Journal of African Earth Sciences 101 (2015) 220–231

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

A cross-section analysis of sedimentary organic matter in a mangrove ecosystem under dry climate conditions: The Somone estuary, Senegal

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ARTICLE INFO

Article history:
Received 7 October 2013
Received in revised form 10 September 2014
Accepted 11 September 2014
Available online 28 September 2014

Keywords:
Mangrove sediments
Organic carbon
pH/redox
Bioturbation
Tide
Somone estuary

ABSTRACT

Mangrove sediments are an important organic matter (OM) reservoir and play a major role in the carbon cycle. Since the 1990s, these ecosystems were subjected to numerous studies, in order to quantify the sedimentary sink for organic carbon (OC) and to characterize the organic matter sources, but remain poorly studied in Western Africa. The aim of our study is to quantify the organic carbon content and to identify the OM origin stored in the Somone mangrove sediments. Studied area is characterized by a (i) dry climate conditions with a higher rate of evaporation, (ii) lack of freshwater input by river, and (iii) tide dominated system. Here, we focus on physico-chemical properties of sediments (temperature, pH and redox), sediment grain size, water content, particulate organic carbon and dissolved organic carbon from a series of 40 cm-deep cores in four tidal contexts: mudflat, *Rhizophora*, and *Avicennia* mangroves and barren area. Results show that total organic carbon (TOC) contents range between 0.34 and 3.92 wt.% and are higher in sediments from mudflat and *Rhizophora* mangrove than in sediments from *Avicennia* mangrove and barren area. Indeed, sediments stored under *Avicennia* is subjected to suboxic conditions initiated by roots system and crabs bioturbation; while under *Rhizophora* and mudflat, local anoxic conditions are prevalent as suggest the negative Eh values and the occurrence of framboidal pyrites. Mangrove sediments of the Somone estuary contain an autochthonous lignocellulosic-derived organic matter. The youngest and stunted form of the Somone mangrove explains the low organic carbon content of sediments; where dry climate conditions limit the organic matter production by the mangrove forest.

The shallow depth at which the organic matter of the former mudflat was found confirms that the Somone mangrove is subjected to a low sedimentation rate. This suggests that organic carbon burial depends on others processes than sedimentation. Then, in the Somone mangrove ecosystem, both of pneumatophores and burrowing crab activities are the main factors that control OM degradation (*Avicennia* station) while anaerobic conditions (mudflat and *Rhizophora*) promote OM preservation.

1. Introduction

75% of world's tropical coasts (>150,000 km^2) are covered by mangroves forests considered as one of the major transitional ecosystems between terrestrial and marine environments (Spalding et al., 1997). Mangroves are present throughout the West African coast, and particularly from Senegal to Sierra Leone where they cover an area of about 3 millions hectares (Marius and Lucas, 1991). Mangrove ecosystems are highly productive, rich in biodiversity and support numerous ecological functions (Chong et al., 1996; Schaffelke et al., 2005; Wolanski, 2007; Alongi, 2008; Nagelkerken et al., 2008; Comeaux et al., 2012) and human services (Rönnbäck et al., 2007; Walters et al., 2008; Alongi, 2011; Badola et al., 2012). Despite its importance, a reduction of surface area occupied by mangroves forests is observed worldwide, and is related as much to natural as to anthropogenic causes (Spalding et al., 1997; Ellison, 1999; Sakho et al., 2011). However, reforestation policy was developed in order to restore and protect mangrove ecosystems (Sakho et al., 2011; Monsef et al., 2013).

Mangroves forests are characterized by a total net primary production of 218 ± 72 Tg C/yr (Twilley et al., 1992; Bouillon

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http://dx.doi.org/10.1016/j.jafrearsci.2014.09.010
1464-343X/

et al., 2008), making them one of the most productive natural ecosystems of the world (FAO, 2007). Due to their high productivity and transitional position, mangroves play an important role in the C, N, P biogeochemical cycles in coastal environments (Singh et al., 2005; Kristensen et al., 2008). Hence, such environments play also a significant role in the global organic carbon budget (Chmura et al., 2003; Duarte et al., 2005; Bouillon et al., 2008). OC in mangrove sediments can be autochthonous (mangrove detritus, litters, benthic vegetation) and/or allochthonous (coastal ecosystems vegetation, riverine transport of eroded soils, freshwater and marine phytoplankton, tidally suspended OM e.g. Goni et al., 2006; Mesnage et al., 2007; Kristensen et al., 2008; Ranjan et al., 2011). They are both an important sink and source of OC (Twilley et al., 1992; Sanders et al., 2010, 2012; Tue et al., 2011; Donato et al., 2011). However, at global scale, particulate OC storage within mangrove sediments is variable as attests the wide range of TOC content measured in sediments varying between <2.00 and <40.00 wt.%, with a median particulate OC of 2.20 wt.% (Kristensen et al., 2008). Accordingly, improve our knowledge in the OC storage and OM dynamics in mangroves require to address to the parameters acting on these two processes in a considered mangrove ecosystem (Tue et al., 2012). Unfortunately, mangrove sediments were very seldom investigated at global scale (Marchand et al., 2008; Bouillon et al., 2008; Sanders et al., 2010) and even more seldom at the African continent scale. Scientific investigations on African mangroves, as in Kenya (Middelburg et al., 1996) and Nigeria (Ukpong, 1995, 1997; Effiong and Ayolagha, 2010) clearly were highlighted the fact that the biogeochemical characteristics of sediments – particulate and dissolved OC contents, interstitial water nutrients concentrations, redox potential, salinity – are the main indicators showing that sediment biogeochemistry influences the way of mangroves development (*Rhizophora*, *Avicennia*). In Senegal, researches have mainly focused on how Saloum's and Casamance's mangrove surfaces have evolved with climate variations (Sall, 1982; Marius, 1995; Diop et al., 1997), but only a few and ancient studies have focused on sediment geochemistry (Vieillefon, 1969; Marius and Lucas, 1982). The sediment colonized by the mangroves is relatively homogenous. In the mineralogical point of view, they are dominated by quartz and clays associated to halite, pyrite and jarosite. The clays suite is mainly composed of smectite and kaolinite (Marius and Lucas, 1991).

In this work, we examine the bulk OM coupled with porewater chemistry in order to discuss (i) the OM sources, (ii) the OM degradation processes, (iii) the impact of bioturbation on the OM dynamics (preservation or degradation), and (iv) the impact of tidal dynamics on porewater chemistry.

2. Materials and methods

2.1. Study area

The Somone estuarine mangrove located on the Petite Côte in Senegal is a 7 km^2 surface tropical ecosystem (Fig. 1A). It extends at the end of a 350 m length sand spit, stretches parallel to the coast (Sakho et al., 2010). This ecosystem comprises of habitats, including mangroves (*Rhizophora* and *Avicennia*), intertidal mudflats, barren area (locally named tannes), sand banks and sand spit (Fig. 1B). The mangrove forest and the mudflats are located in the intertidal zone whereas the barren areas are in the supratidal zone (Fig. 1C). They are submerged by exceptional tides and/or rainfall during the wet season (June to October). The mouth area (Fig. 1B) is relatively deep (>4 m), its width varies depending on the dynamics of the distal part of the sand spit (7 m in January 2010, at the time of the study).

The Somone region lies within the Atlantic Soudanian climatic zone characterized by two contrasted seasons (Leroux and Sagna, 2000). The dry season lasts approximately eight months – from November to June – and is characterized by warm and dry winds while the short rainy season lasts 3 to 4 months – from June/July to October – and is mainly ruled by monsoonal flows.

The hydrographic network of the Somone region drains a 420 km^2 watershed and has little hierarchical organization. It is formed by the confluence of two ephemeral streams that meet at the Bandia reserve (Fig. 1A). Most of the flow occurs in August and September, when the maximum precipitation occurs. Since 1975 at the Bandia station, the maximum discharge has never exceeded 10 m^3 s^{-1} with an annual average of 4 m^3 s^{-1}. The mangrove forest is located in a microtidal zone – tidal range <2 m at the mouth- with a semi-diurnal tide regime. In this ecosystem, salinity is highly correlated to rainfall with rather important seasonal variations. 70% of the time, it increases when going upstream leading to a reverse estuary context. This increase in salinity from the ocean is enhanced by their location in the Northern latitude and the watershed geometry (Diop, 1990).

2.2. Field sampling

We have investigate a cross-section of bulk sediment along a downstream-upstream transect that respectively defines the intertidal mudflat (station 1), the *Rhizophora* mangrove (station 2), the *Avicennia* mangrove (station 3) and the barren area (station 4) corresponding to a hypersaline zone with salt efflorescence (Fig. 1C). This transect was selected according to a salinity and a flooding-dessication gradient. Indeed, stations 1 and 2 are located in the intertidal zone and are therefore submerged at high tide. The tanne is located in the supratidal zone and is only submerged at spring tide. The *Avicennia* mangrove is located at the limit of these two tidal zones.

Field works were conducted during the dry season (January 2010). A set of 42 cm-deep sediment cores was collected at the four stations with some 10 cm-diameter PVC corers. Cores were immediately cut-off into sections from the top to the bottom (0–2 cm/10–12 cm/20–22 cm/40–42 cm); samples were then stored at −20 °C until their analysis.

By using a transparent pierced-PVC corer, the temperature, salinity, pH and redox profiles were carried out in-situ with pH-KCI-saturated glass electrode and Pt/Pt-Ag/Ag-Cl redox electrodes.

2.3. Laboratory analysis

The grain size distribution (sand to clay fractions) was performed with a micro-granulometric laser Bechman-Coulter L230.

The sediment porewater was extracted by centrifugation (3000 R/mn, during 25 mn). The concentrations in anions ($C1^-$ and SO_4^{2-}) and cations (K^+, Ca^{2+}, Na^+, Mg^{2+}) were determined using ionic chromatography equipped with anions and cations specific columns (Metrohm IC 732, IC 733).

The dissolved organic carbon (DOC, measurement uncertainty <5%) was analyzed with a "TOC Shimadzu 5050" carbon analyser.

Pyrite in sediments has been observed using Scanning electronic microscopy – Zeiss Evo40 Ep.

Sediments were air-dried at room temperature? and sieved to <2 mm. TOC was analyzed using the Rock–Eval 6 pyrolyser (Lafargue et al., 1998). This apparatus is now applied to quickly characterize the global geochemistry of recent OM of sediments (e.g. Disnar and Trichet, 1984; Marchand et al., 2008), of soils (e.g. Di-Giovanni et al., 1998), or of suspended load in river (e.g. Copard et al., 2006). Between 50 and 100 mg of dry sample are first pyrolyzed under inert atmosphere (N_2) according to a linear temperature programming (25 °C/min from 250 to 650 °C). This first phase releases signals S_1 and S_2 delivered by an FID detector and corresponding respectively to the release of free hydrocarbon