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Grain Size and Surfaces Features Analysis of Quartz Grains from the Late Pleistocene along the Bizerte Coast, N-E of Tunisia

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***Abstract*: The grain size and the exoscopic analyzes of the late Pleistocene deposits (MIS 5) of the Bizerte coast (N-E of Tunisia) are indispensable tools for sedimentological analyzes providing a wealth of information on the intrinsic properties of the sediments and their depositional environment. The grain size studies are carried out through statistical parameters, *CM* diagram and bivariate scatter graphs. The mean size indicates a fine to medium grained sand for most of the samples. Most of them are well sorted and mainly transported by rolling and bottom suspension. The SEM observations reveal an important microtextures development formed by mechanical and chemical processes. Their examen suggests a complex sedimentary history beginning with a violent eolinisation, a residence in the infratidal horizon then a passage towards an intertidal or fluviatile horizon ending with a possible wind recovery.**

***Keywords :* Grain size analysis, SEM, Late Pleistocene, Bizerte coast**

I. Introduction

Grain size studies are widely used to reconstruct the depositional environment (Folk and Ward 1957; Friedman 1962; Passega 1964; Folk 1966; Friedman 1967; Pettijohn 1984), especially in Quaternary sediments around the Mediterranean basin (Saidi et al. 2004; Chakroun 2009; Atoui and Brahim 2009; Mejri 2012; Aouiche et al. 2015). Indeed, these statistical studies have proved to be an effective and useful tool in the structural and textural characterization since it deciphering the sedimented nature, the depositional environments and the mode of transport.

The Scanning Electron Microscope (SEM) has been introduced to link the observed fractures on the grain surface to a defined sedimentary environment and to understand the post-depositional or diagenetic history of the deposit. Quartz is the most used grain owing to their wide distribution, their high hardness and the absence of cleavage. The first applications of this technique were carried out to identify microtextures on aeolian deposits (Krinsley et al. 1964).

Since then, SEM has been used to characterize different sedimentary environments and has been required in several geological disciplines (Krinsley and Donahue 1968; Krinsley and Doornkamp 1973; Le Ribault 1975; Krinsley et al. 1976; Friedman et al. 1976; Ribault 1977; Krinsley and Wellendorf 1980; Krinsley and Marshall 1987; Legigan and Le Ribault 1987; Legigan et al. 1989; Mahaney et al. 2001; Mahaney 2002; Chakroun et al. 2009; Mejri 2012; Vos et al. 2014). Based on mode of formation, those microtextures are classified into two general groups: mechanical processes such as conchoidal fractures, frictions traces, crescentic fractures, and V-shaped cracks and chemical processes namely dissolution and silica precipitation.

In the present work, a combined study of grain size, shape and microtextures developed on quartz grains from the late Pleistocene deposits (marine isotopic stage 5, MIS 5) of N-E Tunisia coast (Bizerte area) is presented to characterize these deposits and reconstruct their sedimentary environments in order to detect possible sea level fluctuations, leading to a better understanding of the isotopic stage in question.

II. Geographical Setting And Sedimentological Context

The Bizerte area (N-E of Tunisia) is located on the scales area (Rouvier 1977; Paskoff and Sanlaville 1983), characterized by a marine Mesozoic structural succession of upper Eocene-Cretaceous age, being overlapped by the Numidian sheet (Oligo-Miocene) (Fig.1, A).

The northeastern coast is bordered by marine Pleistocene outcrops. These deposits are situated on a few meters (2-4 m) above the current sea level and lie unconformably on Eocene and Paleocene age deposits. They show a superposition of distinct lithostratigraphic units (Ben Ayed et al. 1979; Paskoff and Sanlaville 1983, 1986; Paskoff and Oueslati 1988; Chakroun et al. 2016).

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Based on the coastal palaeo-morphology, these units display several lithological, stratigraphic and granulometric variations recorded through a cross-sections series raised out in 4 sectors, respectively from the west to the east:

- *Grottes section* (GPS coordinates 37°19'58.43'', N 9°50'33.98'' E) :

The present section is logged in a cliff known locally as "les Grottes". This locality shows a significant lateral layout and it is based on angular discordance on the Paleocene. Three lithostratigraphic units are distinguished (Fig.1, B1). The first one starts with a gully pebbles surface (Gr1) from the underlying unit (Paleocene-Eocene) which evolves to a bioclastic limestones layer, a sandy marl level (Gr5) and a continental fine sands testified by the presence of *Helix* shells and calcareous concretions (Gr6), and it ends with a ferruginous surface. Those levels are attributed to the Rejiche Formation (Paskoff and Sanlaville 1983; Paskoff and Oueslati 1988).

The second unit begins with a minor pebble gully followed by limestone-sandstone stratum, correlated to the Chebba Formation (Paskoff and Sanlaville 1983). Above, a thick layer (about 2 m) of clay and silty sand with limestone and sandstone lenses (Gr7), deposited by a fluvial process. This fluvial facies is covered by red silty marl (Gr9) interpreted as the palaeosoil of Ain Oktor Formation (Paskoff and Sanlaville 1983).

The series is capped by the Cap Blanc Formation eolianite (Paskoff and Sanlaville 1983), showing large scale cross-bedded stratification masked by the intense development of the fossilized root traces, which vanished sideways and gives space to fluvial sediments (silt channels with pebble lenses). This third unit is finished by yellowish fine sand (Gr11).

- *Ras Blatt section* (GPS coordinates 37°19'48.48'' N, 9°51'54.48'' E) :

This section starts with a marine erosional surface. At the bottom appear a fine layer of consolidated sand (less than 1 m thin) strongly bioturbated. This level holds centimeter to decimeter sized pebbles showing various forms and shapes. This facies is assigned to the Chebba Formation (Paskoff and Sanlaville 1983; Oueslati 1994). This level is topped by a fine layer (about 10 cm) of reddish sand (Ain Oktor Formation, Paskoff and Sanlaville 1983). These Formations constitutes the first unit (U1, Fig. 1, B2).

The second unit is represented by the Cap Blanc eolianite Formation (Paskoff and Sanlaville 1983) hosting *Helix* shells, at the bottom, and exhibiting preserved cross-bedding stratification commonly destroyed by fossilized root structures at its uppermost part.

-- *Metline section* (GPS coordinates 37°15'04.06'' N, 10°00'50.97'' E) :

This section is subdivided into three distinct lithostratigraphic units (Fig.1, B3). The first unit starts with a thin layer of yellow sand rich on bivalves (Me5) followed by consolidated sands rich in horizontal bioturbations.

The second unit begins with calcareous cemented sandstone enriched with quartz dragee and bivalves mold. The series evolves to grano-decreasing small sequences, deposed by tempestite process. They are overlapping by a fine bioturbated level, a thin sandy layer (Me6) and a lenticular bivalves level.

The last unit restarts the same described facies in the previous unit with a thickening of the tempestite structure and an enrichment in bivalves shells.

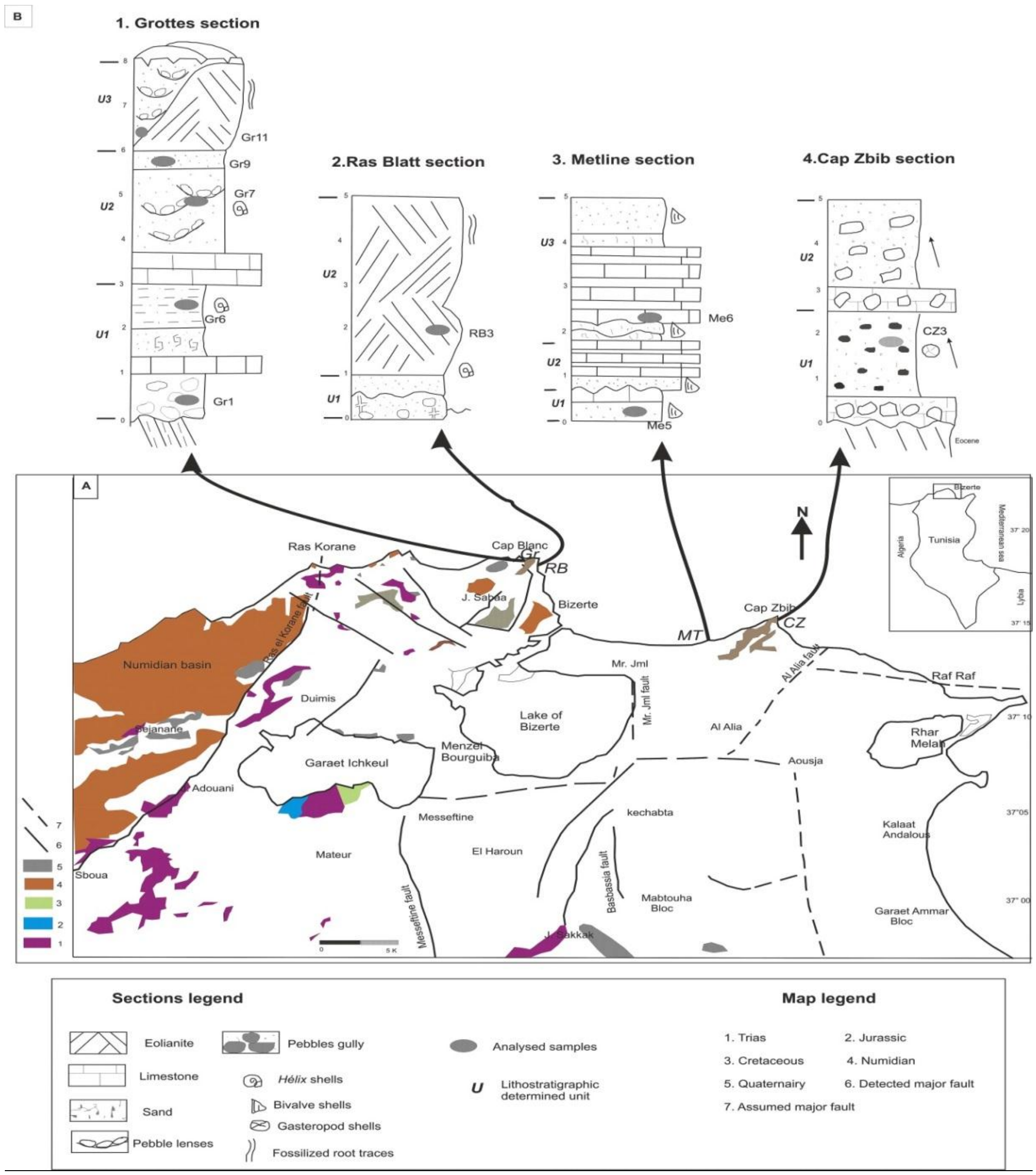

Figure 1 : Geological setting of the study area (A) and stratigraphic logs (B) mentioning the analyzed samples (geological map from Harrab et al. 2013 Simplified

-- *Cap Zbib section* (GPS coordinates 37°16'06.80'' N, 10°04'09.73'' E) :

The series consists of two lithostratigraphic units (Fig.1, B4). The first unit starts with a bioclastic limestones layer rich in decimeter to centimeter-sized pebbles and fossil shells debris (Chebba Formation, Paskoff and Sanlaville 1983).

This level is followed by whitish sands (CZ3) containing entire gastropods shells and pebbles (centimeter-sized, rounded and blunted shaped), interpreted as the palaeosoil of the Ain Oktor Formation (Paskoff and Sanlaville 1983).

The second unit is represented by a thick layer (about 2 m) of red colluvium with angular-shaped decimeter-sized rollers.

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III. Materials And Methods

The grain size analysis was carried out through an "AFNOR" column composite by 9 sieves and shake for 20 mm. At the end of sieving, the sand collected from each sieve represents a grain size class which will be computed as weight percentage frequencies and cumulative weight percentage frequencies.

The grain size parameters used are the graphics mean size (Mz), sorting (So), skewness (SK) and kurtosis (K) and were calculated according to Folk and Ward (1957) method. These parameters are completed by the *CM* pattern and the bivariate scatter graphs.

The samples treatment for an exoscopic analysis consists of eliminating the organic particles by treatment with HCL 15% and removing the organic matter by treatment with H_2O_2 30%. The quartz grains, thoroughly cleaned, are observed under a binocular microscope, picked out and positioned on studs for coating gold. These grains must be same-sized since microtextures depend on grain size (Porter 1962; Mahaney 2002). In this work, selected grains are 0.5 mm sized. 10 grains are examined for each sample, an adequate number for an exoscopic evaluation (Mahaney 2002; Vos et al. 2014).

The studs are finally transmitted under a scanning electron microscope and quartz grains photographs are taken at different scales. The instrument used is JEOL-JSM5400 located at the Tunisian Petroleum Business (ETAP). A systematic study of fractures features, precipitation and dissolution archived on the grain surfaces is carried out with frequency calculation.

IV. Results

1. Grain size results

Table 1 summarizes the statistic results of the different grain size parameters.

The mean grain size of the Ras Blatt section (sample RB3) reflects fine sand, well sorted and its size ranges from 1.91 mm. The skewness is negative and the kurtosis shows a leptokurtic nature. All these granulometric results plead for an aeolian facies.

The Grottes section samples (Gr5 and Gr11) and the Metline section samples (Me5 and Me6) are measured as fine sand, very well sorted with a unique exception (Me6 sample) displaying a moderately sorted sand. Skewness has negative values while kurtosis is leptokurtic in nature (Gr11 and Me5 samples) to mesokurtic in nature (Gr5 and Me6 samples). Those results report these samples to beach deposits.

The mean grain size of the Gr9 sample (Grottes section) varies from medium to coarse sand moderately sorted. The kurtosis shows a leptokurtic nature and skewness is negative. Similar observations are also determined at Cap Zbib section (CZ3 sample) which size ranges from 1.73 mm moderately sorted, a negative skewness value and rather a mesokurtic nature. These two samples (Gr9 and CZ3) are attributed to a continental facies.

The fluvial sedimentary stock from the Grottes section (Gr7 sample) consists of coarse sand, moderately well-sorted with a platykurtic nature and negative skewness

Table 1 :
Summary of grain size statistical parameters

Cross section	samples	Mean size (Mz)	Sorting (SO)	Kurtosis (K)	Skewness (SK)
Grottes	Gr5	1.69	0.49	0.99	-1.43
	Gr7	2.65	0.67	0.75	-0.5
	Gr9	0.91	0.84	1.58	-0.43
	Gr11	1.91	0.38	1.92	-0.46
Ras Blatt	RB3	1.91	0.29	1.37	-0.42
Metline	Me5	1.83	0.098	1.47	-0.31
	Me6	1.65	0.97	0.92	-2.25
Cap Zbib	CZ3	1.73	0.88	0.16	-0.38

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1.1. Bivariate scatter graphs of grain size parameters

The bivariate scatters graphs of grain size parameters are used to distinguish between several depositional conditions, through bi-varied plots, which are based on the assumption that these statistical parameters reliability reflects the differences in the mechanisms of sediment transportation and deposition (Sutherland and Lee 1994; Rajganapathi et al. 2012).

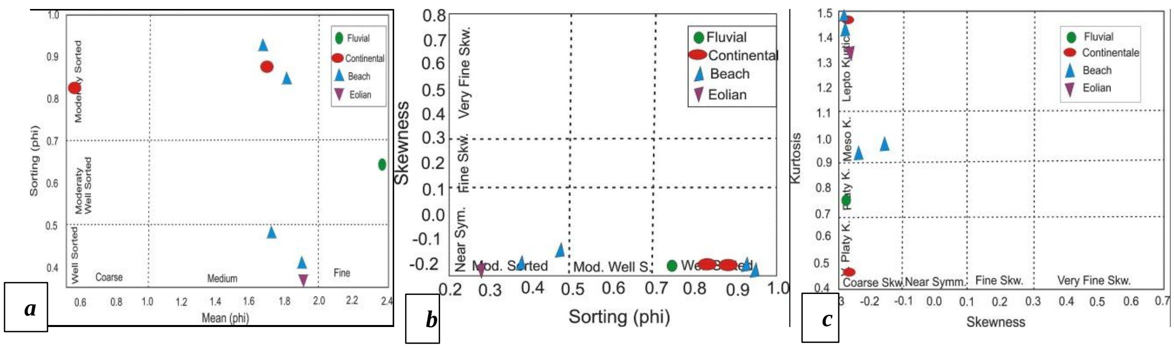

Figure 2: Sector plot showing the bivariate relationship between (a) mean size/ sorting, (b) sorting/skewness and (c) skewness/kurtosis

The first scatter (Fig.2, a) shows the relationship between mean grain size and sorting. It reveals that the aeolian (RB3 sample) and the beach (Gr5, Gr11, Me5, and Me6 samples) deposits show well sorted to moderately sorted medium size sand. The fluvial sediments (Gr7), the finest one, are moderately well sorted, whereas the continental deposits (Gr9), the coarsest one, are moderately sorted. Indeed, the mean grain size and sorting are controlled hydraulically, so that in all sedimentary environments, the best-sorted sediments have mean size belonging to the fine sand class (Griffths, 1967).

The second scatter (Fig. 2, b) shows the relationship between sorting and skewness. All sediments are near symmetric towards medium fractions.

The last one (Fig.2, c) shows the relationship between Skewness and Kurtosis, which represents a powerful tool for interpreting the sediments genesis, by quantifying the degree of normality of its particle size distribution (Folk 1966). All the sediments have negative skewness values, indicating an enrichment on coarse well-sorted particles and preferential removal of fine particles. Generally, the negative asymmetries characterize the littoral sand where the fine sized sand are eliminated by winnowing (Chamley 2000). Nevertheless, their kurtosis shows different nature. Indeed, most of the analyzed deposits (beach, continental, eolian deposits) are leptokurtic in nature suggesting a homogeneous grain size range. Only two of the beach deposits (sample Gr5, Grottes section, and Me6, Metline section) are mesokurtic in nature, where the particle size populations are almost in equal proportion.

Yet the fluvial sediment shows platykurtic nature reflecting a heterogeneous population. The continental deposit (sample CZ3, Cap Zbib section) is very platykurtic (extreme high value) suggesting that part of sediment achieved its sorting in a high-energy environment (Friedman 1962), which is argued by the gully pebbles.

1.2 CM diagram

The *CM* diagram or Passega diagram (1957, 1964) lead to distinguish between different transport mechanism and depositional environment due to a single pattern. Passege (1957) explained the distinct patterns of *CM* plots in terms of different modes of transportation by plotting coarsest first percentile grain size C (P99) and the median size M of the sediment on a double log paper. The M parameter reflects the classification degree of the deposit, and the C parameter testifies the limit of the current competence transporting initially the sediment. The *CM* diagram is made up of 5 segments namely NO (rolling), OP (rolling and bottom suspension), PQ (saltation), QR (graded suspension), RS (uniform suspension) and S (pelagic suspension). In this work, we referred to the original *CM* diagram proposed by Passega (1964).

The *CM* plot (Fig.3) shows that most of the sediment is deposited by rolling and suspension of the bottom except in same beach samples which fall in the graded suspension transport and uniform suspension conditions.

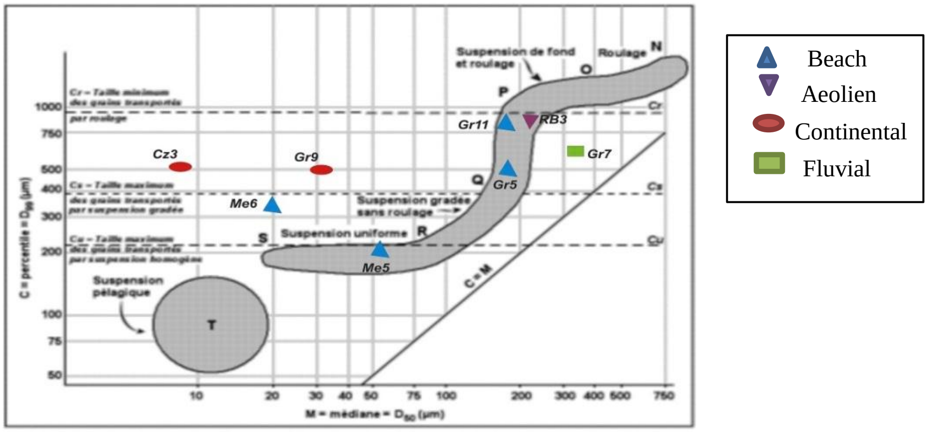

Figure 3 : *CM* diagram (Passega, 1964)

V. Morphoscopic Results

The morphoscopic analysis is required to examine the grain shape, their sphericity degree and their refraction in order to subdivided those grains into 3 main categories namely NU (grain not worn, angular), EL (blunted-shiny grains) and RM (round-matted grains), determined by visual charts like the Pettijohn et al. (1982) proposed one. Those factors seem to have excellent correlation with the different process and depositional environment.

Most of the marine deposit grains (Gr1, Grottes section) shows the dominance of angular to sub-angular grains, followed by shiny blunting grains (Fig. 4, A). Round mat grains are rare (6%). These results suggest marine transportation. Beach deposits (Gr5 and Gr11, Grottes section, and Me5 and Me6, Metline section) are mainly represented by dull blunted grains followed by round-mat and angular shaped-grains (Fig. 4, E) highlighting the marine condition dominance and the minor eolian action. The aeolian deposit (RB3 sample, Ras Blatt section) inherits both of aeolian character and the adjacent marine character which makes it a non-homogeneous deposit. It is made up of only 10% of round-mat grains, while the blunt ones range from 47% and the sub-angular ones 41% (Fig. 4, D). The continental deposits (Gr6 and Gr9, Grottes section and CZ3, Cap Zbib section) reveals that they are also heterogeneous deposits (Fig. 4, B) materialized by the dominance of shiny-blunt and shiny sub-angular grains followed by angular and round-mat grains in a lower percentage. The fluvial facies (Gr7 sample, Grottes section) shows a shiny-blunt shaped grains dominance, followed by angular and sub-angular shiny grains (Fig. 4, C), suggesting an aquatic depositional conditions.

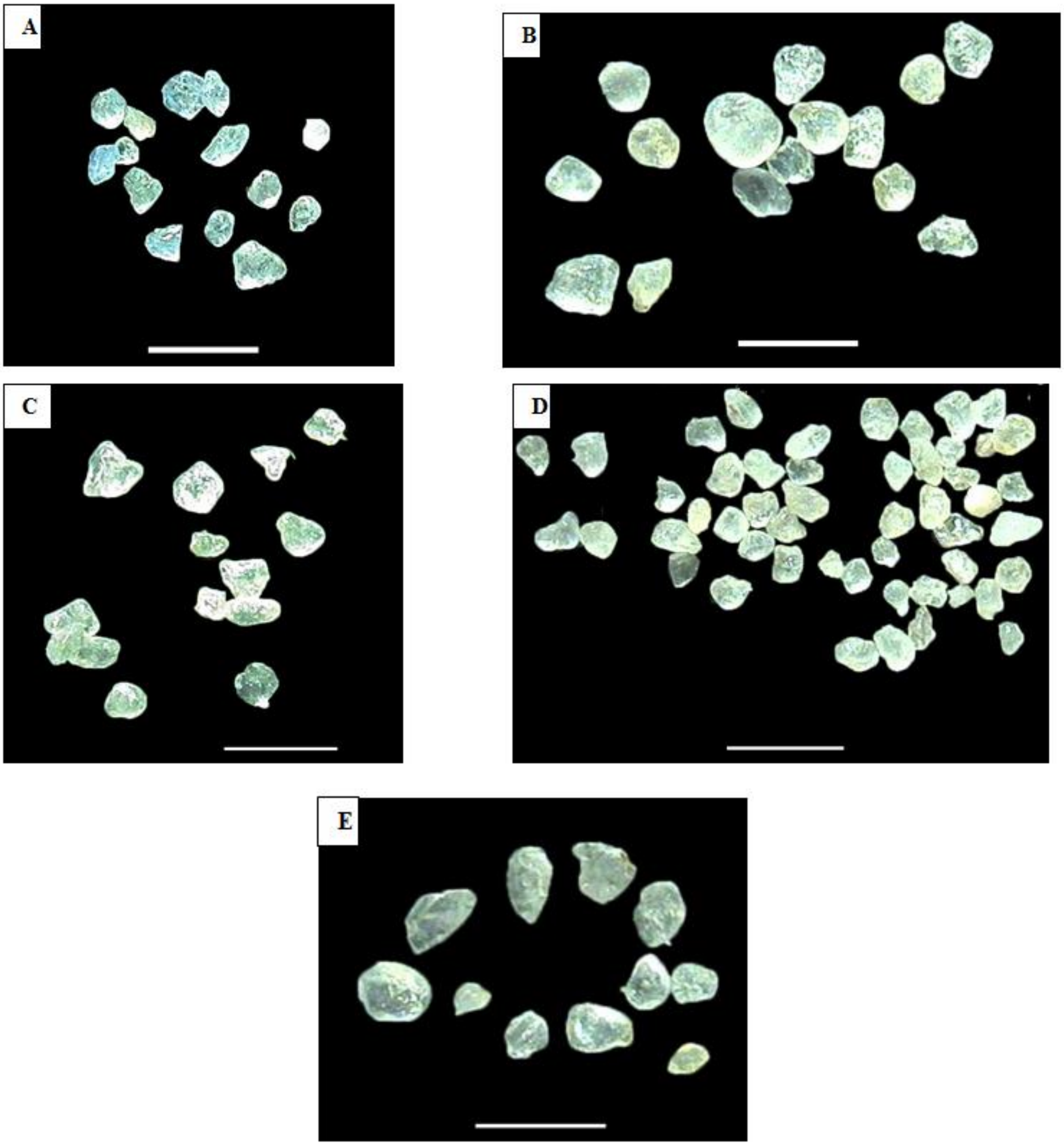

Figure 4: Morphoscopy of quartz grains from Grottes and Ras Blatt section, (A) marine deposit, Gr1 sample (B) continental deposit, Gr6 sample (C) fluvial deposit, Gr7 sample (D) aeolian deposit, RB3 sample and (E) beach deposit, Gr11 sample

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VI. SEM RESULTS

- *Marine deposit*

The SEM examination reveals a complex history with different microtexture generations. Most of the grains show a primary aeolian evolution, which seems to be quite violent, testified by the common development of crescentic marks and V-shaped cracks with blunt edges (Fig. 5,A), followed by an infratidal evolution where these features were exploited by an intense silica dissolution (Fig. 5,B).

On some grains, the precipitated silica obscures the underlying mechanical features by covering them with sheets of silica (Fig. 5, C), witnessing an intertidal environment evolution (Le Ribault, 1975). Some other grains exhibit conchoidal and V-shaped fractures with straight and arcuate steps (Fig. 5,D), reflecting a possible late aeolian recovery, indicating a sea-level regression or a temporarily exposing through a low water-block.

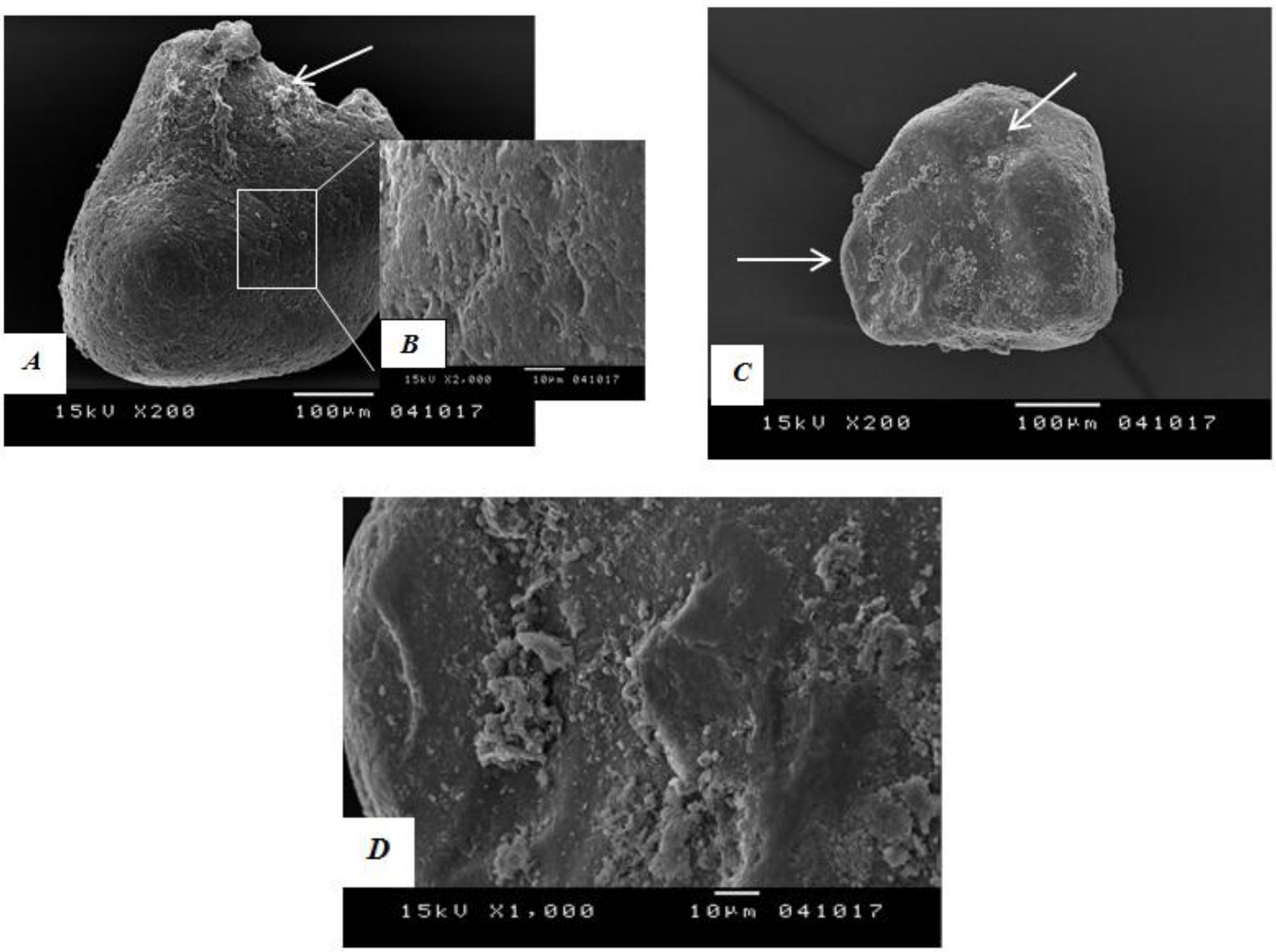

Figure 5: Exoscopy of quartz grains from the marine deposit (Gr1, the Grottes section) *A: general view of quartz grain (Gr1-01 sample) sub-rounded with a sub-angular edge following a conchoidal fracture at large scale, The grain surface is characterized by the development of mechanical features such as crescent-shaped features and V-shaped impacts, the mechanical impacts were later strongly exploited by the chemical dissolution (B). C: general view of quartz grain (sample Gr1-07) rounded with blunt edges and corners, small crescent-shaped marks and friction marks develop over the entire grain surface, Silica deposits precipitate in the depressions and in the central conchoidal mark. D: Higher magnification image of (C) showing details of large V-shaped impacts located on the basal-right corner of the grain with shiny fresh edges and the granular shaped silica precipitation.*

-*Beach deposit*

Most of the observed grains (samples Gr5, Gr11 from the Grottes section and Me5, Me6 from the Metline section) record an earlier violent aeolian evolution where various conchoidal fracture are sparsely present (Fig. 6, A). These grains are subsequently transported to a marine environment where they have acquired a high degree of polishing and oriented etch pits (Fig. 6, C).

Transit to a coastal marine environment guided by emergence/immersion roles characterizes most of the grains.

Indeed, during the emergency period, trapped water in depressions becomes highly concentrated in silica due to evaporation, which favors silica precipitation (Ligigan 2002). Furthermore, grains can be easily transported by wind deflation. Whereas, during the immersion period, the dissolution exploits, firstefull, the superficial fractures and can reaches, sometimes, the crystalline edifice of the grain.

Silica precipitation in both depressions and flat faces can be seen on some grains (Gr5 and GR11 samples) suggesting a passage through a moderate-energy fluvial environment (Fig. 6, B).

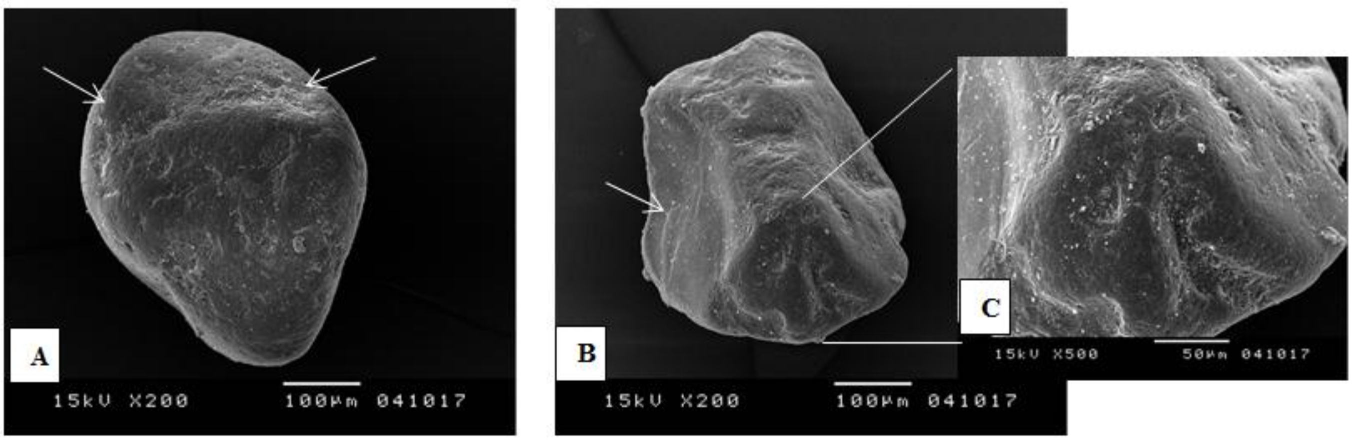

Figure 6: Exoscopy of quartz grains from beach deposits (Gr11, Grottes section) *A: general view of quartz grain (sample Gr11-01) round and elongated in its lower part with well-bent edges, large shock marks dotting its uppermost part showing blunt contours, grazing features are observed on the lower edge, dissolution exploiting the zones of weakness on the whole surface, globular shaped silica precipitation cover earliest marks. B: general view of quartz grain (sample Gr11-10) glistening with round and blunt edges, its surface is the subject of numerous conchoidal fractures with blunt edges, silica globular shaped on both depressions and flat faces of the grain. C: Higher magnification image of (B) showing details of shock features modified by the intense dissolution, crescent-shaped features with a shiny edge.*

-*Continental deposit*

Continental deposits exhibit mainly two-grain trajectories. The first one shows that most of the quartz grains (sample Gr6, Grottes section, and CZ3, Cap Zbib section) are originally transported by a high energy wind proved by the occurrence of various mechanical fractures either on a large scale (conchoidal fractures, parallel striations) or small to medium scale as crescentic marks with blunt edges (Fig. 7, A, B and C).

This aeolian evolution is followed by a transit in several environments beginning with an infratidal horizon, where the dissolution exploits the underlying features (Fig. 7, B, E), then an intertidal horizon testified by the silica precipitation in conchoidal fractures (fig. 7,A) and a possibly beach transit where the absence of brewing during seal level retreat prevents the dissolution and promotes the silica precipitation on the surface (Le Ribault 1977). A rapid and violent later aeolian episode is detected at some grain due to the development of large, deeply marked V-shaped cracks with shiny contours (Fig. 7, D).

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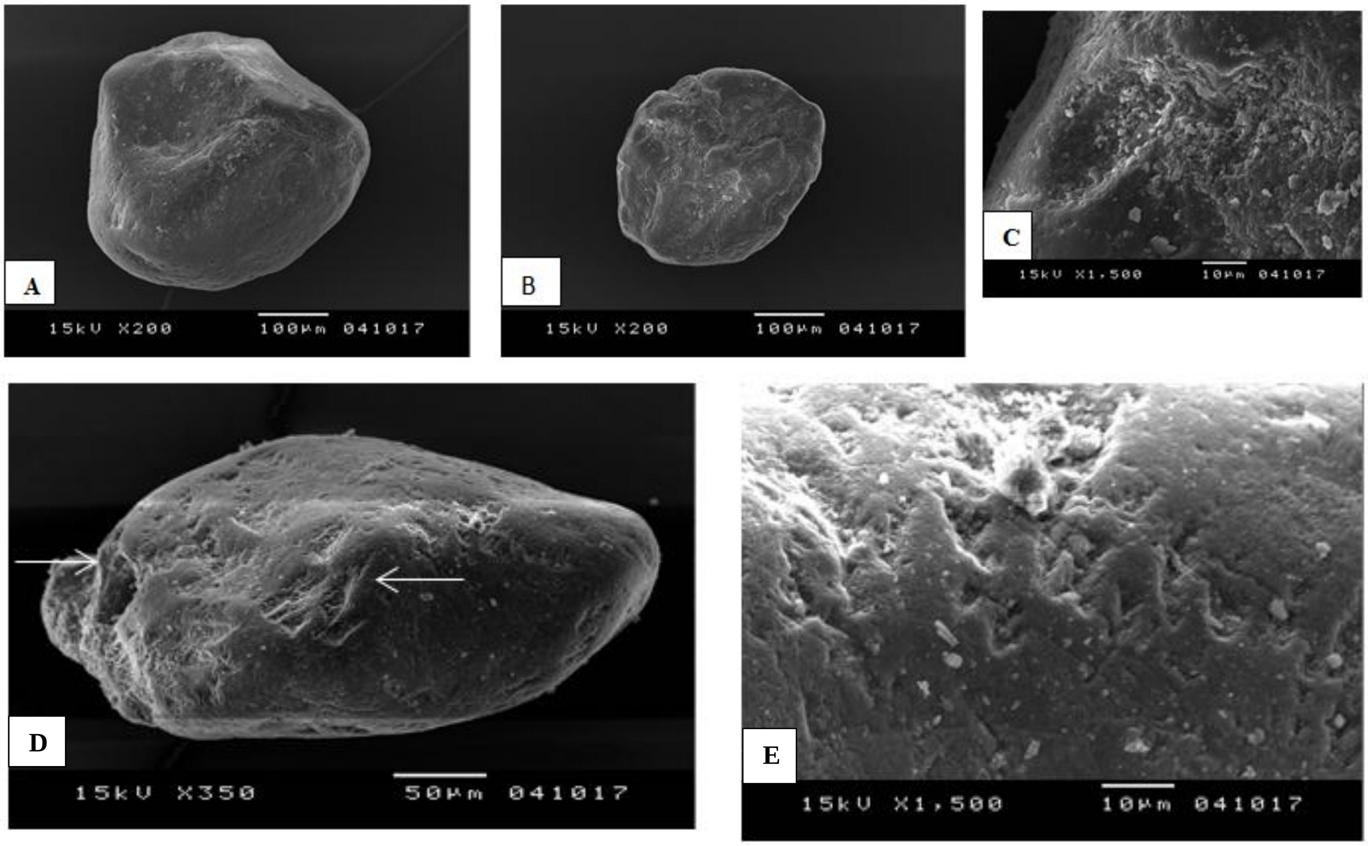

Figure 7: Exoscopy of quartz grains from the continental deposit (Gr6, Grottes section) *A: general view of quartz grain (Gr6-01 sample) sub-angular, in its upper part, and rounded, in its lower part , it presents two large conchoidal fractures with sub-blunt contours, its surface is strewn with multiple shock marks such crescent-shaped features with precipitation of the siliceous globular. B: general view of quartz grain (sample Gr6-04) rounded, its surface is irregular due to multiple mechanical features with pronounced polishing gradient, globular shaped silica precipitation cover the depressions and the left edge (C). D: general view of quartz grain (sample Gr6-07) sub-rounded and elongated, large V-shaped impacts with straight edges, conchoidal breaks. E: Higher magnification image of (D) showing details of small-sized V-shaped impacts with a blunt edge and revealing a preferential direction.*

Unlike the first trajectory, the second one (sample Gr9, Grottes section) is characterized by a long residence in a sub-saturated silica marine environment affected by a thorough polishing and dissolution patterns (Fig. 8, A, C).

Small conchoidal fractures are sparsely seen on same grains suggesting an anterior aeolian origin (Figure 8B). The silica precipitation on the frontal faces and the edges of the same grains lead to transit towards a moderate-energy fluvial horizon (Fig. 8, B).

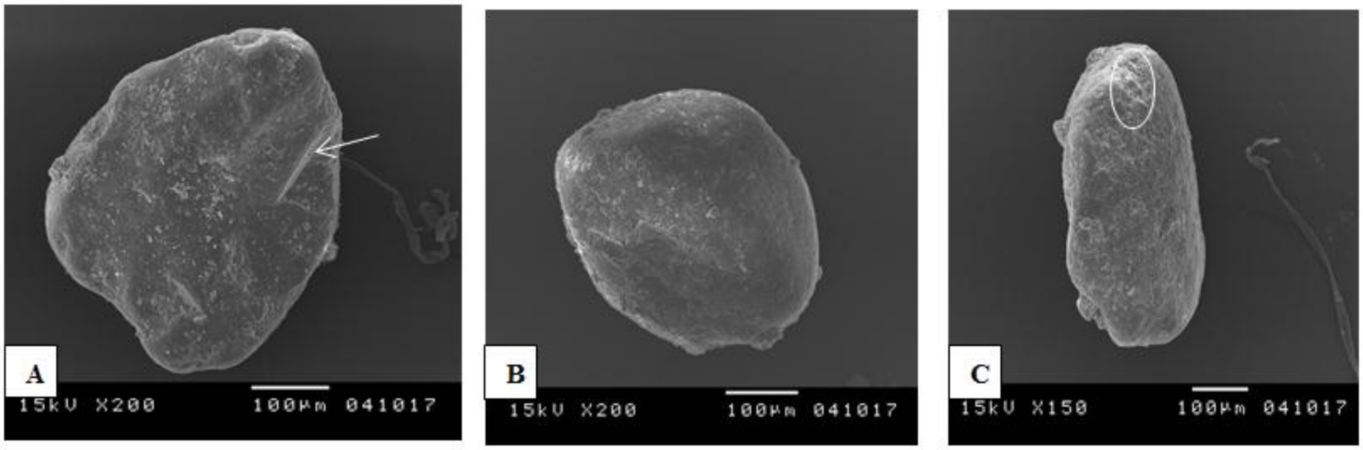

Figure 8: Exoscopy of quartz grains from a continental deposit (Gr9, Grottes section) *A: general view of a sub-rounded quartz grain (Gr9-01 sample) with blunt edges and peaks, two crystalline faces smooth and conchoidal breaks, globular shaped silica precipitation. B: general view of a round quartz grain (sample Gr9-05), multiple blunt-shaped crescent-shaped features, glowing globular shaped silica are located at the ridge uppermost part, at the left corner, and on the front face. C: general view of quartz grain (sample Gr9-09) sub-rounded with an elongated ± shape, an intensely abraded surface, geometrical figures of quartz dissolution.*

-fluvial deposit

The grains from the fluvial deposit (Gr7 sample, Grottes section) record a high energy anterior aeolian phase identified thanks to the small-sized, blunt-contoured crescentic-shaped marks seen especially at the edges (Fig 9, B, C). Furthermore, these grains are either transmitted in an infratidal environment materialized by the dissolution pits (Fig. 9,C), or in an intertidal environment where the depressions seem to be the preferential seat of pronounced silica precipitation.

Some grains can be remobilized according to the tidal rhythm and the marine currents, and are therefore transmitted to moderate-energy continental flows. Silica precipitation at the ridges and on the flat surfaces (Fig. 9, A, C) and the dissolution of the amorphized film are indicators of a fluvial environment evolution where the poor circulation between the silica and the interstitial waters leads to supersaturation in silica globules (Legigan 2002). Some grains have undergone a late aeolian recovery identified by the small conchoidal fractures with shiny sub-angular edges.

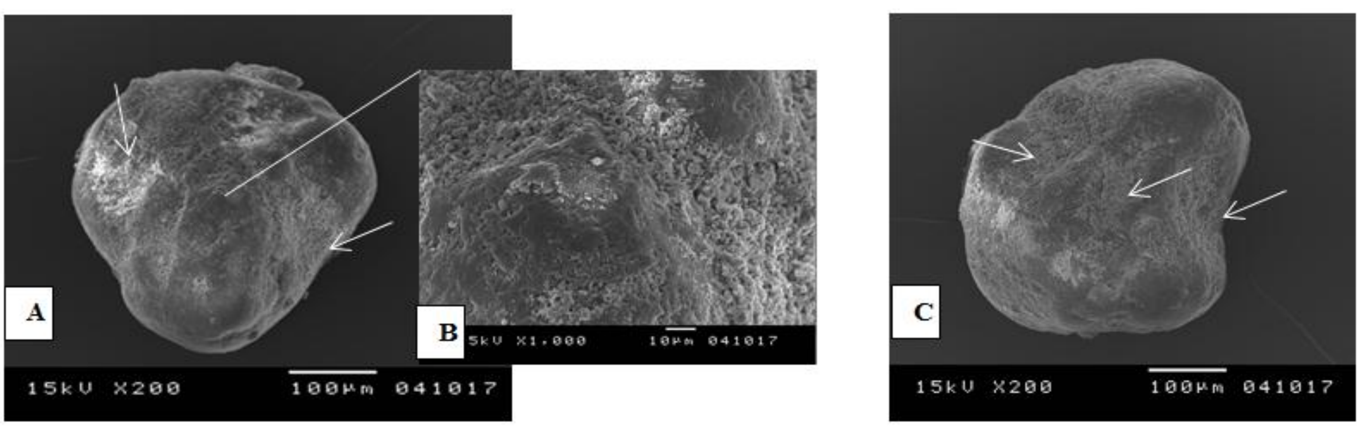

Figure 9: Exoscopy of quartz grains from the fluvial deposit (Gr7, Grottes section) *A: general view of quartz grain (Gr7-01 sample) sub-rounded to sub-angular, intense globular shaped silica precipitation on the plane faces and at the level of the previous shock marks, mechanical features such small-sized crescent-shaped features with blunt contour (B). C: general view of quartz grain (sample Gr7-04) sub-rounded, conchoidal fracture with blunt contour on large scale (covering the entire left side), geometrical figures of quartz dissolution on the front plane face, silica precipitation on both depressions and flat faces*

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VII. DISCUSSION

The sand can be subdivided into two unequal populations. The minimal one belongs either to the coarse fraction, lead to negative skewness values, or the fine fraction with positive skewness values (Friedman 1962). Analyzed samples show negative asymmetries due to the low percentage of coarse grains associated with a leptokurtic or mesokurtic kurtosis nature in most of the samples. Some of them are platykurtic and very platykurtic in nature (respectively fluvial deposit and continental deposit) suggesting the maturity of sediment according to the particles aggregation by compaction.

Whether it is a marine, continental, beach or fluvial deposit, the quartz grains archive on their surfaces a long and complex sedimentary history by acquiring various micro-features.

These features are developed either by mechanical processes (crescentic fractures, conchoidal fractures, V-shaped cracks, frictions) or by chemical processes (dissolution, oriented etch pits, silica precipitation). In fact, mechanical microtextures are the result of abrasion and grain-to-grain impacts during an underwater or a high energy eolian transport. While chemical microtextures can be developed through a long residence in an infratidal environment, a passage by an intertidal environment and also an exposure in beach domain. The microtextures abundance and their coexistence on the same grain highlights the combined control of these two processes and their impact on grain degradation. Statistical analysis (percentage of each microtexture observed on the grain surface) indicate the chemical processes dominance (Tab.2).

Table 2 : Microtextures frequency observed on quartz grains from different deposits

- Absent, + présent, ▲ <5%, ● 5-25%, ■ 25-50%

	Grain shape				Relief			Mechanical									Chemical	
								conchoïdal				V-shaped cracks						
	Round	Angular	Sub-rounded	Sub-angular	low	medium	high	small	medium	large	Parallel striations	small	large	Crescentic marks	frictions	Crystalline fractures	Dissolution Oriented etch pits	Silica globules precipitation
Marin	-	-	+	-	-	+	-	-	▲	●	-	●	▲	●	-	▲	■	■
Beach	-	-	+	+	-	+	-	▲	▲	▲	▲	●	●	●	●	-	●	●
continental	+	-	+	-	-	+	+	●	●	▲	-	■	●	■	▲	▲	■	●
Fluvial (low energy)	-	-	+	+	-	+	-	●	●	▲	-	-	▲	●	●	-	●	●

The Late Pleistocene (MIS 5) deposit along the Bizerte coast was mainly governed by sea level fluctuations. During sea level retreat, grains are easily transported by the wind, which seems to be violent. Whereas, after transgression, grains fall in the infratidal horizon, dominated by salt supersaturation and silica undersaturation conditions. This marine evolution is archived by the high degree of polishing and the development of oriented etch pits. It is also testified by the scarcity of round-mat grains. A possible eustatic decrease may expose grains to the air and thus allow their remobilization. However, intertidal-infratidal passage characterizes their evolution suggesting a significant sea level elevation during the MIS 5.

VIII. CONCLUSION

Grain size analysis of the late Pleistocene deposits along the Bizerte coast reveals that they are mainly composed by fine to medium-sized grains, with an excess of well-sorted coarse grains and a preferential elimination of fine particles. *CM* plot indicates the dominance of rolling and bottom suspension mechanism of transportation.

SEM study of quartz grains displays a variety of microtextures developed by a mechanical process (conchoidal fractures, crescentic fractures, V-shaped cracks) and chemical process (dissolution, silica precipitation).

The determined grain shape, the coexistence of the two microtextures process on the same grain and their frequency plead for a long and polyphase evolutionary history characterized by a long evolution in a marine domain (infratidal-intertidal).

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