Marine Geology 366 (2015) 34–48

Contents lists available at ScienceDirect

Marine Geology

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

Morphodynamics and stratigraphic architecture of compound dunes on the open-coast macrotidal flat in the northern Gyeonggi Bay, west coast of Korea

Kyungsik Choi *, Joohee Jo

School of Earth and Environmental Sciences, Seoul National University, Republic of Korea

ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form 25 April 2015
Accepted 2 May 2015
Available online 5 May 2015

Keywords:
Tidal compound dune
Tidal channel
Morphodynamics
Architecture
Tidal asymmetry

ABSTRACT

Simple and compound dunes are developed on the intertidal tributary channel and channel bank of Yeochari macrotidal flat in the northern Gyeonggi Bay, west coast of Korea. Dunes are asymmetrical with the majority of their steeper lee faces and master bedding surfaces dipping toward the ebb current direction. Dunes consist of cross-bedded medium to coarse sands with a coarsening-up trend. Channel banks are comprised of sand and mud flat facies association, while the tributary channel is composed of channel facies association including fluid muds and channel lags. Three-year morphodynamic observations revealed that simple dunes on the tributary channel migrate seaward as fast as 1.5–2 m per day. In contrast compound dunes on the southern channel bank migrate either landward or seaward at much slower rates of 2–3 m per month. Despite greater current speeds on the channel bank, smaller tidal asymmetry leads to slower migration of compound dunes. In the case of intense wave activity, however, compound dunes seem to migrate at a higher rate. During the study period, compound dunes continued to shift their location toward the northern channel bank direction as the tributary channel migrates laterally back and forth perpendicular to channel thalweg. Concurrent migration of compound dunes and the tributary channel produced a complicated stratigraphic architecture consisting of a point-bar succession overlain by a coarsening-up compound-dune succession. Master bedding surfaces of compound dunes dip in a nearly opposite direction to those of point-bar succession. Tidal asymmetry, wave intensity, discharge fluctuation that controls the migration of tributary channel, and the antecedent topography of resistant substrate are seen to exert an important control on the stratigraphic architecture of compound dunes and point bars in the intertidal environment.

1. Introduction

Dunes are common feature in tide-dominated environments where tidal currents are typically over 0.5 m/s and fine to medium sands are available (Dalrymple et al., 1978; Dalrymple and Rhodes, 1995; Masselink et al., 2009). Extensive studies on hydrodynamics and morphodynamics of dunes revealed that dunes are useful indicator of flow depths (Allen and Collinson, 1974; Dalrymple, 1984; Berné et al., 1993), flow strength (Terwindt and Brouwer, 1986; Carling et al., 2006; Weihua et al., 2008), and bedload sediment transport rate (Mohrig and Smith, 1996; Hoekstra et al., 2004; Kostaschuk and Best, 2005; Masselink et al., 2009). Dune migration is of particular interest because it provides useful information regarding internal architecture. Dunes formed in tidal environments have complicated internal architecture due to the bidirectionality of tidal currents, changing tidal levels and time–velocity asymmetry as well as occasional presence of waves (Dalrymple and Rhodes, 1995). Long-term measurements of dune migration have significant implications on the development of dune architecture in tidal environments (Terwindt and Brouwer, 1986; Allen et al., 1994; Larcombe and Jago, 1996; Hoekstra et al., 2004). However, documentations of dune architecture based on multi-annual morphodynamic observation are scarce.

Tidal compound dunes, large dunes on which smaller simple dunes are stacked (sensu Ashley, 1990), form mainly by forward accretion, and have internal master bedding surfaces that are created by the migration of superimposed simple dunes and dip in the flow directions (Allen, 1980; Dalrymple, 1984; Terwindt and Brouwer, 1986; Dalrymple et al., 1990; Berné et al., 1993; Dalrymple and Rhodes, 1995). Tidal compound dunes constitute a coarsening-up succession because current speed is strongest on the dune crest and is weakest on the trough (Dalrymple and Rhodes, 1995). The architecture of tidal compound dunes contrasts with that of tidal bars, tidally generated sand body with long axis parallel with tidal currents (c.f. Dalrymple, 2010), as the latter is produced by lateral migration with regard to flow direction (Dalrymple and Rhodes, 1995; Dalrymple, 2010; Dalrymple et al., 2012) with exceptions of downcurrent accreting tidal bars (e.g., Féniès and Tastet, 1998; Legler et al., 2013). As a consequence, distinctions between

* Corresponding author.
E-mail address: tidalchoi@snu.ac.kr (K. Choi).

http://dx.doi.org/10.1016/j.margeo.2015.05.002
0025-3227/

the two types of deposits are vital to predict sandstone geometry and stratigraphic architecture formed in tidal environments (Dalrymple and Choi, 2007; Martinius and Van den Berg, 2011; Longhitano et al., 2012; C. Olariu et al., 2012). Tidal compound dunes often occur in close proximity to tidal channels that migrate laterally (Dalrymple et al., 1990; Svenson et al., 2009). Compared with numerous documentations of the architecture of the tidal compound dunes (Terwindt, 1971; Allen, 1980; Dalrymple, 1984; Dalrymple and Rhodes, 1995; Longhitano et al., 2010; C. Olariu et al., 2012), little attention has been given to the mobility of the channels that might affect the architectural development of the tidal compound dunes.

The present study documents multi-year observations on the morphodynamics of simple and compound dunes developed in the channelized lower intertidal zone of an open-coast macrotidal flat, Yeochari tidal flat in the northern Gyeonggi Bay. A time series of dunes and channel profile is described to illustrate temporal and spatial changes of morphology of the dunes and channel. Governing processes involved in the long-term morphodynamics of the dunes and channel are evaluated based on hydrodynamic data as well as the profiling data to understand their roles in the development of intertidal compound dune and channel architecture. Discussion is made on the complexity of the stratigraphic architecture of intertidal dunes and channel with comparison to that of subtidal counterparts.

2. Study area

Field measurements were conducted in the lower intertidal zone of Yeochari tidal flat, which is located south of Ganghwa Island in the Gyeonggi Bay (Fig. 1), the largest macrotidal embayment along the west coast of Korea. Yeochari tidal flat is the most extensively developed tidal flats in Gyeonggi Bay. Bounded by prominent subtidal channels (Sukmo and Changbong channels) that are main distributaries of the Han River, Yeochari flat itself has no significant fluvial upstream reach. Small and sinuous creeks in the upper intertidal zone coalesce to form large and wider main channels running southeastward in the lower intertidal zone (Fig. 1). Main channels are joined by a number of tributary channels in the lower intertidal zone and are linked to Changbong Channel in the south, where well-developed dunes are present.

Tides are semidiurnal with distinct diurnal and fortnightly inequality (Fig. 2A). Mean tidal ranges are 5 m during neap tides and 9 m during spring tides (KHOA, 2012; Fig. 2A). Tidal currents reach 1.5 m/s during spring tides (Lee et al., 2013). Precipitation is seasonal with the highest falls occurring during the summertime rainy season, which accounts for about two thirds of the total annual precipitation of 1300 mm (KMA, 2012, 2013, 2014; Fig. 2B). Winds are generally strongest during winter and early spring, when the NW monsoon prevails, and the summertime typhoon season when SW monsoon dominates (KMA, 2012, 2013, 2014; Kim et al., 2004; Fig. 2C).

3. Methods and materials

High-precision profiling of a tributary tidal channel and channel bank was conducted at three transects (XYZ, AB, CD) in the lower intertidal zone of Yeochari tidal flat to measure the morphodynamics of dunes and channels. Transect XYZ is 1430 m long and was profiled 17 times from August 3, 2011 to July 14, 2014. Transects AB and CD are 120 m and 140 m long, respectively. Both transects were profiled four times from March 31 to April 30 in 2014 to deduce daily migration rate of dunes. A real-time kinematic (RTK) GPS, with 10 mm horizontal accuracy and 20 mm vertical accuracy, was used for the leveling of the transects. GPS points were obtained at about every 3–5 m intervals. Elevations are corrected to the Incheon Datum level. Two types of stainless steel can corer (60 cm × 10 cm × 2 cm, 80 cm × 10 cm × 2 cm) were used to obtain a total of 19 undisturbed cores for the analysis of sedimentary facies and stratigraphic architecture of dunes and channel complexes. Grain size analysis was conducted using conventional sieving and pipetting methods. Orientations and dip angles of dunes and bedding surfaces are measured by clinometer (Suunto Tandem 360PC).

Two Teledyne RDI Acoustic Doppler Current Profilers (ADCPs; 1000 kHz and 1200 kHz) were deployed to measure current profiles and directions within the water column at the tributary channel and southern channel bank over two weeks representing a spring–neap–spring cycle from March 31 to April 16 in 2014. Each ADCP was attached to three stainless steel poles that penetrated into the substrate of the channel and channel bank. The top elevations of the ADCPs were leveled using RTK GPS. Current data were sampled in burst mode at an interval of 5 min for 1000 kHz ADCP (Sentinel V20) and every 1 min with a ping rate of 1 s for 1200 kHz ADCP (ADCP-workhorse). The blanking distance was 0.41 m for both ADCPs. Sampling bins are 0.2 and 0.3 m, respectively. Water depth was calculated from pressure using the Teledyne RDI software and corrected to the Incheon Datum level, taking blanking distance into account. Burst and depth-averaged horizontal current speed and direction were calculated from measured current data. A wave gauge was also deployed to measure significant wave height and period at an interval of 10 min.

4. Results

4.1. Occurrence and morphology of dunes, tributary channel and channel bank

Simple and compound dunes are present on the tributary channel and channel bank in the lower intertidal zone of Yeochari tidal flat (Fig. 3). Simple dunes are located on the tributary channel and channel bank with elevations between −2.1 and −4.3 m below mean sea level, whereas compound dunes are developed on the southern channel bank at higher elevations between −2.1 and −2.7 m below mean sea level. The tributary channel is 1.2–1.4 m deep at bankful stage and is up to 8 m deep during spring high tides. The tributary channel has an asymmetric profile with a gentle slope on the southern channel bank and a steep slope on the northern channel bank. The channel is floored by simple dunes that are 0.5–0.6 m high. The channel thalweg is subaerially exposed only during perigean spring low tides. The northern channel bank has a flat-top morphology, which is submerged during entire neap tides (Fig. 3H). An erosion scarp of the mud flats up to 60 cm relief is present at the cutbank location of the northern channel bank.

Simple dunes are asymmetrical with their steeper (28–44°) lee face toward the ebb current direction (Fig. 4A, B). Simple dune heights and wavelengths range from 30 to 70 cm and 3 to 7 m, respectively. Cross bedding inclinations range between 30 and 42°. Reactivation surface angles vary between 12 and 16°. Simple dunes tend to be more asymmetric with a more subdued morphology on the channel than on the channel bank. Dune height increases with the elevation of the dune within channel. Simple dunes are oriented mainly southwest (20–40° SW), nearly parallel to the channel axis. Compound dunes are ebb-asymmetric with the steeper lee face dipping toward the southeast (5–20° SE) (Fig. 4C, D). Compound dune heights and wavelengths range between 80 and 100 cm and 20 to 30 m, respectively. Simple dunes are superimposed on the lee side of the compound dunes and oriented at an oblique angle to the crest of the compound dunes (Fig. 3A, B). Master bedding surfaces, formed by simple dune migration (Dalrymple, 1984), are present within compound dunes and are typically gentle sloped; less than 6° (Fig. 4C, D). Cross-beddings generated by flood currents are typically preserved as a flood cap in the landward side of simple and compound dunes (Fig. 4A, B, C). Superimposed ripples are occasionally developed on the stoss side of the simple dunes (Fig. 3D, F). During the falling stage of ebb tides, runoff channels form along the dune trough (Fig. 3C). Runoff channels are highly sinuous and locally 50 cm deep. They migrate actively and commonly erode dunes at their cutbank positions (Fig. 3C). Semiconsolidated mud flat deposits are locally exposed at the trough of simple dunes (Fig. 3D, E).