Eco. Env. & Cons. 28 (August Suppl. Issue) : 2022; pp. (S70-S80)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i04s.010

Sedimentological, mineralogical and geochemical investigation of Chichaoua's bassin depot system: potential origin and provenance

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(Received 7 January, 2022; Accepted 14 March, 2022)

ABSTRACT

High Atlas Rivers are common along the Atlas Mountains of Morocco and result from the combined effect of river flow, winds, vegetation and other meteorological conditions. In this paper, we study the textural and compositional parameters of fluvial deposits, from the Chichaoua catchment across the Seksaoua river banks, and their provenance. Morphologically, they are in the form of current active river, Paleozoic deposits. To study the provenance of the grains, we opted for laboratory analyses including grain size, mineralogy, micro textures and micro morphology. Sands from active deposits showed very fine to medium average grain size and moderate sorting, while those from fluvial deposits showed fine to very fine average grain size and very low sorting. The deposits studied showed the dominance of grain forms ranging from angular to freshly angular. As far as mineralogy is concerned, calcite is predominant in the sands on the right bank of the river, whilequartz is more abundant in the deposits on the left bank. In the active streams on the left bank, other carbonates were also detected in the bioclasts such as aragonite, dolomite and magnesian calcite, suggesting a fluvial origin. The siliciclastic grains of the studied stream generations are likely to be of Triassic, Jurassic and Quaternary units origin crossed by the Seksaoua River. Indeed, the results revealed the presence of minerals such as albite, plagioclase, microcline and illite which could come from Triassic a salts which is often associated with Jurassic evaporates associated with Jurassic evaporite rocks. This study has suggested the probable origin of the sands that form these deposits based on the detailed study of their grains, which has not been studied in previous research in the area. Furthermore, this research is particularly relevant as it is part of the current research trend related to the understanding of the evolution of Plio-Quaternary atlasic fluvial systems in the world and may be applicable to other fluvial systems in the mountain ranges of Morocco in the future.

Key words : *Fluvialdeposit, Provenance, Sedimentology, Morocco.*

Introduction

Thus, X-ray diffraction (XRD) has been widely used to provide information on the crystalline components of river sands and to understand their origin (El-Sayed 2000; Muhs *et al.*, 1996). In addition, X-ray

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fluorescence spectroscopy analyses provide a better understand the composition of the sand through the determination of major and trace elements (Hamdan *et al.,* 2015). Other studies on researches have used high resolution petrography and heavy mineral analyses to reconstruct the provenance of sands and trace the sources of sediments (Garzanti *et al.,* 2012). Also, rock fragments, such as mafic volcanic rocks and pyroxenes have been used as good indicators of sand provenance because they can survive long transport distances (Garzanti *et al.,* 2015). Exoscopic analysis using the scanning electron microscope (SEM) has been used by several studies to examine the structural properties of quartz grains and thus to understand the provenance of sand grains and their environments (Chakroun *et al.,* 2009; Tsakalos, 2016).

On the Atlas Mountains of Morocco, fluvial depositional accumulations include aeolian deposits and wadi-derived continental deposits (Weisrock 1978, 1982, 1993; Weisrock *et al*., 1998; Weisrock *et al.* 2002; Weisrock *et al.,* 1998). The fluvial system of the Chichaoua catchment is ideal for studying the texture, composition and provenance of the sand, due to its immense extension and the different generations of deposition that occur in the region. From these we can differentiate the fixed deposits, active longitudinal currents. The whole fluvial system is crossed by the Seksaoua River, which is considered an important supplier of sediment in the region during flash floods (El Mimouni *et al.,* 2014). The sediment dynamics of these depositional fields result from the interaction of controls related to the river flow, winds, vegetation characteristics and other meteorological conditions (Daoudi *et al.*, 2004). The Chichaoua fluvial eolian depositional system has been the subject of a number of studies focusing on geomorphology, sedimentology and stratigraphy, and their paleoclimatic significance.

The earliest was established by Weisrock (1980), who investigated the paleoclimatic significance of the deposits and their genesis using analysis of present-day and paleo directions. Flor Blanco *et al.,* (2013) established a classification of eolian landforms in the fluvial belt and estimated their sand volumes. They also suggested that the sands of the aeolian and fluvial deposits originate mainly from fluvial erosion and runoff from the high mountain that flows into the Seksaoua River.

The depositional fields of the high atlas, although dominated by continental inputs (Lharti *et al*., 2006) studied the morphological and sedimentological aspects of the depositional fields of the river complex to deduce the sediment transport model and sediment budget of the river. In addition, El Mimouni *et al*. (2014), through topographic field surveys, found that the Seksaoua River is the main supplier of sand during major floods as well as wind action inputs. It suggests that sand inputs, both from river action and aeolian action, are discharged into the watershed. However, no textural or compositional research has been conducted in the Chichaoua fluvial deposits for provenance interpretation.

In this paper, we investigate the Chichaoua watershed fluvial deposition system in more detail than previous studies, combining textural and compositional characterization of both deposits on both banks of the Seksaoua River to determine the potential provenance of these sand deposits.

Materials and Methods

Study area

The Chichaoua region, which is the subject of this study, is part of the large basin of the Oued Tensift. It covers an area of 20,222 ha and belongs entirely to the territory of the province of Chichaoua. This basin is limited by:

- To the North : by the Oued Tensift watershed
- To the East : The watershed of the Seksawa wadi (Jbel Bou Ibawene and Jbel Ourgous) and the Assif Elmal watershed
- To the West: by the Oulad Bousbaa plain. Jbel Lemgo and Jbel Oussoud
- South : through the High Atlas Mountains, Jbel Gourzatine

The Chichaoua upstream perimeter is part of the physiographic unit of the high-Atlasic piedmont with an altitude of approximately 339 m. It consists of the low terraces along the

Chichaoua wadi and its tributaries

With a surface area of 2690 km², the Chichaoua basin is part of the Oued Tensift hydraulic system, which comprises ten or so basins of varying importance. Of these, the Chichaoua basin is located the furthest west in the Haouz Mejjat basin (Figure 1).

The Chichaoua basin has an area of about 660 km², located downstream of the basin in an intermediate position between the latter and the Assif ElMal basin. Together, the Chichaoua basin and the inter-

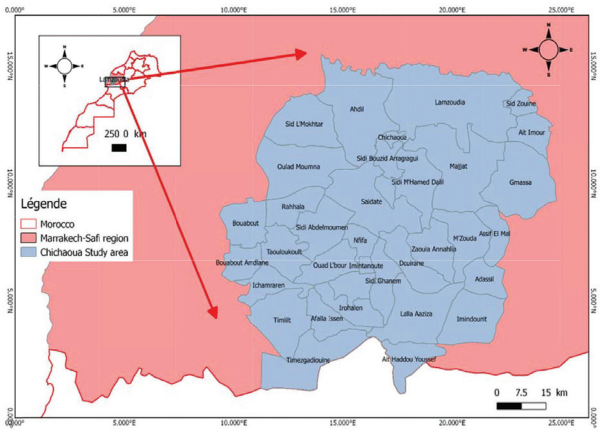

Fig. 1. Geographical location of the Chichaoua catchment

mediate zone cover an area of about 3350 km², which represents about 18% of the Haouz-Mejjate basin.

Sampling

In order to obtain statistically credible results, the analyses must first be preceded in the field by a sampling which, qualitatively and quantitatively, takes into account the needs of the method.

The quality of the sampling depends mainly on the weather conditions and the configuration of the study area. The first two factors are difficult, if not impossible, to control or modify. However, by following a precise and predefined method.

The amount of sample to be taken is influenced by the maximum particle size of the sediment to be studied.

Sample preparation

Several field surveys were conducted to analyze the river units and to select the sampling sites. Samples were collected from both sides of the river. Then they were passed through the analytical laboratory, including grain size analysis, grain morphoscopy, mineralogy determination and sediment facies analysis, to determine the characteristic sediments, provenance and fluvial dynamics.

In the laboratory, the techniques are not directly applicable to the raw sediments collected. They must therefore be prepared to isolate insoluble detrital particles by removing the other components of the collected samples.

The samples are first dry sieved to 2mm, due to the presence of substantial amounts of crystalline and/or carbonate coarse particles. In some studies, there is no need to go through this step. However, in the case of alluvial areas, it is rare to be able to eliminate it.

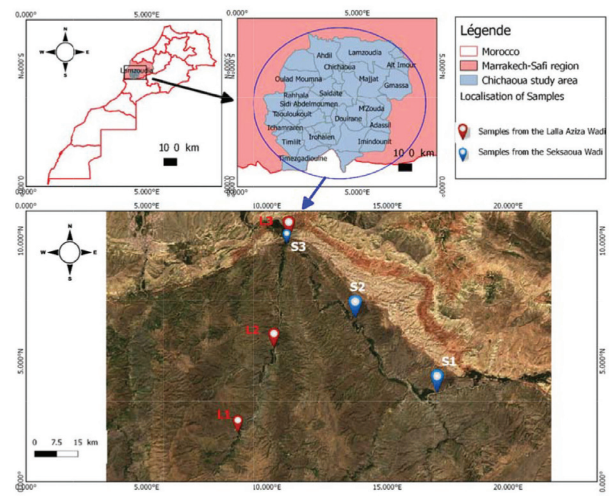

Fig. 2. Location of the samples.

Table 1. Statistical formulae used in the calculation of grain size parameters.
f is the frequency in percent; *m* is the mid-point of each class interval in metric (m_m) or phi (m) units; P_x and are $_x$grain diameters, in metric or phi units respectively, at the cumulative percentile value of *x*.

Mean		Standard Deviation	Skewness	Kurtosis
Arithmetic Method of Moments:	$\bar{x}_a = \frac{\Sigma f m_m}{100}$	$\sigma_a = \sqrt{\frac{\Sigma f (m_m - \bar{x}_a)^2}{100}}$	$Sk_a = \frac{\Sigma f (m_m - \bar{x}_a)^3}{100 \sigma_a^3}$	$K_a = \frac{\Sigma f (m_m - \bar{x}_a)^4}{100 \sigma_a^4}$
Geometric Method of Moments	$\bar{x}_g = \exp \frac{\Sigma f \ln m_m}{100}$	$\sigma_g = \exp \sqrt{\frac{\Sigma f (\ln m_m - \ln \bar{x}_g)^2}{100}}$	$Sk_g = \frac{\Sigma f (\ln m_m - \ln \bar{x}_g)^3}{100 \ln \sigma_g^3}$	$K_g = \frac{\Sigma f (\ln m_m - \ln \bar{x}_g)^4}{100 \ln \sigma_g^4}$
Logarithmic Method of Moments	$\bar{x}_\phi = \frac{fm\,\Sigma\,_\phi}{100}$	$\sigma_\phi = \sqrt{\frac{\Sigma f (m_\phi - \bar{x}_\phi)^2}{100}}$	$Sk_\phi = \frac{\Sigma f (m_\phi - \bar{x}_\phi)^3}{100 \sigma_\phi^3}$	$Sk_\phi = \frac{\Sigma f (m_\phi - \bar{x}_\phi)^3}{100 \sigma_\phi^3}$

The sieving limit was chosen at 2mm, because it corresponds to a limit respected in geology and pedology (AFES, 1995; Gobat *et al.*, 2003).

For practical reasons, the samples are dried in the oven at 105 °C for 24 hours, not in the air, either in their original plastic bag or in appropriate containers. To eliminate organic matter and to know the humidity level,

Once dry, a first dry sieving at 2 mm is carried out, because of the sometimes dominant presence of crystalline and/or carbonated coarse particles.

The particle size distribution was obtained using a series of sieves to determine the particle size distribution.

Statistical parameters (mean, sorting, skewness and kurtosis) were extracted using the open-source GRADISTAT program (Blott and Pye, 2001). In each sample, 100 quartz grains of the sand fraction (315-500 µm) were examined at for exoscopic analysis using SEM and examined for their properties.

The observation of the chemical products and the mechanical alteration characteristics of the grains, in addition to the roundness, allowed a description of the history of their movement, sedimentation and diagenesis.

Portions of crushed and dried sands were analyzed to identify the phases. Then the semi-quantitative estimation of crystalline phases was carried out using a Rigaku Smart Lab X-ray diffractometer (XRD) with a Cu anti-cathode radiation, operated at a voltage of 40 kV and a beam current of 44 mA. The fine fraction of the sands was also analyzed by DRX to identify clay minerals. The same portions of sand were also subjected to energy dispersive X-ray fluorescence (IR) spectroscopy for the qualitative and quantitative determination of their elemental composition. The measurements were made using an Epsilon 4 XRF analyzer.

Results

Particle size distribution and morphoscopic characteristics

The particle size analysis allowed to obtain the particle size distributions and also the parameters textural characteristics of each sample. Interpretation of these data is relevant to understanding sediment sources, transport type and deposition.

The sieve size results are shown as frequency curves (Figure 3) and bivariate scatter plots (Figure 4). Textural parameters of the sands are represented in Table 1. The sands from active rivers show a unimodal distribution on both banks. However, the average grain size is characterized as medium sand on the right bank and fine sand on the left bank.

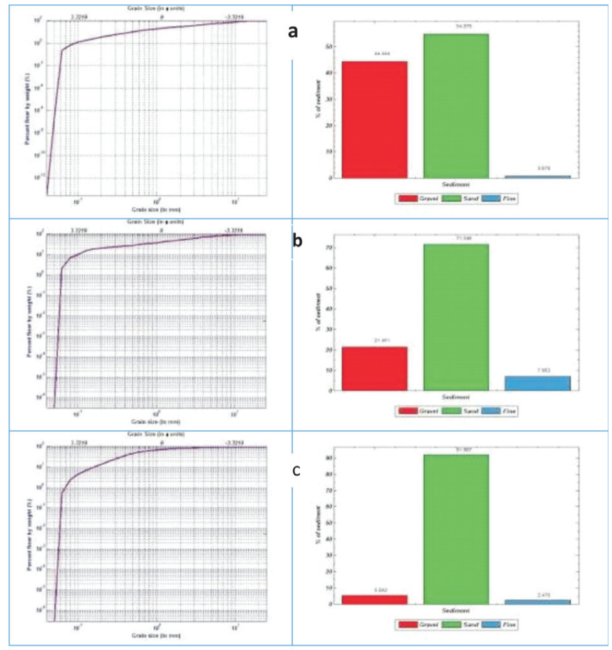

Fig. 3. Grain size frequency curves of sand samples from the right bank: a depot samples of the right bank; b depot of the left bank; c paleozoic depot of the right and left banks

The curves show the same characteristics and the same number of accidents, but also a progressive change from the left bank to the right bank, from a mixed but rather fine sedimentation mode, around (125 µm, between fine and medium sands), to a slightly coarser sedimentation, on average (500 µm, medium sands). The deposits on the left bank have very similar qualities and could well be the result of the same flood event. From the granulometric point of view, the samples of the left bank, located at the very level of the basin plain. It only benefits from an enrichment in fine materials, which would be caused by the action of the fauna.

In summary, the Chichaoua watershed is divided into two parts: one from the upstream and the other from the plain. It has recorded successive episodes of sedimentation, alternating in two modes: sandy-silty and sandy. There is a very slight tendency for the size of the particles to increase during deposition. Skewness reveals that the distribution of sands is symmetrical on the right bank compared to the

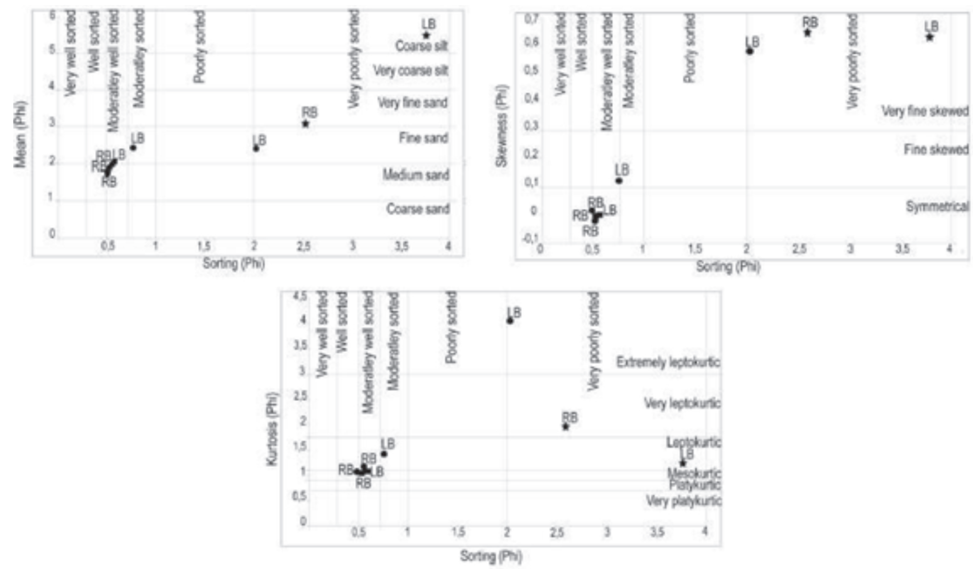

Fig. 4. Scatter plot diagrams of statistical grain size parameters: a sorting versus mean size; b sorting versus skewness; and c sorting versus kurtosis. RB, right bank; LB, left bank.

fine sands on the left bank which are classified as fine to very fine skewed. Sorting indicates that the sands on the right bank are classified as moderately well sorted, while those on the left bank are moderately to very poorly sorted. Kurtosis values reveal mesokurtic to leptokurtic sands on the right bank and leptokurtic to extremely leptokurtic sands on the left bank reveal very leptokurtic sands on the right bank and leptokurtic sands on the left bank.

These results show that the fluvial deposits are much finer and poorly sorted because they contain mixtures of sands and gravels.

The active river sands reveal a distinct change in quartz grain morphoscopy as they are formed to sub- rounded bright grains. Further north on the right bank, as the amounts of fresh-angled grains increase. On the left bank, the active wadis are dominated by bright sub-rounded bright grains followed by fresh-angular grains.

For the schistose bedrock samples, the results reveal an abundance of round to angular bright grains. Exoscopic analyses reveal mechanical and chemical surface aspects in sand grains from different shores.

The site has a mechanical appearance including rub marks, conchoidal fractures and crescent and V-shaped marks, while the chemical characteristics are mainly represented by silica.

Crescent-shaped impacts were also noted on the surface of some grains, as well as silica precipitation. Some grains, as well as silica dissolution pits that can be seen developed on grain depressions (Fig. 8b). While precipitation of globular shaped silica is more frequent in the pits (Fig. 8d), which is due to evaporation of the sub-saturated silica.

Mineralogical characterization

The analysis of the diffractograms obtained for the samples highlights the presence of the following crystalline phases quartz (SiO2: 3.35 /2.80 Å) and calcite (CaCO3: 3.04 / 2.89Å) as main phases.

XRD analysis reveals that calcite has the main percentage for the active river on the right bank while quartz shows the highest percentage on the left bank (Figure 5). In addition to calcite other carbonates. Other minerals were also detected, such as gypsum on the right bank and albite on the left bank, with significant quantities. As for the clay mineral association,it is represented by illite, kaolinite and vermiculite on both banks.

For the samples taken from the fluvial deposits, the results show a higher percentage of calcite on the right bank of the river. While the percentage of quartz is more abundant on the left bank. Apart from calcite, another important mineral in both banks is albite. The analysis also revealed the identification of some minority phases such as Dolomite (CaO MgO 2CO $_2$: 2.4 Å), and Kaolanite (Al $_2$Si $_2$O

$_5(OH)_4$: 2.5 Å),.

The phyllosilicates include smectite, illite and vermiculite on both sides, in addition to chlorite and anorthite.

As for the Paleozoic fluviatiles, they show a dominance of quartz on both shores, followed by illite (Figure 5).

Both the right and left banks of the river show the presence of similar minerals but with slightly different occurrences such as albite, microcline, ...

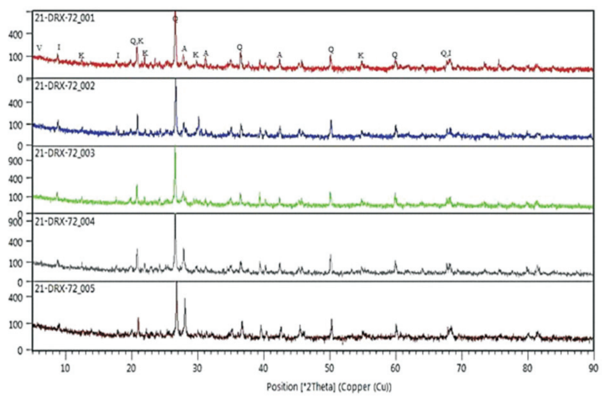

Fig. 5. XRD spectrum. Q: SiO2 /Quartz, C: CaCo3 / Calcite, D: CaO MgO 2CO2 / Dolomite, K: Al2Si2O5 (OH) 4 / Kaolanite

Iron oxides are mainly represented by hematite, which is present in altered zones on both sides of the river.

We also noted the presence of significant amounts of rock fragments were also detected in all samples. X-ray fluorescence spectroscopy analyses were applied to the same samples to determine their elemental composition. 26 elements were detected in this analysis (Ca, Si, Fe, Al, K, Ti, Mg, Cl, Sr, Ag, S, Ba, Mn, Zr, Rb, V, Zn, Cr, Cu, Y, As, Eu, Pb, Yb, Br, Hg) of which only seven major oxides were selected for this analysis.

Major oxides were selected for this study (CaO, SiO2, Fe2O3, Al2O3, K2O, TiO2, MgO, MnO, and Na2O). They were plotted in terms of their spatial variations and concentrations.

The results of the samples collected on the generations of rivers show that the concentration of CaO and siO2 tends to decrease from the right bank to the left bank for the active rivers (Figure 6).

However, SiO2 and Al2O3 concentrations increase from the right bank to the left bank. K2O and Na2O concentrations are higher on the left bank of the river. Lower concentrations of TiO2 were noted on the right bank where they are slightly present.

Scanning electron microscopy allows to observe the texture of the fine sample and to characterize mineralogical assemblages. The images obtained by scanning electron microscopy of the clay sample with different magnifications are shown in Figure 6. The clay particles are presented as clusters of fine aggregates and rod-shaped platelets with irregular contours (Figure 6a) as shown by the SEM. This is a morphology encountered both in poorly crystallized Kaolinites and Illites as observed by Konan [22]. The image of figure 3e and in agreement with what we obtained in DRX, there is no doubt about the presence of carbonates and Quartz

Each type of component appears in the SEM in a particular form; it is possible to know the distribution of the different elements in each of the identified zones.

The carbonates (calcites, dolomites) have a vari-

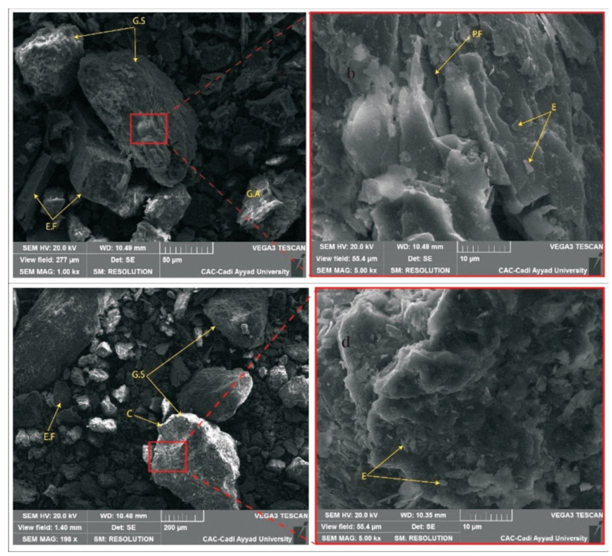

Fig. 6. Examples of SEM photographs of quartz grains showing grain surface characteristics. Grain surface characteristics. a Angular grain with slightly abraded edges and no fresh impact marks. Fractures are conchoidal with concave surfaces and then crystalline with flat surfaces. b Subrounded grain with conchoidal fractures with abraded edges and crescent-shaped impact marks. At the flat surfaces and cavities, dissolution pits are observed. c Dull-grained round grain with very old impact marks and abraded edges. There are several crescent-shaped impact marks, while V-shaped marks are few. Strong pimple marks affect the entire grain surface, suggesting long transport by water. d Silica precipitation occurs in the form of fibres.

able shape rarely rhombohedral, they have a transparent aspect. The silica grains are made up of quartz of spherical form and of brilliant vitreous aspect. The classical ovoid shape of phosphate grains is observed.

Thus, on the images, we were able to detect the main majority compounds already determined by the DRX method, namely: the carbonate grains; the silica/quartz grains;

In parallel to the SEM pictures, we carried out semi-quantitative EDX analyses of the sample for the determination of the chemical composition of the analysed clay. Figure 5 represents the chemical elements contained in the clays (Si, Al, Mg, Fe, K, P, S, O, Ca, C), the copper and the carbon come from the sample support grid. It should be noted that a strong presence of silicon is mainly due to the majority presence of Quartz in the sample studied. These results confirm those obtained by X-ray fluorescence analysis and X-ray powder diffraction which revealed the presence of these chemical elements in the form of oxides: Al2O3, SiO2, Fe2O3, MgO, CaCO3, K2O.

Discussion

This study deals with sediments that have been weathered, then detached from their original geological formation, transported by rivers into the river, and finally deposited as the current velocity decreases.

In fact, the transition from a semi-arid climate to a temperate and humid climate in the Moroccan High Atlas, allowed a decrease in the power of the dominant currents, which led to the stability of the deposits and the installation of vegetation with diagenetic processes allowing the lithification of a sand layer. (Weisrock, 1982). Furthermore, the alternation of rainy and inter-rainy periods allowed the installation of deposits during transgressions. According to Hooghiemstra (1989), there was a progressive increase in eastward currents.

The granulometric and morphoscopic analysis, in addition to the determination of the mineralogical composition revealed the fluvial origin of the grains that constituted the sand deposits of the Chichaoua watershed.

There is no significant difference recorded in terms of average grain size in the active and fixed banks. However, the values of the average grain size in the fluvial system in Morocco vary from 150 to 220 μm. The results showed a much finer sand grain size as it varies from coarse silt to very fine gravel.

However, there is a slight variance in sorting, as the right bank active sands are moderately well sorted, indicating long sediment transport, while the left bank active sands are moderately to very poorly sorted, suggesting that they were deposited near their source of supply and were not transported as far from the source as the right bank active sands.

These particle size values are slightly different from those found in the Holocene deposits of Quiaios- Tocha (central Portugal) (Danielsen *et al.* Portugal) (Danielsen *et al.,* 2012).

These deposits showed well-sorted unimodal sands and fine to medium sands, the rivers show more sands than coarse fluvial sands from Chichaoua due to the more energetic fluvial currents; they are moderately sorted to moderately well sorted, and positively inclined, suggesting an aquatic origin (Granja *et al.,* 2008).

Morphoscopic analysis showed the dominance of sub-angular and shiny grains near the right area. And bright near the right bank of the river, followed by fresh-angular grains, which means that the sands mainly underwent fluvial transport with a contribution from a closer source. The decreasing amounts of fresh-angular grains explain an erosional contribution. For the fresh-angular grains are the result of a short transport of the grains (Le Ribault, 1977).

On the left bank, the quantities of fresh-angular grains decrease slightly on the active banks compared to those on the right bank, which explains the presence of fluvial inputs.

SEM microphotographs showed the presence of mechanical and chemical impact patterns in grains from both sides.

For a better understanding of the origin of the sand grains, we studied the drainage patterns of the Chichaoua watershed.

The main course of the river results from the junction of the Ioulla and lalla aziza rivers. This watershed has a total drainage area of 2290 km^2.

This watershed has topography that ranges from 300 to about 3300 m altitude and complex morphological features shaped, The mouth of the river is characterized by a marked sandy projection, related to sedimentation by the river and accumulations of fluvial sands.

In addition, the river is considered an important trap for northward migrating sands, especially during drought periods (Chahboun, 1988). The stream

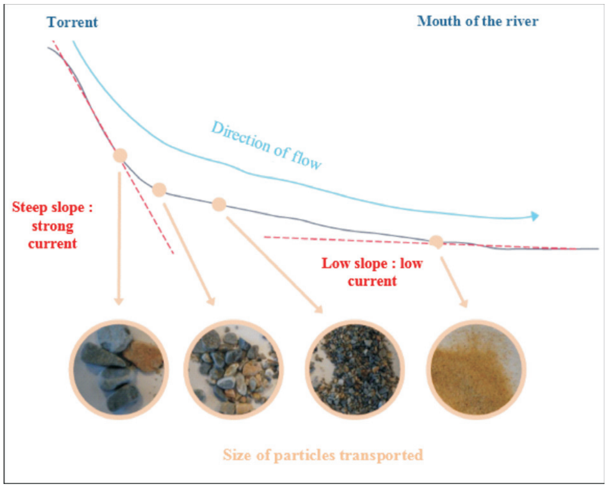

Fig. 7. Diagram of the influence of a river on the dynamics of particles, as a function of slope.

network of the Chichaoua watershed crosses units ranging in age from Triassic to Quaternary (Michard 1976; Içame, 1994) (Table 2). These units could be the main source of supply of the sand deposits because the XRD results revealed the presence of minerals such as quartz, calcite, kaolinite, etc,

Similarly, the presence of gypsum could come from Jurassic evaporitic rocks. Moreover, the presence of calcite and dolomite indicates a provenance of Meso-Cenozoic rocks because the river crosses Eocene and Cretaceous units.

In fact, carbonate rocks represent 60% of the Chichaoua watershed and clasts of these rocks are transported by the river during flood periods (El Mimouni *et al.*, 2010).

On the other hand, the presence of aragonite and magnesian calcite in the sands of the left side of the Chichaoua watershed.

The IR analysis confirmed the XRD results as it showed the presence of major element oxides such as Na2O and K_2O which confirm the presence of Na feldspars like albite and K feldspars like microfeldspars.

Calcium and silicon are mainly found in calcite and quartz, respectively, which showed significant amounts in the samples collected and taken from both banks. In addition, the prevalence of MgO on the left bank confirms the presence of aragonite and magnesian calcite. On the other hand, the analysis revealed less significant quantities of titanium on the right bank, which is probably due to its presence in trace amounts in certain heavy minerals such as pyrite and hematite.

Thus, the sands of the active banks of Chichaoua could have fluvial origins. The river crosses, in its upstream part, carbonate units of the Jurassic and Cretaceous, as well as shales of the Paleozoic. Its contributions are mainly composed of quartz, feldspars and dolomites. Due to the fluvial drift, the sediments from the mouth of the wadi are dispersed, redistributed and deposited offshore.

Streams transfer particles downstream in three forms (Campy and Macaire, 2003), the sum of which is called the stream sediment load:

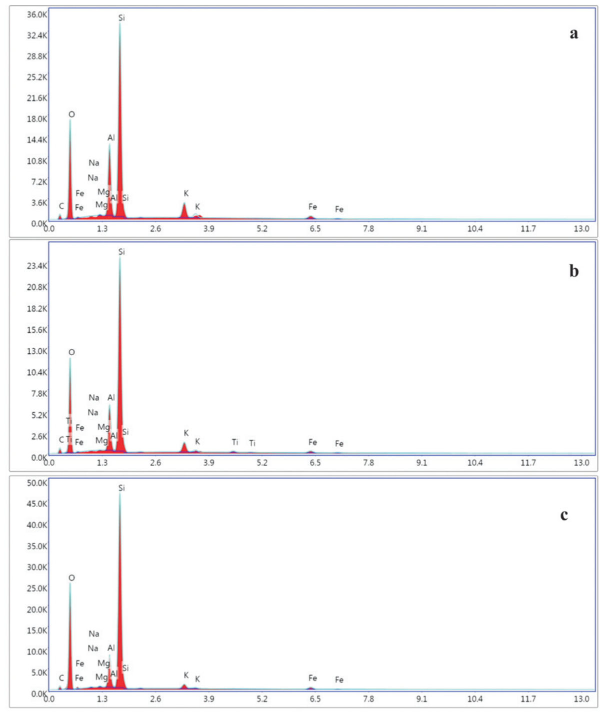

Fig. 8. Distribution of the main abundant minerals in sands at both Riverbanks: a depot samples of the right bank; b depot of the left bank; c paleozoic depot of the right and left banks.

- The bottom load (particles larger than 0.5 mm), which is moved mainly by traction and saltation,
- Suspended matter (particles with a diameter of between 0.5fm and 0.5mm), which represents 90% or more of the load during floods, but is almost absent from the flow during low-water periods,
- The dissolved load, composed of ions and particles smaller than 0.5fm, which precipitate very little. Along the Chichaoua basin, the two banks are depicted as a vast expanse of uncultivated and grassy land, sometimes under the influence

of springs and sometimes of the basin, and frequently flooded. A few meadows and fields are included in its description, especially in Chichaoua. This basin floods almost the entire plain.

Around the left bank there are alders (a typical tree of active alluvial zones), then the river ravages the plain downstream. Thus the river seems to follow a different pattern, having several beds, wandering as it pleases and occupying the plain without flooding it completely. Again, from upstream, this wadi transforms the basin into a large vegetative zone.

On the right bank, the floodplain is already partially developed by man, but still marshy. It narrows, modifying the morphology of the basin bed.

This description may sound rather nostalgic today, but in any case, it highlights the major characteristics between the two banks. The waters of the river then regularly flowed out of the main channel of the river.

The characteristics of each wadi were highlighted in the results section, thanks to the precise characterization of the particularities of each deposit. From these descriptions, the results are discussed mainly by the curves.

Thus, erosion and alteration would not be advanced enough to provide the system with clay. However, the characteristics of the fluvial system may simply be the origin of the absence of clay deposits.

In general, we can observe on the curves, sedimentary modes that vary little in the lower part of the profiles, and then a rather clear tendency to a change of sedimentation mode towards the large particles. These changes could be the consequence :

- The damming of the river (less frequent but more important floods, implying a greater energy),
- Ploughing (which homogenises surface deposits),
- Wind, which easily carries away silty particles on the surface, and which, combined with ploughing, leads to the impoverishment of the soil in fine fractions, rainfall changes leading to a variation in the speed of erosion on the slopes, in the time it takes for the grains to reach the river, and therefore a change in the size of the particles available,
- significant variations in vegetation cover caused by humans,

Conclusion

In this study, we used textural and compositional analysis of sand grains to investigate the provenance of the grains that form the Chichaoua watershed field and their depositional environments.

Grain size analysis has shown that the granulometric indices calculated on our samples of loose sediments (pebbles-sand-silt-clay) are tools that should help to confirm, refute or clarify hypotheses that have arisen in the field. Far from being obsolete tools, indices and research on the relationships between statistical distributions and sediments are being renewed. In this study, account is taken of the variety of particle size data acquisition (sieving, sedimentation rate, ...), all of which give different results when applied to the same sample. Nor will it be discussed whether or not it is worthwhile to analyse the sandy fractions, or the sands and fines, or the fines to pebbles: comprehensive approaches to sedimentation and grain size do exist. which suggests a fluvial origin, but the presence of significant quantities of fresh-angular grains an additional fluvial origin since they were associated with calcite. And its mineralogical distributions constitute several minor elements. Among these elements are C, Ca, O, Si, Na, K, Al, S, Mg, P and Fe. The XRD diffractograms show the presence of the following major phases: quartz SiO_2 and carbonates which are in the form of dolomite $CaMg(CO_3)_2$ and calcite $CaCO_3$, and minority phases such as Kaolinite, Sodium Chloride, Bornite.

Moreover, mineralogy shows that each type of constituent has a particular form; it is possible to know the distribution of the different elements in each of the identified zones. The carbonates (calcites, dolomites) have a variable shape, rarely rhombohedral, they have a transparent aspect. The silica grains are made up of quartz of spherical form and of filamentous and vitreous brilliant aspect.

Acknowledgement

We would like to thank the Semlalia Faculty of Science, the laboratory: Geosciences, Geotourism, Natural Hazards and Remote Sensing and the Centre for Chemical Analysis at the Faculty of Science Semlalia for encouraging us and giving us the opportunity to do scientific research .

Disclosure statement

Conflict of Interest: The authors declare that there are no conflicts of interest.

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