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# Modeling the preservation potential of tidal flat sedimentary records, Jiangsu coast, eastern China

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ABSTRACT

A forward modeling approach is proposed to simulate the preservation potential of tidal flat deposits. The preservation potential is expressed as a function of net deposition rate and a factor that represents the vertical flux of suspended load, or seabed lowering during erosion periods associated with bedload transport. The model takes into account a number of geometric parameters of a tidal flat sediment system and sediment dynamic processes. The former includes high water level, total sediment supply, the annual rate of the supply, the ratio of mud to bilk sediment in the supply, the bed slope of the tidal flat profile, as well as the slope of the stratigraphic boundary; the latter includes spring-neap cycles of tidal water level changes, boundary layer processes, resuspension of fine-grained sediments, bedload transport due to tidal currents, and bed elevation changes in response to sediment movement. Using this model, numerical experiments are carried out for a tidal flat system on the Jiangsu coast, eastern China, with the input data being derived from literature and from a series of sediment cores collected along an onshore–offshore transect. The results show that the preservation potential is highest over the upper part of the inter-tidal zone and in the lower part of the sub-tidal zone, and lowest near mean sea level and at low water on springs. The preservation potential tends to decrease with the advancement of the shoreline. The bed slope, tidal current direction and resuspension intensity influence the spatial distributions of the preservation potential. An implication of these results is that the temporal resolution of the tidal flat record depends upon the location and depth within the deposit; this should be taken into account in the interpretation of sedimentary records. Further studies are required to improve the model, on the hydrodynamic processes associated with extremely shallow water depths, sediment dynamic modeling of bed slope and profile shape, and the combined action of tides and waves for sediment transport on tidal flats.



## 1. Introduction

Sedimentary records contain information on ancient environment changes. Generally, such information is obtained by analyzing bore holes or cores: grain size distribution, mineral and geochemical composition, microfossils, the age of the sedimentary material and sedimentary structures (including primary and secondary/bioturbation structures) are derived from laboratory analyses, and the down-core variations are interpreted as a result of changes in environmental conditions. In this approach, the continuity or completeness of the sedimentary record is a crucial factor that influences the validity of the interpretation, because this factor controls the temporal resolution of the record. There are several methods for the evaluation of the sedimentary record continuity. Facies analysis (Reading, 1986) may be carried out, to obtain qualitative information about what is missing in a sediment sequence. Further, forward modeling for the formation of the sedimentary record may provide useful information (Paola, 2000). Kamp and Naish (1998) have used a forward modeling method to simulate the sequence formed on the New Zealand continental shelf during the late Cenozoic periods, influenced by sea level changes, crustal subsidence and variations in sediment supply, to identify the missing strata and the related mechanisms. Furthermore, the temporal resolution can be evaluated quantitatively on the basis of the definition of the preservation potential for the deposit (e.g. Dalrymple et al., 1990; Li et al., 1999; Fan et al., 2002; Stupples, 2002; Deloffre et al., 2007). Generally, the preservation potential is derived from *in situ* measurements of gross and net deposition rates. However, the measurements are normally associated with low spatial resolution and, therefore, are insufficient for a thorough evaluation of the temporal resolution of a sedimentary system. Recently, Gao (2007) has suggested that the preservation potential may be calculated on the basis of sediment dynamic processes; in this way the spatial distribution of the preservation potential within the sediment sequence can be determined.

Tidal flats represent an important source of information on environmental changes. They are distributed widely along the world coastlines, and are characterized by accumulation of fine-grained

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sediments, gentle bed slopes and the formation of sediment sequences, up to tens of meters in thickness. Progress has been made in the understanding of the characteristics, processes and evolution of tidal flats. In early times, the zonation of inter-tidal flat geomorphology and sedimentation was identified (e.g. Haentzschel, 1939; Wang, 1964; Evans, 1965; Reineck and Singh, 1980). At the same time, the various mechanisms for the landward transport of fine-grained sediment were proposed (Van Straaten and Kuenen, 1957, 1958; Postma, 1961). Hence, for the bulk sediment consisting of both muddy and sandy materials, the fine-grained sediment is deposited near the high water mark, whilst the coarse-grained sediment is deposited on the middle and lower tidal flats. This generates a "fining-upwards" sequence. Then, in the late 20th century, sediment dynamic and morphodynamic studies (e.g. Collins et al., 1981, 1998; Bartholdy and Madsen, 1985; Pejrup, 1988; Wells et al., 1990; Alexander et al., 1991; Gouleau et al., 2000; Andersen and Pejrup, 2001; Davidson-Arnott et al., 2002; Deloffre et al., 2005) made it possible to model quantitatively tidal flat sedimentation and morphodynamics (Allen, 1990, 2000, 2003; Roberts et al., 2000; Pritchard et al., 2002; Malvarez et al., 2004). On such a basis, the formation of tidal flat sediment systems and the information on climate, environmental and ecosystem changes contained in the sedimentary record have become a focus of research (e.g. Dellwig et al., 2000; Vos and Van Kesteren, 2000; Gerdes et al., 2003).

The purpose of this study is to develop a modeling approach to the determination of the preservation potential for the tidal flat sediment record, taking into account the transport processes induced by tidal currents. A transect of the tidal flat system on the central Jiangsu coast, eastern China, is used as an example to illustrate how the model can be applied. Furthermore, the present contribution also attempts to propose additional scientific questions that should be answered in the future, in order to improve the model, in terms of the hydrodynamic processes associated with extremely shallow water depths, the techniques of morphodynamic modeling for bed slope and profile shape, and the combined action of tides and waves that affects sediment transport.

## 2. Regional setting

Tidal flats are formed where there is a supply of fine-grained sediment, and where tides and tidal currents dominate over other hydrodynamic forces (Klein, 1985). Both conditions are satisfied on the Jiangsu coast, eastern China. Here, the Changjiang River discharges into the southern part of the region, whilst the Yellow River discharged for several periods of time (the most recent period being 1127–1855 AD) into its northern part, providing an abundant sediment supply (Ren, 1986). In addition, the mean tide range is between 2 and 4 m along the coastlines of the region; on the central Jiangsu coast, maximum tide range on springs reaches 7 m (Ren, 1986). Hence, a large-scale tidal flat system (the largest in China) has been formed. Along the accretional sections of the Jiangsu coast, the bed slope on the tidal flats is of the order of $0.5\times10^{-3}$–$1.0\times10^{-3}$, with the inter-tidal zone being 6–12 km wide (Gao and Zhu, 1988). In particular, during the period of 1128–1855, when the Yellow River discharged into the southern Yellow Sea via the Jiangsu coast, rapid tidal flat sedimentation and shoreline advancement occurred and a coastal plain 50–60 km wide was formed beyond the sea dyke which represents the shoreline location before the year of 1127 (Zhang, 1984) (Fig. 1). The tidal flats on the central Jiangsu coast are sheltered by a large, offshore radial tidal ridge (or linear sandbank) system (Fig. 1); the highest parts of the ridges near the study area are above high water on neaps (Ren, 1986; Liu et al., 1989; Li et al., 2001).

After the supply from the Yellow River was cut off in 1855, and the Yellow River discharged into the Gulf of Bohai in the north, the coastline near the old Yellow River delta was subjected to severe erosion. So far, the shoreline here has retreated for more than 17 km (Ren, 1986). Coastal recession also occurred in early Holocene periods, as indicated by the formation of cheniers on the Jiangsu coastal plain before the year of 1127 (Wang and Ke, 1989). However, such an event has not yet affected the central Jiangsu coast; here the shoreline has continued to prograde towards the sea, with the sediment supply being from the erosion of the old Yellow River delta and from the offshore areas (Gao and Zhu, 1988; A.J. Wang et al., 2006; Y.P. Wang et al., 2006).

The tidal flats on the central Jiangsu coast have a significant zonation (Zhu and Xu, 1982). Salt marshes occupy the upper parts of the inter-tidal zone and supra-tidal zone (Zhang et al., 2004), among which *Spartina angelica* and *Spartina alterniflora* marshes were formed after these two species were introduced to China in 1963 and 1979, respectively (Chung et al., 2004). Below the marshes there are mud flats which are located on the upper part of the inter-tidal zone, with very gentle bed slopes. Here, the sediment is the finest for the entire tidal flat, with mud (i.e. a mixture of clayey and silty sediments) being the major sediment component. The deposition of coarser sediment, which occasionally occurs in the mudflat sediment layers, is due to extreme events (e.g. storm surges). Between high water on neaps and mean sea level there are mixed sand–mud flats, characterized by alternating deposition of muddy layers on neaps and sandy layers on springs. Finally, sand flats are distributed over the lower parts of the inter-tidal zone and the sub-tidal zone. The sediments here consist mainly of fine and very fine sands, with a mean grain size of 0.06–0.12 mm (Wang and Ke, 1997).

Studies have shown that where the suspended sediment concentration is sufficiently high, mud will be deposited at various elevations of a tidal flat (Amos, 1995). On the Jiangsu coast, the concentration ranges between 0.1 and 3.0 kg m$^{-3}$; this should be considered as being moderate for a tidal flat with strong tidal currents (i.e. over 1 m s$^{-1}$) (Ren, 1986; Li et al., 2006). Hence, fine-grained sediment is mainly found over the upper parts of the tidal flat, and a well defined pattern of vertical sediment distribution has been formed. A mud layer of 2–3 m thick is located on the top of the tidal flat sequence, and sand is deposited between the lower boundary of the mud layer and the stratigraphic boundary between the modern tidal flat sedimentary system and the old strata (Zhu et al., 1986).

## 3. Method

### 3.1. Definition of deposition rate and preservation potential

In marine sediment dynamics, deposition rate is defined as the rate of bed elevation change; it is referred to as accretion rate when it is a positive value, or as erosion rate for a negative value. The instantaneous deposition/erosion rate can be calculated using the sediment continuity equation, which is

$$\frac{\partial h_b}{\partial t}+\frac{1}{\Gamma}\left(\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}\right)=0 \qquad (1)$$

where $h_b$ is the bed elevation (the first term representing the rate of seabed elevation change), $\Gamma$ is the bulk density of sediment, and $q_x$ and $q_y$ are the $x$- (cross-shore) and $y$- (longshore) components of the rate of sediment transport in terms of mass, respectively.

The preservation potential is the probability that a layer of sediment accumulated during an event (e.g. a tidal cycle) can be preserved over a fixed period of time (e.g. one year). Such a probability is controlled by the seabed mobility and the accretion