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Spatial analysis of geochemical elements of continental and marine surface sediments in southern Morocco: as an indicator of environmental and climate change

Analyse spatiale des éléments géochimiques des sédiments de surface continentaux et marins dans le sud du Maroc : comme indicateur du changement environnemental et climatique

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JAWAD EL HAWARI[1] & MOHAMED EL GHACHI[1]
(1) Laboratory of Landscape Dynamics, Risks and Heritage/Department of Geography/ Sultan Moulay Slimane University, B.P: 524, Beni Mellal, Morocco.
Email: jawad.elhawari@gmail.com

KEY WORDS
Southern Morocco, sediments, geochemical elements, spatial analysis, terrigenous input.

Abstract Like other regions of Morocco, southern Morocco is presently subject to severe drought, desertification and socio-economic stress. Studies on climate change, landscape and vegetation have mainly focused on the northern regions of the country. In contrast, the climate and environmental history in the south of the country is largely unknown. In the case of our study, we have chosen the characterization of southern Morocco based on geochemical parameters (major and trace elements). Continental and marine samples are collected along the south of Morocco. The concentrations of chemical elements are obtained by X-ray fluorescence scanning (XRF) in order to define the effects of climate change and rainfall on the local environment and natural resources. The integration of the different results allowed us to reconstruct climate, ocean and environmental changes. That has enabled us to provide data for land-ocean correlations.

MOTS CLES
Sud du Maroc, sédiments, éléments géochimiques, analyse spatiale, intrants terrigènes.

Résumé À l’instar d'autres régions du Maroc, le sud du Maroc est actuellement soumis à de graves sécheresses, désertification et stress socio-économique. Les études sur le changement climatique, le paysage et la végétation se sont principalement concentrées sur les régions du nord du pays. En revanche, l'histoire du climat et de l'environnement dans le sud du pays est largement inconnue. Dans le cas de notre étude, nous avons choisi la caractérisation du sud du Maroc à partir de paramètres géochimiques (éléments majeurs et traces). Des échantillons continentaux et marins sont prélevés le long du sud du Maroc. Les concentrations d'éléments chimiques sont obtenues par la technique (XRF) afin de définir les effets du changement climatique et des précipitations sur l'environnement local et les ressources naturelles. L'intégration des différents résultats nous a permis de reconstituer les changements climatiques, océaniques et environnementaux. Cela nous a permis de fournir des données pour les corrélations terre-océan.

1. Introduction

The Atlantic Ocean receives a significant amount of terrigenous material from the African continent of eolian and fluvial origins [17]. In our study area, terrigenous sediments are transported to the Atlantic coast by two ways eolian and fluvial, which are both sensitive to climate change [13]. Changes in aridity, wind, continental

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precipitation [05] affect the amount and path of sediment transported into the ocean.

Concentration of terrestrial elements has been widely used to identify the source of terrestrial material to the ocean. According to Peterson [16] the increased concentrations of titanium (Ti) and iron (Fe) have been interpreted as an increase in siliciclastic inputs from fluvial sources. At the same time, Yarincik [21] and Kuhlmann [09] used potassium (K) as an indicator of Moroccan fluvial inputs that reflects humid terrestrial conditions. In fact, in most marine sediments, the coarse sediment fractions are enriched in the Ti [19], they are linked to chemical weathering under humid conditions [03]. While Si exists in all clay minerals, especially in quartz grains [15]. Moreover, other studies consider the chemical element ratios as more useful than single elements [20]. The element ratios such as Ti/Al, Si/Al, Ti/Ca, Fe/Ca, Zr/Al, Al/Ti, Mg/Al, K/Al, K/Ca and Rb/Al are the most commonly used for reconstruction of terrigenous inputs. For example, the Ti/Al, Si/Al and Zr/Al ratios have been used as a tracer for eolian dust input [21], while Fe/Ca, Ti/Ca, Mg/Al, K/Al, K/Ca and Rb/Al as indicators for fluvial input [19].

2. Material and methods

This study is focused on the analysis of continental surface sediments that were collected in 2017 in southern Morocco, in the Souss-Massa basin. The continental sampling was carried out during the ECHo sampling campaign within the framework of the Morocco-German program for scientific research PMARS III. These samples were taken from five sites located on different tributaries and rivers in southern Morocco (fig. 1). As well as land surface sediments from continental sediments, the samples studied in this study include marine surface sediments from different sites along the Moroccan Atlantic coast in southern Morocco. The five marine surface sediments used are recovered from the top 3 cm of several cores obtained during several Meteor cruises: M37/1, M45/5 and M58/2.

In this study, we used the XRF method to determine the chemical composition of all kinds of surface sediment materials. The XRF core Scanner at the University of Bremen is a common tool for a highly accurate and non-destructive element analysis system for surface sediments. The X-ray fluorescence spectrometer is equipped with a sample size and tube settings. It is used routinely for investigation of materials in different states: solid, liquid, powder, filtered or other form. The method is fast, accurate and non-destructive, and usually requires only a minimum of sample preparation.

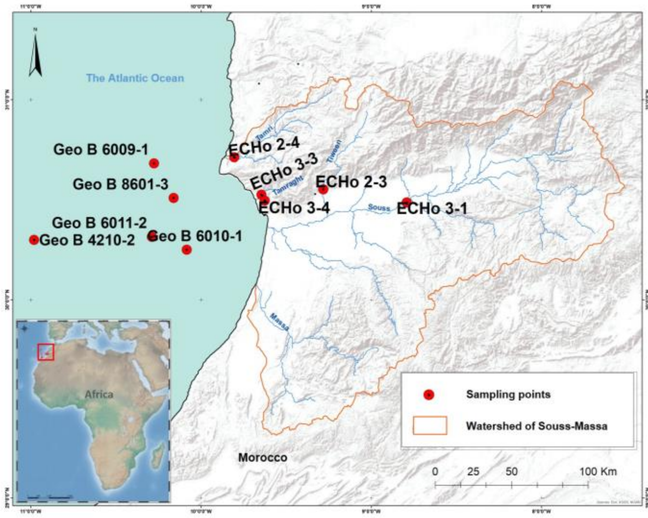

Fig. 1: Location of the sampling sites mentioned in this study

3. Results and Discussion

3.1. Results

3.1.1. Distribution of major and trace elements of continental sediments

The results below (fig. 2 and 3) show the distribution of chemical element concentrations in continental sediment. In the sample Echo2-3, we observed firstly, higher concentrations of Si, followed by average values of Ca, Al, Fe, K and Mg and lowest values of Ti and zero/null for Na. The sample Echo2-4 shows high concentrations of Si, a high concentration of Ca with intermediate values of some elements, such as, Al, Fe, K, Mg and Ti. In the Echo3-1 sample, we also found high concentrations of Si that reached higher values, followed by lower concentrations of Ca compared to the other samples. Al shows a high value too. The other elements Mg and Fr are also present in this sample at a moderate value. We cannot eliminate the presence of other elements such as Ti and Na, even if their concentrations are lower. While the Echo3-3 sample has a relatively similar distribution to the sample ECHo 2-4. The higher concentrations are that of Si, followed by the concentrations of Ca and Al. Elements such as Fe, K, Mg and Ti represent intermediate values respectively. Finally, in the Echo 3-4 samples, we observed a high concentration of Si, followed by Ca. Additionally, the average concentrations at Al, Fe Mg, and lowest concentrations for K and Ti. The values of trace elements in the five samples, such as Zr, Cr, Cu, Ni, Pb, Rb, V, Zn, Ba, Mn, P, S, and Sr generally vary between low to lowest concentrations (fig. 3).

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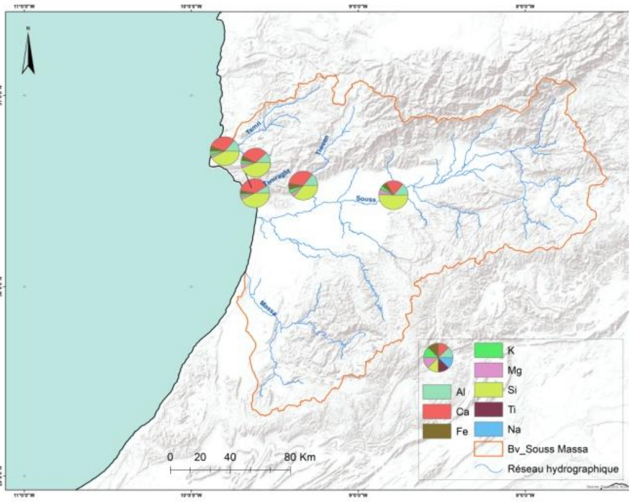

Figure 2: Spatial distribution of major element of continental sediments (mg/kg).

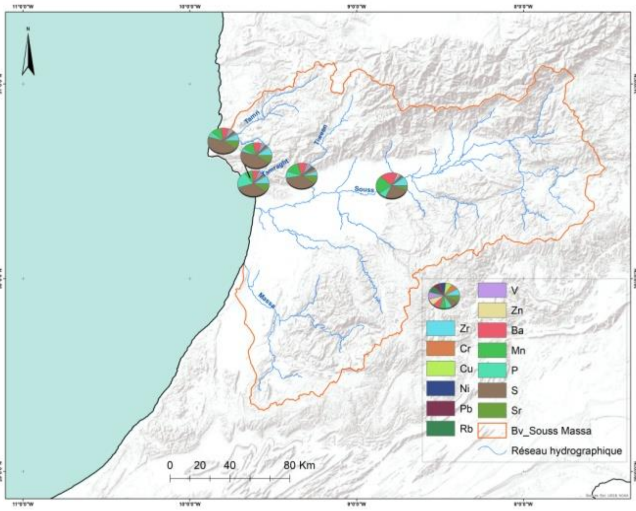

Figure 3: Spatial distribution of trace elements of continental sediments (mg/kg).

3.1.2. Distribution of major and trace elements of marine sediments

Figures (4 and 5) shows the distribution of major and trace element concentrations (mg/kg) of surface marine sediments in the southern Moroccan Atlantic coast. We observe firstly, very similar distributions of the terrigenous elements of Ca, Al, Fe, Ti, Si, Mg. Secondly, a clearly opposite distribution of Ca. The Ca exhibits the lowest concentrations along the Moroccan margins and the highest concentrations farther from the continental margins. Thus, low Ca concentration is parallel to high concentration of terrigenous elements, in particular in areas close to the mouth of the Souss, Tamri and Tamraght rivers. Indeed, the Ca distribution of surface sediments in the Moroccan Atlantic coast follows the distribution of the carbonate content [02]. Most of the Ca contained in Atlantic surface sediments can be assigned to carbonates, probably of marine origin. The contents of terrigenous elements are higher near the Moroccan continental margin. Therefore, these results indicate a clear imprint of terrigenous inputs and the elemental composition of surface sediments located on continental margins (fig. 4).

Additionally, the other trace elements Zr, Cr, Cu, Ni, Pb, Rb, V, Zn, Ba, Mn, P, S, and Sr are generally low in these marine samples. With high intensities of S, P, Mn and Ba, but the other trace elements are very weak and/or zero, as for Pb and Ni (fig. 5).

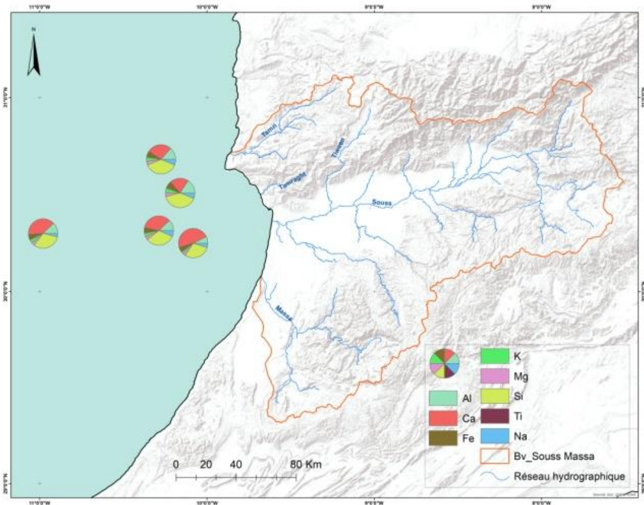

Figure 4: Spatial distribution of major elements of marine sediments (mg/kg).

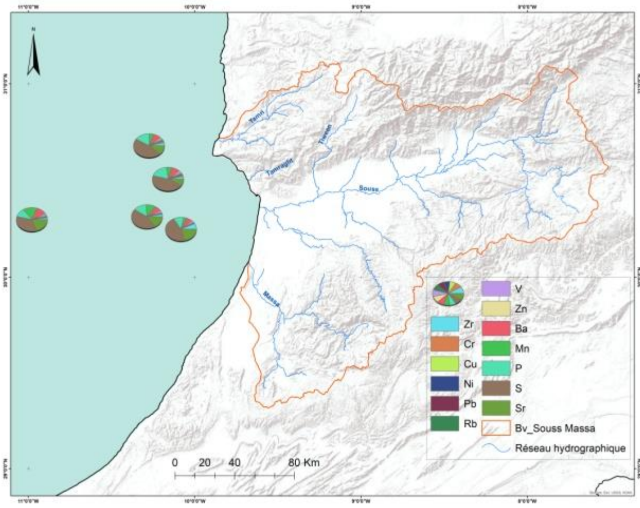

Figure 5: Spatial distribution of trace elements of marine sediments (mg/kg).

3.2. Discussion

3.2.1. Geochemical elements as proxies for terrestrial climate

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All sites located along the Moroccan continental margins have relatively high concentrations of terrigenous elements (fig. 4), with a low content of Ca. Ca concentrations are interpreted as representing the carbonate component deposited at the site. The low values are located near the highly productive Cape Ghir upwelling area; they likely represent marine productivity [09]. We note here that the elemental ratio of Ca do not clearly reflect the amount of terrigenous material deposited on the sea floor. It rather reflects a significant amount of terrigenous input compared to the marine content. Because of this, the concentration of Ca in the sediment depends on changes in marine carbonate productivity and dissolution. The K is generally associated with terrestrial siliciclastics such as illite clays and potassium feldspar [12]. On the one hand, potassium is frequently used to study climate change (arid/humid) in a source region [09] and, on the other hand, to identify source regions of Aeolian dust. There are higher values of potassium in the highly productive Cape Ghir upwelling region. Which explains the high concentrations of K, because this region is located at the mouth of several rivers of southern Morocco (fig. 1).

The distribution of Al contents shows the highest values at Cap Ghir, and the lowest values are recorded in the open ocean (figure 4). Many previous studies have linked Al to intense chemical weathering, producing kaolinite and smectite clays [22]. Potassium (K) and aluminum (Al) are all prolific in the clay minerals, with lesser contributions from feldspars and zeolites, and potassium is mainly present in illite, while aluminum is abundant in all clay minerals [04]. Illite is generally a weathering product in temperature in arid climates where physical weathering is strong, but chemical weathering is weak. Kaolinite is generally a weathering product of chemical weathering in tropical and humid climates [21]. The Fe concentrations also represent relatively high values in the same region (Cap Ghir) and the same distribution as K and Al, in this case. It could be like iron oxy-hydroxide. While, Ti reflects high values along of continental margins and low values far from continental margins. Ti is much less susceptible to diagenesis than Fe. Additionally, the Mg and Rb recorded high values, in particular on site at Cap Ghir. This region mostly receives material mainly from the rivers of southern Morocco, which explains the increase in Mg and Rb in this region. Finally, high values of Si are recorded at sites located along the Moroccan continental margins (figure 4), in particular closer to the mouth of the south Moroccan rivers and relatively at the margins of the Canary Islands. These areas are characterized by a high marine productivity [11], which explains the high Si concentrations of surface sediments. They are therefore located in a region of high siliceous productivity and receive significant input.

3.2.2. Elements ratios of marine sediments represent another proxy of terrestrial input

We present in this study the elements ratios: K/Ca, K/Al as indicators of relative humidity and Si/Al and Ti/Al as Saharan dust tracers.

The spatial distribution of K/Ca ratios shows the highest values in the Cap Ghir region (figure 6). It is assumed that the increase in river inputs of terrigenous materials plays an important role in this region. This interpretation is supported by studies showing that sediment is discharged into the Atlantic Ocean closer to the mouth of the Souss River [07]. In addition, particle size analysis of surface samples in this region is in agreement with these results [07]. These authors have shown that the fine-grained fraction representing river-sourced mud is confined to the area off Cape Ghir, where it constitutes up to 90% of the relative sediment composition. The illite content of marine sediments impressively reflects the percentage and distribution of terrigenous particles introduced by river transport. Significantly increased K/Al ratios of the surface sediments suggest such a fluvial supply. The highest K/Al values are found along the south Moroccan coast (especially between ~32°N and ~29.5°N). It is suggested that two different transport mechanisms (Aeolian and/or fluvial supply) can be responsible for the observed distribution pattern. The geological characteristics in the study area also play an important role when interpreting the K/Al results (fig. 7). Higher values of the Ti/Al ratios observed in some samples indicate the influence of dust from deserts, which could be poor in illite.

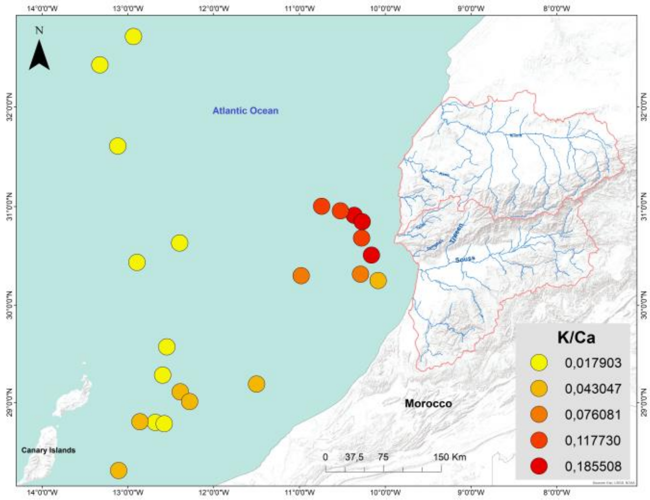

Figure 6: Spatial distribution of K/Ca ratios (mg/kg).

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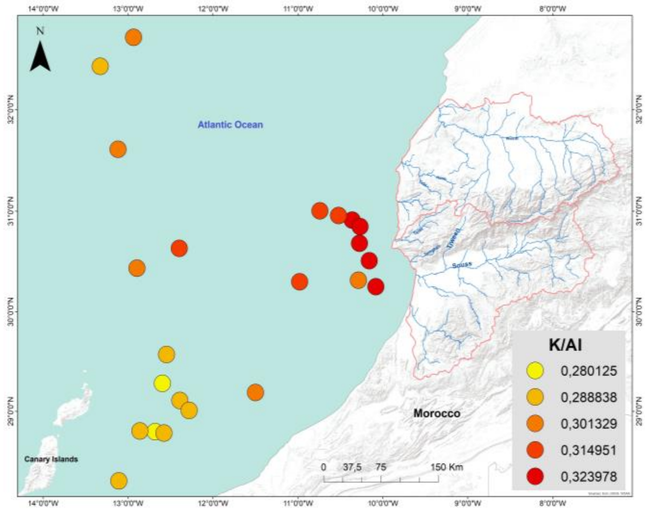

Figure 7: Spatial distribution of K/Al ratios (mg/kg).

The Ti/Al ratio of the surface sediment in the study area shows low values in regions dominated by the input of suspended material along the south Moroccan coast (fig. 8), especially from Tamri, Souss and Tamraght rivers. The distribution of Ti/Al generally represents low values off Cape Ghir and relatively high values north of the Canary Islands. High Ti/Al values indicate an increased contribution of dust input relative to the supply of river suspension matter. It is assumed that the observed distribution pattern can be related to the difference between the mineral assemblage coming from the volcanic basalts and gabbros from the islands [10] and potential from Saharan sources (mainly clay minerals, calcite and quartz). Therefore, surface samples from islands close to the NW African coast are characterized by lower values. Thus, the values of the Ti/Al ratios of surface samples are relatively high; this increasing distance leads to the dominance of Saharan dust as a main source of lithogenic material from the African continent increasing proportionally with the distance from the coastal zone. As well as lateral advection has to be taken into account; it is possible that bottom currents will transport the heaviest grains to deeper oceans [18]. It is important to note that the distribution of the Ti/Al ratios could reveal the different source regions. In addition, the distribution pattern of these element ratios represent the different transport mechanisms, climate types, geology and soil compositions [18].

In addition, according to many authors, silicon and aluminum in the study area are present in detrital clay minerals, zeolites and feldspars. As regards the distribution of the Si/Al ratio, the latter generally represents low values along the Moroccan Atlantic coast and relatively high values in the north and east of the Canary Islands (fig. 9). Indeed, Si in marine sediments is mainly derived from aluminosilicates and quartz. The Si/Al ratio indicates the relative proportion of quartz in aluminosilicates and has been widely used in the study of coastal paleo-records of southern Morocco [23]. Thus, the arid phases are characterized by an increase in the amount of aeolian quartz.

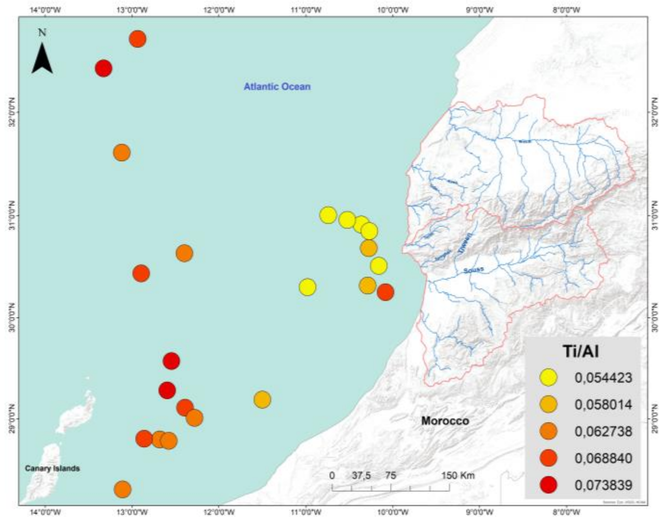

Figure 8: Spatial distribution of Ti/Al ratios (mg/kg).

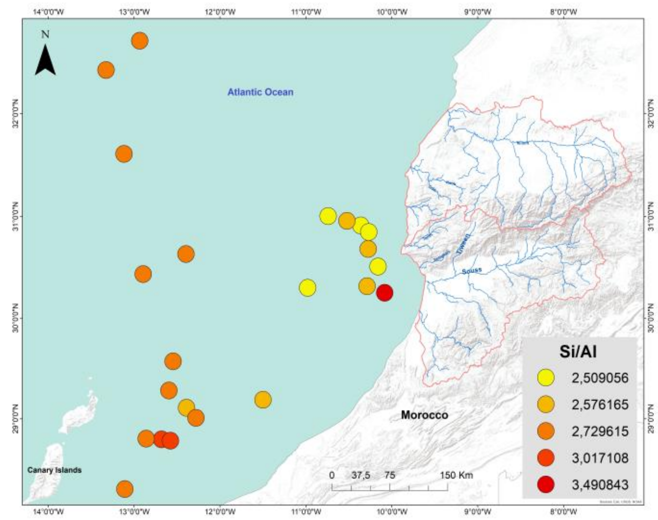

Figure 9: Spatial distribution of Si/Al ratios (mg/kg).

4. Conclusion

The spatial distribution of geochemical element data of marine and continental surface sediments in the south Moroccan reflects relatively coherent terrigenous compositions characterized sediments from site to site. The sedimentation in the study area is affected by a complex interaction of Aeolian and fluvial input from two mainly different source regions: Saharan-desert and Atlas Mountains rivers. There are many factors influencing their distribution characteristics, such as geology, topography of rivers drainage basins and diagenetics. Therefore, in

order to apply these proxies to climate reconstruction, we must consider these factors.

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