



## Tidal sands as biogeochemical reactors

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### ARTICLE INFO

#### Article history:

Received 13 November 2008

Accepted 13 June 2009

Available online 21 June 2009

#### Keywords:

coastal oceanography  
biogeochemical cycle  
sediment–water exchanges  
permeable sediment  
tidal beach  
Aquitania coast

### ABSTRACT

Sandy sediments of continental shelves and most beaches are often thought of as geochemical deserts because they are usually poor in organic matter and other reactive substances. The present study focuses on analyses of dissolved biogenic compounds of surface seawater and pore waters of Aquitanian coastal beach sediments. To quantitatively assess the biogeochemical reactions, we collected pore waters at low tide on tidal cross-shore transects unaffected by freshwater inputs. We recorded temperature, salinity, oxygen saturation state, and nutrient concentrations. These parameters were compared to the values recorded in the seawater entering the interstitial environment during floods. Cross-shore topography and position of piezometric level at low tide were obtained from kinematics GPS records. Residence time of pore waters was estimated by a tracer approach, using dissolved silica concentration and kinetics estimate of quartz dissolution with seawater. Kinetics parameters were based on dissolved silica concentration monitoring during 20-day incubations of sediment with seawater. We found that seawater that entered the sediment during flood tides remained up to seven tidal cycles within the interstitial environment. Oxygen saturation of seawater was close to 100%, whereas it was as low as 80% in pore waters. Concentrations of dissolved nutrients were higher in pore waters than in seawater. These results suggest that aerobic respiration occurred in the sands. We propose that mineralised organic matter originated from planktonic material that infiltrated the sediment with water during flood tides. Therefore, the sandy tidal sediment of the Aquitanian coast is a biogeochemical reactor that promotes or accelerates remineralisation of coastal pelagic primary production. Mass balance calculations suggest that this single process supplies about 37 kmol of nitrate and 1.9 kmol of dissolved inorganic phosphorus (DIP) to the 250-km long Aquitanian coast during each semi-diurnal tidal cycle. It represents about 1.5% of nitrate and 5% of DIP supplied by the nearest estuary.

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### 1. Introduction

We need information about net metabolism of coastal zones in order to better constrain the cycles of carbon, nutrients, or trace metals at the land–ocean transition zone (Jickells and Rae, 1997). Pioneering works showed that filtration through the sands of exposed beaches represented a mechanism that enhanced the decomposition of organic matter in the coastal zone (Riedl and Macmahon, 1969; Riedl and Machan, 1972; McLachlan et al., 1985; McLachlan and Turner, 1994). However, sandy sediments of continental shelves and most beaches are often thought of as geochemical deserts because they are usually poor in organic matter and in other reactive substances (see discussion in Boudreau et al., 2001). Based on the belief that the importance of

sedimentary environment is proportional to its own stock of reactants and organic matter, sandy sediments are generally neglected. Recent observations, however, suggest that it is inappropriate to neglect biogeochemical fluxes from sandy sediments (Rusch et al., 2006). One of the major differences between sandy sediments and muddy sediments is the permeability, which controls the transport of pore waters, and consequently, the fluxes inside, and outside the sediment (Wilson et al., 2008). Permeable sediments are subjected to pressure fluctuations generated by currents. Pressure gradients induce transport of pore water (advective flow) and generate dispersive mixing that can dominate diffusion processes (Huettel et al., 1996). Bacon et al. (1994) showed that permeable sediments could trap and decompose organic matter efficiently enough to consume organic matter wholly. Consequently, permeable sediment constitutes a fundamental component to understand the biogeochemical cycles of the biogenic components (Middelburg and Soetaert, 2004). Advective flow enhances circulation of dissolved oxygen in pore waters.

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Interactions between mineralisation reactions and advective flow generate complex biogeochemical compartments inside the permeable sediment (e.g., Shum and Sundby, 1996). The advective transport of pore water, which is obvious during ebb and flood tides in sandy sediments of the tidal zone, makes this environment particularly transient in terms of saturation of water. Sediments of the Aquitanian coastal beach are extreme examples of advective transport of pore waters because of significant sediment permeability and exposure to waves and tides.

The intertidal zone represents a key environment of nutrient dynamics (e.g., Billerbeck et al., 2006; Deborde et al., 2008), where sandy sediments have been intensely investigated to study subterranean estuaries and ground water discharge (Charette et al., 2005). Freshwater discharge through coastal sandy sediments has been recognized as a widespread phenomenon (Li and Barry, 1999; Moore, 1996; Taniguchi et al., 2002). Freshwater inputs have effects on the carbon and nutrient cycles (Kroeger and Charette, 2008). But when coastal pore water is mixed with fresh groundwater, it becomes difficult to determine the portion of nutrient input originating from fresh water, and that caused by in situ mineralisation of organic matter. Here we report a survey of dissolved biogenic compounds of surface seawater and permeable sediment pore waters of a section of the Aquitanian tidal zone that is not affected by mixing of fresh groundwater. Thus, the portion of the Aquitanian coast studied enables us estimate the magnitude of benthic biogeochemical processes in sandy tidal sediments, based on an in situ study. The purpose of this study was to observe and quantify these processes.

## 2. Materials and methods

### 2.1. Study area

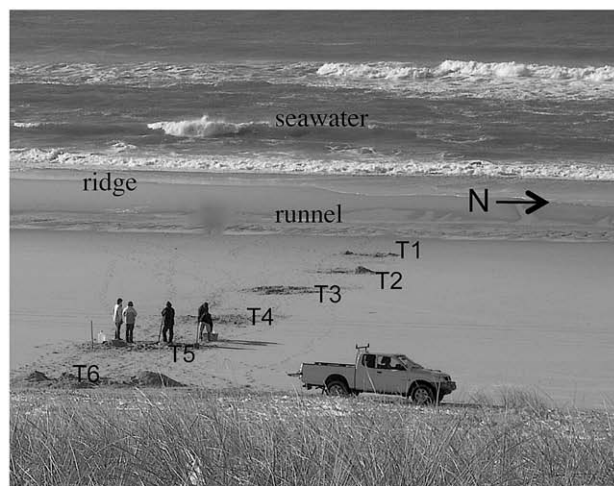
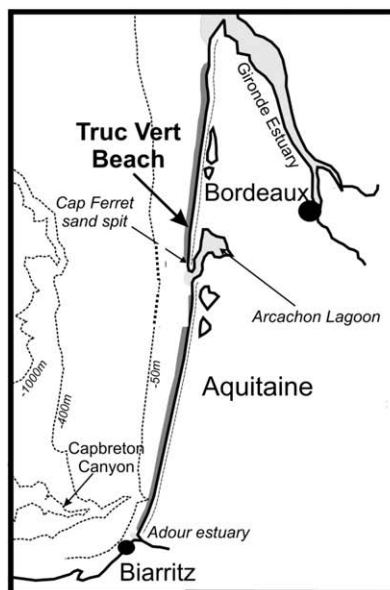
The French Aquitanian coast is a 250-km long straight coast bordered by high aeolian dunes and exposed to high-energy conditions in a meso–macrotidal setting. This coast is located between the Gironde and Adour estuaries, and is interrupted by the Arcachon lagoon tidal inlet that is approximately 5 km wide, and comprises a complex sandbar and channel system (Michel et al., 1995; Cayocca, 2001). The Aquitanian coast commonly displays

double bar beaches with very dynamic rhythmic features (Castelle et al., 2007). Since 1998, several field experiments have been conducted at the Truc Vert beach, which is assumed as being representative of the Aquitanian coast beaches that display balanced sedimentary budget.

Truc Vert beach is located a few kilometres north of the Cap Ferret sand spit. The sediment consists of fine to medium quartz sand with mean grain sizes ranging from 300 to 400  $\mu\text{m}$  (Pedreros et al., 1996). The tide is of meso–macro type, with an average tidal range of 3.2 m, extending up to 5 m during spring tides. This beach is also characterised by the presence of ridge and runnel systems (Fig. 1), developed more or less in relation with meteorological conditions (Michel and Howa, 1999; Castelle et al., 2007).

### 2.2. Sampling

Water samples were collected in winter 2007 during three periods of mean spring tide (January 18th and 25th, and March 8th). Due to prevalence of fair weather conditions, ridge and runnel systems were well developed and the runnels were almost isolated from seawater at low tide. Surface seawater samples were collected at high tide in the intertidal area and at low tide in the supratidal area of the Truc Vert beach, at a depth of 30 cm below the sea surface. To collect interstitial water at low tide, and at the time of each sampling we bored several holes along a cross-shore transect, until the borehole reaching the saturated zone in the intertidal sandy beach. Temperature, salinity and oxygen concentration were immediately recorded in the waters of the bored holes using WTW probes. Sampling sites were identified with a GPS record. Samples were collected at distances between 2 and 65 m away from the low tide shoreline. Interstitial waters were reached close to the surface on the lower beach, and down at depth of 1.2 m on the upper beach. Cross-shore topography and position of piezometric levels at low tide were obtained with kinematics GPS records. The cross-shore profile was made on January 25th 2007. Waters were sampled using a 50 ml syringe and filtered through a 0.45  $\mu\text{m}$  cellulose acetate syringe-membrane. One subsample was acidified with  $\text{HNO}_3$  to analyse dissolved inorganic phosphorus (DIP); another subsample was kept refrigerated until analyses of other dissolved nutrients.



**Fig. 1.** Map of the south-western part of France and location of the study area. View at low tide of the Truc Vert beach on the Aquitaine coast, and location of pore water sampling sites (T1–T6) on January 25th 2007.

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