Application of a deltaic ichnological model to Holocene deltaic deposits: examples from the Nakdong River delta in the Southeastern Korean Peninsula

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Abstract:

Since sensitive reaction of organic behavior to an environmental change, ichnological analyses have given the information about a variety of physicochemical stresses of delta environments. While many analyses have been performed in ancient deltaic settings, little has been done in modern deltas. Through this study we applied ichnological models to the unconsolidated Holocene deltaic deposits of the Nakdong River delta, Korea, at core site ND-2, in order to track the sedimentary evolution and early Holocene sea-level jump recorded in discontinuity surface. Quantitative grain size data and age dating results helped a little interpretation of depositional settings.

The study interval (35-9 m depth) can be divided into six facies associations (lower shoreface, lower offshore, distal prodelta, proximal prodelta, distal delta front, and delta front). Around 8.5 ka ago, the sea-level jumped abruptly, and preserved as *Glossifungites* surface between lower shoreface and lower offshore. Deltaic deposition initiated around 6 ka ago with decelerating sea-level rise. The fining-upward succession of lower shoreface and lower offshore under transgressive system tract changes to coarsening-upward succession at the lower boundary of the distal prodelta facies association. Dominance of deposit feeding structures in sandy substrate of the distal delta front indicates high water turbidity representing proximity to river mouth.

Wave-dominated lower shoreface, lower offshore, prodelta, and distal delta front show uniform and moderate to high bioturbation indices (BI=3-5). Low sedimentation rate indicates a wide colonization window, and stressful condition to trace makers induced by freshets had been buffered by wave agitation. The mixed wave-, storm-, and river-dominated delta front represents a uniform and low bioturbation index (BI=0-2). High sedimentation rate indicates a narrow colonization window. Wave processes were still dominant, but hyperpycnal flow caused by intense storm and flood events easily overprinted original structures. With the proximity to the river mouth, organisms were affected by persistent stressful environments from riverine outflow.

Consequently, this study suggests that the ichnological models of ancient deltaic settings can be applied to the modern Nakdong deltaic setting, and ichnological analysis also might be a valuable tool in reconstruction of Holocene paleoenvironments.

Keywords: delta, Holocene, ichnology, *Glossifungites* surface, depositional processes, Nakdong River

Sedimentary evolution

The postglacial transgression of the study area was initiated around 15 ka ago (Park et al., 2000) and then the sea-level rise was decelerated around 6 ka ago (Park et al., 1996, Yang et al.). According to the result of radiocarbon and OSL age dating analysis of ND-2 sedimentary core, FA1 was deposited around 8.5-9 ka ago. This age dating result and fining upward succession of FA1 indicate that this unit belongs to transgressive system tract. At this age, the BH-1 core site, which is approximately 20 km landward of the ND-2 site, was in an estuary environment, and the ND-1 core site, which is 6 km landward of the ND-2 site, was in a river mouth area. Also, pre-studied Holocene sea-level curves represent the water depth of ND-2 site, at that time, was within the range of fair-weather wave-base. With integrated consideration with facies analysis, intercalated sand with mud facies totally disturbed by intense bioturbation, it can be determined that FA1 was lower shoreface environment at about 8.5-9 ka ago.

According to the research conducted for sea-level fluctuations of the southeastern Korean Peninsula, a sea-level jump occurred caused by rapid transgression around 8 ka ago. The transgressive erosion and non-deposition period because of the rapid landward shift of the depocenter led the formation of firm-ground, which is associated with the *Glossifungites* Ichnofacies observed at the boundary between FA1 and 2. This boundary can be defined as a within-trend flooding surface which is not a surface of sequence stratigraphy, but represents notable facies change owing to rapid transgression (Embry, 2002; Catuneanu, 2006). Reconstructions show the BH-1 site, 6-8 ka ago, as a bay environment, and the ND-1 site as an inner shelf environment. Also, the sea-level curves represent the water depth at this time was within the range of storm wave-base. Consequently, this integrated consideration of facies analysis of landward sites and the sea level curve support the environmental interpretation. The massive mud deposition of FA2 (lower offshore) occurred near storm wave-base, and this environment was seldom influenced by a riverine outflow. The accumulation rate at this period calculated from age dating analyses is very low.

The highstand system tract began 6ka ago, and the sea-level rose to the present level. The boundary between FA2 and FA3 is a maximum flooding surface, since the upward-fining succession changed to a coarsening upward trend at this boundary. A riverine outflow started to affect the sedimentary processes. The initiation of the Nakdong delta also developed during this period. Holocene worldwide delta initiations are within the time range of 6.5-8.5 ka ago. The deceleration of sea-level might cause the deltaic progradation. Despite the deltaic progradation caused by sea-level deceleration, the ND-2 site was located still far from the river mouth, and the sedimentation rate might be very low. Relatively high bioturbation index supports this low sedimentation rate. The opportunistic colonizers such as *Skolithos*, *Diplocraterion*, and *Bergaueria* concomitant with sand layers have relatively small sizes and relatively high abundance. These characteristics infer that these colonizers comprised r-selected populations, and it means that this prodelta environment was unstable to filter feeders. Settling from buoyant plume is the dominant depositional process under low energy conditions, and the sand layers such as tempestites and turbidites were deposited intermittently. Step-wised age dating errors of the upper FA4 can be considered as the intense bioturbation.

Around 3 ka ago, the sediment discharge slightly increased, and the sedimentary environment changed from prodelta (FA4) to distal delta front (FA5). Despite mud-dominated deposits, relatively regular tempestites intervals suggest that FA5 was seasonally influenced from storm or flooding events, and that the sedimentary rate slightly increased. Trace fossils were observed concomitant with sand layers dominated by deposit feeders rather than by filter feeders. These aspects are archetypal in deltaic settings, and with the increase of sediment discharge, water turbidity might become high in these periods. Generally in this facies association trace fossil assemblages represent high diversity, and have moderate size. These characteristics indicate the trace fossils formed r-selected population in this facies association. The moderate to intense bioturbation infers that the sedimentation rate was still low. The deposition might occur under a fair-weather wave-base.

The association of fluid mud and hummocky beds, and sparse bioturbation indicate that FA5 is a delta front facies association. Since the high sedimentation rate and the salinity fluctuation, the bioturbation intensity is very low. The lamination within fluid mud suggests wave processes were the dominant controlling factor in the Nakdong delta system.

Dominant controlling factor during the Nakdong delta evolution

The planform morphology of modern deltas can be classified as three end members by the dominant processes of river, wave, and tides, and there were many attempts to determine this classification by ichnological analyses mainly in ancient deltaic environments (Olariu et al., 2005; 2010; Olariu & Bhattacharya, 2006; Gingras et al., 1998; McIlory, 2004a; 2004b; Carmona et al., 2009). On the other, recent ichnological analyses proposed the mixed influence processes of river, wave, current, storm, and tide in delta evolution rather than the tripartite delta classification (Gani et al., 2008). Likewise the pre-conducted ichnological analyses of the ancient deltaic environments, the integrated analyses of sedimentology and ichnology of the mid to late Holocene deltaic deposits recovered from the ND-2 core site represent the changes of relative influence of river, wave, and storm in response to the Nakdong delta evolution.

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