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Extreme flood events reconstruction during the last century in the El Bibane lagoon (Southeast of Tunisia): A Multi-proxy Approach

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Abstract

Climate models project that rising atmospheric carbon dioxide concentrations will increase the frequency and the severity of some extreme weather events. The floods events represent a major risk for populations and infrastructures settled on coastal lowlands. Recently, study of lagoon sediments contributed to enhance our knowledge on extreme hydrological events such as paleo-floods and paleo-storms and on their relation with climate change over the last millennium. The past flood activity was investigated using a multi-approach associating sedimentological and geochemical analysis of surfaces sediments from the Southeast of Tunisia catchment in order to trace the origin of sediments deposit in the El Bibane lagoon. Three sediments sources were identified: aeolian, fluvial and marine. This multi-proxy analysis on the BL12-10 core shows that finer material, high content of the clay and silt, and high content of the elemental ratios (Fe/Ca and Ti/Ca) characterize the sedimentological signature of the paleoflood levels identified in the lagoonal sequence. For the last century which is the period covered by the BL12-10 short core, three paleo-floods events were identified. The age of these floods events have been determined by ^{210}Pb and ^{137}Cs Chronology. Dating of the three most recent floods provides age of AD 1995 ± 6, AD 1970 ± 9, and AD 1945 ± 9. The results show a good temporal correspondence of floods events recorded in the Southern of Tunisia in the last century (A.D 1932, A.D 1969, A.D 1979 and

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A.D 1995). Such a good correlation between floods events recorded in the core and historical data of the annual precipitations suggests that reconstruction of the history of the hydrological extreme events during the upper Holocene is rendered possible by the use of the sedimentary archives.

Keywords: El Bibane Lagoon; watershed basin; surface sediments; geochemistry; grain size; paleo-floods, Southeast Tunisia.

1. Introduction

The Mediterranean region has experienced numerous extreme coastal events, such as floods events which caused casualties and economic damages (Lionello et al., 2006). However, the meteorological instrumental records are limited to only a few decades, especially in Southern Mediterranean countries. Geological data offer a way to reconstruct the historical records of intense floods event. Deciphering records of extreme precipitation and damaging floods preserved in geologic archives enables society to understand and plan for floods of the future (Parris et al., 2009). The importance of studying river, lake and lagoonal sediments has already been shown for reconstructing extreme flooding events (Becker et al., 1989; Ely et al., 1993; Brown et al., 2000; Benito et al., 2003; Wolfe et al., 2006; Moreno et al., 2008; Wilhem et al., 2012; Gilli et al., 2013; Degeai et al., 2015). Regarding lagoonal sediment deposits, during flood events an increases in stream velocity and discharge cause erosion of sediment in the uplands surrounding the lagoon, and the transport and deposition of this terrestrial sediment into the lagoon basin near the stream input (Noren, 2002). Several studies showed that lagoon offer a great possibility to record flood and storms events where their suspension load is deposited on the lagoon floor as a distinct detrital layer (Liu et al., 1993; Donnelly et al., 2007; Sabatier et al., 2008; Dezileau et al., 2011; Raji et al., 2014).

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Using sedimentological and geochemically analyses on the lagoonal sequence in Western Mediterranean, Raji et al. (2014) showed severe flooding and intense storm during the last millennium.

This paper focuses on the study of paleo-floods from high resolution geochemical and sedimentogical analyses of a lagoonal sequence in the Southern of Tunisia. The first aims of this paper are to identify the different sediment sources and to retrace marine, fluvial and aeolian contributions to sedimentation in the El Bibane Lagoon. The second aims are to date a short core (BL12-10) collected in the lagoon which revealed the presence of fine-grained layers corresponding to floods events by using the ^{210}Pb and ^{137}Cs chronologies. It was important to determine whether these fine- grained layers correspond to historical floods generated in the Southeast of Tunisia.

2. Study site: El Bibane Lagoon and its watershed

The study area is focused on the El Bibane Lagoon and its watershed (EBL: 33° 15' 01''N-11° 15' 41''E; Fig. 1). This lagoon which has an elongated elliptic form (33 km x10 km) and a major WNW-ESE axis covers up an area of about 230 Km^2. It has 6 m maximum depth in the middle part of the basin (Guélorget et al., 1982; Medhioub, 1984). The Eastern wedge of the EBL is separated from the Mediterranean Sea (Gulf of Gabes) by two peninsulas namely Slob El Gharbi and Slob Ech Chargui of about twelve kilometres long (Medhioub, 1979). These two peninsulas are cut at their mid-part by nine small islets and channels: the zone of connection with the Mediterranean waters into the lagoon (Medhioub, 1981). The two slobs are represented by emerged Tyrrhenian aeolian littoral dunes and carbonate sand beach (Jedoui, 2000; Jedoui et al., 2002). The EBL has a microtidal regime where tidal amplitude varies from 0.8 to 1.5 m (Davaud and Septfontaine, 1995; Sammari et al., 2006). The intertidal flats are flooded and exposed daily at regular intervals during the periodically rising and retreating tide. Supratidal flats are flooded at irregular intervals during spring tides or

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strong onshore winds (Bouougri, 2012). This region is known by its very low demographic pressure (Ounalli, 2001). The El Bibane lagoon is relatively unaffected by human activities (Pilkey et al., 1989) and it is only exploited by traditional fisheries (Guélorget et al., 1982).

Morphologically, the southern Tunisia known as the Tunisian platform includes two distinguished morpho-tectonic domains (Fig. 2) namely: The Djeffara and the Dahar. The Djeffara extends over all the coastal plain from Gabes (Southeastern Tunisia) to the Libyan borders. It is limited to the west by the Matmata and the Dahar mountains and to the east by the Gulf of Gabes and the Mediterranean Sea. The Dahar belonging to the Saharan platform domain is constituted by outcrop successions sequences ranging in age from the Late Permian to the Late Cretaceous. The Lithostratigraphic successions could be summarized as following: The Early–Middle Triassic sequence in the Dahar plateau is mainly constituted by continental sandstone, conglomerate and clay; whereas the Late Triassic outcrops exhibit shallow marine carbonate (Busson, 1967). The Jurassic series are represented by a thick Liassic evaporitic sequence, Dogger marine carbonate and late Jurassic–Neocomian mixed facies with continental predominance (Bouaziz et al., 2002). The Cretaceous series are a general gradation from neritic, lagoonal and continental facies (Mejri et al., 2006). The Late Cretaceous is characterized by thick shallow marine carbonates-marl sequences and covered by sand dunes of the Eastern Saharan Erg.

The Mio-Pliocene series represent the substratum of the coastal plain of Djeffara. Jedoui et al. (1998) subdivided these series into two principal facies: (1) the red coloured clays rich in gypsum and (2) the sands which locally associated with conglomerates and grey clays. The Pleistocene marine deposits of the Southeast Tunisian coastal zone assigned to the "Tyrrhenian" overly unconformably the Mio-Pliocene. These deposits form a ridge parallel to the actual coast. They show the superposition of two units described by Jedoui et al. (2002) as the lower "quartz-rich unit" and the upper "carbonate unit" with *Strombus bubonius*.

3. Climate and hydrology

The southeastern Tunisia region is characterized by a pre-Saharan and arid to semi-arid climate. The hot season extends beyond the summer (Amari 1984; Hamza, 2003) and the number of sunny days may reach 64.4%. The rainfall is low with an annual average that does not exceed 200 mm. Furthermore, rainfall is characterized by unequally spatiotemporal repartition, high inter-annual variability and intensity. Most of the rainfall is concentrated only in few days (30 days/ year; Genin and Sghaier, 2003) leading to high fluctuations in water discharge. The highest precipitation occurs in October to Mars while the summer months are drought.

The hydrological data of the studied watershed were conducted on the basis by the use of annual precipitations during the last century in order to reconstruct the floods events which affected these regions. Data of these annual rainfalls used in this study were obtained by the Directorate Research of Water Resource (DGRE; 2010). Figure 3 show that the watershed from Fessi River was affected by period of enhanced regionally precipitations causing the floods events. Five major precipitations were registered at A.D 1932, A.D 1969, A.D 1979, A.D 1984 and A.D 1995. During flood events, most of the sediments are transported by the Fessi River and discharged into the El Bibane lagoon system. This was the case during the exceptionally high rainfall observed in southern Tunisia in 1969 and 1979 (Pias et Stuckmann, 1970; Bonvallot, 1979).

4. Materials and Methods

4.1. Materials

A short sediment core (BL12-10, 40 cm length; Latitude: 33°14'58.7"; Longitude: 11°10'3.7" Fig. 4) was taken from the El Bibane Lagoon (EBL) by a hand corer 75mm diameter PVC Tube. Additionally, 18 surface sediment samples were collected from the watershed (Jerba, Zarzis, Medenine, Tataouine and Ben Guerdane localities) in order to assess

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the origin of the material transported into lagoon (Fig. 4). The location of all sampling stations was recorded by GPS (GPSmap 60, Garmin) (Table 1). Sediments were returned to the laboratory for analysis. In order to characterize main sources, these surface sediments were subdivided into four regions as:

- Three beach area samples (S1, S2 and S3)
- Three lagoon samples (S4, S5 and S6:Top core BL12-10)
- Ten Fessi river catchment samples (S7, S8, S9, S10,S 11,S12, S13, S14, S15 and S16)
- Two Aeolian dune samples (S17 and S18)

4.2. Analytical methods

4.2.1. Sedimentological and geochemically analysis

The BL12-10 core was first split, photographed and logged in detail. Surface and core samples were analysed by combination of sedimentological, geochemical and geochronological multi-proxies approach. The sediment core samples were analysed by X-ray fluorescence (XRF) using an XRF core scanner every 1 cm. A semi-quantitative XRF analysis was performed directly on the surface sediment. Thus, surface samples had been covered with a 4mm thin Ultralene film to avoid contamination of the XRF measurement unit and the desiccation of the sediment (Richer et al; 2006).

The particle size analysis were performed for samples taken directly from the sediment core every 1cm using a Beckman Coulter© LS 13 320. Each sample was sieved at 1cm, suspended in deionized water and gently shaken to achieve disaggregation. After introduction of sediment into the fluid module of the granulometer, ultrasound was used to avoid particles flocculation.

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The ^{137}Cs and ^{210}Pbex activities analyses were performed on the fraction < 150µm by gamma spectrometry using a CANBERRA Broad Energy Ge (BEGe) detector (CANBERRA BEGe 3825). The ^{210}Pbex dating is based on the determination of the ^{210}Pb excess activities in the layers of the core. We used this natural radionuclide ^{210}Pbex to determine sedimentation rate (SR) as established by Goldberg (1963), Krishnaswamy et al. (1971) and Robbins and Edgington (1975). The age dating of ^{137}Cs was conducted according to Robbins and Edgington (1975).

4.2.2 Statistical analyses

Statistical analysis was applied to chemical component in order to understand the relationship between the sediments compositions and grain size in the surface sediments of the El Bibane lagoon. Principal component analysis (PCA) is a multivariable statistical method used to data reduction. It aims at finding few components that explain the major variation within data (Davis, 2002).

5. Results

5.1. Surface sediments

5.1.1. Sediment description: grain size and morphology

Grain size and microscopic observation data have permitted to discriminate surface samples into three groups (Fig. 5 and 6). The first group encompass sediment samples collected along the coastal zone from Jerba to Zarzis beaches and the lido of El Bibane Lagoon (S1, S2 and S3). In this marine area, surface sediments are composed of a mixture of coarse sub-rounded quartz grains, mollusc shells and foraminifera (Fig. 5). The grain size distributions show unimodal form with a mode at 350 and 400µm in diameter (fig. 6). The characteristics of this group will serve to identify the marine source.

The second group of samples came from the El Bibane delta and the Fessi River. It represents the fluvial component (Fig. 6). These samples are characterised by a multimodal distribution of grain sizes with three modes: the first at 2-8 µm, the second at 20-63 µm and the third at 100 µm. Microscopic observations of this group of samples (S7 to S16) reveal reddish-brown heterogeneous particles composed mainly of shiny angular to sub angular quartz grains. Some grains display rust colour with iron oxide (Fig. 5). This group characterize the fluvial source. However, it is possible to have inside this source a mixture with aeolian particles deposited on the watershed and taken by floods events.

The third group consists of two samples (S17 and S18) recovered in the Aeolian sand dunes of southern Tunisia. Grain size data reveals a unimodal distribution with a peak around 100-110µm (Fig. 6). They are composed of homogenous dark yellow sand with angular grains; some of them are coated by iron oxide (Fig. 5). The characteristics of this group will serve to identify the aeolian sand dune source.

5.1.2. Distribution of major and trace elements

The spatial distribution of major and trace elements in surface sediments collected in the El Bibane lagoon and in all the area mainly along the Fessi River, are presented in figures 7 and 8. The iron (Fe) displays its highest percentages in the Fessi River samples (0.53-1.52%). Lower values characterise the aeolian dunes (0.38-0.4%) whereas this element is totally absent in marine sediments (<0.1%) (Table 2). This same distribution pattern is also observed for Ti, K and Al, which are considered as typical terrigenous elements (Pelwa et al., 2012). The highest contents of these elements in the Fessi River samples contrast with the lowest ones retrieved in the marine surface sediment. Aeolian dunes are characterised by intermediate values. These four elements will thus be used as indicators of terrigenous input of material to the lagoon.

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Calcium (Ca) and Strontium (Sr) in the sediment are usually associated to the carbonate fraction, which can be either of allochtonous or of autochtonous origin. In the sediments, carbonates are mainly of biogenic origin. In fact, due to its compatible ionic radius, Sr can replace Ca in calcite, but remains however as trace element. Our results display that Sr concentrations are much lower than those of Ca (Fig.7). Nevertheless, both elements show the same distribution pattern. Marine surface sediments are associated with the highest values (Ca ≈ 14, 7%; Sr ≈ 1548 ppm) whereas the lowest values and thus the lowest calcite contents are retrieved in dune samples (Ca ≈ 0.8%; Sr ≈ 52 ppm). Intermediate concentrations are associated with the Fessi River catchment (Ca ≈ 7%; Sr ≈ 150 ppm) (Table 2). These results corroborate the marine origin of these sediments as revealed by the binocular observations mainly due to the existence of shell debris and confirmed by the grain size distributions (coarse sand with a peak in the 350-400 µm).

Silicon (Si) and Zircon (Zr) follow similar spatial distribution pattern (Fig. 8). Silicon is on one hand structural element of terrigeneous aluminosilicates, but is also abundant as pure quartz, a common mineral in sediments and it appear in sediments as mineral (SiO_2). Higher content of this group are observed in the River catchment samples (Si ≈20 %; Zr ≈ 300 ppm) and in the aeolian dune samples of the southern Tunisia (Si ≈33%; Zr ≈ 400 ppm), whereas beaches areas show generally lower contents (Si ≈ 10%; Zr ≈ 41 ppm) (Table 2).The excess of Si derived from detrital quartz (Shankar et al., 1987; Nath et al., 1989). Also, most of the silicates were deposited as detritus, having originated by erosion and surface runoff. In another hand, Si in these samples could also be brought by sandstorm from western Saharan dunes. This is the case for samples S17 and S18 which are aeolian samples.

5.2. *Core BL12-10*

5.2.1 Core description

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The core BL12-10 was collected from the lagoon near the Fessi delta (Fig.4). This core contains organic-rich clay and silt interbedded with coarse-grained layers comprised of a mixture of siliciclastic sand and shell fragments. X-ray fluorescence and high-resolution grain-size analysis for BL12-10 indicate several thin, fine grained layers preserved and sand sediments. The more prominent mud layers are typically composed of clay and silt sediments. These mud layers preserved in the core seems to be flood layers, i.e., coming from fluvial incursions during intense floods events (Fig. 9).

5.3. ^{210}Pb and ^{137}Cs dating

The measured ^{210}Pb values in the uppermost 30 cm of the BL12-10 core range from 14.5 to 0.1 mBq /g (Table. 3). In general, the down core distribution of excess ^{210}Pb values follows a relatively exponential decrease with depth. Therefore, a constant flux, constant supplies CF: CS sedimentation model was applied. The calculated sedimentation rate (SR) is about 0.48 cm/ year. The down core ^{137}Cs activity profile (Fig. 10) shows maxima at 18 cm depth (Table 3). We attributed this maximum to the period of maximum radionuclide fallout in the Northern Hemisphere associated with the peak of atomic weapons testing in 1963. The ^{137}Cs-derived SR (0.37 cm/ year) is lower than that of the ^{210}Pb (Fig. 10). The difference between the two methods could be explained by a change of the accumulation rate between the beginning and the last part of the 20 century.

6. Discussion

Multiproxy approach has permitted to distinguish three main sources of sediment in Southeastern Tunisia; aeolian, fluvial and marine. To better characterize these different sources, statistical analyses have been applied to geochemical elements measurements obtained in the different sedimentary facies outcropping around the El Bibane Lagoon.

6.1. Principal component analysis (PCA)

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PCA was used to identify the main factors controlling the chemical composition of the catchment and El Bibane lagoon sediments. We correlated major and trace elements in surface sediments from both the catchment area and the El Bibane in order to identify different groups of common origin and process (Windston et al., 1989). Application of PCA varimax rotation has permitted to identify two components that explained 85% of the total variance (Fig.11). Factor 1 account for 67.47% of total variance. This Factor is characterized by high positive loadings for Fe, Ti, K, and Al reflecting the composition of alumino-silicates sediments, which were dominated by clay and silt fractions (Spagnoli et al., 2008). On the other hand, Zr and Si display a moderate positive loading and are included in factor 1 indicating a link with fine sediment. By contrast, carbonates elements (Ca and Sr) show a negative loading with Factor 1. The first component represents therefore the fine fraction of the sediment, which is mainly composed of various types of clay minerals, usually abundant in surface sediments (De Lazzari et al., 2004). Factor 2 accounts for 17.73% of the total variance (Fig. 11). It shows positive loading for Ca and Sr whereas Fe, Ti, K, Al, Zr and Si have negative loadings. This factor provides a better definition of the relatively carbonate fraction of the sediments. These two factors differentiate hence carbonates and both sand and clay sediments.

6.2. El Bibane lagoon: Main sediment sources

Statistical analyses of geochemical data have permitted to characterise the different sediment sources around El Bibane lagoon. To precise the modern contribution of these different sources to the surface sediments of the Lagoon, three elements have been chosen: Ca, Ti and Fe. Ca displays its highest abundances in marine area and is lower in sand dunes of South-eastern Tunisia and river samples. By contrast, Ti characterises the continental source (mixture of fluvial and aeolian material, cf chapt 5.1.1) and shows low contents in marine samples. On the other hand, Fe is present in the continental source and the maximum values are found in the river samples. The iron is found as a trace element in the marine samples.

Taking into account this geographic distribution, Fe/Ca ratio as well as Ti/Ca would be stronger in the continental pole and weaker in the marine pole. If we report the geochemical data obtained on the lagoon surface sediments (samples S4, S5 and S6) on a diagram Fe/Ca vs Ti/Ca, the El Bibane Lagoon surface sediments are situated between marine and continental sources (which regroup in this case the fluvial and probably the aeolian source) (Fig. 12). This result can be explained by the position of surface sediments which are located between the delta and the open sea.

6.3. Identification of floods activity in the El Bibane Lagoon?

In order to identify the paleo-flood events of the El Bibane Lagoon, we applied these previously discussed proxies to BL12-10 core samples. This multi-proxy analysis on the BL12-10 core shows that finer material, high content of the clay and silt, and high content of the elemental ratios (Fe/Ca and Ti/Ca) characterize the sedimentological signature of the paleoflood levels identified in the lagoonal sequence. Three floods events have been identified on the BL12-10 (FL1, FL2 and FL3). FL1 deposit corresponds to a finer grained flood composed of an 5-cm thick silty-clay sediment. The geochemical proxies show a high Ti/Ca and Fe/Ca ratio. FL2 is also interpreted as a finer grained flood and is composed of 4-cm thick silty -clay sediment layer. Their geochemical composition is characterized by a high Fe/Ca and Ti/Ca ratio (Fig.13). FL2 show a good correlation between the grain size and the geochemical proxies. FL3 is also represent an another fine-grained flood which is composed of a 2.5-cm thick silty-clay and their geochemical proxies reveals a good correlation with the grain size signature. From our age model, FL1 would have occurred around AD 1995 ± 6 yrs. This sediment deposit could correspond probably to the 1995 flood event recorded in

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hydrological data (Fehri, 2014) and which affected Tataouine region (Southeast of Tunisia). This heavy event which took place in the watershed of Oued Tataouine on September 24, 1995, caused tremendous floods. These floods reached a maximum discharge of 1200 m^3/s which provoked heavy losses in human lives and agricultural goods, as well as serious erosion (Boujarra et al.; 2009). Moreover, many houses and buildings were demolished and the whole infrastructure was affected. Using the same approach, the event FL2 corresponds to 1970±9 yrs and this was the case during the exceptionally high rainfall observed in southern Tunisia especially in Medenine in A.D 1979 and the most catastrophic flood A.D 1969 which affected most regions of Tunisia and caused many losses in human lives and many houses were destroyed. These floods events can be observed on the annual pluviometric records of Mednine and Tataouine meteorological stations (Fig.3). During latter event, most of the sediments are transported by rivers and discharged into the El Bibane lagoon system (Pias et Stuckmann, 1970; Bonvallot, 1979). FL2 deposit seems to be not associated to a unique event but probably to two or three events (A.D 1969, A.D 1972 and A.D 1979). Finally, the third flood event FL3 is dated at A.D 1945±9. It could be associated to the 1932 flood event registered in south Tunisian historical archives and data. The model-age established by ^{137}Cs chronology gives an age A.D 1932 to the FL3 flood event. But, this age is not confirmed by the ^{210}Pb because we suggest that we do not have enough large constraint on ^{210}Pb chronology.

Considering all these historical pluviometric data, we can assume that FL3 flood deposit corresponds to A.D 1932 flood. FL2 flood deposit is associated to A.D 1969, A.D 1972 and A.D 1969 flood events. FL1 flood deposit could be associated to the A.D 1995 flood event (Fig.13). Hence, this study allows us to show that a one flood deposit is not always associated to a single event but sometimes to two or three events especially when heavily precipitating events are close together in time (FL2 flood deposit for example). On the other hand, this multiproxy approach allows to identify only periods of strongest floods activities in the Southeast of Tunisia.

Conclusion

This study focuses on the characterisation of the main surface sediments sources of El Bibane Lagoon (southeast Tunisia) and its watershed in order to reconstruct the paleo-flood events recorded in the sedimentary core archives. A principal component analysis (PCA) of the geochemistry of the sediments in the watershed of the lagoon and from the coastal area was undertaken in order to discriminate the source of detrital inputs into this lagoon. Three sediments sources were identified: Aeolian, fluvial and marine. Our results display that El Bibane Lagoon surface sediment characteristics are situated between marine and continental (Fluvial and Aeolian) end members. The application of this multi-proxy analysis on the a BL12-10 core shows that finer material, high content of clay and silt, as well as high elemental ratios (Fe/Ca and Ti/Ca) typify the sedimentological signature of paleo-flood events in the lagoonal sequence. The BL12-10 age model based on ^{210}Pb and ^{137}Cs activity profiles have permitted to identify three periods of rainfall increase dated at AD 1995±6, AD 1970±9, and 1945±9. The good agreement between our estimated ages and the timing of the floods events as indicated by the records of the Tunisian Directorate Research of Water Resource (DGRE; 2010) suggests that sedimentological and geochemical data of lagoon sediment cores can be used to reconstruct paleoflood history in South-eastern Tunisia during the upper Holocene.

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Figures captions

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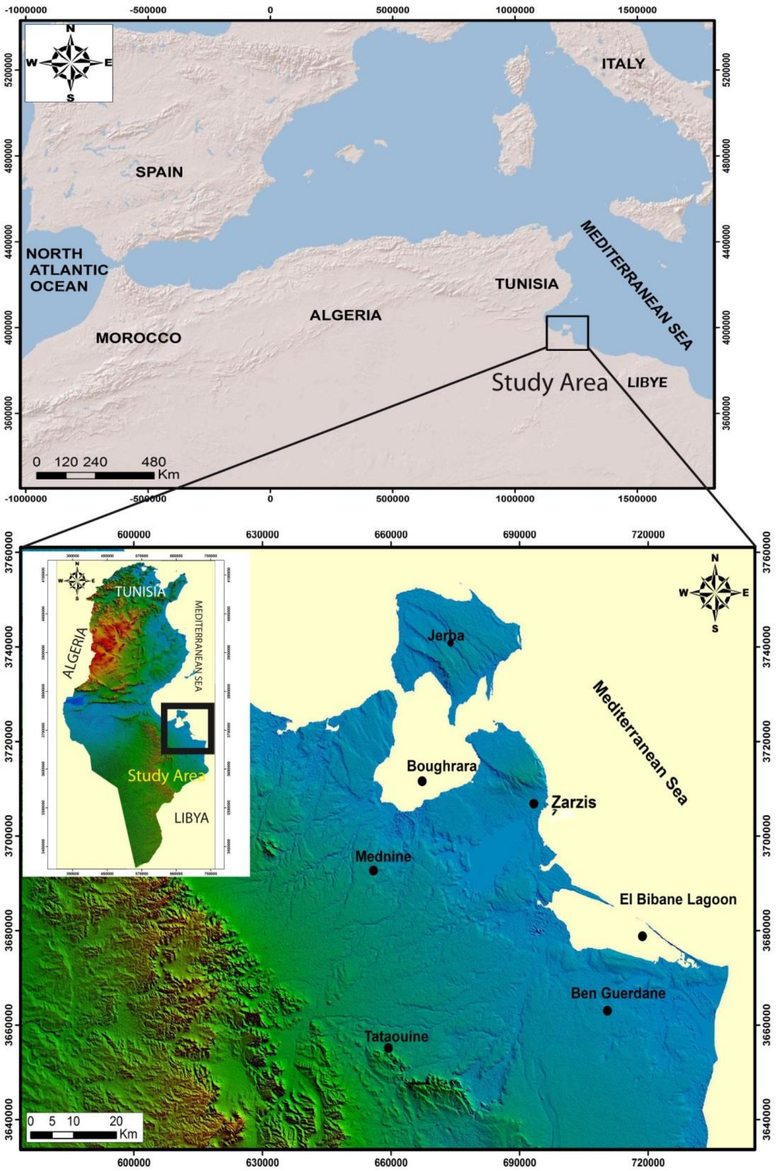

Figure.1. Location of the El Bibane Lagoon (EBL) South East of Tunisia.

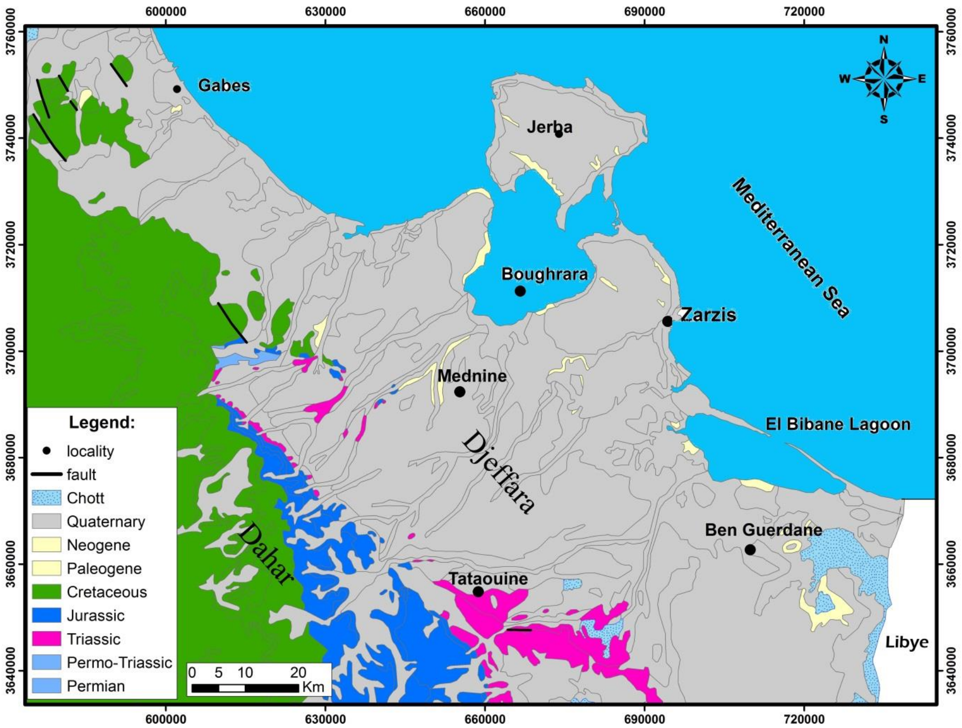

Figure.2. Location of the El Bibane Lagoon on the geological map of South Eastern Tunisia (Modified from the Geological map of Tunisia 1/500000 after Ben Haj Ali et al., 1985).

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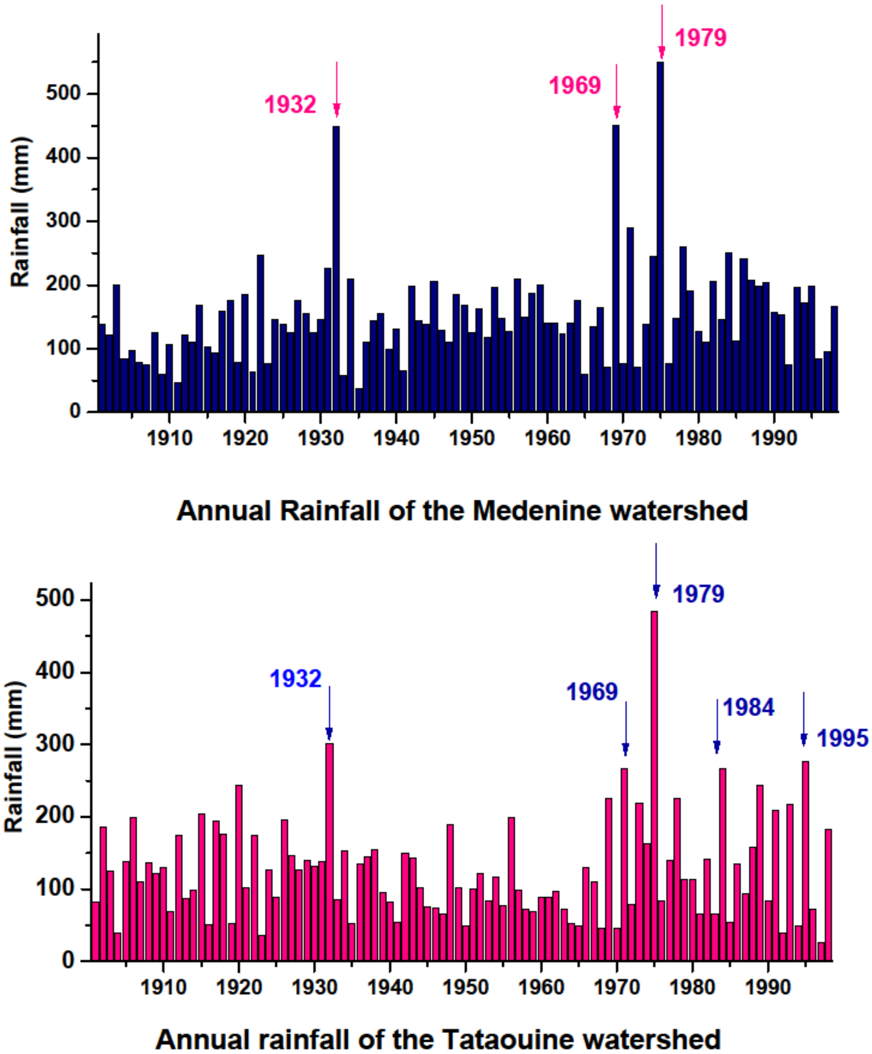

Figure.3. Annual rainfalls of the Medenine and Tataouine watershed during the period between 1900 and 2000.

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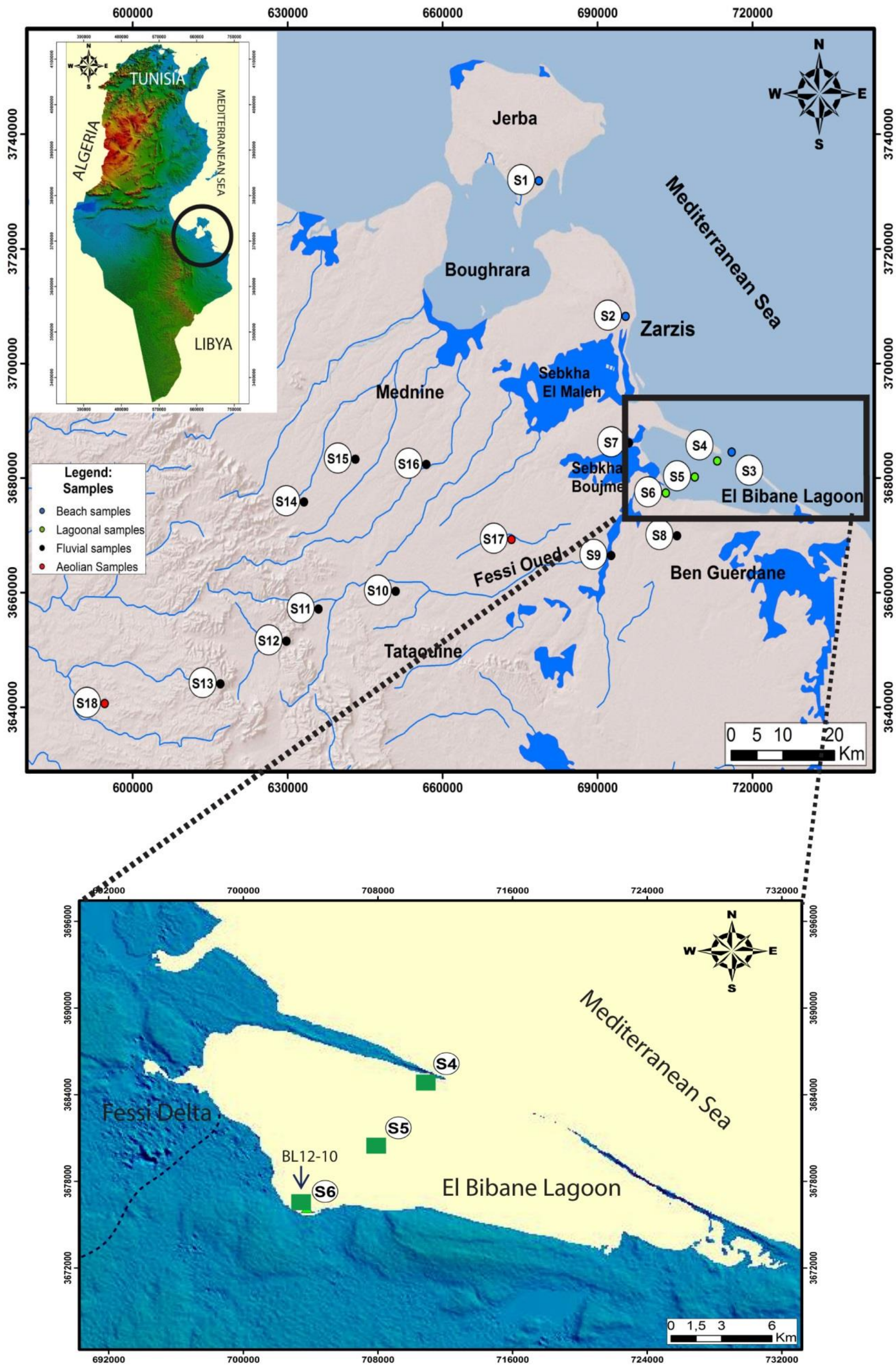

Figure.4. Sampling sites of El Bibane Lagoon surface sediments and of samples from the catchment basin

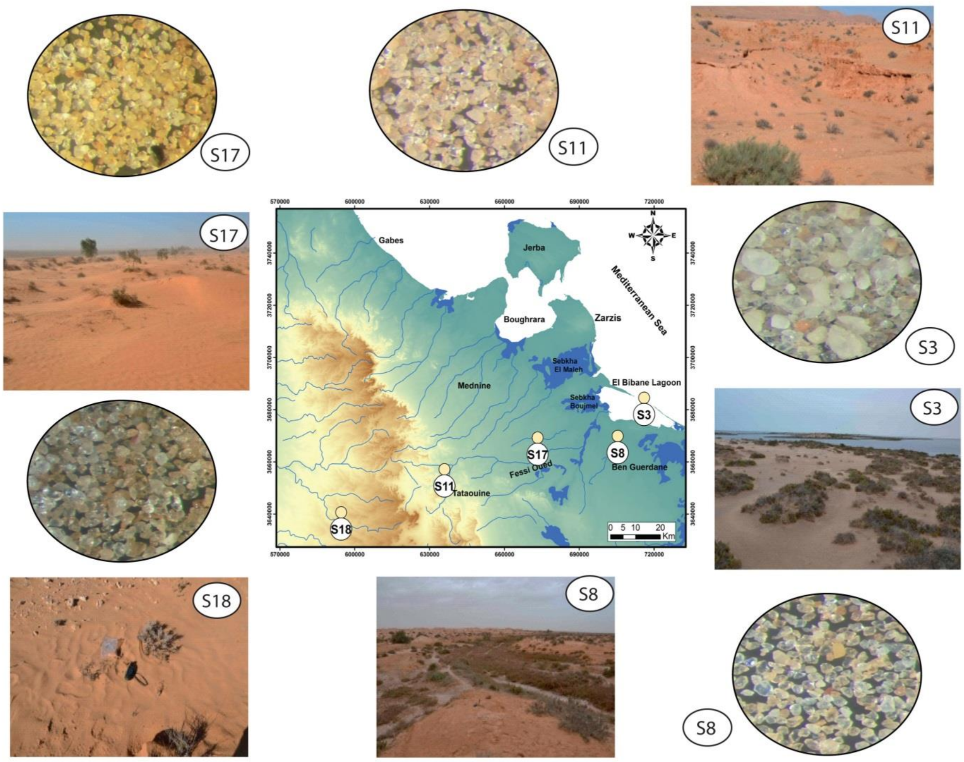

Figure.5. Microtextural observations of four representative samples from the catchment basin of El Bibane Lagoon. A lagoonal samples (S4 and S5), Marine samples (S1 and S3); Fessi River samples (S8 and S11); Dunes samples (S17 and S18). (G x 6.5)

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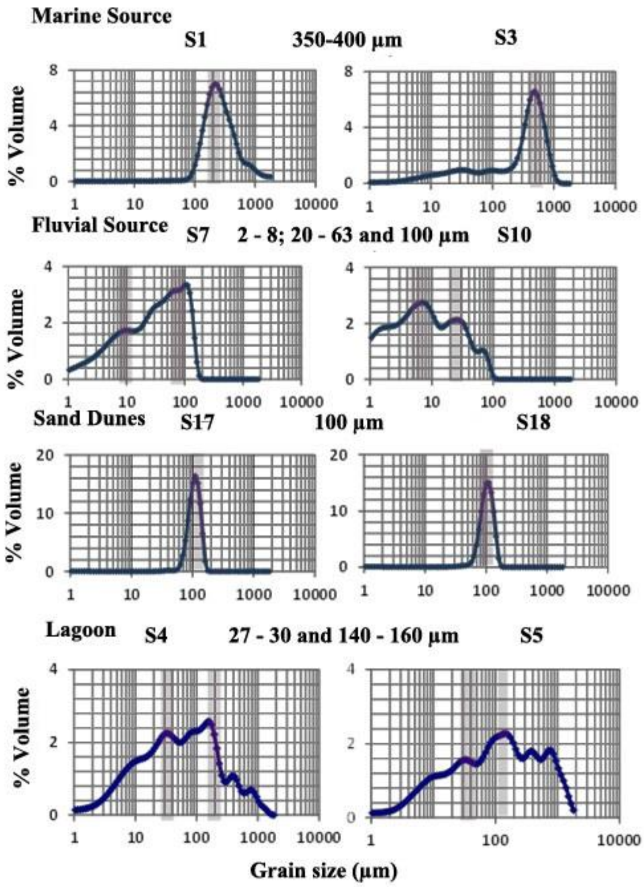

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2 Figure.6. Particle size distributions of selected and representative samples from the catchment

3 basin of the El Bibane Lagoon.

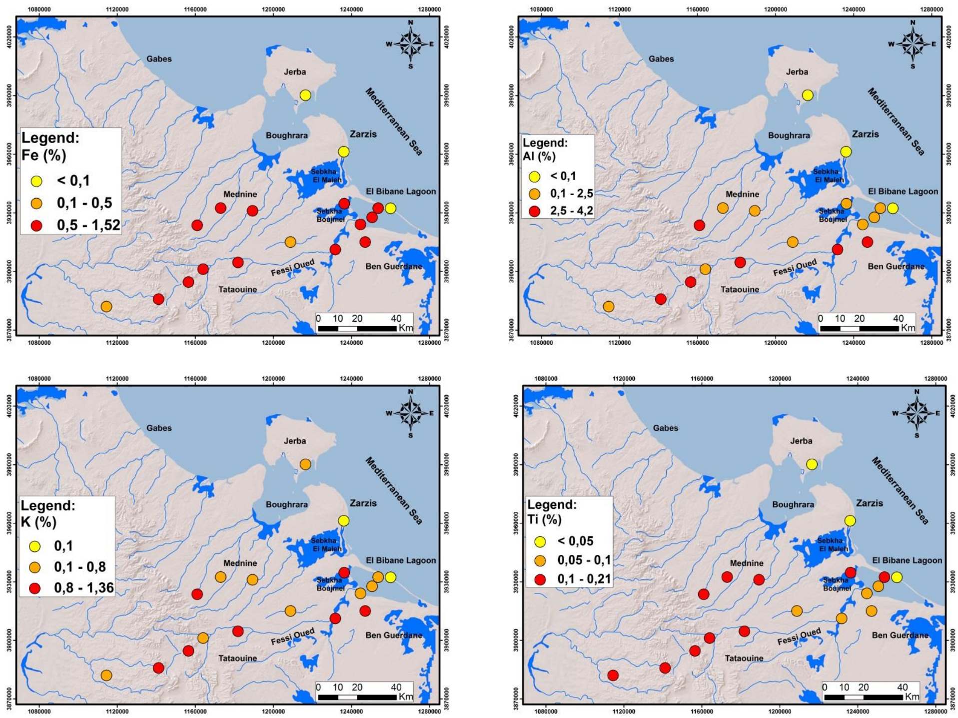

Figure.7. Spatial distributions of Ti, Fe, K and Al from catchment basin and El Bibane lagoon (values are expressed in percentage).

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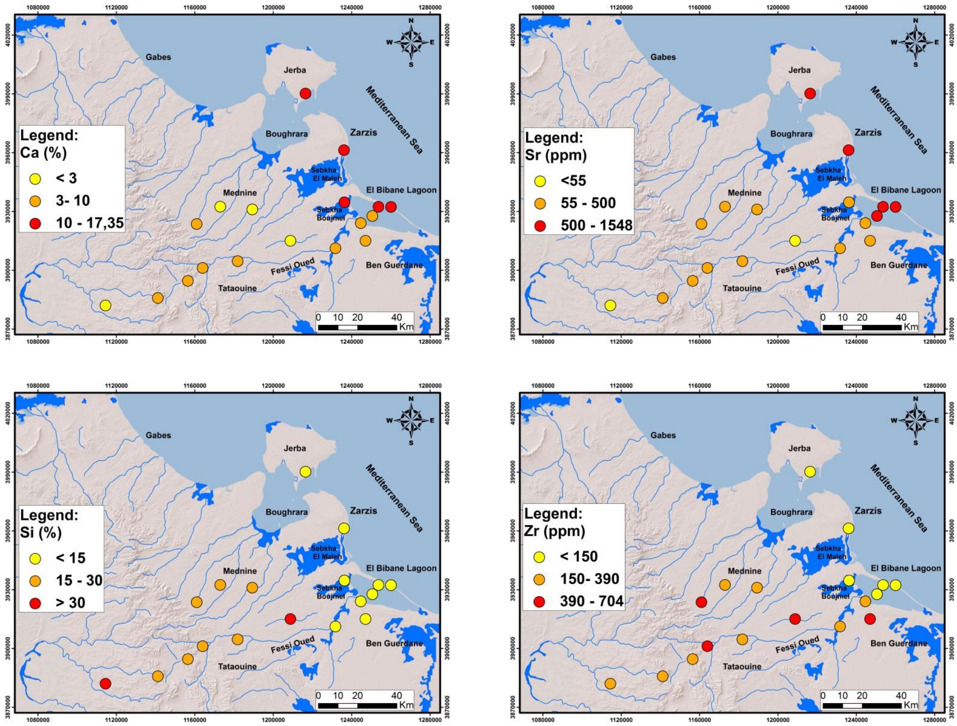
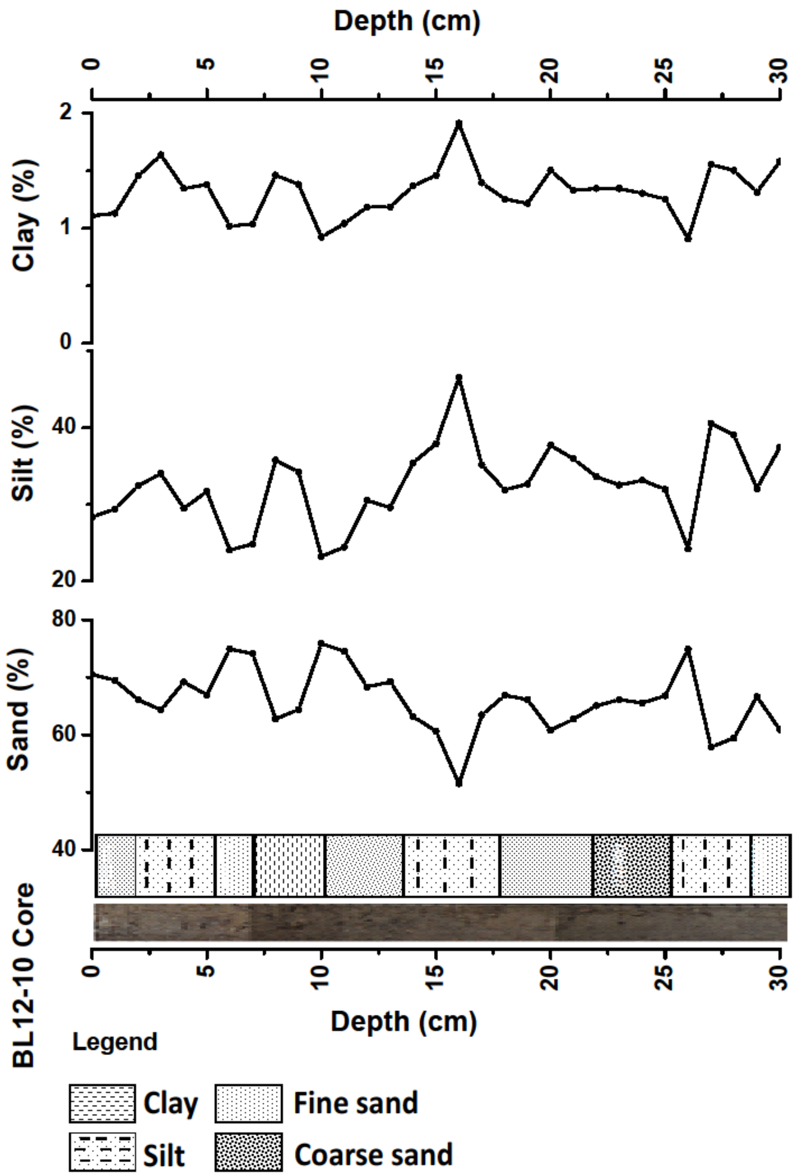


Figure.8. Spatial distributions of Zr (ppm), Sr (ppm), Si (%) and Ca (%) from catchment basin and El Bibane lagoon.



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2 Figure.9. Different granulometric classes of BL12-10 core.

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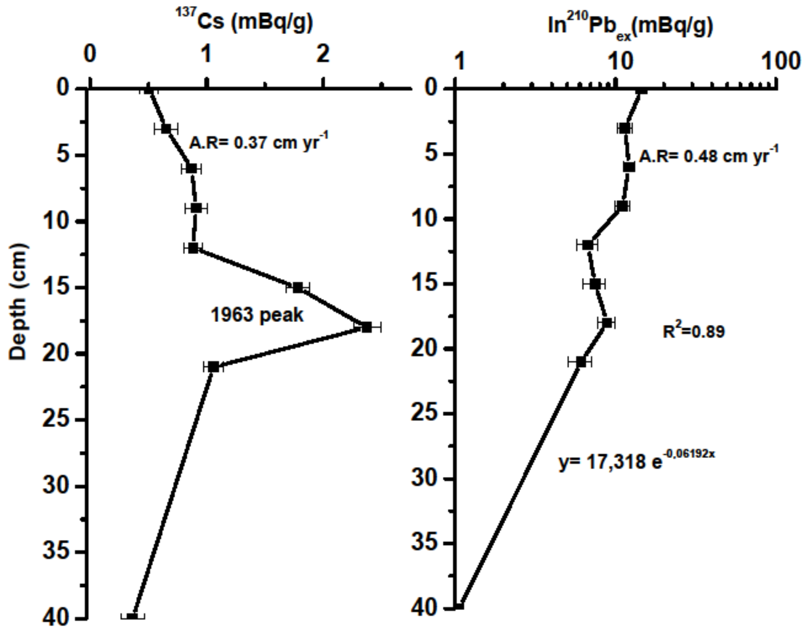

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3 Figure.10. ^{210}Pbex and ^{137}Cs activity-depth profiles in core BL12-10.

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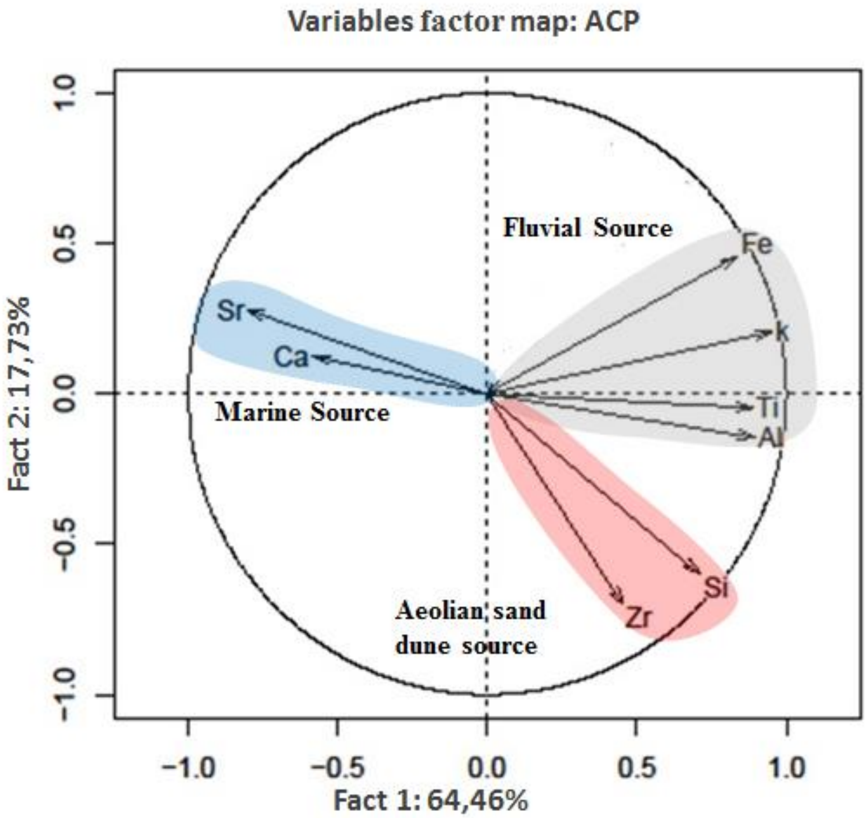

Figure.11. Principal Component Analysis (PCA) loadings plot of major and trace elements concentrations building three poles.

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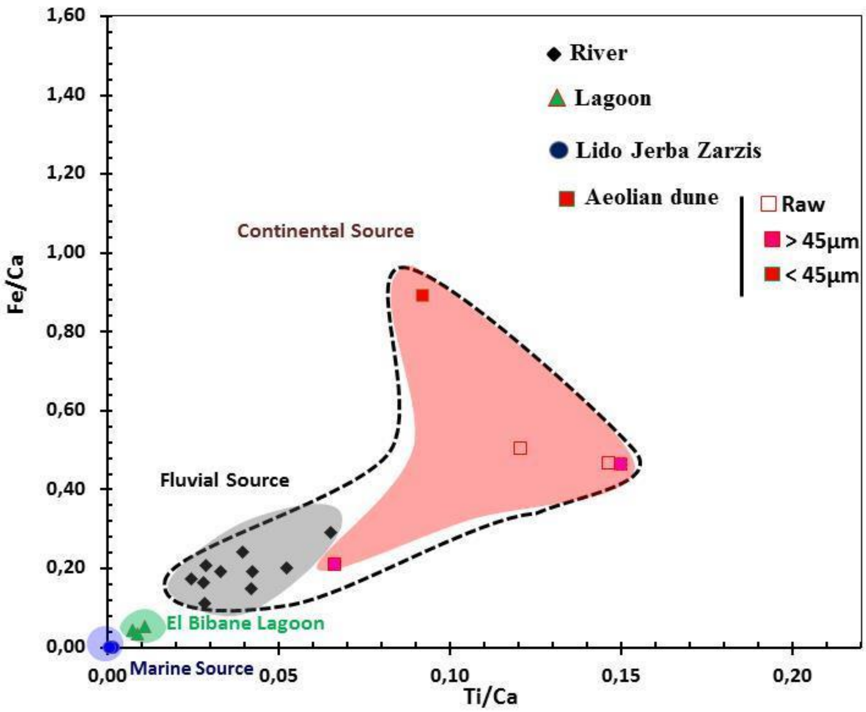

Figure.12. Fe/Ca *vs* Ti/Ca diagram, these ratios are useful to discriminate provenance of surface sediment of the El Bibane Lagoon (EBL).

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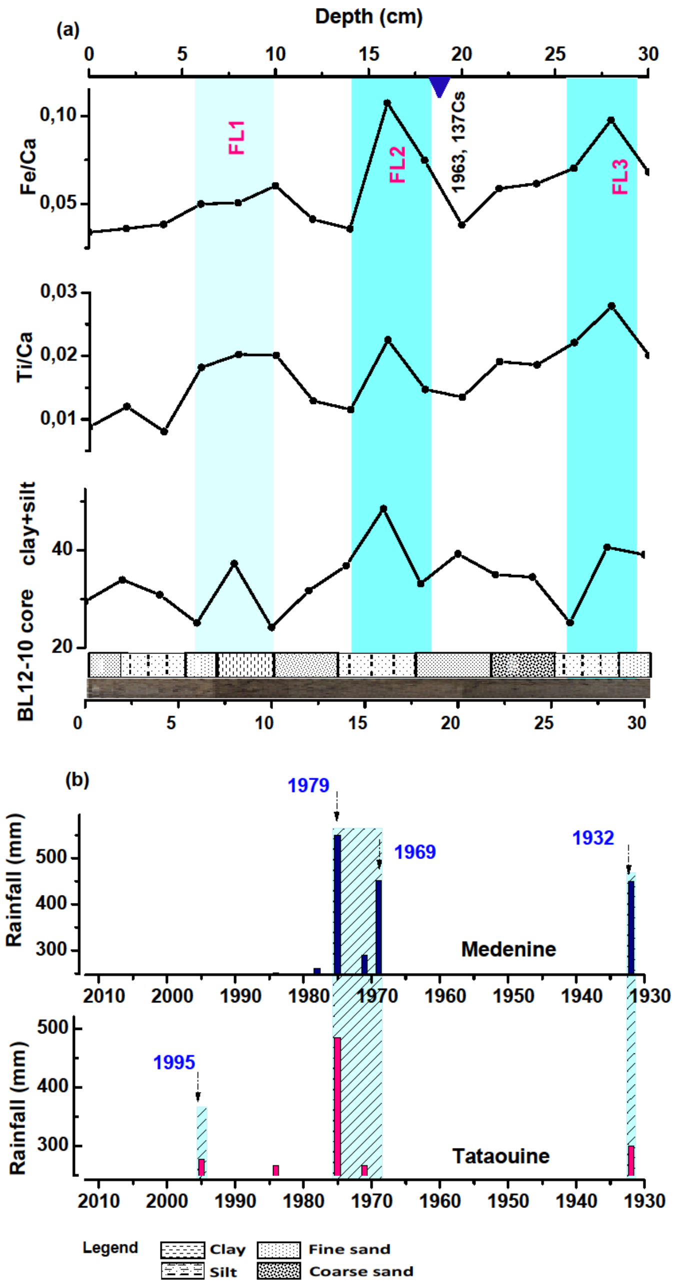

Figure.13 (a). Comparison between Fe/Ca, Ti/C and content of clay and silt in the BL12-10 core: FL1, FL2 and FL3 represent period of high floods deposits. (b). Historical rainfall in the watershed of Tataouine and Medenine: Three high period of rainfall were observed during the period between A.D 1900 to A.D 2000: A.D 1932; A.D 1969/1979 and A.D1995.

Table captions

Sample	Locality	GPS coordinates	
		Latitude	Longitude
S1	Beach	33°45'12,4"	10°59'57,9"
S2	Beach	33°35'31,5"	11°04'45,2"
S3	Beach	33°16'39,9"	11°17'39,6"
S4	Lagoon	33°16'47.3"	11°16'23.2"
S5	Lagoon	33°16'15.5"	11°13'31.2"
S6	Lagoon	33°14'58.7"	11°10'3.7"
S7	River	33°16'52,3"	11°07'31,3"
S8	River	33°08'03,0"	11°06'51,6"
S9	River	33°03'32,1"	11°02'00,4"
S10	River	33°04'13,6"	10°40'56,0"
S11	River	32°59'23,4"	10°28'12,7"
S12	River	32°55'18,0"	10°24'15,1"
S13	River	32°55'09,7"	10°22'35,3"
S14	River	33°03'38,0"	10°24'05,6"
S15	River	33°09'59,2"	10°21'35,8"
S16	River	33°12'25,37"	10°26'46,78"
S17	Aeolian	33°07'18,9"	10°44'58,6"
S18	Aeolian	32°50'28,4"	10°13'43,7"

Table.1. Names, geographic location and GPS coordinate of the studied samples.

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Sample	Locality	Zr ppm	Sr ppm	Rb ppm	Ca (%)	Fe (%)	Ti (%)	K (%)	Al (%)	Si (%)
S1	Beach	113	1497	13	14.67	0.00	0.03	0.14	0.00	9.71
S2	Beach	41	1548	10	14.51	0.00	0.01	0.10	0.00	6.85
S3	Beach	24	899	7	13.36	0.00	0.01	0.10	0.00	8.38
S4	Lagoon	133	1035	56	17.35	0.75	0.13	0.74	0.40	15.00
S5	Lagoon	85	747	32	9.00	0.47	0.10	0.47	0.18	8.70
S6	Lagoon	203	418	35	7.90	0.27	0.07	0.56	0.69	12.00
S7	River	134	358	54	17.35	0.75	0.13	1.10	2.08	15.00
S8	River	488	90	23	9.00	0.53	0.10	0.81	2.60	8.70
S9	River	178	97	45	7.90	0.98	0.07	1.13	2.76	12.00
S10	River	235	105	49	7.30	1.52	0.21	1.36	4.20	26.16
S11	River	704	92	14	6.00	0.59	0.16	0.56	2.20	26.93
S12	River	275	173	38	7.37	1.22	0.21	1.12	3.60	27.43
S13	River	391	123	23	7.35	1.28	0.18	0.93	2.60	27.13
S14	River	458	186	26	7.16	0.79	0.20	0.87	2.70	26.18
S15	River	350	102	28	3.95	0.59	0.17	0.77	2.40	29.08
S16	River	263	73	23	3.22	0.62	0.11	0.74	1.80	25.62
S17	Aeolian	473	52	24	0.80	0.40	0.10	0.75	2.50	33.38
S18	Aeolian	357	54	24	0.81	0.38	0.12	0.74	2.40	33.09

Table.2. XRF analysis results of the major and trace element in studied samples. ppm: parts per million.

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Depth (cm)	^{226}Ra dpm/g			^{210}Pb mbq/g			^{137}Cs mbq/g		
0	0,586	±	0,007	14,584	±	1,157	0,507	±	0,081
3	0,556	±	0,009	11,486	±	1,202	0,655	±	0,098
6	0,592	±	0,008	12,142	±	0,924	0,872	±	0,085
9	0,574	±	0,008	11,066	±	1,221	0,908	±	0,096
12	0,596	±	0,008	6,729	±	1,048	0,883	±	0,080
15	0,598	±	0,003	7,466	±	1,175	1,782	±	0,104
18	0,582	±	0,008	8,877	±	1,103	2,375	±	0,115
21	0,592	±	0,005	6,110	±	1,005	1,060	±	0,084
40	0,659	±	0,011	1,058	±	1,476	0,365	±	0,101

Table.3. Activities of radionuclides ^{210}Pb, ^{137}Cs and ^{226}Ra in core BL12-10.