Morphodynamics, hydrodynamics and stratigraphic architecture of intertidal compound dunes on the open-coast macrotidal flat in the south of Ganghwa Island in Gyeonggi Bay, Korea

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Morphodynamics and hydrodynamics of intertidal dunes on the macrotidal flat in Gyeonggi Bay, western coast of Korea were investigated to understand the external controls governing stratigraphic architecuture. Simple dunes migrate faster in the channel than on the bank due to greater tidal asymmetry in the channel. The displacement of compound dunes is affected by seasonal storm waves and tidal cycle in the event of storms. Dune morphodynamics are further influenced by the proximity to tidal channel. Combined effects of tidal asymmetry, seasonal variation in the direction of wind-induced waves, precipitation-induced channel mobility, and tidal cycle make the architectures of tidal compound dunes more complicated than those of subtidal setting.

1. INTRODUCTION

Dunes are subaqueous bedforms that are ubiquitously distributed in tidal environments where tidal currents are faster than 0.5 m/s and fine to medium sands are available (Dalrymple and Rhodes, 1995). Dune morphodynamics has been regarded crucial in understanding bedload sediment transport rate and residual tidal currents over various time scales. Non-tidal effects such as wind-induced waves and channel migrations are also known to complicate dune morphodynamics in tidal environments (Choi and Jo, 2015). However, hydrodynamic observations to relate dune morphodynamics to the non-tidal effects are still rarely conducted for intertidal environment.

Tidal dune architecture has received attentions because it differs from that of tidal bars which have a flow-normal architectural component. Depending on tidal asymmetry and current speed, tidal compound dunes exhibit various internal architecture. As tidal environments are influenced by waves and channel migration as well as tidal currents, resultant architecture is presumed to be more complicated. However, impact of non-tidal processes on the stratigraphic architecture of compound dunes is scarcely explored.

The present study documents multi-year observations on the morphodynamics of intertidal dunes in the open-coast macrotidal flat in the northern Gyeonggi Bay, west coast of Korea. Various hydrodynamic conditions governing the morphodynamics of dunes and channel were analyzed based on long-term mooring data. Stratigraphic architecture of intertidal compound dunes was reconstructed based on detailed facies analysis of short cores. Discussion is made on the relative role and significance of tidal and non-tidal processes in formulating the stratigraphic architecture that varies in time and space.

2. STUDY AREA

Yeochari tidal flat is located in the south of Ganghwa Island in the northern Gyeonggi Bay, the largest macrotidal embayment. Bounded by Sukmo Channel in the west and Jangbong Channel in the south, Yeochari tidal flat measures about 6 km in width during spring low tides. Lower intertidal zone of the flat is heavily dissected by large channels that are 200-600 m wide and 1-2.5 m deep at bankfull stage. Tides are semidiurnal with

mean tidal ranges ranging from 5 m during neap tides to 9 m during spring tides. Tidal current speeds reach 1.5 m/s during spring tides. Annual precipitation ranges between 1300 and 1400 mm with two thirds occurring during summertime rainy season. Winds are generally stronger during winter and early spring when winds are northwesterly, and during summertime typhoon season when southwesterly to southerly winds prevail.

3. MATERIALS AND METHODS

High-precision profiling of dunes and tidal channel were conducted twenty times from 2011 to 2015 along four transects using RTK GPS. Current profiles and directions were measured using RDI ADCP moored at three locations for three times representing summer and winter. Wave data were obtained using pressure wave gauges at two locations for summer and AWAC at one location for winter. SSCs were measured at one location using OBS. A total of 34 undisturbed short cores were collected for the analysis of sedimentary facies and stratigraphic architecture of dunes and channel.

4. RESULTS

Dunes are present on the tributary channel and channel banks in the lower intertidal zone of Yeochari tidal flat (Figure 1). The tributary channel has an asymmetric profile with steep slope on the southern channel bank and a gentle slope on the northern channel bank (Figure 2). Simple dunes on the tributary channel migrate seaward as fast as 1-4 m/day. In contrast, those on the southern channel bank migrate either landward or seaward as fast as 0.1-1 m/day during spring to fall and 1-2 m/day during winter. Compound dunes on the southern channel bank migrate either landward or seaward at much slower rates of 2-3 m/month. Tributary channel migrates at variable rates ranging from 1 to 18 m/month with greater rates occurring during summertime rainy season. Tributary channel is ebb-dominated with pronounced tidal asymmetry, whereas tidal flats on the southern channel bank are flood-dominated with smaller tidal asymmetry. Wind-induced waves with significant wave heights over 0.4 m seem to modulate tide-induced sediment supply. Westerly to northwesterly waves during winter to spring accentuate ebbward migration of compound dunes, whereas southerly to southwesterly waves during summertime typhoon result in floodward migration. Channel migration and displacement of compound dunes resulted in a composite architecture in which a coarsening-up compound dune succession formed on the channel bank overlie a fining-up simple dune succession formed in the point bar of the channel. Master bedding surfaces within the compound dune succession dip nearly opposite to or in the same quadrant to the accretion surfaces of the point bar.

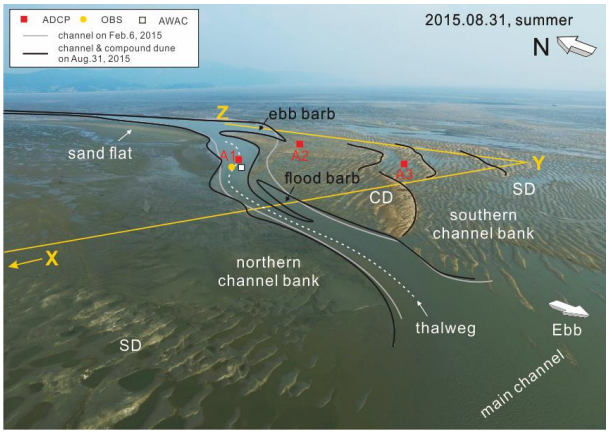

Figure 1. Drone image showing the location of compound dunes (CD) and simple dunes (SD) in the lower intertidal zone of Yeochari tidal flat. Profiles along transect XY and YZ are given in Figure 2.

5. DISCUSSION

Compound dunes on the southern channel bank migrated either landward or seaward. Considering nearly symmetrical tides with slight flood dominance, seaward migration of the compound dunes cannot be explained by tidal currents only. Significant wave heights over 0.6 m were frequently measured during wintertime and summertime. Observed waves are sufficient to trigger the migration of the compound dunes. During wintertime, westerly to northwesterly waves with significant wave height over 0.6 m were mainly developed around high tide slack and early ebb tides. Notable seaward migration of the compound dunes indicates that sediment transport occurred during ebb tides. In summer of 2014,

storm events with strong southerly to southeasterly winds occurred during the early stage of ebb tide after flood slack. Despite the prevalence of onshore winds, however, compound dunes migrated seaward. Choi and Jo (2015) documented a similar but opposite trend in which the landward displacement of the compound dunes occurred under the presence of strong offshore winds during wintertime. This suggests that the timing of wave activity over a tidal cycle is critical in the migration of the compound dunes. This assertion is congruent with the fact that waves are responsible for the resuspension of sandy sediments and the transport of resuspended sediments is controlled by the direction of residual tidal currents and wind-induced currents. Unlike subtidal setting, the duration and fetch distance of wind-induced waves are limited by tidal cycle on the intertidal flat.

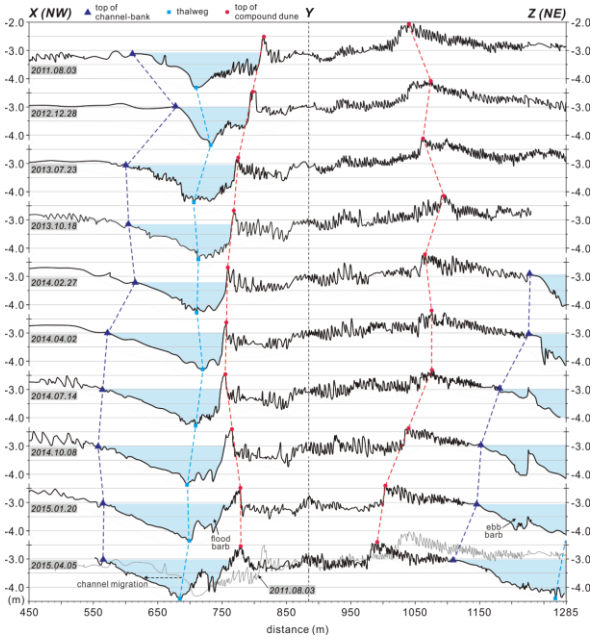

Figure 2. Repeated profiles of tributary channel and dunes along transect XYZ. Compound dunes displaced either floodward or ebbward while the tributary channel continued to migrate northwestward or northern channel bank direction along transect XY. Note the contraction of simple dune-covered area as a result of tributary channel migration along transect YZ.

Subtidal compound dunes can migrate toward subordinate current direction in the case of non-tidal events such as seasonal river discharge and wind driven currents (Le Bot and Trentesaux, 2004; Kostaschuk and Best, 2005; Ferret et al., 2010). Considering that the events are annual and semidiurnal tidal currents are unable to reverse the asymmetry of subtidal large dunes that requires longer response time, the presence of bidirectional master bedding surfaces substantiates the effects of non-tidal events in the otherwise tidal compound dune architecture. However, the impact of non-tidal events is not easily identifiable in the intertidal setting as the response of the compound dunes to non-tidal events can be modulated by tidal cycle, proximity to channel, and prevailing wind directions that vary in time and space. In addition, the response time of the intertidal compound dunes to the non-tidal events is much shorter than that of subtidal equivalents. As a result, the effect of non-tidal events can be frequently commingled with that of tidal currents within the architecture of compound dunes.

6. CONCLUSIONS

Compound and simple dunes on the channel and channel bank in the lower intertidal zone of Yeochari tidal flat in the northern Gyeonggi Bay migrate actively in response to tides, waves and rain-induced discharge fluctuation. Combined influences of tidal asymmetry, seasonal variation in the direction of wind-induced waves, and the mobility tidal channel, and tidal cycle complicated the architecture of intertidal compound dunes whose master bedding surfaces may dip nearly opposite to or in the same quadrant of those of accretion surfaces of point bars of the channel.

7. ACKNOWLEDGMENT

This study was supported by the Energy Efficiency and Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Ministry of Trade, Industry and Energy (MOTIE), Republic of Korea, and Research Institute of Oceanography (RIO) at Seoul National University.

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