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Physical properties of muddy sediments from French Guiana

J. Caillaud [a,*], L. Lesourd [b], S. Philippe [a], S. Gontharet [a], M. Sarrazin [c], A. Gardel [a,d]

[a] Univ. Littoral Côte d'Opale, Univ. Lille, CNRS, UMR 8187, LOG, Laboratoire d'Océanologie et de Géosciences, F 62930, Wimereux, France
[b] Normandie Univ, UNICAEN, CNRS, M2C, 14000, Caen, France
[c] Centre IRD de Cayenne, US 191, LAMA, Laboratoire des moyens analytiques de Cayenne, route de Montabo, BP 165, 97323, Cayenne Cedex, French Guiana
[d] CNRS Guyane, USR 3456, Cayenne, French Guiana

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ABSTRACT

The North West migration of long and discontinuous mud banks along the French Guiana coast has been extensively studied during the past years, in particular with a large-scale vision, which consequently has integrated morpho and hydrodynamic data. The aims of the present paper were to use intrinsic sediment properties (grain-size, mineralogy, concentration, and cohesion) to (1) highlight the sedimentary conditions during the consolidation processes from fluid deposit to vegetation development, and (2) verify the apparent homogeneously derived sedimentary facies.

Two intertidal transects, Macouria and Cayenne, were compared from the coast to offshore. Their altitude averages of 1 m and 2.8 m above mean sea level, respectively, were different enough to compare the influence of the hydrodynamic impact and emersion time on their sediment properties. The latter, *i.e.* grain size distribution, mineralogical content, mud concentration, and shear strength (cohesion), were determined from sampled surface sediments (first cm) and along sediment cores (20–30 cm depth) from each transect. A specific X-ray technique was applied to the whole core to differentiate clearly its thin layers.

On both intertidal sites, the grain size dominated by the fine silt fraction (2–20 μm) and the bulk mineralogy characterized by five major minerals (quartz, feldspars, chlorite, illite, and kaolinite) appeared homogeneous along both transects and cores. In spite of this apparent uniformity of particle size and mineralogical parameters, as well as for visual observation along the core, high precision X-rays still showed a cyclic sedimentation at a micro-scale level. This cyclicity with intercalation of fine layers was related to distinct dynamic deposits marked by both tidal processes and hydrodynamic factors (swell propagation). The cohesion and concentration results were dependent on the topography, where high topography was characterized by sediments with high cohesion and concentration values, and vice versa. A comparison between these two parameters was done to define critical limits between soft and stiff muds, as well as unvegetated and colonized muds. The favorable intrinsic sedimentary properties for consolidation and colonization were also discussed according to the field observations and bibliographic data.

1. Introduction

The French Guiana coast is strongly influenced by the Amazon River's considerable discharge of fine sediments (8.10^8 t year^{-1}, Martinez et al., 2009), which creates a NW migration of 40 km long forming discontinuous mud banks along the shoreline, which in turn are influenced by both currents and swells. In fact, around 15–20% of the suspended sediment supply from the mouth of the Amazon migrates along the French Guiana coast (Augustinus, 1978; Eisma et al., 1991; Allison et al., 2000) under the influence of the North Brazilian and Guiana currents (Wells and Coleman, 1981). The mud banks migrate at velocities ranging from 1 km to more than 5 km y^{-1} (Gardel and Gratiot, 2005), under the influence of waves induced by tidal (e.g. Wells and Coleman, 1981; Rodriguez and Mehta, 1998) and wind-forced currents (Gratiot et al., 2007; Vantrepotte et al., 2013).

* Corresponding author.
E-mail addresses: jacinthe.caillaud@univ-littoral.fr (J. Caillaud), sandric.lesourd@unicaen.fr (L. Lesourd), sylvie.philippe@univ-littoral.fr (S. Philippe), swanne.gontharet@univ-littoral.fr (S. Gontharet), max.sarrazin@ird.fr (M. Sarrazin), antoine.gardel@univ-littoral.fr (A. Gardel).

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Often associated with luxuriant mangroves, this mud coast provides one of the most dramatically changing examples of mud–vegetation interfaces. Quantification of the changes in shoreline position (Gardel and Gratiot, 2005) shows that the erosion of mangroves can reach up to 200 m per year in an interbank sector (Gardel and Gratiot, 2006). Complementary works about the timing of the redistribution of sediment and migration of the mud banks embracing the entire coast of Guiana suggest the control of ocean forcing by the 18.6-year nodal tidal cycle (Gratiot et al., 2008). Recently, Walcker et al. (2015) demonstrated that the nodal tidal cycle accounts for only 1.5% of the observed temporal variations of French Guiana's coast, the main forcing factor being the multi-decadal fluctuations in trade-wind-generated waves associated with the North Atlantic Oscillation.

Anthony et al. (2008), and more recently Gensac et al. (2015), highlighted the role of individual muddy bars generated by waves in the protection and drainage of the intertidal mudflat. Once the relative topography is 20–30 cm higher (estimated measurement) than 2.05 m [considered to be equal to the mean water level (Fiot and Gratiot, 2006)], mud bars are no longer submerged at each tide and therefore become exposed to evaporative and drying processes.

The development of biofilms over the mudflat also plays an important role in sediment trapping and erosion prevention (Gensac et al., 2015).

Once sufficiently consolidated, the mudflat, if protected from wave forcing, can then be colonized by mangroves. Comparison between topography and presence and height of mangroves allowed identifying critical altitudes above which the mangroves could begin to appear (Proisy et al., 2009). The formation of mud cracking, which plays a determinant role in mangrove propagules being trapped, requires an elevation of muddy bars superior to 2.6 m above the hydrographic zero, and five consecutive days of emersion (CDOE) (Fiot and Gratiot, 2006; Gardel et al., 2009; Proisy et al., 2009). Mangrove expansion over the mud bank is then conditioned by progressive mud dewatering and consolidation starting at a critical topography, which depends on the emersion frequency and sheltering from wave forcing (Fiot and Gratiot, 2006; Anthony et al., 2008; Proisy et al., 2009; Gensac et al., 2015). Despite the numerous studies dealing with the sedimentary dynamics and instability of the French Guiana coast (Vantrepotte et al., 2013; Gardel and Gratiot, 2005, 2006; Anthony et al., 2010), few studies have examined precisely the intrinsic physical properties of sediments and their relationships to sedimentary facies. A scarce example is the study of Fiot and Gratiot (2006) that used the changes in physical properties, such as erodability (yield stress) and water loss, to investigate progressive mud compaction. Notably, they compared mud responses according to various times of emersion (from none to total emersion). Through significant concordance between laboratory experiments and field surveys, they demonstrated the importance of altitude on intertidal mudflats and inducing air-exposure periods.

In addition to morpho- and hydro-dynamic data, using the physical properties of sediments can provide guidance for the conditions suitable for consolidation processes and future mangrove colonization. Thus, these conditions can be described by values of cohesion and critical concentration, which constitute complementary sedimentary markers for the first stages of mud bank stabilization until vegetation colonization. In this context, the physical properties (grain size distribution, bulk mineralogy, cohesion, and concentration) of sediments from two distinct intertidal transects were examined, with respect to the field data, both from a surface sample and along a core.

The objectives of this study were to compare the consolidation response of sediments from two deposits (distinct according to their location), topography, and environmental influences; and to identify the processes responsible for the different sedimentary facies.

The structuring of intertidal deposits was particularly observed along the cores. In fact, during desiccation of fresh stratified muddy sediments, Weinberger (1999) observed that mud cracks nucleate at or near the bottom of the polygons, propagate vertically upward and laterally outward; this three-dimensional propagation strongly depends on the flaws, discontinuities and layer limits occurring in the bottom material.

Another aspect of this study was to verify that the mudflat, as shown by visual description of sediment, has a homogeneous and monotonous facies because of the simple process of decantation.

2. Materials and methods

2.1. Materials

French Guiana is situated on the northeast coast of South America, and is bordered by Brazil to the south and east, and by Surinam to the west (Fig. 1). The climate is tropical and is characterized by a relatively high mean annual temperature exceeding 25° C and a constant high humidity percentage (>70%). The dry season extends from August to November (75 mm/month) and the rainy season starts from November/December through to July (>300 mm/month), with a less rainy, intermediate period called “the little summer”, usually in March. The tidal range varies from microtidal to low-mesotidal (2–3 m). Tides are semi-diurnal, i.e. air exposures and flooding phases are uniformly time-spaced. The surface bank influenced by this regular tidal rhythm is at a height of 2.05 m, considered equal to mean water level (MWL) (Fiot and Gratiot, 2006).

Two cross-shorelines were chosen along the French Guiana coast in relation to their distinct morphology, hydrodynamics, and plant cover.

The first transect called “Macouria” (05°04′N and 52°31′W), was located near the mouth of the river Macouria. It extends over 1 km north-eastward from an eroding coastline with a well-developed mangrove towards a seaward mud flat (Fig. 2A). This flat is separated from the shore by a fluid mud lake and a compacted mud bar. The waves are consequently strongly damped and their energy at the shoreline is extremely limited (Gratiot et al., 2007; Winterwerp et al., 2007). The mudflat has an altitude of about 1 m above sea level overall, and is covered by the sea at every tide; hence, no desiccation cracks were observed as its access requires nautical ways for sampling.

The second transect named “Cayenne” (04°56′N and 52°18′W), was located in the city of Cayenne in front of the IRD (Institut de Recherche pour le Développement) building. It extends over 500 m north-eastward from the coastal Precambrian basement to the seaward fluid mud along a mudflat with pioneer mangrove (Fig. 2B). The average altitude of 2.8 m above sea level (compared to the mean water level (MWL)), allows emerging periods of varying durations, notably occurring under neap tide waters, involving the formation of desiccation cracks and the development of phytobenthos or algal films. Mainly dominated by compact mud, this transect is directly accessible from the shore.

2.2. Methods

The two areas were investigated at the beginning of dry season, in July 2006, corresponding to the period of low wave forcing (Gratiot et al., 2007) and during the spring tides.

Surface sediments (first cm) were sampled on both sites along a transect “coast to offshore” (arrows in Fig. 2A and B indicate the