Record of the Anthropocene-Great Acceleration along a core from the coast of Sfax, southeastern Tunisia

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Abstract

This work is aimed to investigate radical changes in the sedimentary filling of the subtidal coast of Sfax using a 68 cm-long core to study the onset and the limit of the Anthropocene-Great Acceleration within this wetland located in Tunisia. The sampling was done 2 cm intervals to obtain a total of 34 samples. The measurement of the magnetic susceptibility along the core showed an obvious upward increasing related to high content of heavy metals. Also, the distribution of clay, silt and sand percentages showed an increasing sediment flux which took place on the deltas during the Anthropocene-Great Acceleration. The Principal Component Analysis indicates that some variables related to pollution; others are related to eustatism and/or climate change. This may be caused by the overlap of the natural and anthropogenic activities during the Anthropocene-Great Acceleration. Clustering shows the individualization of the Anthropocene-Great Acceleration strata comparably with the Holocene. The application of the Climate Change and Impact Research: the Mediterranean Environment (CIRCE) project climate models shows that the Anthropocene-Great Acceleration is marked by an increase of the sea surface temperature and the number of alien species. Future simulations indicate that the case is candidate to worsen at the perspectives of 2050.
Key words: Anthropocene-Great Acceleration, geochemistry, grain size distribution, the subtidal of the coast of Sfax, southeastern Tunisia

1. Introduction

The contamination of surface sediments in coastal regions of Tunisia shows the current pollution threatening in the region (e.g., Gargouri et al., 2011; Ghannem et al., 2011, 2014; Mosbahi et al., 2019). Compared worldwide, this pollution is related to the industrial activities taking place since the beginning of the Anthropocene (Waters et al., 2014; 2016), which was also marked by obvious modifications of the climate (Hébert and Lovejoy, 2016). Actually, the Anthropocene is a geologic epoch related to the setting of obvious anthropogenic effects on the environment (Yusoff, 2013; Young et al., 2016). Recently, it has become in the heart of earth and environmental sciences (Crutzen, 2006). In this vein, some micro-biofacies marking this epoch were found (Wilkinson et al., 2014). Nonetheless, until the release of the last report in 2019, the International Commission of Stratigraphy and the International Union of Geological Sciences has not approved the term as official subdivision of the geological scale (Castree, 2017). Due to the different criteria and disciplinary perspectives, different controversial dates were proposed to mark the beginning of the Anthropocene. The term “Anthropocene” was first proposed to identify the latter part of the 18th century as boundary between the Holocene and Anthropocene (Crutzen and Stoermer, 2000). In this period, the global effects of human activities were obviously recorded. Then, Certini and Scalenghe (2011) had rejected the use of atmosphere greenhouse gasses increase related to the industrial revolution as an onset marker of the Anthropocene. Instead, they attributed, based on the anthropogenic soils, the beginning of the Anthropocene to approximately 2000 yrs B.P. After reviewing previous works related to the setting of the Anthropocene, Smith and Zeder (2013), controversially with Waters et al. (2016), proposed that the Anthropocene is equivalent to the Holocene. In terms of natural environmental
conditions, climate and sea level variations in coastal areas during the Anthropocene have not been expressed as they reflect the interplay of slow and fast climate processes. The Anthropocene limit depending on the region has been one of the difficulties of its definition as geologic era. In spite of the controversy, some features were commonly considered as indicator of the setting of the Anthropocene: polluted environment, climatic change and eustatic variability. On the other hand, the Great Acceleration is an emerging concept describing collected data documenting the increase of anthropogenic pressure on Earth (Steffen et al., 2015). The abrupt increase of most environmental parameters related to pollution and climate change taking place since ca. 1950 has been linked to the increasing effect of human populations on Earth’s systems (Zalasiewicz et al., 2012). Chronologically speaking, the Great Acceleration is imbedded within the late Anthropocene.

Although no precise dating is available, this work aimed to show a radical variation of sediment and water geochemistry (heavy metals content) as related to increasing anthropogenic activities during the Anthropocene-Great Acceleration. Such activities resulted in a great acceleration in the increase of curves of all parameters.

2. Study area

Located in south-eastern Tunisia (Figure.1), the coast of Sfax is the outlet of the drainage basin of Chaffar (Figure.1b,c,d). The semi-arid Mediterranean climate characterizing the region is influenced by (i) a gentle and mild topography varying between 225 m and 0 m (Figure.1a) (Smida et al., 2006) and (ii) the maritime effect. Along the drainage basin of Chaffar, a developed hydrographic network including converges toward the base level of the Mediterranean Sea (Figure.1c). The vast plains of Sfax contain different soils rich in silica, limestone and gypsum. Along the drainage basin of Chaffar, outcropping clayey, silty, and sediments crusted with carbonate and gypsum are basically of Holocene and Upper Pleistocene ages. Also, some Messinian sediments outcrop due to erosion of recent sediments
Over this region, the average annual precipitation reaches 200 mm/yr. The coast of Sfax has witnessed ever increasing urbanizing activities (Figure 1). The southern coast contains, in particular, a site of collecting wastes of the town of Sfax, the liquid and solid rejections of SIAPE (Société Industrielle d’Acide Phosphorique et d’Engrais). Heavy metals concentrations of (Cd, Cr, Zn, Cu, Ni, Pb, Fe and Mn) in surface of the coast of Sfax were studied (e.g., Ghannem et al., 2011) to evaluate the degree of contamination of surface sediment by metals. For instance, Ghannem et al. (2011) noticed a wide spatial variation in metals concentrations of two different groups. The first group made of Fe and Mn was originated from natural sources. On the other hand, the Cd, Cr, Zn, Ni, Cu and Pb elements consisting the second group resulted from anthropogenic sources. Such activities resulted in sediments contamination especially those located close to the coast. In addition, the coast of Sfax is characterized by the contamination with hydrocarbons probably of the Arabian light crude oil type (Louati et al., 2001). Being part of the eastern side of the Mediterranean basin, the coast of Sfax experienced global modification of the depositional environment due to major climate changes during the Holocene and Pleistocene. Thus, the region is the recorder of global climatic changes as well as localized polluting activities.

3. Materials and Method

During field expeditions (November 2017), a 68 cm-long core was recuperated based on rotation-penetration of a 63 mm diameter plastic tube. Within laboratory, the sampling was carried out at 2 cm intervals to obtain 34 samples. The grain size distribution measurements and the magnetic properties (Low Frequency (LF) and High Frequency (HF) magnetic susceptibility (MS)) were evaluated by FRITSCH laser granulometer and Bartington MS2B probe, respectively. The results were expressed as mass susceptibility High Frequency Magnetic Susceptibility (XHF) and Low Frequency Magnetic Susceptibility (XLF). The frequency-dependent susceptibility was obtained as difference percentage: XFD = (XLF –
In addition, clay, silt and sand percentages were found out from the cumulative curves (Folk, 1974; Folk et al., 1970). After tri-acids (Nitric HNO₃, perchloric HClO₄, chloridric HCl) attack of dry and powdered sediment, the heavy metals concentrations (Ni, Cr, Zn, Cu, Cd, Al, Fe) were measured by Atomic Absorption Spectroscopy (ZEEnit 700 spectrophotometer, Analytik Jena) and a geoaccumulation index (Geo Index) was evaluated according to Müller (1981) to determine the heavy metal pollution and thus the metal contamination degree in sediments by the comparison of the current concentrations with preindustrial values. This index was calculated according to the following formula. Geo Index=\log_2(Cn/1.5*Cbn): where Cn is the concentration measured of the examined metal (n) in the sediment. Cbn is the background metal (n) concentration. Taking into account lithogenic effects, 1.5 is the background matrix correction factor. Based on Müller scale (1981), different levels of contamination may be shown (Tab.1).

**Table 1: Sediment classes according to Müller (1981)**

<table>
<thead>
<tr>
<th>Geo Index value</th>
<th>Class</th>
<th>Quality of sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0</td>
<td>0</td>
<td>Unpolluted</td>
</tr>
<tr>
<td>0-1</td>
<td>1</td>
<td>From unpolluted to moderately polluted</td>
</tr>
<tr>
<td>1-2</td>
<td>2</td>
<td>Moderately polluted</td>
</tr>
<tr>
<td>2-3</td>
<td>3</td>
<td>From moderately to strongly polluted</td>
</tr>
<tr>
<td>3-4</td>
<td>4</td>
<td>Strongly polluted</td>
</tr>
<tr>
<td>4-5</td>
<td>5</td>
<td>From strongly to extremely polluted</td>
</tr>
<tr>
<td>More than 5</td>
<td>6</td>
<td>Extremely polluted</td>
</tr>
</tbody>
</table>

Not only analytical techniques are useful for detecting the Anthropocene-Great Acceleration signal. Instead, some computing and statistical methods such as the Clustering Techniques (CT) and the Principal Component Analysis (PCA) could help to set a standalone
population showing the individualization of anthropogenic samples. To link parameters related to the Anthropocene-Great Acceleration, the PCA of the LFMS, HFMS, FDMS, heavy metals (Cr, Fe, Cu, Zn, Ni), geoaccumulation indices, clay, silt and sand percentages all was computed and plotted in the plane of the first two statistical factors. Highlighting pollution and following its origins, clustering techniques has recently emerged as the most used to, identify the Anthropocene-Great Acceleration strata (Essefi, 2020). All computed variables were included to distinguish between the Anthropocene-Great Acceleration of later Holocene strata from the remaining part of the earlier Holocene. Many studies discussed the radical biological and geological changes of the of the study area (Gulf of Gabès) and included in the framework of the Mediterranean region, but few studies integrated these changes in the framework of the Anthropocene-Great Acceleration. For instance, climate Change and Impact Research: the Mediterranean Environment (CIRCE) project aims to highlight the impacts of climate change and human adaption in the Mediterranean regions of North Africa, Europe, and the Middle East. Moreover CIRCE project studied the effects on ecosystems, forests agriculture, air quality and human health. One of the major goals of this project is the study of the future variability of extreme events and their impacts. This project was applied in many localities in the Mediterranean sites following a standard sheet such as the Tel Hadya, Syria (Sommer, 2011) and Gulf de Gabès, Tunisia (Harzallah et al., 2010). In this work, results of this project in the study area (coast of Sfax) were used to highlight the setting of the Anthropocene-Great Acceleration.

4. Results and discussion

4.1. Geophysical and sedimentary signals of the Anthropocene-Great Acceleration

For the bottom upward, 10 facies may be distinguished: (F1) from 68 cm to 60 cm, a red clay facies with high magnetic susceptibility indicating continental sedimentation taking
place along the Tunisian coast at ca. 4000 yr BP (Pirazzoli, 2005). (F2) From 60 cm to 56 cm, a marine sedimentation of beige clay with organic matter indicating shallow depositional environment. (F3) From 56 cm to 51 cm, the sedimentation of beige gravelly clay indicates deeper depositional environment. (F4) From 51 cm to 43 cm, the sedimentation becomes richer with beige sandy fraction and maintaining the same content of gravel. (F5) Between 43 cm and 40 cm (repeated from 26 cm to 20 cm), the sedimentation is beige sandy indicating calmer depositional environment. (F6) From 40 cm to 26 cm, the sedimentation of the grey gravelly sand is richer with organic matter; it is the deepest depositional environment. (F7) Between 20 cm and 10 cm, the sedimentation becomes finer with disappearance of the gravelly fraction. (F8) From 10 cm to 7 cm, silt rich with organic matter indicates the setting of new strata related to the Anthropocene. (F9) between 7 cm and 5 cm, the sedimentation becomes finer and richer with organic matter. This facies is related to pollution resulting form urbanizing activities in Sfax town. (10) The upper part (5 cm) is marked by finer sedimentation and lower content of organic matter. Coupled with Mn and Fe amounts and magnetic properties, the descriptive grain size distribution including clay (less than 2 microns) percentage (Figure. 2) all together should give further details on the depositional environment characteristics and the climatic conditions during the Anthropocene-Great Acceleration. At the top of the core (8 cm), the high amounts of clay fractions coincide with high values of Mn and Fe amounts. This coexistence may be due to the capacity or larger surface area of fine sediment to fix heavy metals related to pollution (Hass and Fine, 2010; Aliff et al., 2020) as it may be related to the enrichment of eolian dust by Mn and Fe (Salama et al., 2019). The upcore-increased magnetic susceptibility may be due to enrichment with heavy metals, such as Fe and Mn. Furthermore, the setting of a new Anthropocene-Great Acceleration microbiology (Gillings and Paulsen 2014) may be the origin of magnetobacteria development, which are responsible for the increasing magnetic susceptibility. Actually the starting of the
Anthropocene-Great Acceleration is characterized by magnetic susceptibility increase (Oldfield, 2015). The increase of the magnetic susceptibility is basically due to the formation of iron oxide. There are higher HFMS and LFMS values between 14 and 10 cm depths. However, this increase is not combined with an increase of Fe and clay amounts. For this reason, they may not be attributed to the setting of the Anthropocene. As for HFMS, LFMS, Fe and clay values increase below 48 cm depth, they are related to a radical change toward a continental depositional environment probably taking place ca. 4000 BP (Pirazzoli, 2005) due to a marine regression along the Tunisian coasts. This regression is more obvious below 60 cm depth with the setting of continental depositional environment giving yellowish sediment rich with Fe.

**4.2. Heavy metals (Cd, Pb, Cu, Ni) content during the Anthropocene-Great Acceleration-Holocene transition**

Along the upper 8 cm of the core, heavy metals (Cd, Pb, Cu, Ni), magnetic properties and the fine fraction increased (Figure.3). In wetlands, the fine particle size giving high preservation of organic pollutants and heavy metals fixation allowed the record of the Anthropocene-Great Acceleration signal. The Anthropocene-Great Acceleration records are worldwide characterized by an obvious increase of heavy metals concentrations in the polluted wetlands due to either human induced and/or natural origins (e.g., Álvarez-Vázquez et al., 2016). Along the atmosphere-biosphere interface, the geochemical processes of heavy metals in different phases interfered. In doing so, they influenced the climate of the Anthropocene-Great Acceleration (Pöschl and Shiraiwa, 2015). In wetlands, the overlap of anthropogenic and natural factors makes the setting the Anthropocene-Great Acceleration based on heavy metals more relevant by eliminating the background levels (e.g., Gopal et al., 2017). As for HFMS, LFMS, Fe and clay values increase below 48 cm depth, they are related to a radical change toward a continental depositional environment probably taking place ca.
4000 BP (Pirazzoli, 2005) due to a marine regression along the Tunisian coasts. This regression is more obvious below 60 cm depth with the setting of continental depositional environment giving yellowish sediment rich with Fe.

The plot of the geoaccumulation indices along the core (Figure.4) confirmed the limit of the Anthropocene-Great Acceleration already identified by sedimentary and other geochemical parameters. The heavy metals geoaccumulation indices showed a remarkable rise from the eight centimeters depth towards the surface of core (Figure.4). The geoaccumulation indices of Pb, Cu, Ni and Cd varied between 1 and 2. They belong to the second class of moderately polluted soil. The Anthropocene-Great Acceleration-Holocene transition is obvious at the upper 8 cm of the core, when the intensity of contamination is classified as moderately strong. Thus, the distribution of the heavy metals content probably showed upward increasing levels as likely related to pollution to the setting of the Anthropocene-Great Acceleration. According to Gharsalli et al. (2020), the polluted era may have started 300yr ago. Since this date, all heavy metals together increased indicating hence values exceeding the background. We notice an increase of values of the dependent frequency magnetic susceptibility basically correlated with enrichment with heavy metals and Fe-clays.

4.3. Statistical detection of the Anthropocene-Great Acceleration

According to the PCA of all variables, three groups may be distinguished (Figure.5). The first group with lower factor loadings is made of LFMS, HFMS, Clay, and Mn variables and it seems that there exists no significant relation to; instead, it should be rather associated with sea level fall (Pirazzoli, 2005) and/or wetter climate. An increasing of continental sediment flux during the Anthropocene-Great Acceleration (as a result of increased land-use) may result in increasing magnetic susceptibility, iron and clay. The second group with slightly higher factor loadings is characterized by the heavy metals Cr, Cu, Zn, Ni and DFMS; as it is shown by heavy metals geo-accumulation indices, it thus can partly be explained by the
influences from environmental pollution. During the Anthropocene-Great Acceleration, metal accumulation comes from anthropogenic as well as natural origins. In spite of the contribution of several anthropogenic origins, the most important origin of heavy metals pollution is fossil fuel combustion. Sand and iron make up the third group that indicates an increasing erodability and/or sea level rise. Recent studies (e.g., Gammoudi et al., 2019; Gammoudi, 2020) had given evidences for African Sahara dust storms blowing towards North Africa during the late Holocene. The PCA indicates the interplay of anthropogenic and natural effects during the Anthropocene-Great Acceleration. Combined together, pollution and climatic changes participated in the setting of the Anthropocene-Great Acceleration conditions.

The clustering of all sedimentary, geochemical and geophysical parameters of the 34 samples from the core of the (Figure.6) shows the individualization of the upper four samples (above 8 cm depth). The Anthropocene-Great Acceleration signal at the top of this core drill is caused by the radical variation of the sedimentary environment taking place due to changes of climatic conditions and/or anthropogenic pollution. The origin of polluting activities has been recently discussed by numerous studies (e.g., Mosbahi et al., 2019). The SIAPE produces more than 10,106 tons/year of phosphogypsum containing high levels of impurities including heavy metals. Added to the shipping activity, agricultural activities including the storage of olive oil wastes and salt marshes have impacted the coastal area of Sfax. In addition, municipal wastewater treatment plants and the Thyna domestic waste landfill versed quantities of urban wastes along the coastal regions (e.g., Mosbahi et al., 2019).

4.4. Scenario of Anthropocene-Great Acceleration evolution

The CIRCE project climate model runs were used in the Gulf of Gabès to investigate climatic changes from 1950 to the perspectives of 2050. Detailed description of the mathematical model was previously discussed in Harzallah et al. (2010). Figure.7a displays
the Sea Surface Temperature (SST) evolution in the Gulf of Gabès simulated by the CIRCE models for the period 1950-2050 (Harzallah et al., 2010). All simulation methods show a dramatic scenario toward an increasing; this increase should have a direct effect of dissolution of heavy metals and their transition from sediment to water (Lüders et al., 2020). As other repercussions of this SST increase, Harzallah et al. (2010) indicated that the counting of alien species had increased by 15% in the Gulf of Gabès (Figure. 7b).

5. Conclusion

If humankind may deal with pollution, dryness of the Anthropocene-Great Acceleration (Vörösmarty et al., 2015) is foresee threatening many sites namely in fragile regions. This work adopts a multidisciplinary approach to set the limit of the Anthropocene-Great Acceleration. At this epoch, some heavy metal concentrations and their evaluated geoaccumulation indices increased upward toward the surface of the core which can be interpreted in part as a result of anthropogenic activities in the region. However, the sedimentary variables are not directly related to the setting of the Anthropocene-Great Acceleration. The Principal Component Analysis found out three families. Two related to natural change of environmental conditions. One family is relation to the setting of polluting activities. Many previous discussed the pollution and its geological and biological repercussions; nonetheless, few are the studies explicitly discussing the setting of Anthropocene-Great Acceleration in the region of Gulf of Gabès. The reinterpretation of previous works may find the link between the setting of the Anthropocene-Great Acceleration and dramatic modification of some geological and biological parameters. Mathematical simulation recorded this modification since 1950 and it anticipates more increase of these parameters at the perspective of 2050.

In spite the absence of precise dating, this work recorded a radical modification within the study area taking place in surface sediment. In doing so, the Anthropocene strata is
individualized along the upper cm along the core. In the framework of attempts to set a
chronological limit of the Anthropocene, radiocarbon dating may give a relevant contribution
to the international effort (International Commission of Stratigraphy and the International
Union of Geological Sciences) to set a universal limit.

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Figure 1. Localization and geological setting of the studied site: (a) Site of Sfax town in southeastern Tunisia. (b) Localization and topography of the drainage basin of Chaffar. (c) Hydrography of the drainage basin of Chaffar basin. (d) Lithology and geological ages along the drainage basin of Chaffar (Smida et al., 2006)
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Figure 3. Distribution of the heavy metals content (Pb, Cu, Ni, Cd), magnetic properties and particle size distribution (silt percentage, Average Medium Grain Size AMGS) along the 68 cm drilled core within the subtidal coastline of Sfax.
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