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Morphology, sedimentology and stratigraphy of Korean tidal flats – Implications for future coastal managements

Kyungsik Choi*

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

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ABSTRACT

Tidal flats constitute a unique and extensive depositional system encompassing the entire west coast of Korea. Tidal flats are classified into three types on the basis of morphologic setting, open-coast, embayment, and channel-margin. Macrotidal regime and highly indented coastlines favored tidal current-induced sedimentation, resulting in seaward coarsening sediment distribution. Tide-dominated sedimentary processes are complicated by the strong monsoonal climate, and associated seasonal wave activity and precipitation-induced discharge. Different exposure to wave activity leads to contrasting sedimentary processes, sedimentation and morphologic response among various types of tidal flats. Summertime heavy rainfalls accentuate runoff discharge-driven sedimentation in the tidal flats, irrespective of the presence of rivers. Tidal flats have been venue for government-driven mega reclamation projects such as Saemankeum, Sihwa, and Youngjong–Yongyou islands due to their geographic proximity to urban area and flat morphology. Massive destruction of tidal flats was justified by mandatory environmental impact assessments that failed to predict irreversible effects on coastal depositional system, triggering a nationwide controversy. Future reclamation projects must be supplemented by studies that can evaluate properly the complexity and dynamic behavior of tidal flats so as to minimize socio-economic cost as well as the loss of tidal flats.

1. Introduction

Tidal flats fringe the highly indented rocky coastline of the west and south of the Korean Peninsula. Shallow water depths and macrotidal conditions have created extensive tidal flats ranging in shore-normal width from hundreds of meters at channel margin to more than several kilometers along the open coast near river mouths. Tidal flats are incised by sinuous and dendritic tidal channels, which constitute drainage system linking subtidal environment with intertidal and supratidal environments (Choi et al., 2013). Korean tidal flats have no seaward bars and extensive salt marshes, which make them morphologically unique compared to other tidal flats in the world. Due to muddy nature of surface sediments and lack of fluvial drainage channels, many have suggested Korean tidal flats and channels are less dynamic than the well-studied tidal flats in the North Sea (Frey et al., 1989; Wells et al., 1990; Alexander et al., 1991). However, recent studies have documented that Korean tidal flats and channels are dynamic features that are actively responding to seasonally varying wave condition linked with the monsoonal climate (Choi et al., 2004; Yang et al., 2007; Choi, 2011a; Choi et al., 2013). In protected areas, rhythmic tidal sedimentation prevails because of strong tidal currents and high concentrations of suspended sediment (Choi and Dalrymple, 2004; Choi, 2010, 2011a, b).

Korean tidal flats have been extensively exploited for agricultural and industrial purposes. As a result, a significant portion of tidal flats have disappeared over the past 40 years (Hong et al., 2010; Sato and Koh, 2004). Nationwide controversy has been sparked over potential ecological and economic consequences of mega tidal-flat reclamation projects such as Saemangeum and Sihwa (Cho, 2007). Part of the controversy stems from the lack of understanding of natural processes occurring in the tidal flats and channels. This is because little information was available for the evaluation of the environmental impact of the reclamation at the time of development. In most cases, mandatory environmental impact assessment studies are unable to distinguish natural cycles over which tidal flats and channels behave from overprinted variations due to artificial development.

This paper reviews morphological, sedimentological and stratigraphic characteristics of Korean tidal flats to highlight the

* Tel.: +82 2 880 6748, +82 2 872 0311.
E-mail address: tidalchoi@snu.ac.kr.

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complexity of natural processes that shape tidal flats and channels. Special focus will be given to the temporal and spatial variability of the processes that are registered in the tidal flats and channels. This paper aims to give insight on the future development of coastal areas along the west coast of Korea.

2. Physiographic setting

The west coast of Korea is characterized by highly indented coastlines, formed by coastal submergence in response to post-glacial transgression (Fig. 1). Extensive muddy tidal flats and sandy tidal bars are present along funnel shaped coastlines. On the other hand, narrow strips of sandy tidal flats and beaches are developed at protruded coastlines. Coastlines of the west coast of Korea have been progressively modified due to reclamation for industrial complexes and rice paddies, which started in early 60s (Sato and Koh, 2004). Constructions of the Saemankeum dyke and the Sihwa dyke culminate man-made alterations of coastlines. As a result of reclamation, coastlines become straightened by the expense of huge tidal flat and salt marsh.

Tides along the west coast of Korea are predominantly semi-diurnal with distinct diurnal and fortnightly inequality (Fig. 2). Tidal range varies between 4 m in the coastal area of Jeonnam Province and 9 m in Gyeonggi Bay. Tidal range increases northward along the west coast, because tidal waves rotate anticlockwise as they propagate onward (Lee and Jung, 1999). Tides are further amplified in the bay area due to funnel shape morphology (Dalrymple and Choi, 2003). Tidal currents are bidirectional, ranging 1–2 m/s in shallow tidal channel and 3–4 m/s in offshore tidal channels between large tidal sand bars.

Wave energy increases during winter time due to the strong monsoonal climate and during summer typhoons (Wells, 1988). Significant wave heights increase up to 2–3 m within shallow subtidal region. Wave directions are northerly to northwesterly during winter, whereas they are southwesterly during summer.

Major rivers (Han River and Keum River) deliver moderate amounts of sediment into the coastal and shelfal regions of the west coast of Korea (Yoon and Woo, 2000; Lee and Chu, 2001). Most of this discharge occurs during summertime between July and September (Yoon and Woo, 2000; Park et al., 2002), when nearly 70% of annual precipitation is recorded (Fig. 2). Precipitation and river discharge are very seasonal due to the strong monsoonal climate.

3. Geographic occurrence

Korean tidal flats are present in a highly indented, rocky coast along the west coast of Korea, encompassing 2 489 km^2 (MLTM, 2011). The area of tidal flats reduced from 3 905 km^2 in 1964 to 2 489 km^2 in 1998 by reclamation (Hong et al., 2010; MLTM, 2011). In terms of total surficial area, Gyeonggi Province and Incheon have 36% of tidal flats along the west Korean coast (914.9 km^2), Chungnam Province has 14% (387.3 km^2), Jeonbuk Province has 5% (132 km^2), Jeonnam Province has 40% (1 017.4 km^2), and Gyeongnam Province including Busan and Jeju has 5% (118.8 km^2).

4. Morphology

Korean tidal flats can be divided into three types on the basis of morphologic setting, i.e., open coast tidal flat, embayment tidal flat, and channel margin tidal flat (Fig. 3). Open coast tidal flats are wide and gentle sloped (Fig. 3A and B). Open coast tidal flats are typically channelized (e.g., Choi et al., 2011). Tidal channels are straight to sinuous (Fig. 4A). Open coast tidal flats are mainly present along the northern Jeonbuk Province, Youngkwang-Baeksu region, western

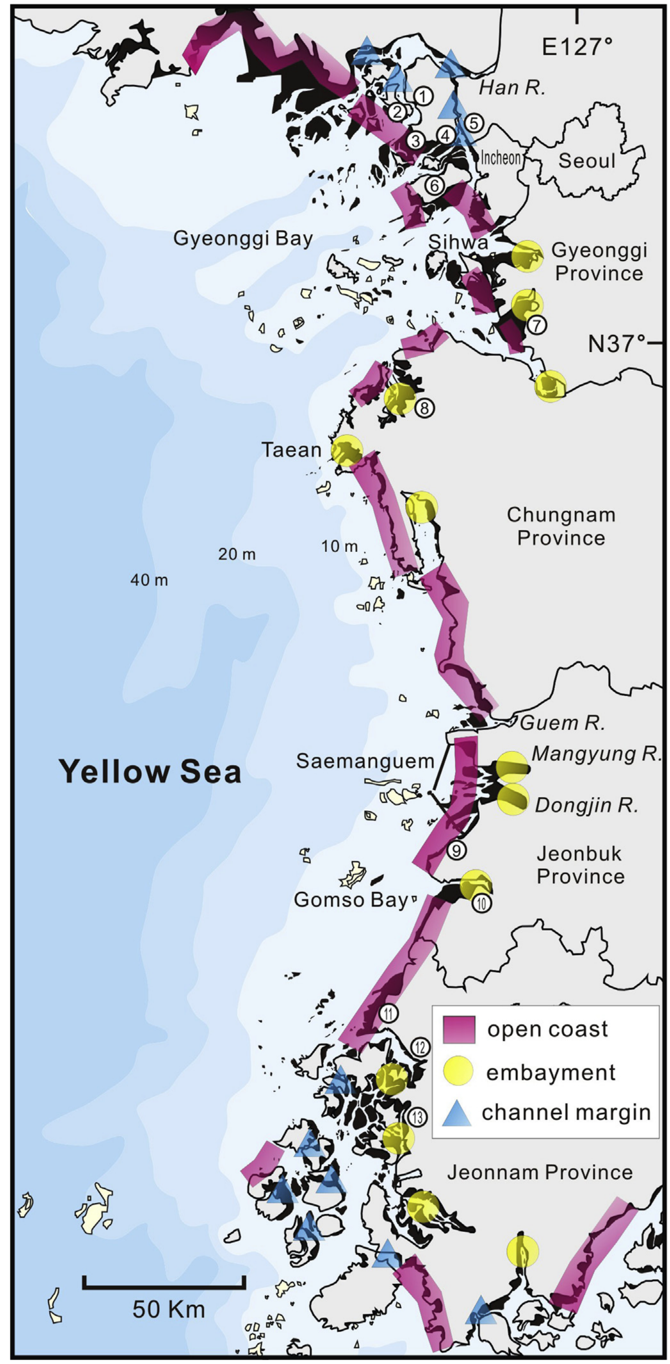

Fig. 1. Map showing the distribution of tidal flats along the west coast of Korea. (1) Oepori tidal flat, (2) Maeumri tidal flat, (3) Yeochari tidal flat, (4) Donggeumri tidal flat, (5) Kimpo tidal flat, (6) Youngjong–Yongyou tidal flat, (7) Namyang tidal flat, (8) Garolim Bay, (9) Byunsan tidal flat, (10) Sunwoonri tidal flat, (11) Baeksu tidal flat, (12) Hampyong Bay, (13) Muan Bay.

side of offshore bedrock islands, Taean region (Fig. 1). Slope gradient of tidal flat is greatest near high tide level and decreases seaward (Fig. 5). In Gomso Bay (4–7 km wide), slope gradient decreases from 0.3° in the upper intertidal flat to 0.07° in the middle to lower intertidal flat (Lee et al., 1994; Yang et al., 2007). In the inner part of Gomso Bay, the slope is much smaller, 0.03° in the upper to middle intertidal flat, and 0.13° in the lower intertidal flat near main channel (Choi et al., 2012a). Greater slope gradient in the upper intertidal flat is due to either erosion by wave activity or