Late Quaternary Transgressive Stratigraphy and its Depositional History in the Southeastern Continental Shelf, Korea

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Abstract: Analysis of high-resolution seismic profiles acquired from the southeastern continental shelf of Korea reveals that the late Quaternary transgressive deposits consist of six seismic units created in response to sea-level rise. These units with different seismic facies and geometry can be grouped into two distinct depositional wedges (paralic and marine) bounded by a ravinement surface. The paralic component underlying the ravinement surface consists of the sediment preserved from shoreface erosion and contains incised-channel fill, ancient beach-shoreface deposit and estuarine deposit. The top of paralic unit is truncated by a ravinement surface and overlain by marine component. The marine component consists of the sediment produced through shoreface erosion during landward transgression and contains mid-shelf sand sheet, mid-shelf sand ridge and inner shelf sand sheet. Such transgressive stratigraphic architecture of six sedimentary units is controlled by a function of lateral changes in the balance among rates of relative sea-level rise, sediment input and marine processes at any given time.

Key words: Late Quaternary, Transgressive systems tract, Sea-level change, Korea Strait

Introduction

The sea-level rise after the Last Glacial Maximum (LGM) was one of the most important events of the present geological history on continental shelves (Demarest and Craft, 1987; Nummedal and Swift, 1987). As the shelf was flooded, coastal environments progressively migrated landward accompanying erosional and depositional processes (Swift, 1968). Various sedimentary units were formed and left over a wide area of the shelf showing different seismic facies and lithologic associations. For the reconstruction of the depositional environments of these deposits, sequence-stratigraphic concepts (e.g. Vail, 1987) have been applied to the study on modern continental shelves. After the successful test for the late Quaternary sequence of high sediment accumulation on the Gulf of Mexico (Boyd et al., 1989), the application of...
the concept to Quaternary sequence has been common sense, using high-resolution seismic profiles and sediment data (Tesson et al., 1990; Saito, 1994; Trincardi et al., 1994; Morton and Suter, 1996; Tortora, 1996; Karisiddaiah et al., 2002; Lobo et al., 2004). Especially, Demarest and Kraft (1987) showed that the transgressive vertical sequence can be divided into three distinct realms, such as fluvial, paralic and marine realms, based on the environmental change in response to coastal retreat during the transgression. Here, the paralic realm refers to the entire area from the shoreline landward to the limit of tidal or marine influence (Swift, 1968; Demarest and Craft, 1987; Nummedal and Swift, 1987). They also suggested that the paralic beach, tidal flat, estuarine/lagoon, tidal shoal or channel and back-barrier overwash are grouped as a paralic component. The marine realm is dominated by marine processes. The transition from paralic to marine is erosional due to processes of shoreline retreat in response to sea-level rise (Nummedal and Swift, 1987). Trincardi et al. (1994) showed that the transgressive deposits within the late Quaternary sequence in the Adriatic Sea consist of paralic and marine components bounded by a ravinement surface. Lee and Yoon (1997) also suggested the existence of transgressive deposits in the Yellow Sea, consisting of two distinctive units separated by a ravinement surface.

The study area located between the Korean Peninsula and Tsushima Island is a seaway connecting the East Sea to the East China Sea (Fig. 1). Many studies, using the combined data of high-resolution seismic profiles and sediment analyses, in this area revealed that relative sea-level changes coupled with sediment input from the Nakdong and Seomjin rivers have played a major important role in the development of the late Quaternary sequence on the shelf (Park and Yoo, 1988, 1992; Suk, 1989; Min, 1994; Yoo et al., 1996; Yoo and Park, 1997). Especially, during the postglacial transgression, various sedimentary units were formed on the shelf of the study area (Suk, 1989; Min, 1994; Park and Yoo, 1992; Yoo and Park, 1997; Yoo et al., 2003). Such deposits are well recorded on the seafloor and bear witness to complex interplay between depositional and erosional processes, associated with sea-level changes. For reasons of these features, the study area is an important site for better understanding of depositional and erosional processes during the late Quaternary. The present study focuses on the area from the inner shelf to shelf margin, where abundant seismic evidences are linked to the existence of transgressive depositional and erosional processes. In this paper, we attempt to describe acoustic characters and geometries of transgressive units based on high-resolution seismic data, to discuss depositional and erosional processes during the postglacial transgression and finally to reconstruct the transgressive stratigraphic architecture.

Description of the Study Area

The study area can be divided into three regions: inner, mid- and outer shelves based on morphology and surface sediment distribution (Park and Yoo, 1988). The inner shelf (< 80 m deep) occupies a near-coastal area and shows a flat-lying seafloor covered with Holocene mud from Nakdong and Seomjin rivers (Min, 1994; Lee and Chung, 2000). The mid-shelf is a wide area of the central part and forms a relatively flat platform seafloor of about 0.12° gradient blanketed by sandy sediments with gravels and shell fragments (Park and Choi, 1986; Min, 1994). The outer shelf is occupied by the NE-SW trending Korea Trough, which is as deep as 230 m. It is about 20 km wide and 100 km long. The bottom sediments on the central trough consist of sandy mud or muddy sand deposited during the last glacial period (Yoo
Late Quaternary Transgressive Stratigraphy and its Depositional History in the Southeastern Continental Shelf, Korea

Oceanic circulation in the study area is dominated by the northeastward-flowing Tsushima Current which is a branch of the Kuroshio Current. The speed of the Tsushima Current is about 30 ~ 90 cm/s, being strongest during summer (Korea Hydrographic Office, 1982). A coastal current flows northeastward along the southeastern coast of the Korean Peninsula (Kim et al., 1986). Two major sediment dispersal systems, the Nakdong and Seomjin rivers, deliver sediments and fresh water to the study area. The Nakdong River discharges annually about $6.3 \times 10^{10}$ tons of fresh water and about $1.0 \times 10^7$ tons of sediments into the Korea Strait, which are mainly concentrated during the rainy season from July to August. During summer floods, the discharged water extends about 20 km offshore, forming the turbid river plumes, and their dispersal pattern appears to be parallel to the coast influenced by coastal currents (Kim et al., 1986). The Seomjin River discharges annually about $0.8 \times 10^6$ tons of suspended sediments to the south of Namhae Island (Kim et al., 1986). The sediments derived from these rivers are mostly confined to the inner shelf of the study area and transported northeastward by strong coastal currents.

Data

The data used in the present study is high-resolution (3.5 kHz and sparker) reflection profiles acquired by the Korea Institute of Geoscience and Mineral Resources (KIGAM) (Fig. 2). The sparker profiles were collected with a 1 ~ 2 kJ sparker system (model EG&G 231A triggered capacitor bank, 232A power supply, 402-7 sparkarray, Benthos MESH 50/24P hydrostreamer). The signal was bandpass-filtered in the 150 ~ 1000 Hz range and printed at a 0.5 second sweep. For the uppermost part, very high-resolution seismic profiles were also acquired simultaneously with the sparker profiles, using a GeoAcoustic 3.5-kHz Subbottom Profiling System (model 137D transducer, 5430A transmitter, 5210A receiver). Analog recording of all data relied on EPC 4600 and 9800 graphic recorders. Shipboard navigation was controlled by a global positioning system (GPS) and LORAN-GPS system (model 10X, Trimble Navigation).

Interpretation of Seismic Data

On the basis of high-resolution seismic profiles, we divide the late Quaternary transgressive deposits in the study area into six sedimentary units: 1) incised-channel fill (unit F), 2) ancient beach/shoreface deposit (unit P1), 3) estuarine/deltaic complex (unit P2), 4) mid-shelf sheet sand (unit M1), 5) transgressive sand ridge (unit M2), and 6) inner-shelf sheet sand (unit M3), respectively (Figs. 3 ~ 5). Distribution patterns of four sedimentary units (units F, P1, M1 and M2), except for two units (P2 and M3), are shown in Fig. 6A. Units P2 and M3 in the inner shelf are completely covered by recent muds (HST) (Fig. 6B).

Unit F, defined by cut-and-fill structures with an irregular erosional base, occupies the incised channels across the shelf (Fig. 3A and B). The channels, extending north-south, probably represent the older Nakdong and Seomjin rivers that eroded the shelf during the LGM (Fig. 6A). On the southern mid-shelf of the study area, it is deeply entrenched into the underlying Pleistocene sedimentary strata (Fig. 3A). The channel fill, here, is over 20 m thick and about 1 ~ 2 km wide. Unit F is acoustically characterized by divergent and/or prograding reflectors (Fig. 3A and B). Chaotic or hummocky reflectors are also seen. Unit F consists of sands or muddy sands with gravels and shell debris (Min, 1994; Yoo et al., 1996). The gravels are sub- to well-rounded and its content is more than 50% at the basal part of core sediment. Unit F is draped by units M1 or M3 (Fig. 3A and B).

Unit P1 is found only on the present shelf margin at water...
depths of about 120 ~ 150 m and forms a narrow fringing belt parallel to the contour line (Figs. 3C and 6A). It extends more than 100 km long in the direction of NE-SW with 2 ~ 4 km in width. Unit P1 is characterized by hummocky or chaotic reflection patterns (Fig. 3C). It also locally contains subparallel and seaward inclined strata and has a lobe or bank-shaped external form. The thickness of unit P1 is commonly 5 ~ 10 m, but reaches up to 20 m. Study of core sediment reveals that unit P1 consists of sands with abundant gravels and shell fragments, upward fining from gravelly sands to fine sands (Park and Yoo, 1992; Yoo et al., 1996).

Shells within unit P1 were dated around 15 ka BP. (Min, 1994; Yoo et al., 1996). Toward the mid-shelf area, unit P1 pinches out updip at water depth of about 120 m and is draped by unit M1 (Fig. 3C).

In contrast to unit P1, unit P2 directly overlying the erosional sequence boundary is found on the inner shelf near the eastern part of the Geoje Island and off the Namhae Island (Figs. 4A, B and 6B). It is acoustically characterized by transparent or semi-transparent reflections. In some area, it contains small-scale progradation or coastal onlap patterns with faintly stratified reflections. Unit P2 is commonly 5 ~ 10 m thick, but reaches up to 20 m on the eastern part of the Geoje Island off the Nakdong River. Based on drill core sediment (KIGAM, 2000), unit P2 consists of sandy mud or muddy sand with some shell debris. Radiocarbon ages of benthic foraminifera show unit P2 spans ca. 11.5 ~ 7.6 ka BP (KIGAM, 2000; Yoo and Park, 2000). Unit P2 is covered by unit M3 (Fig. 6B).

Unit M1 covers a wide area of the mid-shelf, directly overlying the sequence boundary (Fig. 6A). It is defined by
Late Quaternary Transgressive Stratigraphy and its Depositional History in the Southeastern Continental Shelf, Korea

semi-transparent subbottoms with weakly stratified reflectors. Some hummocky or chaotic reflections exist within unit M1. This unit shows a sheet-type external form and is less than a few meters thick and laterally discontinuous (Fig. 5A). The unit M1 has been recognized as relict sand sheets at the surface of sea bottom (Suk, 1989; Park and Yoo, 1988; Min, 1994). Sediment data (Park and Yoo, 1992) show that unit M1 consists of medium to fine sands with abundant shell fragments; the sand content reaches up to 90%. Unit M1 also contains iron-stained quartz grains of brownish or reddish color.

Unit M2 occurs on the mid-shelf off Namhae and Geoje Islands where the water depth range from 60 m to 90 m (Fig. 6). This unit forms a series of sand ridges (15 ~ 40 km long and 2 ~ 4 km wide) oriented near parallel to the present bathymetric contour (Fig. 6). Unit M2 is characterized by seaward inclined reflectors with some hummocky or chaotic reflections (Fig. 5B and C). It shows a bank-shaped external form and is commonly 5 ~ 10 m thick, but reaches up to 20 m at the crest. Bottom sediment samples retrieved from unit M2 are composed mainly of moderately to well-sorted sands (Park et al., 2003). Toward the inner shelf, unit M2 is partly covered by HST (Fig. 6).

Unit M3 is well preserved on the inner shelf between the Geoje Island and the present Nakdong River mouth (Fig. 4A and B). This unit is characterized by semi-transparent with some weakly stratified reflections. Unit M3 has a sheet-shaped external form, similar to that of unit M1. It is less than 5 m thick with discontinuous lateral extension. In some places, this unit shows an irregular patch with varying lateral extent. According to KIGAM (2000), unit M3 consists mainly of sands with some shell debris. Unit M3 is covered by recent muds (HST) (Fig. 6B).

Postglacial Sediment Deposition in Response to Sea-level Rise

Sedimentary processes in the study area during the late Quaternary were related to the sea-level changes in association with sediment supply from the Nakdong and Seomjin rivers (Lee and Chung, 2000; Yoo and Park, 2000). Based on the interpretation of high-resolution seismic records, the TST deposits, formed during the landward migration of a coastline, consist of two distinct groups: paralic and marine components of Demarest and Kraft (1987). The former consists of three sedimentary units: incised channel-fill (unit F), ancient beach/shoreface deposit (unit P1) and estuarine/deltaic deposit (unit P2). The latter contains three units: mid-shelf sheet sand (unit M1), sand ridge system (unit M2) and inner-shelf sheet sand (unit M3).

Paralic component

On the basis of AMS radiocarbon dates, the basal part of unit P1 was dated about 15 ka BP (Park and Yoo, 1992; Yoo et al., 1996), which can be correlated with the early stage of Holocene transgression (Min, 1994; Park et al., 2000). At that condition, the sea level was about 120 ~ 130 m lower than the present. The shoreline was located near the shelf margin southeast of its present position (Min, 1994; Park et al., 2000). Unit P1 is regarded to have formed during that time and/or the early period of sea-level rise at slower rate. The study area was a narrower seaway, connecting the East China Sea to the East Sea (Park and Choi, 1986). So the longshore current, passing through the seaway, was much stronger than that of today to play an important role in shaping and creating unit P1. This interpretation is supported by the orientation of unit P1, parallel to the present shelf.
margin, extending NE-SW (more than 100 km long) (Fig. 6). Thus, unit P1 is regarded as an ancient beach/shoreface deposit formed during the early stage of the transgression and belongs to the paralic component. As the sea level rose, unit P1 was abandoned near the shelf margin as a relict facies and the shoreline migrated northwestward across the shelf (Min, 1994; Yoo and Park, 2000). The fluvial and coastal sediments preferentially filled paleo-channels, forming unit F as incised-channel fills (Fig. 3A and B). Where sediment supply was high, the sequences show onlap patterns on the low-lying part of the underlying deposit. Unit F also belongs to the paralic component (Fig. 7) and the top surface of the paralic component was capped by transgressive marine deposits (units M1 or M3) (Fig. 3A and B).

According to KIGAM (2000), the basal part of unit P2 was dated to be 11.5 ka BP. Sea level curves in this area indicate that the water depth at that time was approximately 80 m lower than present. Approximately 11.5 ka BP the shoreline approached near the southern part of the Geoje Island about 70 ~ 80 m in water depth (KIGAM, 2000; Park et al., 2000). Since that time, a funnel-shaped estuarine environment has prevailed around the seaward extent of Nakdong and Seomjin rivers. The inner shelf gradually became a depocenter of terrigenous sediments. Sediments derived from the rivers were trapped in these estuaries. This interpretation is supported by the dominance of brackish species of benthic foraminifer in unit P2 such as A. beccarii, E. advenum and Q. seminulum (KIGAM, 2000). Barrier islands near the estuary mouth trapped the fine-grained sediments in paralic domains until the barrier was eroded or the coastal system was displaced landward. The sedimentation during this period has resulted in the formation of unit P2. We interpret this unit lying below the ravinement surface to be the paralic component in the terms of Demarest and Craft (1987)'s suggestion, consisting of the sediment preserved from shoreface erosion (Fig. 5). Formation of such backstepping paralic units was common during the Holocene transgression (Boyd et al., 1989; Trincardi et al., 1994; Tortora, 1996). In the shallow area off the Namhae Island, unit P2 includes several channel-like depressions filled with acoustically transparent sediment (Min, 1994). The variable and small-scale geometry of these features within unit P2 may suggest that the channels represent tidal inlets and/or estuaries resulting from localized tidal scours of drowned fluvial valleys. Similar channel features formed during transgression also have been identified on other continental shelves (Demarest and Kraft, 1987; Oertel et al., 1991; Trincardi et al., 1994).

Marine component

The top of paralic component (units P1 and P2) is truncated by a sharp erosional surface (Fig. 5). Such erosional truncation of the paralic unit marks a dramatic change in depositional environments from deltaic/estuarine to marine, and the surface is interpreted as a ravinement surface (i.e., marine transgressive surface of erosion) (Demarest and Craft, 1987; Nummedal and Swift, 1987; Trincardi et al., 1994). This surface, showing a change in lithofacies, is characterized by truncation of underlying beds and by the presence of gravel or shell lags above (Yoo et al., 1996; KIGAM, 2000). This surface was capped by three marine units (M1, M2, and M3), produced by shoreface erosion that shifted landward during the transgression. During the transgression, the erosional coastal environment may be prevalent so that coarse sedi-
ments containing gravels and shell fragments were favorably deposited on the wide shelf area, forming unit M1. The rate of addition of new space might have exceeded the rate of sediment supply because the shoreline migrated rapidly landward due to a low gradient of the shelf (Min, 1994; Yoo et al., 1996), and for the most part, unit M1 contains a thin lag of sands (Park and Yoo, 1992). Park and Choi (1986) confirmed that the sandy sediments in the study area represent relict facies which have experienced subaerial and/or subaqueous weathering during late Quaternary. These sediments contain weathered carbonate fragments, iron-stained quartz grains and well-rounded gravels, resulted from subaerial and/or subaqueous weathering during the transgression (KIGAM, 2000). Such transgressive sheet sand has been widely recognized on many other continental shelves of the world (Yang, 1989; Saito, 1994; Trincardi et al., 1994; Tortora, 1996; Lee and Yoon, 1997).

By about 11 to 12 ka BP, the shoreline approached the mid-shelf around 70 ~ 80 m in water depth. During a given period of time, it may have stabilized at that position with minor stillstands or slowly rising (Park et al., 1996), and for the most part, unit M1 contains a thin lag of sands (Park and Yoo, 1992). Park and Choi (1986) confirmed that the sandy sediments in the study area represent relict facies which have experienced subaerial and/or subaqueous weathering during late Quaternary. These sediments contain weathered carbonate fragments, iron-stained quartz grains and well-rounded gravels, resulted from subaerial and/or subaqueous weathering during the transgression (KIGAM, 2000). Such transgressive sheet sand has been widely recognized on many other continental shelves of the world (Yang, 1989; Saito, 1994; Trincardi et al., 1994; Tortora, 1996; Lee and Yoon, 1997).

The late Quaternary transgressive systems tract deposits in the southeastern continental shelf of Korea form a succession of retrograding or backstepping depositional arrangements of six sedimentary units. These sedimentary units constitute paralic and marine realms bounded by a ravinement surface. The paralic component underlying the ravinement surface contains three sedimentary units: (1) incised-channel fill (unit F), (2) ancient beach/shoreface deposits (unit P1), and (3) transgressive estuarine/deltaic complex (unit P2). The marine component overlapping the surface includes three sedimentary units: (1) mid-shelf sheet sand (unit M1), (2) transgressive sand ridge (unit M2), and (3) inner-shelf sheet sand (unit M3). Paralic units consist of the sediment left behind shoreface erosion, whereas marine units are composed of the sediment produced by the shoreface erosion during landward transgression. The top of paralic units is marked by the sharp erosional ravinement surface.

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**References**


Park, S. C., and Yoo, D. G., 1988, Depositional history of Quaternary sediments on the continental shelf off the southeastern coast of Korea (Korea Strait), Marine Geology, 79, 65-75.

Park, S. C., and Yoo, D. G., 1992, Deposition of coarse-grained sediments in the Korea Strait during late Pleistocene low sea level, Geo-Marine Letters, 12, 19-23.

Park, S. C., Han, H. S., and Yoo, D. G., 2003, Transgressive sand ridges on the mid-shelf of the southern sea of Korea (Korea Strait): formation and development in high-energy environments, Marine Geology, 193, 1-18.


Yoo, D. G., and Park, S. C., 1997, Late Quaternary prograding lowstand wedges on the shelf margin and trough region of the Korea Strait, Sedimentary Geology, 109, 121-133.


