

## Sedimentological evidence of lagoon–marine transitions in the Quaternary deposits of Dhar Eddoum (Atlantic coast, Morocco)

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### ABSTRACT

The Dhar Eddoum formation, located along the Moroccan Atlantic coast near Moulay Bousselham, records the Quaternary evolution of a dynamic beach-lagoon system. Field surveys, lithostratigraphic logging (DED1- DED2- DED3), and sediment sampling revealed alternating depositional environments, including high-energy beach sands, low-energy lagoonal and marsh clays, and transitional conglomeratic layers associated with episodic energetic events. Clay-silt layers reach up to 20 m thick, while bioclastic sand layers show mean grain sizes of 0.244  $\phi$  and a Trask sorting index of 1.25  $\phi$ . Granulometric analyses, conducted according to AFnor standards, demonstrate bimodal grain-size distributions in both ancient and modern deposits, indicating persistent hydrodynamic fluctuations over time. Petrographic observations and fossil assemblages of terrestrial gastropods (Helicidae, Trissexodontidae, Geomitridae) further constrain the paleoenvironment, with fossil abundance averaging 250 specimens per m<sup>3</sup>, suggesting alternating freshwater and slightly saline conditions consistent with wet-dry climatic cycles. Karstic and travertine features indicate post-depositional carbonate precipitation linked to fluctuating water tables, highlighting the interplay between sedimentation and local hydrogeology. These results provide a reproducible stratigraphic and sedimentological record that integrates granulometry, lithology, and paleontology, enabling reconstruction of Quaternary coastal dynamics and hydrosedimentary cycles along the Moroccan Atlantic coast. The study demonstrates that recurrent processes, sea-level variation, wave energy, and sediment supply have consistently controlled both ancient and modern depositional systems, supporting the temporal and spatial continuity between the Dhar Eddoum formation and the contemporary Moulay Bousselham lagoon and beach.

**Keywords:** Atlantic coastline, south-western Rif, Quaternary, Moulay Bousselham coastline, granulometry, sediment budget, paleoenvironments, chronostratigraphy.

### INTRODUCTION

Quaternary coastal systems appear as high-resolution archives of past sea level fluctuations, climatic oscillations, and tectonic deformation. Barrier lagoon complexes, in particular, are extremely sensitive to the interaction between eustasy, sediment supply, and neotectonics. They therefore provide essential information for reconstructing the environmental changes that occurred during the Late Pleistocene and the Holocene.

Despite the fact that multiple studies have focused on Mediterranean coastal archives, the Atlantic border of North Africa remains relatively

unexplored, even though it is strategically located at the junction between temperate Atlantic circulation and Saharan climatic impacts.

The northwestern Atlantic coast of Morocco, especially within the Rharb Basin, preserves extensive wetlands including lagoons, estuaries, salt marshes, lakes and merjas. This region is strongly influenced by the hydrographic network of the Sebou River and by Quaternary sea-level oscillations. The Rharb plain contains approximately 40,070 ha of wetlands (Mouihi, 2013), distributed on both sides of the Sebou River (Figure 1). Among them, the Moulay Bousselham lagoon (Merja Zerga), Sidi Boughaba Lake, and the

coastal merjas (Fouarates, Daoura, Benmansour) also the Rharb plain Merjas (El Khart, Tadjina, Tihili, Boukharja, Sidi Amer, Sidi Makhfi) constitute major sedimentary depocenters that record environmental changes linked to climatic variability and basin subsidence. Previous investigations have described several Quaternary lagoonal and lacustrine formations along this coastal sector, including the lagoon deposits of Moulay Bouselham (Benmohammadi et al., 2007), the lacustrine formations of Sidi Boughaba (Aboumaria et al., 2015), the paleosols of Sidi Taibi (Aberkan, 1989), and the lagoon deposits of Sidi Moussa near Salé (Carbonel et al., 1981; Alaoui et al., 2010). These studies have demonstrated that the genesis of these humid environments was controlled by interactions between climatic oscillations and tectonic movements affecting the Rharb Basin. However, despite this regional framework, the Dhar Eddoum formation, located along the Atlantic coast northeast of Moulay Bouselham, has not been previously characterized in detail. Its stratigraphic architecture, depositional environments, and chronological position within the Quaternary evolution of the Rharb Basin remain insufficiently constrained. Moreover, its apparent facies similarity with the modern Moulay Bouselham lagoon raises fundamental questions regarding possible paleoenvironmental continuity, coastal migration processes, and the role of neotectonic subsidence in shaping successive lagoon systems. In this context, several key

questions arise: What depositional environments are recorded within the Dhar Eddoum formation? Does its sedimentary architecture reflect lagoonal, paralic or fully marine conditions? Can sedimentary cycles within the formation be linked to sea-level conditions? During specific Marine Isotope Stages? What is the relative contribution of climatic forcing versus tectonic subsidence in controlling its development?

Addressing these questions is crucial for improving the understanding of morphosedimentary evolution along the Atlantic Moroccan coast and for refining regional models of Quaternary coastal dynamics. The Dhar Eddoum hill occupies a narrow coastal strip extending over approximately 2 km<sup>2</sup>, parallel to the present shoreline and adjacent to the Moulay Bouselham lagoon. Morphologically, this coastal sector records successive shoreline migrations expressed by ancient coastal ridges and cliffs carved into Quaternary carbonate and sandstone formations (Guilcher, 1954; Aberkan, 1989; Akil, 1990). These geomorphological markers suggest repeated transgressive–regressive cycles driven by sea-level changes and sediment supply variations.

Geologically, the study area is located within the western part of the Rharb Basin, a subsiding depression belonging to the South-Rifian trough. Its individualization dates back to the Upper Miocene (Messinian) (Cirac, 1985; Carruesco et al., 1985). The basin is bounded by the Rif domain to the north and east and by the Meseta to the south

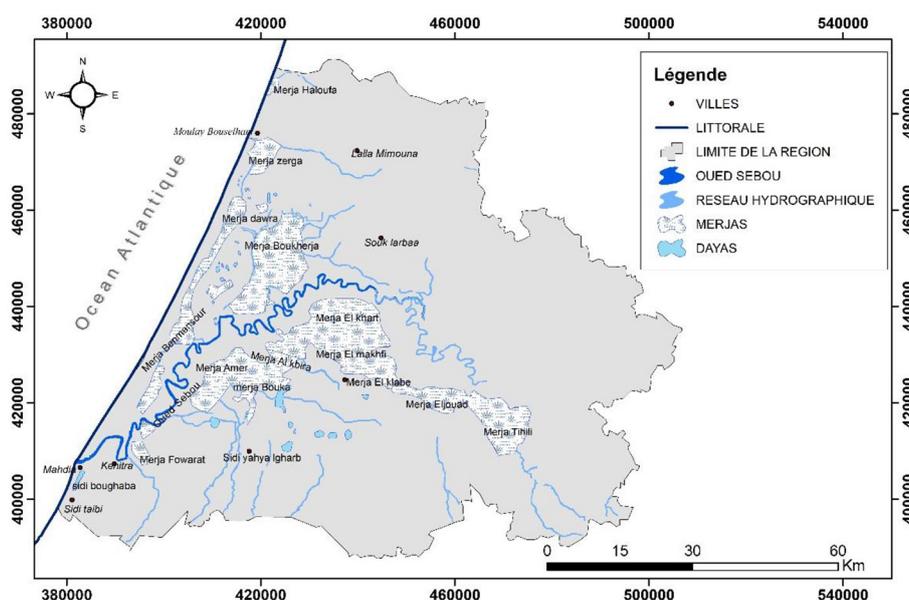


Figure 1. The Merjas and Dayas of the 20th-century floods and the hydrographic network of Oued Sebou in the Rharb basin (after Mouihi, 2013, modified by Redouani, 2025)

(Zouhri et al., 2003) (Figure 4). Ongoing subsidence and neotectonic activity may have significantly influenced Quaternary sediment accommodation space and coastal configuration.

This study aims to (i) provide a detailed sedimentological characterization of the Quaternary formation of Dhar Eddoum using field observations and laboratory studies, (ii) determine the depositional facies and reconstruct the paleoenvironmental conditions, (iii) examine the vertical structuring of sedimentary sequences to identify potential hydrosedimentary cycles, and (iv) analyze the respective influence of climatic variability, sea level fluctuations, and tectonic controls on the creation of this coastal system. This study further seeks to establish temporal correlations between the Dhar Eddoum formation and the present Moulay Bouselham lagoon, thereby contributing to a broader understanding of Quaternary coastal evolution along the Atlantic margin of Morocco. By integrating sedimentological, paleoecological and structural data, this work aims to refine the morphosedimentary model of the Rharb coastal plain and to provide new insights into the dynamics of lagoon-marine transitions in a tectonically active Atlantic setting.

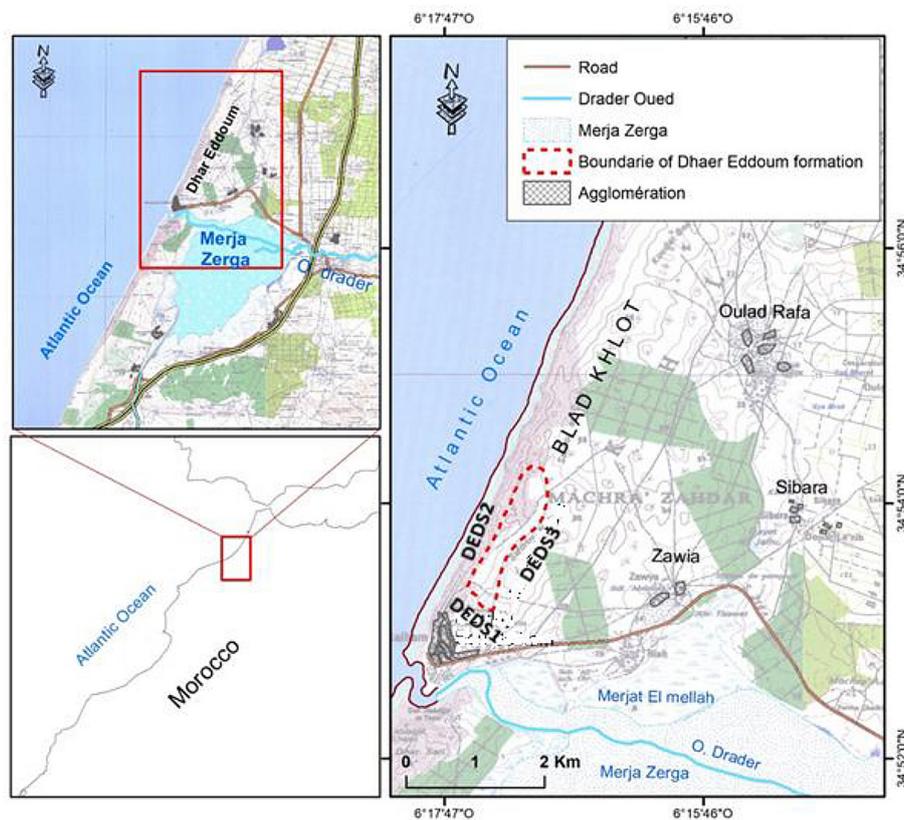
## MATERIALS AND METHODS

### Geological and geographical context

The Dhar Eddoum study area is situated within the western Meseta structural unit, specifically in the Gharb basin. The western Meseta comprises sedimentary sequences ranging from Precambrian bedrock to Miocene formations, overlain in places by Plio-Quaternary transgressive deposits (Gigout, 1951). The Dhar Eddoum formation is located adjacent to the commune of Moulay Bouselham and the local pumping station, near the Atlantic coastline of Morocco, north of the Gharb Plain (Kenitra Province, Rabat-Salé-Kenitra region). The formation extends over an area of approximately 2 km<sup>2</sup>, with a northwest orientation parallel to the current coast. The geographical coordinates that define it are latitudes 34°51'–34°57' and longitudes 6°15'–6°18' (Figure 2; Figure 3).

### Climate context

The Rharb region exhibits a Mediterranean climate strongly influenced by Atlantic oceanic conditions, resulting in mild, relatively humid winters



**Figure 2.** Situation of the Dhar Eddoum formation on the coastline of the Moulay Bouselham commune



**Figure 3.** Location of the lithological sections of the Dhar Ed Doum formation (DEDS)

and hot, dry summers with a seasonal precipitation pattern (Maychou, 2009). The annual average temperature is around 18.5 °C, while the average annual precipitation amounts to 525 mm/year. Regarding the prevailing winds, the general observation in the Gharb is that they mainly blow from the north for most of the year, particularly toward Kénitra. Average speeds of 12 to 15 km/h are observed.

### Morphodynamics and the influence of waves

Atlantic swell is a dominant factor controlling morphosedimentary processes along the Moroccan Atlantic coast. Early studies demonstrated its role in sediment transport and coastal silting (Mahé, 1957) and in the development of coastal ridges and dune systems, with seasonal alternation between winter erosion and summer replenishment (El Mostapha, 1994). More recent work confirms that swell, particularly during storm events, drives granulometric variability and rapid sediment redistribution along beaches (Idrissi, 2004; Chaïbi, 2010; Doghmi, 2014; Belrhaba et al., 2025). All sampling sites were georeferenced using GPS to ensure their reproducibility, each sample being accompanied by precise details on the lithological and morphological context (Figure 4).

### Stratigraphic sections and sampling

Three lithostratigraphic units have been defined along the cartographic boundary of the Dhar Eddoum formation (DED) in order to identify lateral and vertical changes: DED1: is located at the southern end of the formation, buried beneath the soil of the Moulay Bouselham forest. DED2: refers to the western lateral extension of DED1, which

is parallel to the beach of Moulay Bouselham. DED3: is located at the northern end of the formation (Figure 5).

At each section, stratigraphic logs were measured with a meter tape, and bed thicknesses, sedimentary structures, color, and texture were recorded. Lithological boundaries were described in detail and photographed. The coordinates of the sampling points were recorded in the field using a portable Garmin Montana 750i GPS (degrees and decimal minutes format), referencing WGS84. The horizontal accuracy is on the order of a few meters, depending on satellite reception conditions.

### Sample collection protocol

From each layer, at least three representative samples (~2 kg each) were collected for granulometric and petrographic analysis. Fossiliferous horizons were sampled separately and labeled with stratigraphic position and lateral coordinates. Loose surface sediments from each morphological unit (beach, dunes, interdune depressions) were collected to analyze spatial granulometric variations. This procedure ensures that the observations and samples can be reproduced at the same locations and depths, critical for validating lateral and vertical facies correlations.

#### *Dhar Eddoum 1 cross-section*

The base of the first section of Dhar Eddoum consists of a brick-red clay-silt-sandy layer approximately 8 meters thick, which overlays Soltanian calcarenites dating from 120,000 to 40,000 years BP. The center of this first section consists of ochre to blackish clay-silt layers arranged in decimetric to metric strata (up to 2 meters thick),

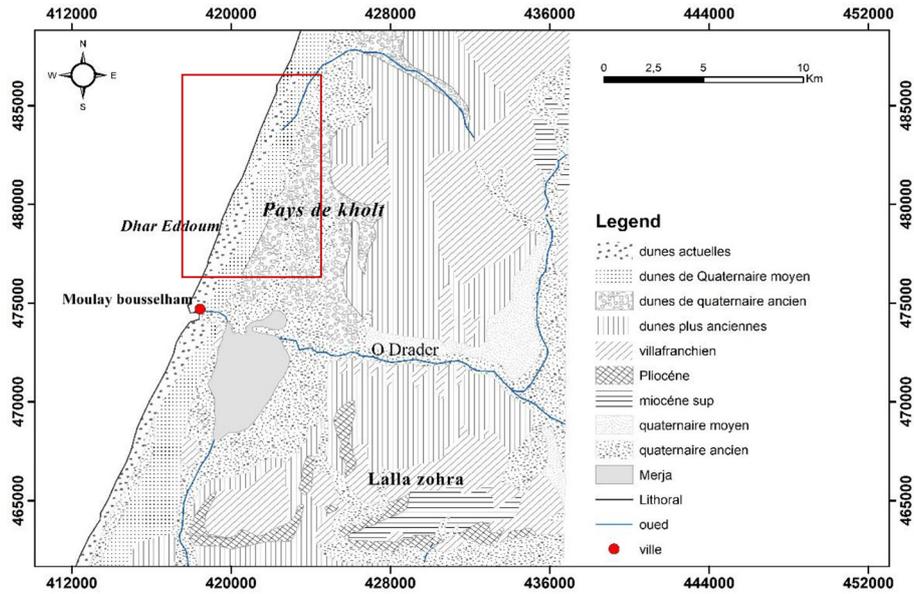


Figure 4. Simplified geology of the study area

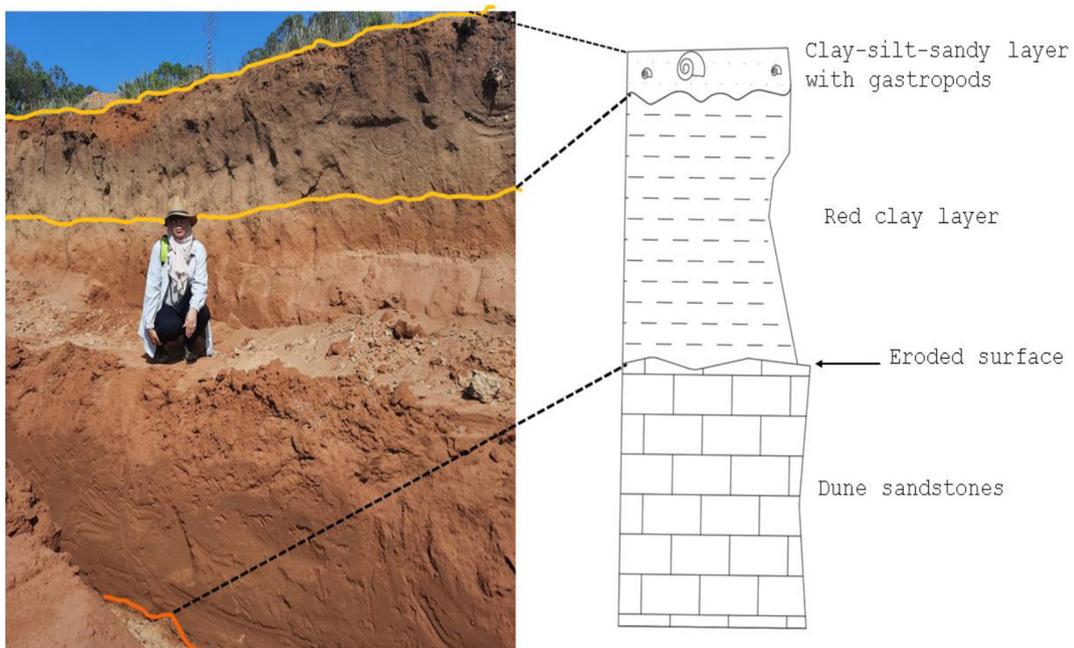


Figure 5. Stratigraphic log of the Dhar Eddoum 1 cross section

teeming with intact gastropod shells (seven species belonging to four families) (Redouani et al., 2026). The upper section consists of clays ranging from grayish green to light brown, with an approximate thickness of 8 meters, considered as low-energy lagoonal or marsh sediments (Akil, 1990; Idrissi, 2004) (Figure 5).

*Dhar Eddoum 2 cross section*

The basal layer of the second stratification presents a brick-red hue and a thickness that

can vary, adorned with sporadic syndimentary faults. It is a decimetric conglomerate layer ( $\leq 50$  cm) composed of rounded and flattened pebbles, integrated into a reddish-pink silty-clayey matrix (Figure 6). It is interpreted as a high-energy coastal or fluvial addition, in accordance with the detrital deposits of the Villafranchian (Aberkan, 1989; Texier et al., 1994).

Similar facies have been identified based on the coastal formations of Moulay Bouselham and Sidi Boughaba, where they indicate the

transition between infralittoral marine deposition and the first continental inputs. (Akil, 1990; Texier et al., 1994). The main fossiliferous layer (~12 m) contains terrestrial gastropods belonging to the families Helicidae, Trissexodontidae, and Geomitridae (Redouani et al., 2026; El Gharbaoui, 1981). The samples show minimal fragmentation, indicating in-situ accumulation and low hydrodynamic displacement.

*Dhar Eddoum 3 cross section*

The lower level of the third section consists of consolidated gray sands exhibiting horizontal stratification, suggesting a shallow low-energy lagoonal or marine deposit (Aberkan, 1989).

In the center, there are yellowed sands exhibiting inclined and intertwined stratification, characteristics of oriented flows, typical of active fluvial/deltaic environments (Texier et al., 1994). The upper section refers to a conglomeratic layer of rounded and flattened pebbles, indicating a high-energy deposition phenomenon during a regression or flooding episode (Figure 7).

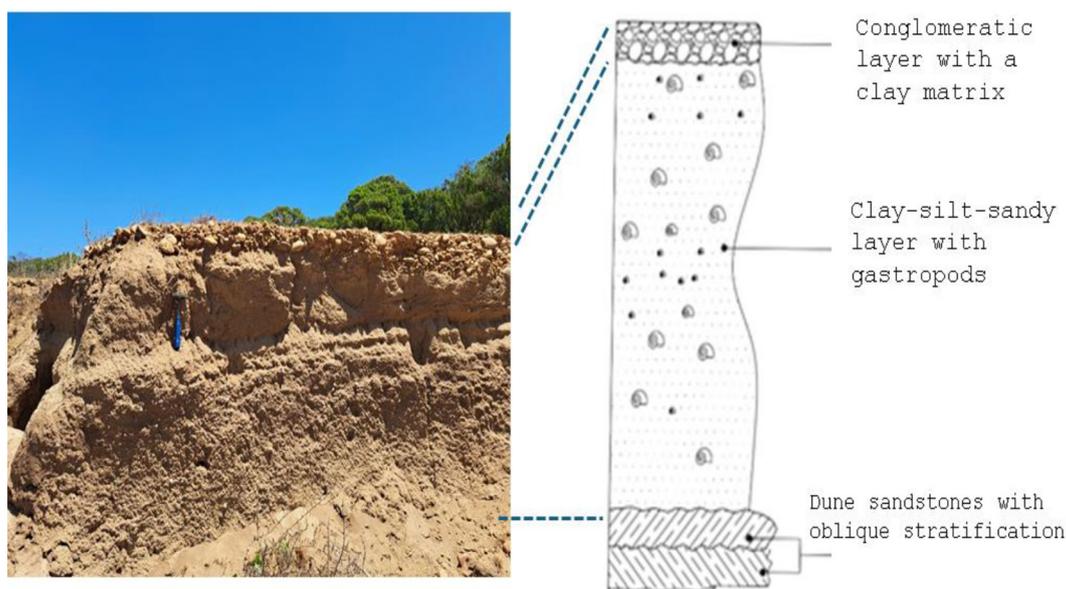
Idrissi, (2004) have made similar observations, associating the presence of these clay layers with recurrent phases of moisture during the quaternary period, favorable to the formation of hydromorphic soils in the coastal depressions of the Gharb.

This fluctuation illustrates an active karst process, often observed in the carbonate structures

of the Moroccan Atlantic coast dating back to the Quaternary. The dissolution features observed in the travertines and continental limestones of the Gharb (Texier et al., 1994) indicate post-sedimentary processes related to the lowering of the water table and the resumption of karst dissolution after the deposition phase. The third facies consist of a dense limestone block, very resistant and full of voids, known as lapiez with a diameter that can reach 30 cm (Figure 8 B). The pores are channeled and resemble plant ramifications (Figure 8 C D). These facies reflect a period of intense carbonate precipitation in a limestone-saturated environment, characteristic of calcareous spring regions. The vacuolality results from the trapping of air bubbles and plant residues during the rapid crystallization of carbonate, a phenomenon widely studied in dam-type travertines (Texier et al., 1994).

The appearance of these imposing banks is associated with an oversaturation of bicarbonate and calcium ions, facilitated by the decarbonation of groundwater as well as by slight changes in temperature and pH in a vegetated environment (El Mourni, 2003). Similar facies have been identified in the travertines located north of the Gharb basin, where limestone formation is associated with vacuolization processes and progressive hardening (Aberkan, 1989; Akil, 1990).

DEDS3 contains three carbonate facies associated with travertinization and karst processes: Brown–gray clay paleosol over limestone



**Figure 6.** Section 2 of the Dhar Ed Doum formation shows the lateral development of the fine detrital facies with gastropods and the recent conglomeratic spreads reminiscent of Villafranchian detrital deposits from the pre-Rif ridges



Figure 7. Stratigraphic log of the Dhar Eddoum 3 cross section

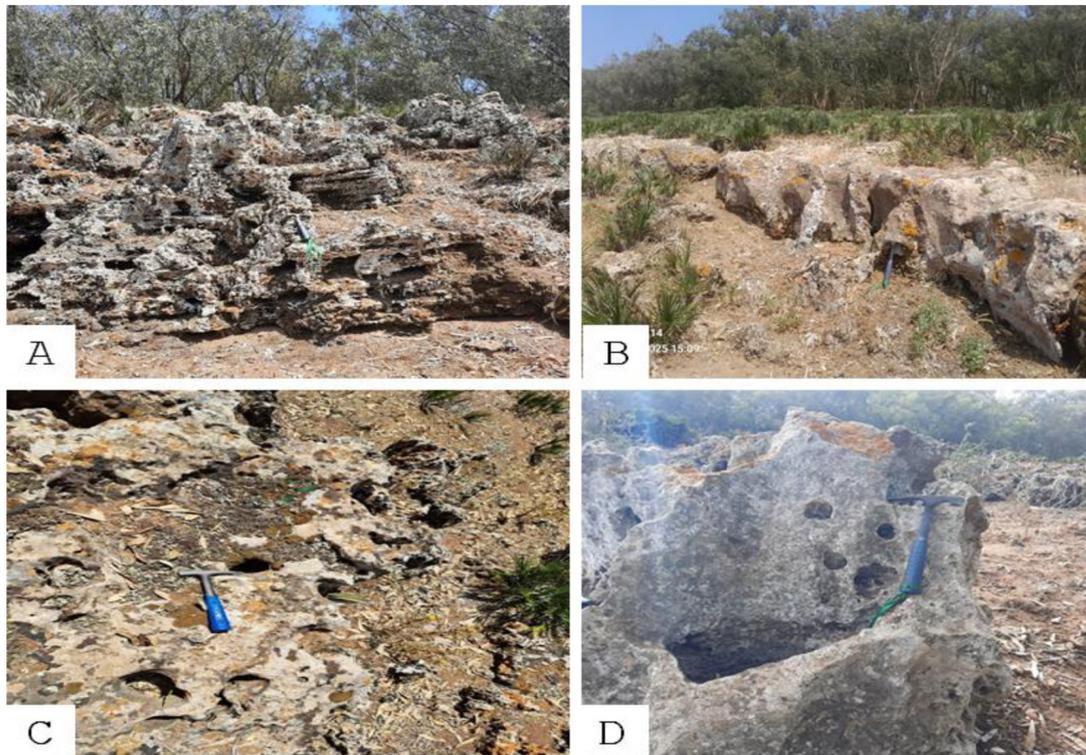


Figure 8. The 3 facies with pores and dissolution features of the DEDS3 section of the Dhar Ed Doum formation

(Aberkan, 1989; Idrissi, 2004) (Figure 8 A). Fine sandstones with hard calcareous cements, showing inclined stratification and dissolution features, indicative of early diagenesis and aquifer-mediated carbonate precipitation (Akil, 1990). Dense limestone blocks with lapiez, pores, and vacuoles, showing plant-like channels (Texier et al., 1994; El Moumni, 2003). These observations were documented in field with detailed sketches and photographs, ensuring that micro- and macro-facies can be revisited and compared.

### Granulometric analysis

The sedimentology laboratory of the geology department at the Faculty of Sciences in Kénitra contains several instruments intended for granulometric analysis. It has a workbench dedicated to washing and decanting samples. The laboratory also has workstations dedicated to weighing and observing samples (Figure 9).

The methodology used is based on previous references that have established the relationship

between sediment granulometry and their distribution along sandy beaches (Short, 1992; Kroon, 1994; Masselink and Hegge, 1995; Aernouts, 2005; Anthony et al., 2006; Tamura et al., 2010). In this perspective, the samples collected on Moulay Bouselham beach as well as in the Dhar Eddoum formation were analyzed according to a granulometric protocol compliant with AFnor standards. Each sample was first subjected to wet sieving using a 63 µm mesh, aiming to separate and eliminate the fine fraction (silts and clays), to concentrate the analysis on the sandy fraction's representative of hydrodynamic and sedimentary processes.

All samples were oven-dried at 90 °C for 48 hours. Wet sieving through a 63 µm mesh was performed to remove silts and clays. 100 g of sand fraction was dry sieved using standard sieves (4 mm → 40 µm) for 20 min at 20 shakes/s using a mechanical agitator (Figure 10, Figure 11).

### Data processing

The residues from each sieve were carefully weighed; cumulative and frequency curves plotted using OriginLabPro (Figure 12 and 13).

Granulometric parameters (mean, median, mode, Trask sorting index, skewness, kurtosis) calculated using logarithmic method of Folk and Ward (1957), expressed in phi (Ø) units.

This protocol allows quantitative comparison across sections and with modern beach deposits, providing reproducible data to evaluate sedimentary energy conditions and lateral variability.

### Petrographic analysis

Thin sections were prepared from representative samples of each lithostratigraphic section. Observed under a polarizing microscope; microfacies classified according to Durham (1962) as packstone and grainstone limestones (Figure 14),



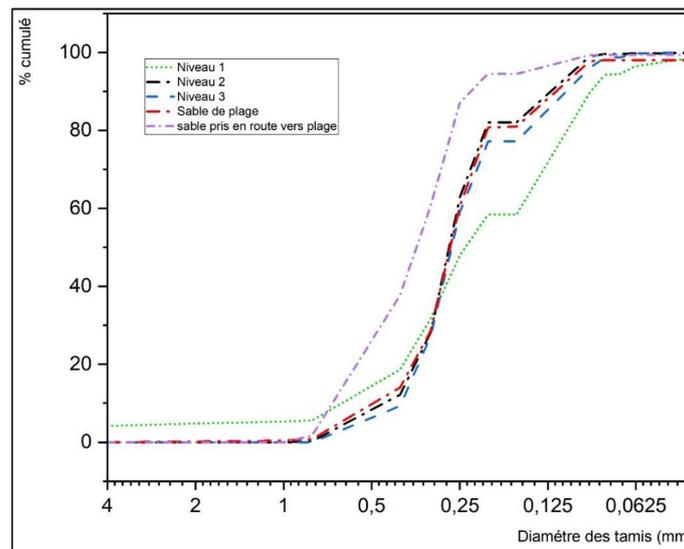
**Figure 9.** Laboratory equipped for granulometric analysis



**Figure 10.** Washing of samples and removal of the clay fraction



**Figure 11.** The samples are placed in an oven to dry



**Figure 12.** Cumulative curves of samples from the Dhar Eddoum section and Moulay Bouselham beach

(Table 1). Petrography enabled microscopic facies correlation with field descriptions, supporting paleoenvironmental reconstruction.

## RESULTS AND DISCUSSION

### Paleoenvironmental synthesis

Because of its location between the Hercynian basement of the Moroccan coastal meseta and the subsiding Gharb basin, which represents a significant hydrogeological potential on a Moroccan scale, the study area is a reference point where the

effects of coastal sedimentation and neotectonics related to the region's evolution during the Quaternary period intersect.

The study of the three sections surveyed within the Dhar Eddoum formation highlights a complex sedimentary and paleoenvironmental evolution, reflecting the climatic and eustatic fluctuations of the Quaternary period on the Moroccan Atlantic coast. These successions record the alternation of wet and arid phases, from marine to continental environments, and from active phreatic conditions to periods of marked pedogenesis.

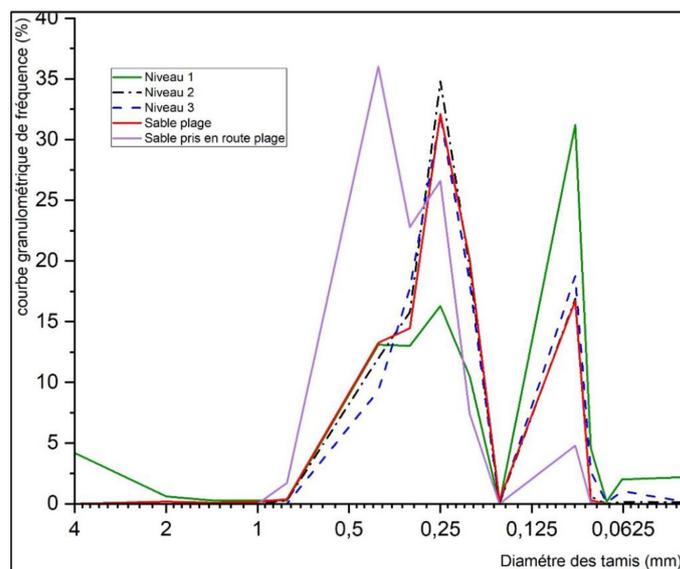


Figure 13. Frequency curves of samples from the Dhar Eddoum formation and Moulay Bousselham beach

Table 1. Summary table of the elements observed on the thin sections of the FDD samples

Sample	Main minerals	Lithic fragments	Matrix / Cement	Bioclasts	Texture	Microfacies Durham, 1962)
Lapiez limestone	Quartz (abundant), feldspaths, oxides	Present (dark, angular)	Ferruginous + clayey (abundant)	Absent	Jointive	Packstone limestone
Limestone	Quartz, feldspars, lithoclasts	Multiple, variable sizes	Clay-iron	Absent	Jointive	Limestone packstone
Bancs du calcaire lenticulaires	Quartz (abondant), feldspaths	Dark lithoclasts (Abundant)	Ferruginous + clayey	Present (foraminifera / echinoderms / bivalves)	Jointive	Limestone packstone
Calcarinite	Quartz (dominant), feldspaths, oxide	Present	Abundant ferruginous	Rare/absent	Jointive	Grainstones

The three sections of Dhar Eddoum reflect the same morphosedimentary dynamics responding to the climatic and eustatic variations of the Quaternary. They demonstrate to:

- The alternating influence of marine, lagoonal, and continental environments.
- High hydrological variability that alternately favored carbonate precipitation, pedogenesis, or clay sedimentation. And relative morphological stability during wet phases, followed by episodes of fluvial or torrential reactivation during more arid phases.

Thus, the formation of Dhar Eddoum is fully integrated into the paleoenvironmental chronosequence of the Moroccan Atlantic coast, like sites such as Merja Zerga, Sidi Boughaba, or Moulay Bousselham (Aberkan, 1989; Akil, 1990; Texier et al., 1994; Idrissi, 2004; Bouimetarhan et al., 2009). It serves as a representative example of the morphosedimentary dynamics of the recent Quaternary

period, integrating the combined effects of ductile tectonics, climate, and eustatic oscillations.

In summary, the Dhar Eddoum formation corresponds into the paralic model of the Rharrb: an alternation of fine deposits and more energetic episodes along the lagoon gradient, under the influence of coastal ridges. However, it is distinguished by travertine-type carbonate precipitations, linked to hydrogeochemical conditions and probably modulated by tectonics, which sets it apart from the predominantly siliciclastic successions of Merja Zerga.

### Granulometric synthesis

The semi-logarithmic cumulative curves of the sediments from Moulay Bousselham beach and the Dhar Eddoum formation usually have an “S” shape. This configuration reflects a sandy deposit resulting from a relatively agitated hydrodynamic environment, where fine particles are evacuated offshore under the effect of return currents.

It also suggests a homogeneous sedimentary stock and marine energy generally in balance with the transported load (Atoui and Brahim, 2009).

The study of the granulometric frequency curves of the samples taken from Moulay Bous-selham beach and the Dhar Eddoum formation reveals interesting differences in the way the sedi-ments were deposited.

The beach sands currently exhibit a well-de-fined unimodal distribution, with the peak located in the medium sand class of 0.25 mm, reflecting different sorting processes and a certain homoge-neity of the sedimentary stock. This is character-istic of an open, high-energy marine environment where the action of waves and return currents clean and remove fine particles while ensuring evacuation and selectivity based on particle size (Folk and Ward, 1957; Atoui and Brahim, 2009).

Conversely, the sample taken outside the area directly influenced by the swell shows a more dispersed distribution, with an increased propor-tion of fine fractions, indicating sediments sub-jected to secondary processes, especially wind or surface runoff.

The Dhar Eddoum formation deposits also ex-hibit a unimodal structure dominated by medium sands but accompanied by a larger proportion of fine sands (0.125–0.0625 mm). This characteristic indicates a less selective sorting and more variable deposition conditions, reflecting less constant hy-drodynamic energy than that of the current beach. The vertical organization into several levels (L1, L2, L3) suggests paleo-environmental variations, probably related to Quaternary eustatic fluctua-tions and a paralic or lagoon-type dynamic (El Mostapha, 1994; Anthony et al., 2006).

The granulometric analysis shows a real dif-ference between the Dhar Eddoum formation and Moulay Bous-selham beach. Level 1 of Dhar Ed-doum, with poor sorting ( $S_o = 1.73$ ) and a flat-tened distribution ( $K_g = 0.799$ ), reflects a hetero-geneous deposit marked by unstable conditions.

Level 2, which is better organized ( $S_o = 1.25$ ) and more concentrated ( $K_g = 1.404$ ), reflects more regular energy and more homogeneous medium sands. Level 3 ( $S_o = 1.29$ ;  $K_g = 1.257$ ) occupies an intermediate position, confirming the variabil-ity of a sheltered environment, typical of a paralic or lagoonal context.

Conversely, Moulay Bous-selham beach stands out clearly. Its sorting is more efficient ( $S_o = 1.26$ ), and its leptokurtic distribution ( $K_g = 1.339$ ) illus-trates active shaping by the swell. The medium sands clearly dominate there ( $M_d = 0.268 \phi$ ;  $M_o = 0.25 \phi$ ) and the slightly positive asymmetry ( $S_k = +0.004$ ) shows that the sea finely selects the grains, removing the finest particles. Finally, the sample taken near the beach reveals less pronounced sort-ing ( $S_o = 1.366$ ) and an enrichment in fines ( $S_k = +0.029$ ), indicating a more heterogeneous deposit, shaped not by the swell but by secondary processes such as wind or runoff (Table 2).

## Petrography synthesis

### Interpretation of microscopic observations

Lapiez limestone: According to the observa-tion under a polarizing microscope, the presence of quartz grains is often noted, often xenomor-phic (irregular shapes), with low relief, some-times fractured. Feldspars (plagioclases or po-tassium feldspars): lighter gray-white grains. Lithic fragments (pre-existing rocks): dark grains, angular to sub-rounded in shape, indicat-ing a detrital origin. Oxides/iron: dark reddish marks (probable hematite/limonite), indicating pedogenic alteration. The thin section shows a combination of quartz grains, feldspars, and lith-oclasts embedded in a fine micritic matrix of a darker color. The shape of the grains is predomi-nantly sub-angular to sub-rounded (packstone limestone) which reflects moderate transport. These observations point to a feldspathic arenit-ic (arkosis) (Figure 14 A).

**Table 2.** Granulometric parameters of the Dhar Eddoum section and Moulay Bous-selham beach

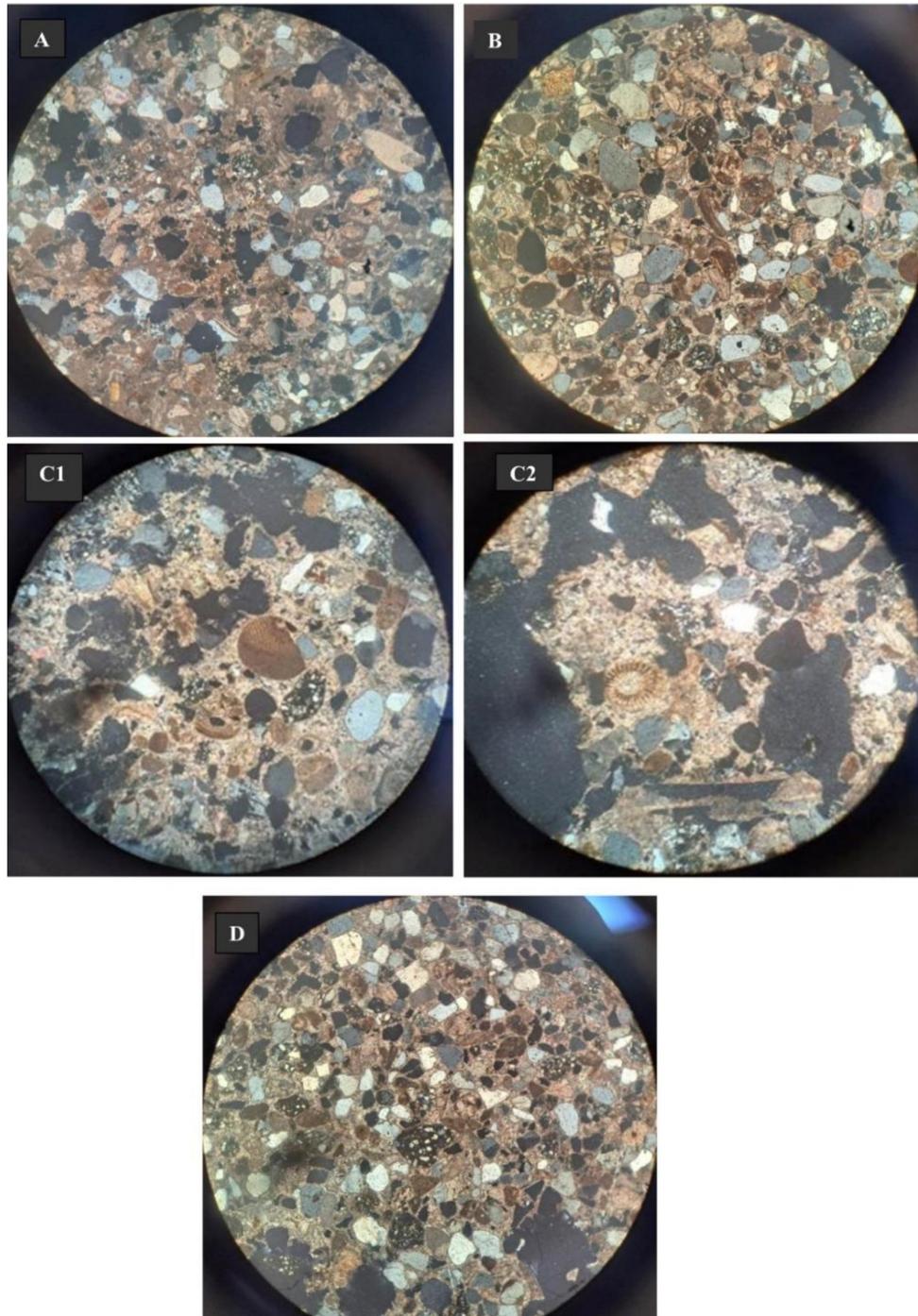
Granulometric parameters in phi ( $\phi$ )						
Parameter	$S_o$	$M_d$	$M_o$	$Moy$	$K_g$	$S_k$
Level 1	1.73	0.24	0,09	0.216	0.799	-0.0035
Level 2	1.25	0.271	0,09	0.244	1.404	0.002
Level 3	1.29	0.265	0,25	0.226	1.257	-0.0013
MBS beach	1.26	0.268	0,25	0.231	1.339	0.004
Towards the beach	1.366	0.353	0,4	0.373	0.652	0.029

Limestone: the figured elements of this sample consist of Quartz, which appears in clear grains and sub-rounded shapes, Plagioclase Feldspars in whitish to light gray grains, the matrix is abundant composed of clays and iron oxides, with all grains bound together by a clay-ferruginous cement.

This thin section corresponds to: Lithofeldspathic wacke microfacies with a ferruginous matrix. This type of microfacies reflects a

fluvial to paralic depositional environment, with varied detrital inputs (quartz, feldspars, lithic fragments), subject to ferruginous pedogenesis (oxidation) (Figure 14 B).

Lenticular limestone layers: this thin section corresponds to a detrital silicoclastic rock of bioclastic grauwacke type, dominated by quartz, feldspar and lithoclast, bound by a ferruginous matrix. A few marine fossils can be observed:



**Figure 14.** Microscopic observation of microfacies, A: Lapiez limestone microfacies, B: Limestone microfacies, C1 and C2: Lenticular limestone layers microfacies, D: Calcarinite microfacies

foraminifera, echinoderm fragments, and a probable lamellibranch (bivalve). The combination of these elements reflects a transition from continental to lagoon to marine environment, characteristic of the deposits of the Dhar Eddoum formation (Figure 14 C1 et C2).

Calcarinite: Petrographic observations reveal an abundance of altered quartz and feldspars, associated with dark lithic fragments in an abundant ferruginous- clay matrix, with some iron oxides and rare carbonated bioclastic debris (Figure 14 D).

## CONCLUSIONS

The Dhar Eddoum formation provides a detailed sedimentary record of the Quaternary evolution of the Moulay Bouselham coastline, integrating field observations, granulometric data, petrography, and fossil assemblages. The formation captures a continuum of depositional environments, ranging from high-energy beach and upper foreshore sands, characterized by well-sorted and rounded grains, to low-energy lagoonal and marsh clays and silts that preserve in situ gastropod assemblages. Transitional layers, including conglomeratic and mixed sands, reflect episodic energetic events such as storms or overwash episodes, illustrating the system's sensitivity to hydrodynamic fluctuations.

Granulometric analyses reveal consistent bimodal distributions in both the ancient Dhar Eddoum deposits and the modern beach sediments, confirming the persistence of alternating hydrodynamic conditions over time. The gastropod assemblages indicate fluctuations from freshwater to slightly saline conditions within the lagoonal environment, corresponding to wet and dry climatic cycles. Lateral correlations between stratigraphic sections show continuity of facies, while synsedimentary faults and localized conglomerates record sediment redistribution under high-energy events. In addition, karstic and travertine features document post-depositional carbonate precipitation under fluctuating water tables, linking the sedimentary evolution to local hydrogeological dynamics.

Together, these results demonstrate that recurrent coastal processes – including sea-level variations, wave energy, and sediment supply – have consistently controlled both ancient and modern depositional systems along this segment of the Moroccan Atlantic coast. The Dhar Eddoum formation therefore represents a reproducible archive of Quaternary

hydrosedimentary cycles, allowing reconstruction of coastal dynamics and environmental shifts over time, and providing a framework for linking past and present lagoonal and beach systems.

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