisrock 1980; Mustaphi et al., 1997), this repetitive genetic system has built a coastal morphology of stepped terraces with both marine and continental deposits.

2.2 - MORPHOSTRATIGRAPHIC UNITS (UMS) AND PALAEO-SEA-LEVELS (PSL)

As well established at Casablanca (Lefèvre, 2000; Lefèvre & Raynal, 2002), at the foot of the associated dead-cliff, a well-registered marine highstand and its following regressive supra-tidal and continental deposits clearly correspond to a morpho-litho-stratigraphic unit (UMS) with a well developed morphological feature. The basal marine deposit (PSL) and its subsequent littoral and continental cover — more or less thick dune calcarenites (NSD) and/or colluvial slope debris and sometimes fluvial deposits — build a sedimentary “formation” including both first marine and following continental members. But, very often, the PSL member and its following regressive members are shaped in a polygenic upper “glacis” that can even mask both palaeo-shorelines and dead-cliffs (fig. 3, see UMS 2). So, several formations and several PSL may be included within only one visible UMS. Previously invisible marine deposits, distinct from the main basal palaeo-sea-level, are found in new outcrops. It is clear that only the most important marine stages, with high and long marine standing, could have a full and unique morphological UMS expression. Minor stages are masked, or even eroded, in spite of continuous uplift of the Atlas chain, which drive a stepped-like system to the UMS (fig. 3).

2.3 - UMS AND PSL BETWEEN IMSOUANE AND AGADIR: GEOMORPHOLOGY AND FIELD OBSERVATIONS

The most complete morphological stepped-like example can be found at Assif Tamraght mouth, with at least five or more main UMS (fig. 4):

- UMS 1 (ASSIF TAMRAGHT MOUTH UNIT, near zero meter) is the present shoreline (PSL 1) area, with alternating low cliffs cut in the Pleistocene calcarenites and beaches of marine biodetritic sands, covered by gravelly bars at the mouth of the wadi. A low sandy terrace was here formerly described as “Mellahian” by Ambroggi and Gigout (1953); it was in fact a near-shore dune capped by several kjökenmödding (Weisrock, 1980), that had today disappeared because of strong climatic and anthropogenic erosion. Only notches cut in the calcarenitic low cliffs and gravelly low fluvial terraces can be found in the estuary (Rohdenburg, 1977; Weisrock, 1980).

- UMS 2 (IGOURAM UNIT = CAPE RHIR UNIT = AGADIR-PORT UNIT, between zero and ca + 20 m a.s.l., or more in some cases) is the true oulja morphogenic system inherited since the last interglacial (fig. 4). Its basal marine PSL lies between zero and + 8 m a.s.l., with fluvial and/or colluvial interbedded deposits, then more or less thick cemented sand-dune accumulations overlain by new continental silty and gravelly deposits (Lecointre, 1952; Weisrock & Rognon, 1977; Sabelberg, 1978). The related dead-cliff is still observable at Tamraght, as at Cape Rhir. In most of the cases, the dead-cliff has been covered by dunes and colluvial deposits that have joined UMS 2 and UMS 3 in a continuous glacis
(fig. 3). At Agadir-Port and at Assif Lamahyane, outcrops have shown a second well-developed marine deposit near +20 m a.s.l. At Imouane, two another marine deposits are included in the same UMS, at +8-10 m a.s.l. (see below 3.4) and at ca +30 m is (fig. 3).

– UMS 3 (DOUAR SIHEL UNIT = AGADIR-ANZA UNIT, between ca + 40 and 60 m a.s.l.), is the most important morphological unit that can be seen at the front of the main Pleistocene dead-cliff of the Atlantic Atlas coast. It consists of a basal shelly and gravelly marine deposit,
then a second silty marine deposit, and very thick dune sands and/or thick colluvial and alluvial silty and gravelly detritic accumulations, with inner and upper laminated calcretes. Finally, this built UMS and its wide glacis surface were cut in new cliffs by the following transgressions. So, as said before, intermediate palaeo-shorelines can be found at the uncertain limits of UMS 3 and UMS 2.

- UMS 4, at 70 m a.s.l., was found only at Imsouane-Redan with a well-developed marine deposit (Weisrock, 1980) but not at Tamraght.
3 - HOLOCENE, LATE PLEISTOCENE AND LATE-MIDDLE PLEISTOCENE SEA-LEVELS BETWEEN AGADIR AND IMSOUANE: A BRIEF CHRONOSTRATIGRAPHICAL OVERVIEW

Details of stratigraphy, sedimentology and study of gastropods and bivalves can be found through our previous works (Weisrock, 1980; Weisrock, 1993; Weisrock et al., 1999). The previously studied palaeo-sea-levels and coastal aeolianites are here summarized in regard to their \(^{14}\)C and U/Th ages, and included as well as possible in the MIS global chronology.

3.1 - UMS 1, PSL 1 AND NSD 1: LACK OF DIRECT PROOFS OF CLASSICAL HOLOCENE SEA-LEVEL, MIS 1

Along the northwestern Atlantic coast of Africa, the last Holocene marine maximum, called “Mellhian”, is generally known to occur at ca. 5-6 ka (Gigout, 1952; Choubert et al., 1967, on the Moroccan Meseta; Faure & Elouard, 1967; Ortlieb, 1975; Petit-Maire, 1980, along the Moroccan Sahara and Mauritania). The “Mellhian” sea-level of Tamraght (Ambrogi & Gigout, 1953) was not a beach deposit but a dune capped by several kjökkenmödding of historical ages (Weisrock, 1980). This small recent bay-accumulation is today completely eroded. As the “Reddad Ben Ali formation” of Casablanca, that is dated between 1.2 ± 0.2 and 4.7 ± 1.1 ka by radiocarbon and OSL (Lefèvre, 2000; Texier et al., 2002), a marine shell of Thais haemastoma sampled in a fossil gravelly littoral bar preserved at Moulay Douraine, north from Essaouira, gave a \(^{14}\)C age of 2 770 ± 100 BP (Weisrock, 1980). This last formation belongs not to the ca. 6 ka highstand generally described, but to a new more recent high level. Nevertheless, another evidence of the post-glacial littoral rise, with a probable maximum at 6 ka, is the wide extent of the Low-Holocene coastal dunes NSD 1 that accumulated here since ca. 12 ka to 6 ka (Weisrock & Fontugne, 1991; Weisrock et al., 2002; see also fig. 5).

3.2 - UMS 2: RECORDS OF TWO REGRESSIVE LEVELS (PSL 2, PSL 3) AS NEAR-SHORE DUNES (NSD 2, NSD 3) DURING MIS 2-3

In certain parts of the coast, UMS 2 remains as a truncated oulfa where the basal PSL member is often absent but where the following coastal dunes members are exposed in the present high cliffs.

3.2.1 - Littoral dunes of UMS 2: sedimentology and chronology (fig. 5)

Well-developed coastal dune systems accumulated under the NNW dominant winds on the left sides of the mouths of wadi Tamri and wadi Souss during the MIS 2, 3 and 4, and are now persistent. Today, in similar littoral dune systems, the sedimentological evolution of marine sands happens very quickly: only after 8 km of wind transport, the coarse (200 µm and more) biodetritic carbonated sand of the beach becomes a fine (80 µm) aeolised quartz sand (Weisrock et al., 2002). Sedimentological properties of coastal dune sands are indicators of their more or less proximity to the coastline. Based on these field observations and several outcrop studies in Cape Rhir, Tamri (Sabelberg, 1978; Weisrock, 1980; El Ouahidi, 2008) and along the Chouka coast, south of Agadir (Barrada, 1996; Adele, 1998), it appears that the strand line rose near zero at ca. 70 ka, at more than 38 ka and at ca. 28 ka (fig. 5). Dune sands of these three periods are abundant, coarse and rich in biodetritic grains, which indicate the shore proximity. The older wide coastal dune system (NSD 4) is banded to the last MIS 5a sub-stage at ca. 70 ka (see below 3.3). The following dune system (NSD 3) accumulates before 38 ka and is also very thick in some places. Called “Hauptdünenserie” by Sabelberg (1978) near Cape Rhir, this coastal dune system often covers the MIS 5 dead-cliff and is itself overlain by a continental member that contains several red or brown soils, silty alluvial sediments and laminated calcareous crusts. Man was present at this time along the shoreline and abandoned palaeo-kjökkenmödding. Associated Middle-Paleolithic tools are also often found in NSD 3. The last coastal dune member at ca. 28 ka (NSD 2) is generally more restricted and consists in alternating scarce true coastal sands with coarse biodetritic grains and more frequent continentalized sands of small quartz grains linked to the regressive trend. So, these records show the possible occurrence of two MIS 2 and MIS 3 PSL near zero (PSL 3) or near beyond zero (PSL 2) along this coast, with two well-developed NSD. This history of the coastline during MIS 2-3 can be compared with those of the Iberian coasts, which demonstrated the nearly same global features (Zazo et al., 2003; Benedetti et al., 2009;
Fig. 5: Near-shore dunes of the Atlantic Atlas.
A/ Cliff in the near-shore dunes of Oued Tamri (photo A. Weisrock, 2010).
1/ MIS 5 PSL, 2/ MIS 5a dunes, 4/ MIS 3 dunes, 7/ MIS 2 dunes.

B/ Synthetic section of the MIS 5-MIS 4-MIS 3-MIS 2 dune system (after Weisrock et al., 2002).
1/ Low Pleistocene carbonated sandstones, 2/ Upper Pleistocene cross-bedded calcarenites, 3/ sands without stratification, 4/ silty red sands, 5/ roots, 6/ powder calcite horizon, 7/ laminated calcrust, 8/ marine shells, 9/ burnt marine shells in kjökkenmödding, 10/ Helix, 11/ Prehistoric tools, M/ Middle Paleolithic, At./ Aterian, Ib./ Iberomaurusian, Neo./ Neolithic.

Fig. 5 : Dunes littorales de l'Atlas atlantique. A/ Falaise dans les dunes littorales de l'oued Tamri (photo A. Weisrock, 2010). 1/ PSL du stade isotopique 5, 2/ dunes du sous-stade 5a, 4/ dunes du stade 3, 7/ dunes du stade 2.
B/ Coupe synthétique du système dunaire des stades isotopiques 5-4-3-2 (d'après Weisrock et al., 2002). 1/ Grès biodétritiques du Pléistocène inférieur, 2/ calcarénites à lits entrecroisés du Pléistocène supérieur, 3/ sables non stratifiés, 4/ sables et limons rouges, 5/ racines, 6/ horizon carbonaté poudreux, 7/ croûte calcaire lamellaire, 8/ coquilles marines, 9/ coquilles marines brûlées dans un kjökkenmödding, 10/ Helix, 11/ Outils préhistoriques, M/ Paléolithique moyen, At./ Aterien, Ib/ Iberomaurusien, Neo./ Neolithique.
Fornós et al., 2009). Detailed OSL measurements on quartz and feldspars are however now undertaken, in order to improve these assumptions.

3.2.2 - PSL 3: a MIS 3 high stand at ca. 44 ka?

Four U/Th measurements made on *Thaïs (Stramonita) haemastoma* L. shells from two lumachelic marine deposits of PSL 3 presently standing respectively at +2 and +4 meters high, at Cape Rhir and Assif Lamahyane, gave a lot of ages between 44 ± 2 and 55 ± 2 ka (tab. 1). We initially thought we had discovered traces of a Middle “Soltanian” highstand (Hoang et al., 1978) that could be parallelized to the Mauritanian “Inchirian” (Faure & Hébrard, 1977). But these results were not adequate to explain most of the other data concerning the low (zero to +4 m a.s.l.) PSL deposits of the studied area (tab. 2). Nothing in macrofauna composition (i.e. more cold species) allows us to particularize these two samples. A possible explanation of the seemingly aberrant results was the choice of the gastropod species *Thaïs haemastoma* that presented a thick favorable shell for the U/Th analyses, but could be removed from more recent kjökkenmödding located just above and redeposited on the

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample</th>
<th>Reference</th>
<th>U/Th age (ky)</th>
<th>231Pa age (ky)</th>
<th>Climatic stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cap Rhir</td>
<td>USM 72/19</td>
<td>Sabelberg (1978)</td>
<td>(34.1±1)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Cap Rhir</td>
<td>C.R. 30-1 I</td>
<td>Hoang et al. (1978)</td>
<td>44 ± 2</td>
<td>46 ± 2</td>
<td>3</td>
</tr>
<tr>
<td>Cap Rhir</td>
<td>C.R. 30-1 II</td>
<td>id</td>
<td>44 ± 2</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Assif Amahyane</td>
<td>A.L. 22 I</td>
<td>id</td>
<td>46 ± 2</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Assif Amahyane</td>
<td>A.L. 22 II</td>
<td>id</td>
<td>55 ± 2</td>
<td>49 ± 3</td>
<td>3</td>
</tr>
</tbody>
</table>

Tab. 1: Apparent $^{14}$C and U/Th ages of palæokjökkenmödding and shelly tempestites in post-PSL 4-5-6 deposits.

Sabelberg (1978): $^{14}$C age on shells; Hoang et al. (1978): U/Th and Pa ages on *Thaïs (Stramonita) haemastoma* L.

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample</th>
<th>Reference</th>
<th>U/Th age (ky)</th>
<th>231Pa age (ky)</th>
<th>Climatic stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agadir-Port</td>
<td>A. 10 I</td>
<td>Hoang et al. (1978)</td>
<td>72 ± 2</td>
<td></td>
<td>5 a (?)</td>
</tr>
<tr>
<td>Agadir-Port</td>
<td>Hoang, unpubl.</td>
<td></td>
<td>75 ± 4</td>
<td></td>
<td>5 a (?)</td>
</tr>
<tr>
<td>Agadir-Phare</td>
<td>A. 17</td>
<td>Hoang et al. (1978)</td>
<td>76 ± 2</td>
<td></td>
<td>5 a (?)</td>
</tr>
<tr>
<td>AgadirCentrale</td>
<td>A. 11</td>
<td>id</td>
<td>92 ± 7</td>
<td></td>
<td>5 a (?)</td>
</tr>
<tr>
<td>Cap Bouzellou</td>
<td>CB 1</td>
<td>Meghraoui et al. (1998)</td>
<td>92 ± 5</td>
<td></td>
<td>5 a (?)</td>
</tr>
<tr>
<td>Agadir-Port</td>
<td>A. 10 II</td>
<td>Hoang et al. (1978)</td>
<td>96 ± 5</td>
<td>114 ± 18/13</td>
<td>5</td>
</tr>
<tr>
<td>Assif Tamghart</td>
<td>A.T. 19</td>
<td>id</td>
<td>97 ± 5</td>
<td></td>
<td>5 c (?)</td>
</tr>
<tr>
<td>Anza</td>
<td>96 14-1</td>
<td>Meghraoui et al. (1998)</td>
<td>101 ± 12/11</td>
<td></td>
<td>5 c</td>
</tr>
<tr>
<td>Agadir-Port</td>
<td>A. 129 a</td>
<td>Hoang, unpubl.</td>
<td>103 ± 9</td>
<td></td>
<td>5c</td>
</tr>
<tr>
<td>Arhedis</td>
<td>96 15-1</td>
<td>Meghraoui et al. (1998)</td>
<td>105 ± 6</td>
<td></td>
<td>5 c</td>
</tr>
<tr>
<td>Anza</td>
<td>96 14-2</td>
<td>id</td>
<td>108 ± 11/10</td>
<td>5 c ou 5 e</td>
<td></td>
</tr>
<tr>
<td>Agadir-Port</td>
<td>A. 129 b1</td>
<td>Hoang, unpubl.</td>
<td>109 ± 6</td>
<td>5 c ou 5 e</td>
<td></td>
</tr>
<tr>
<td>Arhedis</td>
<td>ARH 1</td>
<td>Meghraoui et al. (1998)</td>
<td>115 ± 7,5/7</td>
<td></td>
<td>5 e</td>
</tr>
<tr>
<td>Founti</td>
<td>F 2</td>
<td>id</td>
<td>116 ± 9,7/9</td>
<td></td>
<td>5 e</td>
</tr>
<tr>
<td>Anza</td>
<td>Anza 1</td>
<td>id</td>
<td>119 ± 9,8/3</td>
<td></td>
<td>5 e</td>
</tr>
</tbody>
</table>

Tab. 2: Apparent U/Th and Pa ages of in situ shells of PSL 4-5-6.

Hoang et al. (1978): U/Th ages on *Thaïs (Stramonita) haemastoma* L., except for A. 129a (Ostrea), A. 129b1 (Mytilus) and A. 129b2 (Yetus).

Tab. 2 : Âges U/Th et Pa apparents de coquilles en situ des paléorivages 4-5-6. Hoang et al. (1978) : âges U/Th sur Thaïs (Stramonita) haemastoma L., sauf pour A. 129-a (Ostrea), A. 129-b1 (Mytilus), et A. 129-b2 (Yetus).
fossil beach. However, the samples were nearly entire and not burnt. Recent field re-examination shows that, at Cape Rhir, samples were taken in a 50-cm-thick fossil berm, with gravels and well-preserved samples of *Thaïs haemastoma* lying in a silty red sediment, just over a basal crushed lumachelle, and that at Assif Lamahyane, the previously studied deposit looks like a storm-berm tempestite. The material of the true basal marine deposits is not yet dated, and the given ages are those of new fore-shore re-depositions, even perhaps of very high storm deposits as those studied along the Moroccan Meseta Atlantic coast (M’hammedi *et al*., 2008). Nevertheless, these two results indicate that a marine sea-level was not far from the present zero, with the possibility of moving and deposition of shells, mainly of *Thaïs haemastoma*, which is an infra-littoral species. In otherwise, the two samples are situated just on the southern side of the most elevated antcline axis of the Atlantic Atlas (fig. 1): these two MIS 3 sea-levels near beyond zero could be elevated to ± 2-4 m today, as shown by several cases along the Spanish atlantic coast (Zazo *et al*., 2008; Gracia *et al*., 2008). Much detailed microtectonic field observations are however needed for this supposed explanation based on a local hypothetic higher rise.

### 3.3 - UMS 2, RECORDS OF THREE MIS 5 PSL (PSL 4, 5, 6)

These PSL are located on the basal marine abrasion surface of the UMS 2 (true “oulja” morphologic unit) and have long been called “Ouljien marine deposits” (Gigout, 1949). They were sampled for U/Th analysis mostly at Agadir and its northern surrounding loci, Anza and Tamraght (Hoang *et al*., 1978; Meghraoui *et al*., 1998). Due to the new development of the harbour of Agadir after 1980, field observations of these strandlines become difficult: the old outcrops of Agadir-Port (fig. 6) and Anza have today nearly disappeared, and only the right side of Assif Tamraght mouth remains as before. Between Assif Lamahyane and Cape Rhir, strong marine erosion has also destroyed previously studied sites as Moukni. Three distinct groups can be seen through the available 15 U/Th ages (tab. 2), corresponding to:

- (1) PSL 4, sub-stage 5a: two dates, 72 ± 2 and 76 ± 2 ka, on *Thaïs haemastoma* shells that were sampled respectively at Agadir-Port I and Agadir-phare, both in westernmost outcrops of 1-m-thick continuous beach deposits; in these loci, correlative near-shore dunes were abundant (see 3.2.1.);

- (2) PSL 5, sub-stage 5c: possibly 6 or 7 dates, between 92 ± 7 and 108 ± 11/- 10 ka; the samples of Meghraoui *et al*. (1998) are unfortunately not precisely located; for our own samples the location of Agadir-Port II was at 10 m inner from Agadir-port I, in the same outcrop but not at the foot of the associated dead-clip that marked the top extent of the highstand, at ca. + 8 m a.s.l (fig. 6); Agadir-centrale was also sampled in a beach deposit lying at the bottom of a little bay at ca. 50 m in back of the present shore and at ca. + 6 m a.s.l.; Assif Tamraght was sampled in a cliff cutting a PSL beach deposit that had already registered a notable erosion; this last deposit was not far from the dead cliff and situated at ca. + 4 m a.s.l.;

- (3) PSL 6, sub-stage 5e: possibly 3 or 4 dates, between 114 and 119 ka; three of them are from Meghraoui *et al.* (1998), all at Agadir and Anza; our sample Agadir-Port II (see precise location before) gave an apparent U/Th age of 96 ± 5 ka; a second measure, using 206Pa method, gave an age of 114 + 18/- 13 ka; later, three other shells, respectively of *Ostrea, Mytilus* and *Vetus* sp. (A. 129-a, A. 129-b1, A. 129-b2, fig. 5) were sampled at the foot of the dead-clip; their apparent U/Th ages were 103 ± 9, 109 ± 6 and 75 ± 4 ka, indicating a more probable linking to MIS 5c (Hoang, unpublished datings).

The results seem to indicate that the MIS sub-stages 5a, mostly 5c and perhaps 5e were recorded at Agadir and as far as Tamraght. There is a generally good accordance between the precise location of the shells and their measured ages. However, the scarcity of 5e results, even at the foot of the dead-clip, is surprising based upon the knowledge of the Canary Islands (Meco *et al*., 1992; Zazo *et al*., 2002), Western Mediterranean Sea (Bardaji *et al*., 2009; El Mejeloub & Jedoui, 2009) and even global sea-level fluctuations at this time (Hearty *et al*., 2007). We must observe (1) that the oolitic MIS 5e deposits observed in Tunisia and Spain are absent here; we believe that it doesn’t occur in such a mountainous area, or that similar deposits were eroded; and (2) that the given U/Th ages are those of marine shells deposited on small beaches, which have known an animated sedimentary history. From another source, a more recent bulk of 78 U/Th dates of mollusk shells “from various Ouljian terraces between Agadir and Tamri” (Choukri *et al*., 2001, 2007) estimates that, due to the inherent errors of the method, only the results regarding sub-stage 5e are indeed reliable. After these authors, the date dispersion (two main groups, at ca. 50 and between 100-130 ka) “results from diagenetic processes that affected the shells after their fossilization”. In spite of this opinion, we believe that each measurement needs to be discussed in regard to the precise morpho-stratigraphic location and the diagenetic history of the corresponding sample.

### 3.4 - UMS 2: MIS 7 PSL 7 AND MIS 9 PSL 8 AT IMSOUANE AND AGADIR

#### 3.4.1 - Two well-developed PSL at + 8-10 and +18-20 m a.s.l.

The UMS 2 is not well delimited elsewhere by its inner dead-clip, except at Tamraght or Cape Rhir. In most of the locations, this dead-clip disappears under dunes and colluvial accumulations. As said before, at the uncertain limit of UMS 2 / UMS 3, outcrops sometimes revealed, however, a well-developed PSL at + 18-20 m a.s.l., especially at Agadir-port (or Founti) and Assif Lamahyane (Weisrock, 1980), and another one at + 8-10 m a.s.l. at Imouane (Lecointre, 1952). PSL at + 18-20 m from Agadir-port and Assif Lamahyane are clearly distinct from PSL 3-4-5-6, located in the same places just under, between zero and + 8 m. This is also the case at
Fig. 6: UMS 2 with two main PSL at Agadir-Port, as seen before 1984 (after Weisrock et al. (1999), modified).

A/ Location map of samples collected at Agadir.
1/ fault, 2/ valley slope, 3/ wadi, 4/ UMS 1, formerly beach, now urbanized, 5/ low cliff, 6/ main Quaternary dead cliff, 7/ UMS 2, 8/ UMS 6-7, 9/ location of samples.

B/ The Founti cave filling at Agadir-Port + 20 m (photo, A. Weisrock, 1976).
1/ beach deposit (sand, gravel, shells), 2/ near-shore dune of cross-stratified sands, 3/ rock-fall, limestone blocks issued from the cliff, 4/ aeolian sand deposits.

C/ Simplified outcrop:
PSL 4-5-6 lie between 0 and + 8 m a.s.l. and PSL 7-8 at ca. + 20 m. 1/ Upper Cretaceous, 2/ beach deposit with shells, 3/ bar deposit with pebbles, 4/ cross-bedded aeolianites, 5/ rock-fall, 6/ colluvium, 7/ red silts, 8/ laminated calcrites. For each sample: sample number, shell species, U/Th age; note that sample A. 127-2, Yetus, 185 ± 15 ka, was collected 20 m northern and cannot be seen here.

Yetus, 185 ± 15 ka, a été récolté 20 m plus au nord et ne peut être représenté ici.
Imsouane cape, 60 km north from Agadir, where two low stepped marine terraces are preserved: the first lies near the present ocean shore, but the second appears at ca. +8-10 m a.s.l. All sampling of these PSL were made at Agadir-port (“Founti” for Meghraoui et al., 1998) and Imsouane, but unfortunately not yet at Assif Lamahyane.

3.4.2 - The +8-10 m a.s.l. PSL 7 of Imsouane (fig. 7)

It consists in a 1.20-m-thick accumulation with (1) a coarse marine-shaped gravel assemblage in a sandy and shelly matrix at the bottom, and (2) a lumachellic sandstone at its top, capped by a laminated calcareous crust. This deposit could not be regarded of Ouljian age (= MIS 5), due to its too elevated altitude and the presence of Nucella (Acanthina) plessisi (Lec.), a fossil gastropod species very scarcely found in the Ouljian deposits (Lecointre, 1952; Brébion, 1979). Indeed, a unique U/Th age of a Thaïs haemastoma shell taken from the deposit (2) was measured here and gave an age of 179 ± 11 ka to this higher part of the deposit, meaning a possible MIS 7 palaeo-sea-level (PSL 7).

3.4.3 - The +18-20 m PSL of Agadir-Port (fig. 6): two possible records of PSL 7 and PSL 8

At Agadir-Port or Founti (today ancient port), a generally 2-m-thick marine gravelly and sandy shore deposit with a very rich macrofauna of mollusks can be observed along the road of Anza, at ca. +18-20 m a.s.l. At the first small cape (today Petroma station), the associated dead-cliff is still preserved and, at its bottom, the filling of a basal cave (fig. 6B and 6C), made of consolidated fine sands and shells of little size (1), covered by sand dunes and a great rock fall issued from the cliff. After that, new slope-deposits and coastal dunes covered a fossil gravelly and sandy bar with a fauna of large shells (2) that lies at a similar altitude as the deposit (1). In our previous publications (Weisrock, 1980; Brébion et al., 1984), a sample of Thaïs haemastoma (A. 73) was taken in the deposit (1) and gave an U/Th age of 275 ± 35/- 30 ka (tab. 3). A sample of Charonia nodifera (127-1) and another of Thaïs (A. 8-2), taken in the proximal part of the coastal bar (2), gave respectively two U/Th ages of 265 ± 45/- 30 ka and 240 ± 30/- 25 ka. Two other samples of large shells of Yetus cucumis (A. 127-2 and A. 127-3) were sampled in the distal part of the bar and gave U/Th ages of 185 ± 15 and 180 ± 17/- 13 ka. Four samples of Meghraoui et al. (1998), whose precise locations are unfortunately unknown, confirmed ages ranging between 267 ± 41/- 31 and 158 ± 34/- 27 ka for shells of this marine terrace. It is clear that the top point of the marine highstand was reached at the end of MIS 9a, in the cave basal deposits (1). The proximal deposits of the bar (2), near the rock-fall, are contemporary. The ages obtained for the last deposits of the gravelly bar (2), in more distal
locations, indicate that they would not be late deposits of the same high-stand, but may belong to MIS 7.

4 - SYNTHESIS TENTATIVE AND DISCUSSION

4.1 - LATE PLEISTOCENE PAST SEA-LEVELS (PSL) AND NEAR-SHORE DUNES MEMBERS (NSD) OF THE ATLANTIC ATLAS INCLUDING GLOBAL MIS CHRONOLOGY

4.1.1 - U/Th ages of PSL deposits and MIS chronology

In short, along this coast, eight Holocene, Late Pleistocene and Late-Middle Pleistocene PSL are recorded (fig. 8): PSL 1 near zero, with Holocene NSD 1, PSL 2 as NSD 2 only, PSL 3 as NSD 3 and/or as true level at zero +4 m; PSL 4, 5, 6 generally between zero and +4 m, but possibly also at ca. +8 m along the entire coastline, with also well-developed NSD 4, PSL 7 at +8 to 10 m, but only at Imsouane, and perhaps near +20 m at Agadir-Port, and PSL 8 at +18-20 m a.s.l., at Agadir-Port and probably Assif Lamahyane. The respective U/Th datings for PSL 3 are comprised between 44 ± 2 and 55 ± 2 ka for two cases (Cape Rhir and Assif Lamahyane). In most of the cases, ages for PSL 4, 5, 6 are between 72 ± 2 and 119 ± 9/-8 ka. There is only one result at ca 179 ± 11 ka for Imsouane PSL 7, and, for Agadir-Port, the U/Th dates are between 158 ± 34/-27 and 275 ± 35/-30 ka, meaning records of PSL 7 and PSL 8.

In the first place, there is generally well-accepted agreement between PSL locations and their apparent ages: MIS 5 for PSL 4, 5, 6, MIS 7 for PSL 7, MIS 9 for PSL 8. The result obtained for PSL 7 at Imsouane is coherent, in regard to its morphological location and its malaco-fauna. But at a more detailed level, there is not overall good correspondence between the field observations of the PSL and the U/Th results. Along the coast, between zero and +4 m, PSL deposits can correspond to MIS 3, MIS 4, MIS 5a, MIS 5c and MIS 5e, and at +18-20 m at Agadir-Port, PSL deposits can appertain to MIS 7 and MIS 9. The observation made earlier with regard to MIS 1, MIS 3 and MIS 5, indicating a possible successive re-covering of several high sea-levels in the same location and in a very limited area, may be extended to older ages. But this assumption is very difficult to believe at Agadir-Port, where the cave deposits and the following deposits are quite continuous. Each sample must be replaced not only in a PSL global deposit, but in a very detailed stratigraphical history of this PSL.

Another difficulty is found in the uncoupling between the age of the top deposit of PSL 8 at Agadir (275 ± 35/-30 ka) and the global MIS chronology, for which MIS 9 occurs mainly between ca 340 and 280 ka. When one refers to the global chronostratigraphical chart, the deposits of PSL 8 in the basal-cliff cave of +20 m at Agadir-Port would be that of MIS 9a ad maxima. It can be thought (i) that only the last deposits of the MIS 9a highstand were preserved in this cave, and (ii) that the following regressive beaches and bars had have a wide extent out of the cave. Apparently, their ages represent MIS 7 high-stands, but referring to Choukri and Reyss (see Plaziat et al., 2008), these U/Th ages are probably rejuvenated by diagenetic processes.

4.1.2 - 14C ages of NSL dunes

14C ages of NSL dunes are very insufficient for an adequate study of the MIS 3 palaeo-sea-level fluctuations history. We need to undertake a new OSL dating project about this question. For MIS 2 and the early Holocene rise of sea-level, more 14C ages in the Late Pleistocene - Early Holocene coastal dune system are also required.
4.2 - OTHER DISTINGUISHING ATTEMPTS

4.2.1 - Malacofauna

Malacofauna are very rich in PSL deposits: 102 species of gastropods and 29 of bivalves for PSL 4-5-6, 97 species of gastropods and 24 of bivalves for PSL 7-8 (Brébion & Weisrock, 1976; Weisrock, 1980). A notable part (often more than 20 %) of these species indicates warm waters, especially the Purpura family. In this family, Brébion (1979) pointed out the progressive replacing of Nucella (Acanthina) plessisi by Thaïs (Stramonita) haemastoma between PSL 4-5-6 and PSL 7-8, but this criterion was insufficient for more detailed distinctions. As compared with Fuerteventura malacofauna of MIS 5 (Meco et al., 1992), the absence of Strombus bubonius is surprising and must probably be correlated with modified courses of the Canary Islands current (Plaziat et al., 2008; Bardaji et al., 2009).

4.2.2 - Amino-acid ratios

In order to obtain more distinctive features, amino-acid ratios of Patella, Mytilus and Thaïs samples of PSL 4-5-6-7-8 were measured by Occhietti and Pichet at the UQAM Geotop Laboratory. The results, published by Weisrock et al. (1999), showed two distinct aminogroups, respectively well correlated with MIS 5 for PSL 4-5-6 samples, but still uncertain (MIS 7 or MIS 9) for PSL 7-8 samples.

4.2.3 - Geomorphotectonic data

In order to explain the different heights of a same PSL, geomorphotectonic evidences were of course evoked and related to the regional morphe-structure (Weisrock, 1981) or more precisely to the Atlasic thrust front at Agadir (Meghraoui et al., 1998). PSL 4-5-6 and PSL 7-8 are here globally uplifted in a higher way than on the Meseta or the Anti-Atlas belts. After Meghraoui et al. (1998), at Agadir-port, the estimate uplift is ca. 28 m for PSL 4-5-6 and 35 m for PSL 7-8. The value seems correct for PSL 4-5-6, but not for PSL 7, which stays still at + 10 m at Imsouane, not far above its original position. At Agadir-Port, the value seems correct for PSL 8, but not for PSL 7. At a more detailed level, many difficulties remain: how to explain a possible higher elevation of PSL 3 in two precise locations, at Cape Rhir and Assif Lamahyane? It may be difficult also to demonstrate how the PSL 7 (MIS 7 stage) would be today at + 8-10 m at Imsouane and perhaps at + 18-20 m at Agadir. Here also, more detailed field investigations and measurements are needed.

5 - CONCLUDING REMARKS: THE ATLANTIC ATLAS COASTAL REACH SUPPLY IN THE PLEISTOCENE MARINE CHRONO-STRATIGRAPHY OF MOROCCO

Despite great differences of knowledge between the Late Pleistocene and more ancient epochs, the Atlantic Atlas records still offers many exciting research perspectives.

5.1 - COMPARISONS WITH CASABLANCA

As compared with the litho-chrono-stratigraphy of the Pleistocene formations of Casablanca (Lefèvre & Raynal,
2002; Texier et al., 2002), PSL 1 can be parallelized with the Reddad Ben Ali formation (MIS 1), PSL 4-5-6 with the Ain Roummana member (MIS 5), PSL 7 with the Bir Feghloul member (MIS 7) and PSL 8 with the Oulad Aj Ajmel member (MIS 9) (fig. 9). In the two areas, the succession of PSL records is nearly the same for the Late Pleistocene and the Late-Middle Pleistocene. A primary difference appears between the wide development of MIS 5 deposits at Agadir, with a rich warm, tropical mollusks fauna, and its more scarce expression at Casablanca. The main difference is on a morphological point of view, i.e. in the UMS arrangement: as at Casablanca, MIS 7 and MIS 9 PSL built together the Kef Haroun UMS, at Agadir PSL 4 to PSL 8 appear to appertain to the same UMS 2, due to the thickness of their regressive continental deposits in a mountainous environment. Except at Cape Rhir, where the colluvial supply is scarce, the dead cliff of PSL 4-5-6 does not appear clearly, in spite of a higher vertical uplift as at Casablanca. In this perspective, PSL 8 visible deformations at Agadir-Port will offer future special attention.

5.2 - RELATIONS WITH INNERLAND GEOMORPHIC EVIDENCES

The relatively high position of PSL 8 at Agadir in regard to more stable areas such as the Meseta and the Anti-Atlas coastlines indicates that, before MIS 5, a more rapid tectonic uplift followed here MIS 9. This fact is corroborated by geomorphic evidence in the inner Atlantic Atlas, as seen with the deeper cuts of the wadis before MIS 8 and more especially before MIS 5. These uplifts initiated successive high-stepped waterfall- travertines deposits which occurred mainly during MIS 8 and MIS 3, with a wide gap during MIS 7 and MIS 6 (Weisrock et al., 2008). After MIS 5, rates of uplift were lower and in good correspondence with the aggradational trend during MIS 3, independently of decisive climatic changes.

5.3 - NEW INTEREST FOR MIS 3 COASTAL DUNES

As studied recently in Western Australia (Hearty & O’Leary, 2008), accretion of coastal sand ridges are
linked to successive sea-level stands. Coastal eolianites are generally correlated with interglacials and rarely with glacialis. On the Atlantic Atlas off-shore, the rapid decrease of isobaths allowed an accumulation of the sands against the dead-cliffs which were not far from the regressive shorelines during glacial times. In spite of the great complexity of the stratigraphy, changing characters of the deposits are related with the straight-line position and the concomitant climatic conditions, especially with palaeowind directions and occurrence of the oceanic upwellings (Rognon & Coudé-Gaussen, 1996). This encourages further revisions of the present knowledge of the last interglacial (Soltanian) along the Atlantic coast of Morocco.

ACKNOWLEDGMENTS

I gratefully acknowledge Larbi Boudad and Jean-Pierre Texier for their helpful comments of this paper, William P. Weisrock and Jean-Jacques Bahain respectively for their helpful comments of this paper, William (Rognon & Coudé-Gaussen, 1996). This encourages complexity of the stratigraphy, changing characters of the deposits, and occurrence of the oceanic upwellings (Rognon & Coudé-Gaussen, 1996). This encourages

BIBLIOGRAPHY


GIGOUT M., 1952 - La transgression flandrienne a dépassé de 2 m le niveau actuel de la mer à Rabat, Maroc. Compte Rendu sommaire des séances de la Société géologique de France, 5, 78-79.


