

Spectral Analysis of a Core from the Sebkhah of Sidi Mansour, Southern Tunisia: The Holocene Cyclostratigraphy

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Abstract

The Milankovitch Theory explaining the ancient cyclostratigraphy does not file a case for the Holocene cyclostratigraphy. Instead, other astronomical and oceanographic mechanisms control the cyclicity within Holocene sediment. This work aimed to find out the climatic cyclicity along a core from the sebkhah of Sidi Mansour located along the Mediterranean coast in Tunisia, through using different proxies: the magnetic susceptibility, carbonate percentages and chemical elements (Ca, Na, and K). Based on previous radiocarbon and tephrochronological dating in the study area, the core was estimated to cover the two last millennia with a sedimentation rate of 0.35 mm/yr. This rate allows the elaboration of a depth-age model to carry the spectral analysis. Not all the proxies visualize the same climatic cycles. For instance, the spectral analysis of the magnetic susceptibility and Sodium data visualized a 1000 yr cycle. The spectral analysis of Potassium data did not visualize significant cycles. The spectral analysis of the carbonate percentages and calcium data visualized dual cycles of 1700-700 yr and 493-329 yr respectively. The about 500 yr and 1000 yr cycles are related to Sun activity. Other oceanographic and atmospheric factors could generate other cycles of 1700 yr, 700 yr, 493 yr, and 329 yr. The majority of these cycles were worldwide recorded as interplay between the oceanography and the solar forcing. Contrary to the earth-driven cyclostratigraphy related to orbital parameters and geographical positions, the Holocene cyclostratigraphy is sun-driven.

Keywords: Sun-driven cyclostratigraphy; Holocene; Sebkhah of Sidi Mansour; Southern Tunisia

Introduction

Sun activity and its effect on climatic cyclicity

The Milankovitch Theory explaining the ancient (e.g., Cretaceous and Miocene) cyclostratigraphy does not file a case for the Holocene cyclostratigraphy. For instance, the decadal to millennial scales cycles of the Late Holocene sediment in lakes and sebkhahs recorded based on geophysical and geochemical parameters were less than likely explained by this Theory. Instead, other astronomical and oceanographic causes have been recently highlighted to explain short climatic cycles [1-6]. As a matter of fact, Sun activity and its effect on climatic cyclicity have gained univoqual popularity. The short term cyclicity of Sun activity is inferred through sunspots number and activity. The Schawbe cycle (9 to 14 yr with an average of 11 yr) [7-9] is governed by the Sun internal dynamics whereas the 22 yr Hale cycle is linked to solar convection [10]. The Gleissberg cycle (87 yr) is due to the variability in Sun diameter [11]. Other cycles such as that of Vriès (210 yr) are still unknown [12]. These cycles are directly seen through telescopic sunspots and historical naked-eye sunspots observations of solar activity. Other proxies including the cosmogenic isotope ^{10}Be , cosmogenic isotope ^{14}C and the climate record allows inferring the longer cyclicity of Sun activity [7-12 and reference therein]. Nonetheless, climatic cyclicities are not always related to Sun activity. Instead, other oceanographic and atmospheric mechanisms and processes created hybrid cycles [6]. For instance, in the westernmost Mediterranean Sea, major periodicities at 1300 yr and 1515 yr, linked with North Atlantic climate variability and the African monsoon system were found out along the past 20,000 yr. Other major periodicities of 2000 yr and 5000 yr are related to solar activity. Minor secondary millennial to centennial cycles stretching along 650 yr, 1087 yr, and 3000 yr are still unknown [13]. In this work, the aim was studying the Holocene cyclostratigraphy along a core from an endorheic system (sebkhah Sidi Mansour) located at the coast of the Mediterranean Sea.

Study area: The Gulf of Gabes within a Mediterranean Sea and Atlantic Ocean connection

The focus on the Mediterranean regions is due to its sensitivity to global climate changes as result of being a semi-enclosed basin [6]. The Mediterranean Sea is hydrologically and climatically depending on the Atlantic Ocean. During the few geological periods in which it behaves as a stand-alone basin, such as the Messinian Salinity Crisis, the Mediterranean Sea totally dried and its coastal regions were dominated by an arid climate [14]. Currently, the Atlantic Ocean feeds it with constant quantities of water through Gibraltar (Figure 1a). This connection ensures that the climate at coasts (exoreic and endorheic systems) of the Mediterranean Sea is controlled by solar activity as well as the oceanographic circulation. Depending on their geographical position, relative to the sea, we can distinguish three kinds of systems: exoreic (e.g., Chaffar system), semi-exoreic (e.g., El-Guettiate) and endorheic (e.g., Sidi Mansour and Mhabeul sebkhahs) systems (Figure 1b). The exoreic systems are regarded as coastal marine processes having close relation with the sea, whereas endorheic systems never have a link to the sea due to the uplifted reliefs avoiding any contact. On the other hand, semi-exoreic systems consist of a continental side out of reach of sea water and a marine side occasionally or permanently covered by water.

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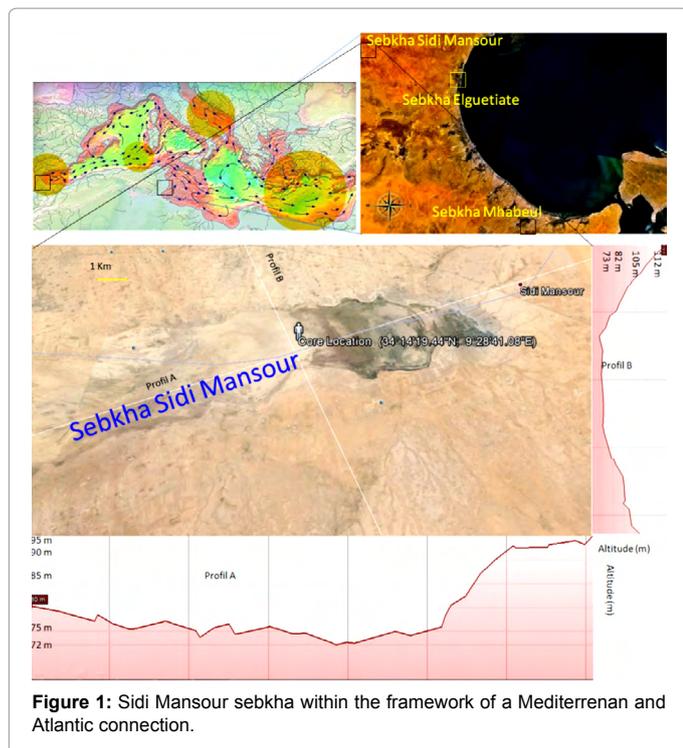


Figure 1: Sidi Mansour sebkhha within the framework of a Mediterranean and Atlantic connection.

The sebkhha of Sidi Mansour is located in the south of Tunisia, belonging to the Gafsa governorate. It is an inland system which is characterized by a semi arid climate. The topographic profiles (Figure 1c and 1d) show an average altitude ranging between 70 m and 85 m. The sebkhha El-Guettiate is located on the coastline of southeast Tunisia. It is a semi-inland system having continental and marine sides. In this work, we use the dating core to estimate the depth-age model at sebkhha Sidi Mansour. The 4-km² sebkhha Mhabeul is located on the northern edge of the coastal Djefara plain (Figure 1b). The sebkhha is disjointed from the eastern larger sebkhha of Melah by an accumulation of upper Pleistocene sediments, which avoid any connection of the former to the sea. Its sedimentation mode is mainly controlled by precipitation and runoff from small hydrographic networks. This sebkhha was also used to estimate the depth-age model at sebkhha Sidi Mansour.

Methods and Materials

During field expeditions, an 80 cm core was carried out in the sebkhha of Sidi Mansour (Figure 1e). Within laboratory, the sampling was carried out each 0.5 cm to obtain 160 samples. Then, we carry out the measurement of the magnetic susceptibility MS, CaCO₃ percentage and concentrations of chemical elements.

As geophysical parameters, magnetic properties of soils are differently used in earth and environmental sciences. High values of the magnetic susceptibility are attributed to a continental depositional of ferrimagnetic and ferromagnetic minerals such as clayey minerals. Low values of the magnetic susceptibility due to the sedimentation of diamagnetic minerals such as carbonate and quartz. The low frequency MS were measured by the Bartington MS2B probe in the laboratory of Sedimentary Dynamics and Environment, National engineering School of Sfax. The samples were packed into 10 cm³ cylindrical perspex pots for MS analysis. The carbonate percentage is the measuring of CaCO₃ percentage in sediment by Bernard calcimeter. Chemical elements including K, Na, and Ca were measured by Flame Photometer. To

interpret results, we started first by introducing the geochemical convolution. The sodium has always the higher percentage than calcium and potassium with coefficient of ten as indicated in works of Tagorti et al. [15,16]. Therefore, to improve the significance of the minor fraction on the identification of climatic change condition, we supposed the convolution term which has as mathematical definition the equation below:

$$\text{Convolution term} = (\text{calcium rate} \times 10) + (\text{potassium rate} \times 10) + (\text{sodium rate}) \quad (1)$$

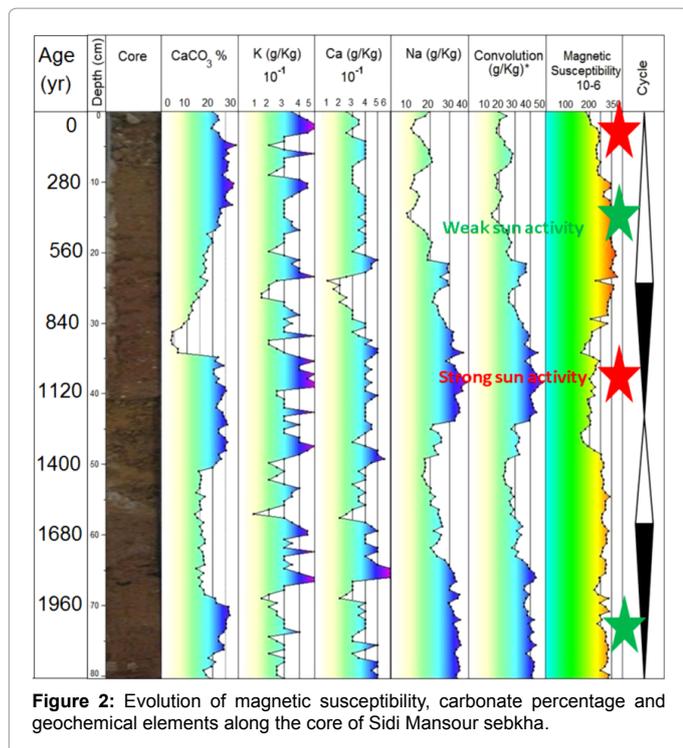
As for data treatment, the simple spectral analysis and sinusoidal fitting was carried out through PAST software. Concerning the spectral analysis, PAST includes the Lomb periodogram algorithm for unevenly sampled data [17], with time values given in the first column and dependent values in the second column. The data are automatically detrended prior to analysis. The highest peak in the spectrum is presented with its frequency and power value, together with a probability that the peak could occur from random data. The 0.01 and 0.05 significance levels are shown as dashed lines. For the time series analysis, we need dating to find out temporal climatic cycles. In our present work, we have no precise dating. Nonetheless, the rate of sedimentation in endorheic Tunisian saline systems may be estimated based on the dating of cores collected from sebkhhas of the same region namely the sebkhhas of Mhabeul and El-Guettiate (Figure 1b). For instance, tephrochronological dating indicated that the rate of sedimentation during the Late Holocene at sebkhha Mhabeul was in the range of 0.33 mm/yr [3] and 0.37 mm/yr [18]. In the continental side of sebkhha of El-Guettiate, the radiocarbon dating indicated that the rate of sedimentation during the Late Holocene was in the range of 0.32 mm/yr [19] and 0.38 mm/yr [20]. Based on mean rate of sedimentation of 0.35 mm/yr, we can adopt an age-depth model to carry out the temporal spectral analysis in sebkhha Sidi Mansour.

The Principal Component Analysis PCA of the magnetic susceptibility MS, carbonate percentage CaCO₃, calcium Ca, and sodium Na and potassium K rates was computed and plotted in the plane of the first two statistical factors.

Results and Discussion

Values of the magnetic susceptibility along the core from the sebkhha of Sidi Mansour show 2 obvious cycles (Figure 2). The first stretches on 45 cm; it consists of two parts. The first part (25 cm) is characterized by a downward increasing of the magnetic susceptibility due to the coming of ferromagnetic and ferrimagnetic minerals from continental vicinity. As it was proven by Boyle et al. [21], we can interpret this increase in magnetic susceptibility as a result of wet climatic conditions, which are the responsible agent for reaching the sebkhha by an amount of detritic material via Wadis. This amount may be originated from Djebels surrounding the sebkhha system which is considered as depression or local base level receiving sediment supply. The second part ranging from 25 to 45 cm is characterized by low values of magnetic susceptibility, due to the deposition of diamagnetic mineral like carbonate. Thus, a dry period is accountable for this drop which allows the sedimentation of diamagnetic minerals. A second cycle stretches to the bottom of the core.

Along the core, the percentage of CaCO₃ presents a fluctuation and values ranging between 10 and 30 percent (Figure 2). Indeed, the first 35 centimeters are characterized by a high percentage of carbonate with average rate of 25%. The second interval stretches until 50 cm characterized by a decrease in carbonate percentage. To the end of the core, the first and second intervals are repeated as indication of the



setting of the conditions revealing at the top of the core. We note that the variation in carbonate percentage is probably due to Sun activity. Thus, high values are indicators of arid climate, whereas low values are indicators of humid climate.

The geochemical study dealt on three elements: sodium, calcium and potassium. Indeed, the results prove that sodium is the most representative elements, whereas calcium and sodium exist with minor proportions. The calcium rate shows a little variation as indicated (Figure 2) and values range between 0.2 and 0.6 g/kg. Thus, the proportions along the core are very low unlike the carbonate percentage which presents a relative high rate. Therefore, we could say that the rate of calcium is not only related with carbonate, while it could also be probably linked to the existence of gypsum fraction (CaSO₄). Along the core, the proportion of potassium (K) presents low values that range from 0.1 to 0.5 g/Kg with slight fluctuation. This fraction is probably due to the existence of KCl. Values of sodium content show an obvious oscillation. Thus, the rate of sodium presents two intervals of decrease which stretch between 0-25 cm and 43-60 cm, characterized by an important amount of sodium with average of 30 g/Kg. Between these two intervals, we note a increase in the sodium proportion and values exceed 30 g/Kg. At the end of the cores, this interval is repeated as indication of periodicity. We deduce then that rate of Na had a close link with precipitation of salt mineral (NaCl), thus, the periodicity shown in the graphic is probably due to change in climatic conditions which explain the fluctuation of sodium rate. Subsequently, oscillation may results from period of Sun activity. Indeed, in arid period we distinguished a precipitation of high amount of (NaCl), while in humid period the decrease in the rate of salt can be identified.

Along the core, the convolution term shows a significant fluctuation. Thus values allow subdividing the curve on 4 parts. The first part stretches on 20 cm, characterized by low values, ranging around 20 g/kg. The second part, stretching on 23 cm, presents an increase in the

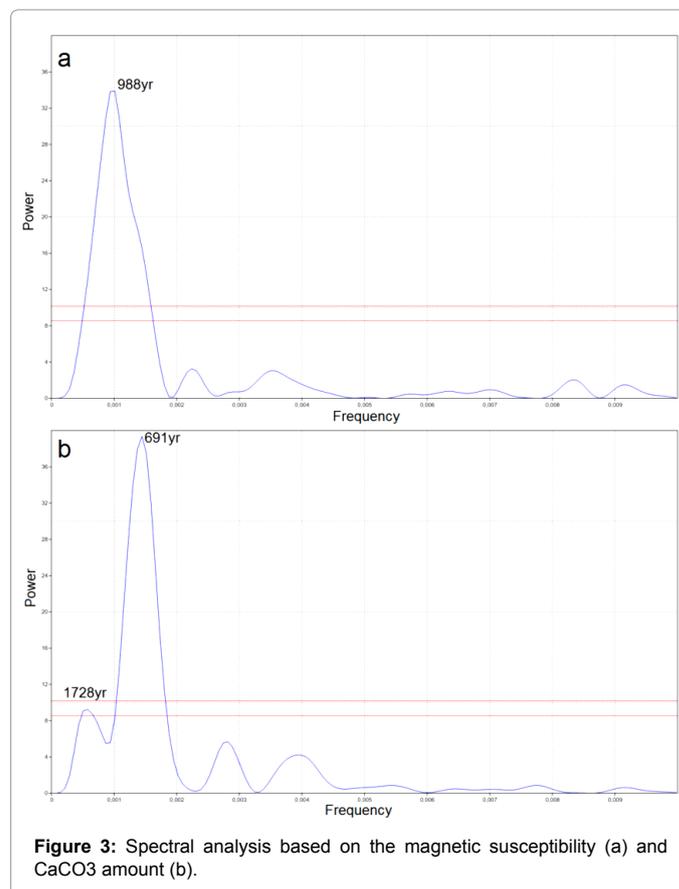
rate and values ranged around 40 g/Kg. The third and the fourth part show respectively a similar evolution to the first and the second parts.

Cyclostratigraphy based on the magnetic susceptibility and CaCO₃ percentages

The cyclicity obviously identified along the core may be found out through the spectral analysis of data of the different parameters. First, the spectral analysis of Potassium data did not visualize significant cycles. The spectral analysis of data of the magnetic susceptibility shows the individualization of a cycle stretching along about 1000 yr (Figure 3a). Within sebkhah Mhabeul, the about 1000 yr cycle was found out based on the magnetic susceptibility data [3]. This also confirms the age-depth model used to estimate the dating at sebkhah Sidi Mansour. On the other hand, the spectral analysis of data of the carbonate percentages shows the individualization of two cycles stretching along about 1700 yr and 700 yr (Figure 3b). The 700 yr cycle is barely ascribed to the second harmonic of the 1500 yr cycle in oceanic thermohaline circulation [22]. This cycle may also indicate a tight linkage between the Indian Ocean and African rainfall, and could result from coupled ocean-atmosphere variability inherent to the tropical monsoon system [23]. As for the 1700 yr cycle, [24] highlighted a 1660 yr frequency based the study of sediment color as a proxy of carbonate content. This is also confirmed along a core from Iceland with a 1700-years cycle in the *Emiliania Huxleyi* concentration record, a proxy of surface hydrology [25].

Cyclostratigraphy based on chemical elements Ca and Na

Ca was used as proxy for the presence of the two first precipitated evaporitic minerals calcite and gypsum. Na was used as a proxy for

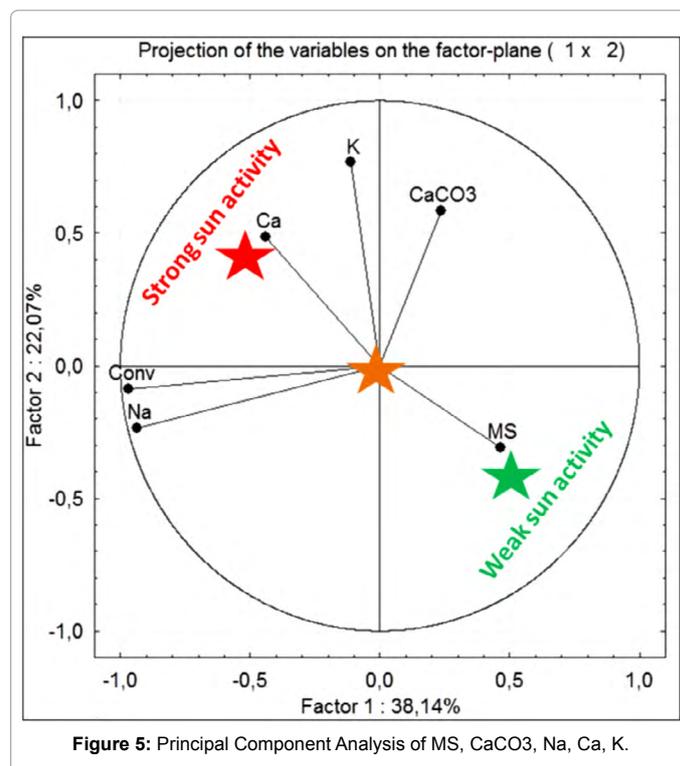
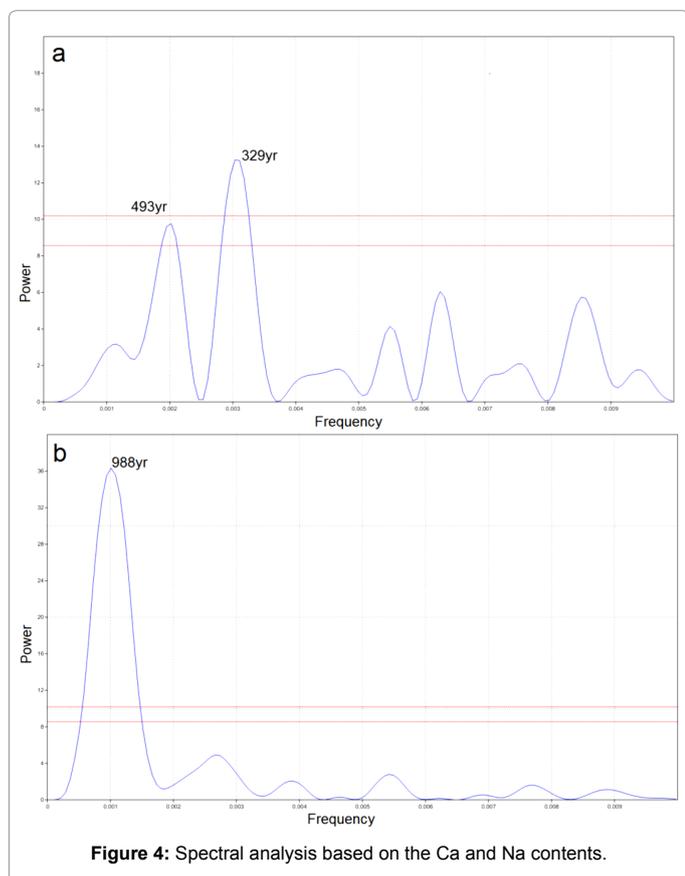


available moisture because the principal source of Na is plagioclase feldspar that is easily decomposed by hydrolysis with sufficient available moisture, releasing Na [26]. The spectral analysis based on Sodium shows the individualization of a cycle stretching along about 1000 yr (Figure 4). On the other hand, the spectral analysis based on Calcium shows the individualization of two cycles stretching along about 500 yr and 350 yr (Figure 3b). The about 500 years was recorded in many other studies [27]. But a cyclicity of about 350 yr was never recorded in the literature.

The Principal Component Analysis of different parameters PCA (factor1×factor2) of five parameters (Figure 5) magnetic susceptibility, carbonate percentage, calcium, and sodium and potassium rate of Sidi Mansour sebkhah proves that magnetic susceptibility is anti-correlated with rate of sodium, the convolution term and the carbonate percentage. The PCA has proven that climatic variability shown in magnetic susceptibility as indicator of climatic change can be explained by the fluctuation of carbonate percentage. Indeed, during the humid period, the sediment supply coming from continental vicinity through hydrographic network increase the rate of magnetic material and causes the dissolution of CaCO₃ and salt mineral. While during arid period, a decrease in values of MS due to the deposition of diamagnetic material such as carbonate and quartz, whereas the CaCO₃ percentage, and halite mineral rate shown a significant increase is explained by the drop of stream and river activity.

Conclusion

The study of the sebkhah Sidi Mansour, considered as inland system along the Mediterranean coast, through the investigation of magnetic susceptibility, carbonate percentage, and geochemical elements, show



the identification different climatic cycles. The spectral analysis of the magnetic susceptibility and Sodium data visualized a 1000 yr cycle. Potassium data did not visualize significant cycles. The spectral analysis of the carbonate percentages and calcium data visualized dual cycles of 1700-700 yr and 493-329 yr respectively. Sun activity generated 500 yr and 1000 yr cycles whereas the oceanographic circulation between the Atlantic Ocean and the atmospheric link between the Indian Ocean and African rainfall generated other cycles of 1700 yr and 700 yr. The 329-350 yr cycle has never been discussed in the literature; it may be an artifact. Nonetheless, further coming studies should verify and deny the presence of this cyclicity. Nonetheless, the majority of recorded Holocene cycles were worldwide recorded regardless of the geographical position. Contrary to the earth-driven cyclostratigraphy advocated by the Milancovitch Theory, the Holocene cyclostratigraphy is sun-driven since it is mainly governed by the Sun and has no relation with terrestrial orbital parameters and geographical positions.

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