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Effect of irregular, complex underlying topography in Holocene sedimentation revealed from late Quaternary sequences in the mid-western coast of Korea

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ABSTRACT

Through a detailed analysis of seismic profile and vibra-/drilling-core sediments (up to 25.5 m long) with AMS ^{14}C ages from a tidal flat in the mid-western coast of Korea, we reconstruct development of coastal sedimentary sequences in response to sea-level changes for more than about 150 ka, and reveal effect of irregular, complex underlying topography in the Holocene coastal sedimentation. Unit I overlying rock basement and the lower part of Unit II consist of fluvial sediments deposited during sea-level lowstands prior to interglacial period of Eemian Stage (MIS 5e). During the sea-level highstand of MIS 5e, muddy tidal sediments between 7.40 and 10.76 m deep below the present tidal-flat surface were deposited in the upper to middle part of Unit II. The study area had been subaerially exposed for a long duration from MIS 5e to ca. 10 ka. During this period, the muddy tidal sediments in Unit II had been underwent oxidization and significant erosion by fluvial process, forming irregular and complex morphology of the upper boundary of Unit II with a large topographic relief (up to ca. 7 m) even over a short (ca. 560 m) distance. On the upper boundary of Unit II, topographic highs could act as barriers for weakening wave effects from ca. 8–9 ka to 3–4 ka (period of relatively rapid sea-level rise), depositing muddy tidal sediments (Unit III-B). As the muddy tidal sediments (Unit III-B) filled the irregular, complex underlying morphology, surface topography was nearly flat without barriers around about 3–4 ka. Since then, the nearly flat surface morphology without barriers, together with relatively slow sea-level rise and direct exposure of strong onshore winter waves/storms, could promote to deposit wave-/storm-driven sandy sediments (Unit III-A). This study suggests that change in surface morphology could affect stratigraphic evolution of the Holocene coastal sequence by variation in depositional regime.

1. Introduction

The Yellow Sea is typical of shallow (ca. 55 m in average water depth) epicontinental sea which have undergone sensitively changes of sea-level, hydrodynamics, and sediment supply from the adjacent lands during the Quaternary (Milliman et al., 1989; Chough et al., 2000; Jin et al., 2002; Uehara and Saito, 2003; Liu et al., 2004, 2007; Yang and Liu, 2007; Lee et al., 2009). In the Yellow Sea, a variety of the Quaternary coastal deposits (or sequences) are formed in response to the changes in sea-level, hydrodynamics, and sediment supply (Kim et al., 1999; Choi and Dalrymple, 2004; Chang et al., 2014; Yi et al., 2014; Sun et al., 2015; Liu et al., 2016). Sedimentary characters of these deposits or sequences have provided important clues to understand the Quaternary changes in depositional processes, geomorphic features, sedimentary environments and stratigraphy in the Yellow Sea.

Tide-influenced coastal deposits from late Pleistocene to Holocene occur extensively at various geomorphic settings from embayments with/without major rivers to open, straight coasts along the eastern coast of the Yellow Sea (Wells et al., 1990; Alexander et al., 1991; Chough et al., 2000; Choi and Dalrymple, 2004; Yang

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et al., 2005). Present geomorphic features of these tidal coasts are characterized by rare presence of offshore barriers and salt marshes (Lee et al., 1994; Chough et al., 2000; Yang et al., 2006). Many studies using surface and subsurface sediments in these coastal areas have documented detailed depositional characters from sedimentary processes to stratigraphic evolution of tide-influenced coastal sedimentary sequences from late Pleistocene to Holocene (Park et al., 1998; Kim et al., 1999; Chang and Choi, 2001; Choi and Park, 2000; Choi and Dalrymple, 2004; Lim et al., 2004; Yang et al., 2006; Chang et al., 2014). These depositional characters have provided invaluable information for understanding late Quaternary (late Pleistocene to Holocene) changes in depositional regimes and sedimentary environments in the coastal areas of the Yellow Sea.

Because of very shallow water depth and salty pore waters in modern tidal coast areas including tidal flats, conventional marine seismic and GPR systems cannot be easily applied (Watabe and Sassa, 2008; Cassidy, 2009; Buyenevich et al., 2009). Rare acquisition of seismic data together with relatively sparse-spaced vibracores and boreholes in these coastal areas have made impossible to document detailed subsurface geomorphological characters of sedimentary sequences. Effect of morphologic change on the stratigraphic evolution in these coastal areas has been, therefore, rarely studied. In this study, a seismic profile was acquired from a macro-tidal sandy flat along the mid-eastern coast of the Yellow Sea using a land seismic system when the tidal flat was exposed during ebb tide. Based on detailed seismic characters with lithological features of subsurface sediments (5.5–25.5 m deep) in the study area, we propose development of coastal sedimentary sequences in response to sea-level changes for more than about 150 ka, and highlight effect of irregular, complex underlying topography in the Holocene coastal sedimentation.

2. Geological and oceanographic setting

The study area is a macro-tidal flat located at the eastern side of embayment entrance near the northern tip of Taean Peninsula, mid-western coast of Korea (Fig. 1A). The embayment was reclaimed for agriculture by dyke in December 2000. The coast in the study area is directed to NE–NNE, directly exposing to offshore without barrier islands (Fig. 1A). It is connected northward to open, relatively straight (N–S) coast. Before construction of the dyke, tidal flat (i.e., from mean high water level to mean low water level) along the coast was less than ca. 500 m in width, and it has expanded to offshore since the dyke construction (Fig. 1A; KORDI, 2002). Surface sediments in the study area were mostly fine to medium sands (>ca. 85% in contents) before the dyke construction (KORDI, 2000). The surface sediments after the dyke construction were nearly similar to those before construction of the dyke, except for a narrow zone of muddy sediments along the dyke (KORDI, 2002). In the study area, changes in topographic elevation for three years (2000–2002) ranged from −9.6 cm to 3.1 cm with the seaward gentle (<0.15°) slope gradient (KORDI, 2002). The study area is directly bounded landward by cliffs of Precambrian gneiss and schist (KIER, 1982).

The tide in the study area is semi-diurnal with a tidal range of 2.8–6.6 m (mean tidal range: 4.7 m) (KOHA, 2009). In offshore subtidal zone, tidal currents show a clockwise rotation with E–SE direction in flood tide and W–NW direction in ebb tide, and their speeds range from 0.3 to 2.0 m/sec at seawater surface (KORDI, 2000, 2002). Because the study area is directly exposed to offshore without barrier islands, it is also influenced by seasonal waves caused by the East Asia Monsoon (KORDI, 2002; Yang et al., 2006). During summer, weak, southerly winds are dominant, forming low waves, whereas higher storm waves, generally exceeding 1–2 m in significant wave height, are caused by strong, north-to northwesterly winds during winter (KMA, 1998; KORDI, 2002; Yang et al., 2006).

During the last glacial maximum (LGM), the Yellow Sea was exposed subaerially (Chough et al., 2000; Liu et al., 2004). Sea-level rose rapidly after termination of LGM, and reached its present position around about 5–6 ka (Kim et al., 1999; Chang and Choi, 2001; Liu et al., 2004). Prior to the present sea-level highstand, sea-level was in highstand during the interglacial period of Eemian Stage (MIS 5e), about 2–10 m above the present sea-level (Shackleton, 1987; Chappell et al., 1996; Grant et al., 2012). Between these two sea-level highstands, sea-level was never higher than −30 m in the South Yellow Sea (Berné et al., 2002; Liu et al., 2004).

3. Materials and methods

In order to provide subsurface geometry of sedimentary sequences in the study area, about a 560 m-long seismic profile was acquired from a sandy tidal-flat in early 2000 (Fig. 1B). Seismic data were collected using a land seismic system when tidal flat was exposed during ebb tide (Fig. 1C). Using a 10-kg sledge hammer and 100-Hz geophones, we acquired 48-channel seismic data with shot and receiver spacing of 1 m (Table 1). Therefore, common depth point (CDP) coverage was 24-fold. Distance of the source to the nearest receiver was 1 m. Two shot gathers were stacked vertically at each shot point to enhance signal-to-noise ratio. An OYO Das-1 seismograph recorded reflection data using a 0.125-ms sample interval. Main procedures for processing the data included assignment of field geometry, muting of ground roll, velocity analysis, and CMP (common mid-point) stacking.

In a shot gather, four types of seismic waves are recognized; refraction, ground roll, air waves, and reflections (Fig. 2). Ground roll is the most dominant noise appearing as low-velocity, low-frequency (<100 Hz), and high-amplitude waves. However, reflections are not significantly disturbed by ground roll which is only present at near offsets (Fig. 2). Air waves with velocities around 340 m/sec also do not significantly deteriorate the records (Fig. 2). Reflections are characterized by higher frequencies with dominant energy ranging from 150 to 350 Hz. This frequency range is much higher than that achieves usually by shallow seismic surveys on land, considering that surface seismic sources such as a sledge hammer hardly produce a pulse with a spectral peak in excess of 200 Hz (e.g., Feroci et al., 2000; Keiswetter and Steeples, 1995). In tidal-flat area where surface sediments are mostly water-saturated and compacted, a weathered layer is not present just below tidal-flat surface and seismic velocities exceed water velocity of 1500 m/s. Consequently, most reflections are separated from ground roll and air waves having much lower velocities. These effects are most likely to provide a good hammer-to-ground coupling as well as much less anelastic absorption. Water saturation can be also expected to effectively suppress high-amplitude ground roll by causing surficial sediments to behave like fluid.

In 2000, sediment cores (5.5–25.5 m long) were obtained using vibracorer (diameter 7.2 cm) and drilling system (diameter 8 cm) at four sites along the seismic line (Fig. 1B). Drilling system penetrated into basement (Precambrian gneiss and schist) at two sites. Recovery rates of sediment cores collected by a drilling system are 62% and 45% at DC-1 and DC-2, respectively. All cores were described by splitting lengthwise and X-radiographs of 1-cm thick slab were taken to observe micro-scale sedimentary structures. For grain-size analysis, dried sand fraction was analyzed using standard sieves interval of 0.5ϕ, while mud fraction was analyzed using a Micromeritics Sedigraph 5100.

Ages of core sediments were determined by radiocarbon dating.

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