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The Quaternary dune complex of Jorf Lasfar (Moroccan western coastal Meseta): lithostratigraphy, sedimentology and neotectonics)

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Abstract:
The Quaternary dune complex of Jorf Lasfar, transversally dug during the Maroc Phosphore III and IV industrial complex installation, reveals the most developed and detailed cutting in the region. It consists of calcarenites in which red paleosols are interspersed. It reflects a dry quaternary period climate, probably Soltanian, interrupted by humid and temperate phases. The biocalcarenitic sands constituting this dune complex result from a range of sediment resumption which terrigenous elements coming from several sources such as the Middle Atlas, the coastal Meseta and Rehamna massif. The Jorf Lasfar dune complex is affected by neotectonic proving that this sector of the Moroccan coastal Meseta was not stable during the Quaternary, contrary to what was agreed in previous work.

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1. Introduction

In the Jorf Lasfar sector, South of El Jadida, coastal dune ridges have not been concerned by a previous detailed geological study. The works of GIGOUT (1947), GIGOUT (1951) and AKIL (1990) focus on the Quaternary calcarenites of the Doukkala but the Jorf Lasfar complex has not been studied. With the construction of Jorf Lasfar port and the Maroc Phosphore III and IV industrial complex, new cuts appeared and allowed us to study this coastal resort in detail. This note aims to highlight the origin and the dynamics responsible for the implementation of these calcarenites. In addition, it describes, in this area of the Moroccan coastal Meseta deemed to be stable during the Quaternary, a neotectonic activity. It is materialized by normal and reverse faults that especially affect the paleosol 1 and dune 2 of this dune complex.

2. Geographic location

The Jorf Lasfar area is located just south of Maroc Phosphore III and IV industrial complex of El Jadida. Its Lambert coordinates are X = 284.5 km and Y = 198.5 km (Figure 1).

Figure 1. Geographical location of the studied zone (Source of the Photographs: Google Earth).

3. The Jorf Lasfar dune complex lithostratigraphy

We can distinguish from bottom to top (see Figure 2):

3.1 The dune edifice 1 is a consolidated biocalcarenite with large intersected stratifications, with fragments of marine shells and well preserved land-shells, at the top. Its maximum thickness is 3 m and its color is yellow at the base and light red brick at the top. At the top, fossilized roots marks in life position (10 cm long) and some limestone nodules (2-10 cm diameter) can be observed. The lower limit of this unit is not visible.

3.2 The paleosol 1 represents the lower horizon of a reddish pedologic profile whose upper layers have been eroded. It is 2.5 m thick at most. It contains many whole or broken shells of pulmonate gastropods. The roots are abundant with maximum length up to 20 cm and some extend into the underlying dune edifice. They are associated with carbonate nodules (2-8 cm diameter), particularly at the base of this paleosol. The structure of the latter is polyhedral and its lower limit is progressive.

3.3 The dune edifice 2 is a consolidated biocalcarenite of 4 m maximal thickness which colours are light yellow at the base and light red brick at the top. Its lower limit is clear. As in the case of the dune edifice 1, we note the presence of fragments of marine shells at the base and relatively well preserved ground shells and limestone nodules up to 5 cm in diameter at the top. The cross-bedding is less visible than in the dune edifice 1.

3.4 The paleosol 2 is less reddish colored and less rich in carbonate concretions than paleosol 1 and reaches a thickness 0.8 m. Its lower limit is gradual. This paleosol also represents an eroded pedologic profile. It has a prismatic structure and contains numerous broken shells or whole pulmonate gastropods.

3.5. The dune edifice 3 is a consolidated biocalcarenite of 4 m maximal thickness which colours are light yellow at the base and light red at the top. At its top, there is the presence of some roots (maximum length 10 cm) and some limestone nodules from 2 to 10 cm in diameter. Its lower limit is sharp but the oblique stratification is inconspicuous. Fragments of marine shells are observed at the base and land shells are relatively well preserved at the top

3.6 The paleosol 3 reddish, is 0.7 m thick. The roots are abundant and some extend into the underlying dune edifice. Their maximum length is 12 cm and they are associated with carbonate concretions (2 to 5 cm in diameter). The lower limit of this paleosol is progressive. Its structure is slightly polyhedral and it contains many, often unbroken, pulmonate gastropods shells.

3.7 The dune edifice 4 corresponds to a less consolidated biocalcarenite, of 2 m maximum thickness and which colours are light yellow at the base and bright red at the top. Land shell debris are less common than in previous dune edifices. At the top, we note only the presence of some limestone nodules of 3 cm in average diameter.

3.8 The paleosol 4 is at most 0.5 m thick, reddish and can be divided into two horizons by a thin limestone crust (about 1 cm thick). It often contains broken shells of pulmonate gastropods and its lower limit is indistinct.

3.9 The dune edifice 5 consists of a biocalcarenite sand of light beige colour, unconsolidated but set by the current vegetation. Its limit with the paleosol 4 is clear. Land shell debris are infrequent and very small. Its maximum thickness reaches 0.8 m. It is surmounted by a broken limestone crust of about 3 cm thick.

3.10 A brown soil, sub-current

About 0.5 m thick and brown-red colour. Its lower limit is brutal. It contains some pebbles of limestone crusts and debris of land pulmonate shells.

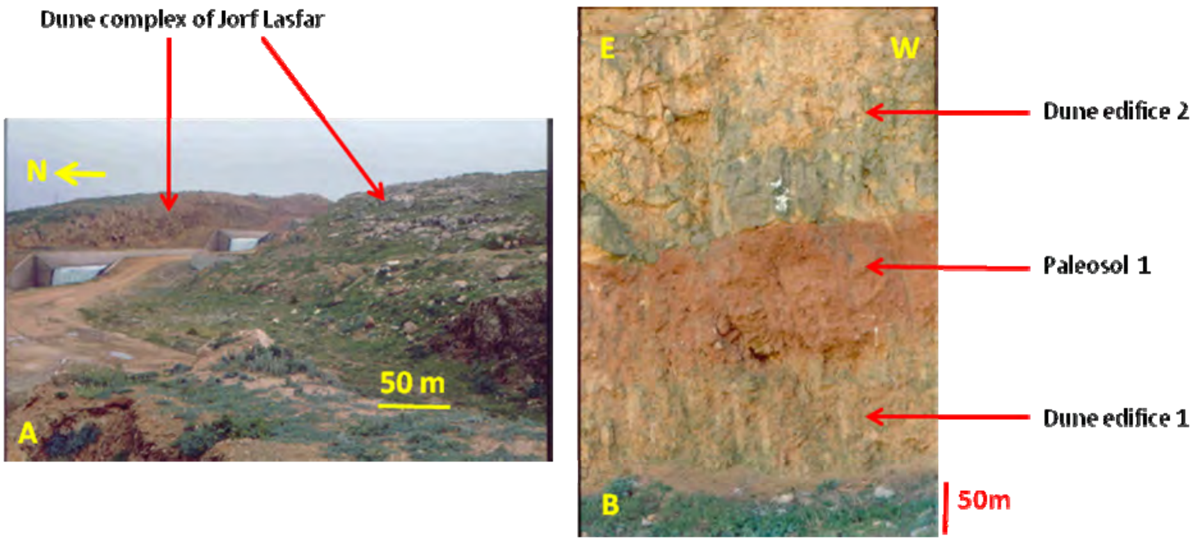

Figure 2. Lithostratigraphy of the Jorf Lasfar dune complex.

4. Sedimentology

4.1 Microfacies

The microfaciologic study of biocalcarenits shows a particular richness of bioclast bivalves associated with debris of gastropods and reworked echinoderms (crushed testes) in beach deposits. They constitute about 60% of present elements. Terrigenous elements consist of quartz grains (over 30%) and rock fragments associated with some heavy minerals and plagioclase. The carbonate cement is in the form of meniscus at the contact points between the elements showing a early cementation in vadose zone (DUNHAM, 1969). Late cement corresponds to a mosaic microsparities clogging the intergranular voids. At the top, cement is only partially preserved, affected by a dissolution due to modern vadose circulations. The dissolution affects both bioclast and cement, causing the formation of larger vacuolar emptiness more important at the top than at the base. Bioclast structure is partially preserved, despite a partial recrystallization (especially fragments of bivalves) and replacement by microsparitic crystals and sparitiques drusy characterizing a diagenesis in continental medium (PURSER, 1980) (see Figure 3A).

The paleosols contain many terrestrial gastropods generally poorly maintained. Carbonate elements including pellets, have a recrystallization in micritic to microsparitic crystal. The quartz fraction is very abundant, the often altered plagioclase and opaque minerals are often covered with a ferruginous film. The elements of the soil skeleton are surrounded by a silty clay coating indicating a contribution by leaching of the alteration products from the upper horizons. The residual voids are partially or completely clogged by the microsparite (see Figure 3B).

4.2 Granulometry

The sieving (AFNOR type sieve stack) of dune edifice equipment shows that it is rich in sand relatively to silt and clay, with a percentage that varies between 22 and 54%. The median value, between 102 and 128 µm, corresponds to fine sands. Low values of the distribution index [Cd = (Q1-Q3) / 2] which varies between 20 and 40 µm (see Table 1) and that of the Sorting index [So = (Q1 / Q3) 1/2], which is between 1.24 and 1.35 indicate that the sediments are well sorted. The Skewness Sk index, which oscillates between 0.71 and 0.98, shows that sediment selecting privileges coarser particles (see Table 1).

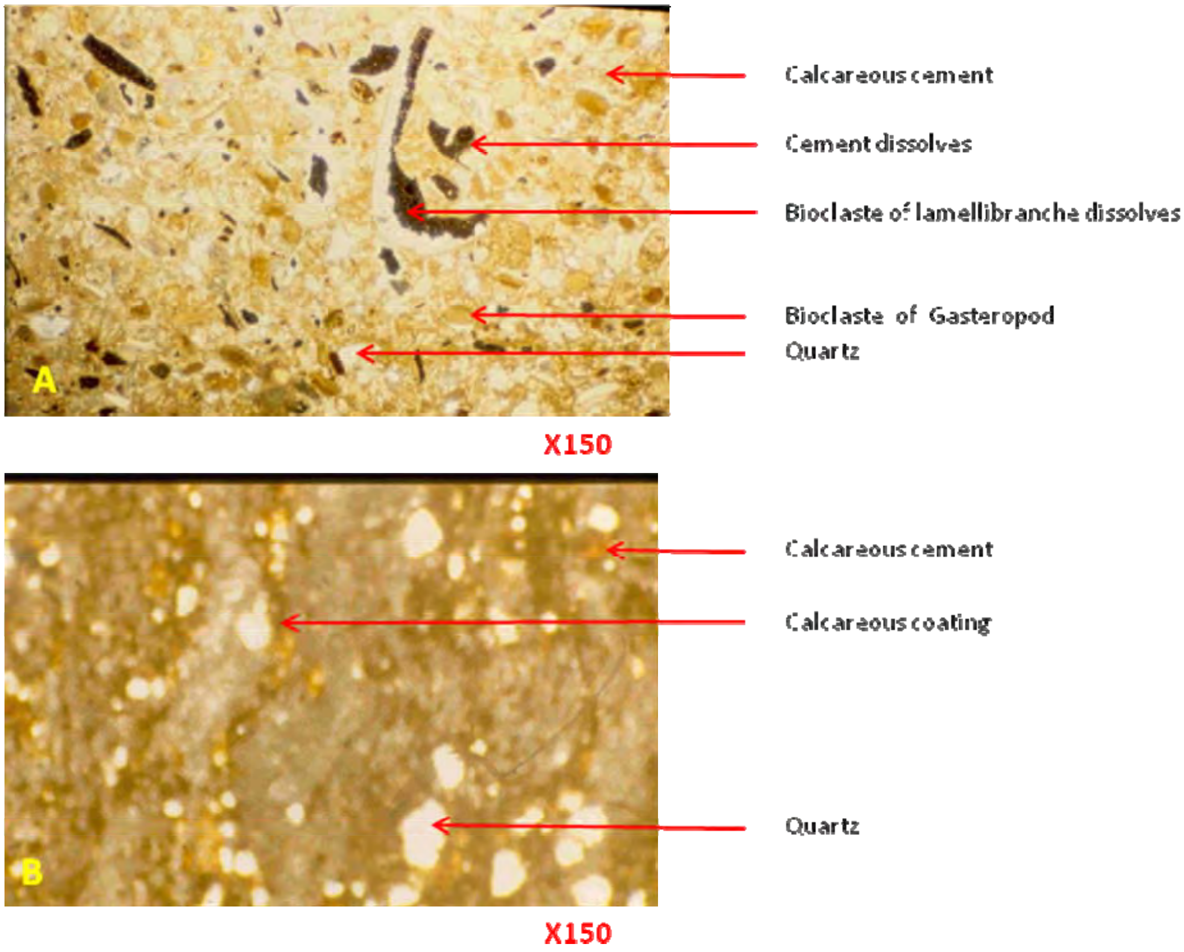

Figure 3: Microfaciès of dune edifice1 (sample d1-s) (A) and of the paleosol (S1-s sample) (B).

4.3 <u>Morphoscopy of quartz grains</u>

After hydrochloric acid attack, quartz grains observed under a binocular microscope, are yellowish for dune calcarenite and pink, sometimes red, for paleosols. This color difference is caused by the presence of clays and the thin film of Fe and Mn oxide which covers the quartz grains within palaeosol. In dune edifices, the prevailing quartz grains are round mats (41 to 62%), glistening blunted (26 to 42%) and unworn (12 to 25%) (see Table 1). Intermediate types of quartz grains were observed in particular in the dune edifices 1 and 2. These are round and gleaming matt blunt with percentages not exceeding 15%. The presence of these two types of quartz grains demonstrates an interaction between the coastal and marine wind dynamics. The same was done on quartz grains from the coastal dunes of the quaternary Rharb (ABERKAN & LEGIGAN, 1984; ABERKAN, 1989), of Larache (ADIL & ABERKAN, 1993; ADIL, 1996) and of Casablanca (ZANNIBY, 1997).

4.4 Mineralogy

a) Heavy minerals. The weight content of heavy minerals Jorf Lasfar calcarenites dune is relatively low, it is between 0.07% (dune edifice 1) and 1.92% (dune edifice 3) reflecting the poverty of sources of heavy minerals. They are dominated by hornblende (4-43%), which would come, in part, from metamorphic formations of the Rehamna massif. The presence of pyroxene is explained by the basaltic volcanism of the Middle Atlas and the coastal Meseta drained by the Oued Oum Rbia and by NS direction littoral drift (OUADIA & ABERKAN, 1996). Three heavy mineral origins are possible: the Rehamna massif, Middle Atlas and coastal Meseta. The heavy minerals maturity index ((% tourmaline + % zircon + % rutile + % anatase + % brookite) / % other transparent heavy minerals) is slightly higher. It oscillates between 0.01 recorded at the dune edifice 4 and 0.43 registered at the paleosol 1 and reflects a deterioration of fragile mineral during the formation of the paleosols.

b) Clay minerals. The mineralogical procession of clay minerals in the sampled palaeosols is dominated by illite (40%), smectite (25%), chlorite (15%) and kaolinite (5%) associated with cross-laminated (illite- smectite and smectite-chlorite (15%)). The degree of crystallinity of clay minerals is generally low except in the case of illite having relatively sharp peaks. These clays are essentially inherited (ABERKAN, 1989; ABOUMARIA, 1993).

4.5 Physical and chemical characteristics of dune edifices and paleosols of Jorf Lasfar

a) pH: the pH of the Jorf Lasfar Quaternary formations is slightly basic. Its values vary between 7.6 in the paleosol 2 and 8.37 in the dune edifice 1 (see Table 1). The basic nature of these formations is related, at least in part, with the high calcium carbonate content of the latter (over 70% in the dune edifices). The pH differences between the edifices and dune paleosols result from their $CaCO_3$ content. In fact, we find that the value of the basic pH is less than that of the paleosols whose carbonates rate is relatively low (17% maximum).

b) Organic matter: its levels are low and vary between 0.02% (dune edifice 1) and 0.48% (top of paleosol 2). The relative increase in the organic content at the top of the Jorf Lasfar dune complex is probably related to the installation of the current vegetation (see Table 1).

c) Assimilable phosphorus: the assimilable phosphorus value shows values oscillating between 0.14% at the dune edifice 4 and 0.72% at the base of paleosol 1 (see Table 1). The relatively high values of assimilable phosphorus level in the palaeosols can be explained by the relative richness of these in organic matter, reflecting biological activity, which tends to influence the P_2O_5 content.

d) The total iron: the total iron content varies. It is higher in paleosol 1 (2.11%). In addition, in all the overlying levels, this content decreases and reaches a minimum value of about 0.43% in the dune edifice 3 and paleosol 3. The relatively high content of iron in the paleosol 1 would be in close connection with the iron liberation phenomena by primary minerals because of the marked reddening of this level. Paleosols are richer in iron than dune edifices because of the relative concentration of iron and clay by the decarbonisation of dune calcarenite (ABERKAN, 1989) (see Table 1).

Table 1. Analytical data of Jorf Lasfar dune complex formations.

Formations	***Level & n° Samp.***	***Granulometry***				***Morphoscopy of quartzs***			***Physical and chemical analyses***			
		Md (µm)	*Cd (µm)*	*Sk*	*So*	*NU (%)*	*EL (%)*	*RM (%)*	*MO (%)*	*P_2O_5 (%)*	*Fe (%)*	*pH*
Paleosol 4 (0,3m)	*s4-s*	*118*	*20*	*0,85*	*1,24*	*26*	*34*	*40*	*0,32*	*0,14*	*0,64*	*7,90*
	s4-m	*120*	*21*	*0,84*	*1,25*	*27*	*35*	*38*	*0,34*	*0,16*	*0,67*	*8,20*
	s4-b	*124*	*22*	*0,85*	*1,26*	*28*	*37*	*35*	*0,33*	*0,14*	*0,64*	*8,34*
Dune edifice 4 (1,9m)	*d4*	*124*	*23*	*0,76*	*1,27*	*19*	*39*	*42*	*0,24*	*0,14*	*0,62*	*7,90*
Paleosol 3 (0,4m)	*s3-s*	*112*	*22*	*0,73*	*1,26*	*23*	*32*	*45*	*0,24*	*0,24*	*0,43*	*8,34*
	s3-b	*119*	*24*	*0,82*	*1,28*	*24*	*33*	*43*	*0,19*	*0,33*	*0,43*	*8,37*
Dune edifice 3 (2,2m)	*d3*	*178*	*40*	*0,71*	*1,35*	*25*	*34*	*41*	*0,19*	*0,24*	*0,43*	*8,00*
Paleosol 2 (0,6m)	*s2-s*	*114*	*25*	*0,96*	*1,33*	*21*	*23*	*56*	*0,48*	*0,28*	*0,81*	*7,60*
	s2-b	*126*	*27*	*0,98*	*1,32*	*23*	*25*	*52*	*0,33*	*0,33*	*0,91*	*7,80*
Dune edifice 2 (3,2)	*d2*	*152*	*28*	*0,72*	*1,35*	*12*	*26*	*62*	*0,19*	*0,48*	*1,15*	*8,00*
Paleosol 1 (3m)	*s1-s*	*102*	*22*	*0,96*	*1,26*	*15*	*38*	*47*	*0,28*	*0,67*	*2,11*	*8,10*
	s1-b	*116*	*25*	*0,98*	*1,29*	*16*	*39*	*45*	*0,24*	*0,72*	*2,00*	*8,00*
Dune edifice 1 (2,5m)	*d1-s*	*114*	*24*	*0,76*	*1,28*	*19*	*38*	*43*	*0,19*	*0,33*	*1,77*	*8,00*
	d1-b	*128*	*23*	*0,78*	*1,27*	*17*	*42*	*41*	*0,02*	*0,24*	*1,58*	*8,37*

4.6 Calcimetry

The carbonate content is on average 27% in paleosols and 70% in the dune edifices. The relative enrichment in carbonates at the base of paleosols proves the existence of a carbonate buildup gradient due to leaching from upper horizons that have been eroded.

5. Tectonic

At Jorf Lasfar, the quaternary dune complex, probably soltanian age (würmien according to European terminology, TEXIER (1986), was affected by a series of normal and reverse faults, both in the paleosol 1 and in the consolidated dune surmounting it. Maximum vertical displacement of these normal faults can reach 80 cm. Their dominant direction is N20 and the dip varies from 65° to 75° to the ESE (see Figure 4) (ABOUMARIA *et al*., 1993; OUADIA *et al*., 1997).

In order to look for relationships between these faults and joints of the abrasion platform and those of complex coastline flush whitewater cliff, we compared the directions of these bunk accidents. The prevailing direction of the joints is between N20 and N90 (OUADIA *et al*., 1997; OUADIA, 1998). This coincidence (N20 measured both in the platform in the quaternary dune complex) makesnit possible to suggest that the tectonic activity that affects the quaternary Jorf Lasfar complex dune may be a continuation of the ante-Quaternary movements making replay accidents Hercynian direction NS dominant in Doukkala (GIGOUT, 1951). This is confirmed by the work of RUELLAN & AUZENDE (1984) on fracturation affecting the base of the continental shelf surrounding El Jadida and Jorf Lasfar since it has a dominant direction between N20 and N90.

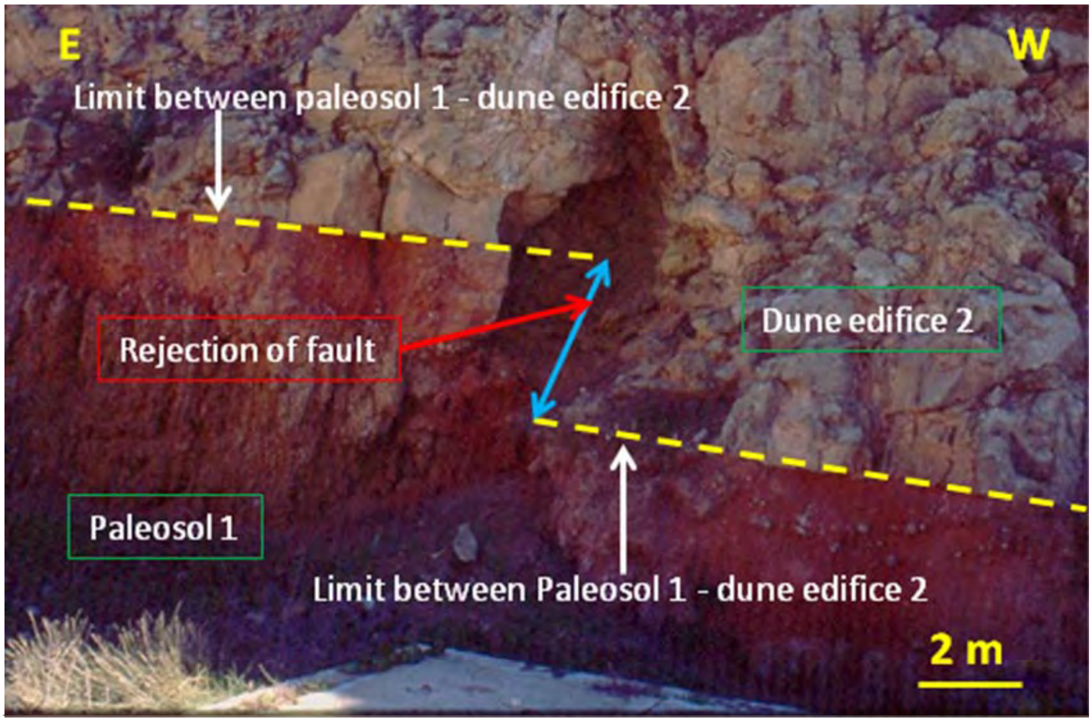

Figure 4. Reverse fault in Jorf Lasfar dune complex

Neotectonic movements of the Jorf Lasfar sector correspond to replays of the Hercynian and Alpine tectonics. This neotectonic activity appears to be similar to that reported in the region of Rabat (MOREL, 1987), in the Rabat-Kenitra region (ABERKAN 1989; ABERKAN, 1996), in the coastal Meseta (ABERKAN, 1993) and in the region of Larache (ADIL & ABERKAN 1993; ADIL, 1996). Finally if GIGOUT (1951) considered the coastal Meseta as a sector where there is no evidence of Quaternary deformation, the neotectonic movements in Jorf Lasfar (covered in this article) question that conclusion.

6. Discussion

The Jorf Lasfar quaternary complex consists of four consolidated dune edifices surmounted each by a paleosol whose upper layers were eroded before the next wind deposit.

The fine sands of the resort are generally well classified, their size is average (124 µm average). The most common quartz grains in dune edifices are mats round (over 35%). The glistening blunted come second (34% average), suggesting their implementation under the action of wind dynamics on a subaquatic material. Furthermore, the presence of large fragments of marine bioclasts shows that these edifices were formed near the shoreline. The presence, in dune edifice, of intermediate quartz grains between dull and shiny matte-round (round shiny and dull matt) proves repeated exchanges between the two areas of dynamic (coastal and eolian). (OUADIA *et al*., 1993). Comparable results were found in barrier beaches North of Rabat (ABERKAN & LEGIGAN, 1984; ABERKAN, 1989) Larache (ADIL & ABERKAN, 1993; ADIL, 1996) and Casablanca (ZANNIBY, 1997).

The carbonates rate is generally greater than 60% with the abundance of marine bioclast shaped by the wave on the beach and then taken up by the wind (smaller bioclast and blunt shape). The low weight content of heavy minerals and the greater or lesser value of their maturity index show a significant alteration of detrital (ABERKAN *et al*., 1982; AKIL & GAYET, 1988; AKIL, 1990). The heavy minerals association is characterized by the abundance of hornblende outcome of Rehamna metamorphic massif formations. Pyroxene comes more probably from Pliocene-Quaternary volcanism watershed drained by the Oued Oum Rbia such as the Middle Atlas and the coastal Meseta (OUADIA & ABERKAN, 1996) through longshore drift NS direction.

After their edification, these dunes have undergone diagenetis with dissolution and recrystallization of bioclasts and the transformation of the micritic matrix into cement, which is a mosaic of microsparitic crystals clogging the intergranular emptinesses, lithification of dune edifices is performed in the continental environment under the influence of meteoric water.

Paleosols overcoming each of the dune edifice evidenced a damp climatic context. All palaeosols are eroded in their upper part due to aneolian deflation that announces the end of the wet phase and the beginning of the dry phase which succeeds. This erosion affects the paleosols before their fossilization by the dune contributions that overcome. The most advanced being the paleosol 1 (see Figure 2). The relatively high percentage of organic matter and assimilable phosphorus in these palaeosols are related to the biological activity of the soil. The basic pH is explained by the high content of carbonates from the dissolution of bioclasts. The slight rise in carbonate rates at the base of paleosols and occurence, especially in paleosols 1 and 3, of a blocky structure also show a pedogenic accumulation. The iron content of paleosol 1 could be explained by a relatively greater degree of reddening at this paleosol.

The Jorf Lasfar dune complex edifice were set up during a relatively dry period called soltanian. The deposition of each edifice is contemporary to an arid episode at the beginning of which a deflation of the upper horizons of the underlying soil profile occurred. This period was interspersed with four relatively humid climatic episodes that have promoted the development of paleosols or rise in the water table bringing moisture to the favorable areas.

The upper coastal Jorf Lasfar Quaternary record a neotectonic activity particularly observed on the paleosol 1 and the dune edifice 2.

Our observations on the formations of Jorf Lasfar confirm those of RUELLAN & AUZENDE (1984) who showed from the seismic survey of the continental shelf of El Jadida that the modern limestone abrasion platform is cut in a succession of tilted blocks. This division into blocks is done according to a network of cracks whose predominant directions are N20, N90, N120 and N160. The first of these directions is very close to what we measured for the joints observed on the surface of the platform and abrasion in the complex coastline of El Jadida cut in sharp cliff (OUADIA *et al.*, 1997) . This allows to conclude to a vertical tectonic activity until the Present, which is manifested by Jorf Lasfar Pleistocene deformation. Neotectonics affecting the area of the Jorf Lasfar is not exceptional on the Atlantic coast. MOREL *et al.* (1987) were able to show, according to microtectonic analysis of fractures and faults in the Rabat region, NE-SW compression movements during the early and probably late Pleistocene. These coastal movements are comparable to those observed further north in the Rif area and assigned to a compression phase at the Plio-Quaternary limit (MOREL et al., 1987). The same neotectonic activity is described in the regions of Rabat-Kenitra (ABERKAN, 1989; ABERKAN, 1996) and in the region of Larache (ADIL & ABERKAN, 1993; ADIL, 1996). Two trends: rejection of the Hercynian and Alpine tectonics can be drawn from Jorf Lasfar neotectonic movements of the sector parted by their directions.

7. Conclusion

The Jorf Lasfar dune complex, represents the most detailed and most comprehensive cutting in the study area, with four consolidated Quaternary dune edifices interspersed with four developed paleosols, the oldest (paleosol 1) seems most evolved. The upper horizons of fossil soils were eroded before fossilization, indicating deep repeated changes in climatic conditions. The establishment of calcarenites in Jorf Lasfar complex dune is attributable to wind dynamics confirmed by the abundance of mat round quartz grains despite the proximity to the beach. The frequency of intermediate types of quartz grains (round shiny and dull matt) demonstrates the interaction of coastal and wind dynamics. The study of heavy minerals suggests three possible sources of materials: the massif of Rehamna, the Middle Atlas and the coastal Meseta (OUADIA & ABERKAN, 1996). The role of the NS littoral drift is not to be neglected since the Oum Rbia opens into the Atlantic 25 km further north.

Paleoclimatic conditions during the edification of the Jorf Lasfar dune complex, corresponding to an alternance of arid conditions permetting the establishment of dune edifice and humid temperate phases during which rubeified palaeosols develop.

The oldest Jorf Lasfar units of the complex have been affected by neotectonic activity that could be related to reactivation of Hercynian or Alpine bedrock faults. This neotectonic activity is comparable to that reported in other areas of the Moroccan Atlantic coast. The Moroccan coastal Meseta which includes the Jorf Lasfar sector was therefore not a stable area during the Quaternary as it was described previously.

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