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Late Quaternary Seismic Stratigraphy and Sedimentation of the Southeastern Continental Shelf, Korea Strait

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한국 남동해역(대한해협) 대륙붕지역의 후 제4기 탄성파 층서 및 퇴적작용

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Abstract : Interpretation of high-resolution seismic profiles from the southeastern continental shelf of Korea reveals that the sedimentary deposits consist of seven seismic units formed during the late Quaternary. These units comprise lowstand, transgressive, and highstand systems tracts. The lowstand systems tract consists of a lowstand prograding wedge (SU1) and a mass flow deposit (SU2) including slumps and slides. The transgressive systems tract contains four seismic units: an ancient beach/shoreface deposit (SU3), a channel-fill deposit (SU4), a transgressive sand layer (SU5), and a transgressive sand ridge (SU6). The highstand systems tract consists of an inner-shelf mud deposit (SU7) derived from the Nakdong and Seomjin rivers during the last 6 ka when sea level was close to the present level.

Keywords : Late Quaternary, Seismic stratigraphy, Sea-level changes, Korea Strait

요 약 : 한국 남동해역에서 취득한 고해상 탄성파 탐사자료의 해석에 의하면 연구해역에 분포하는 해저퇴적층은 후 제4기 동안 형성된 7 개의 퇴적단위로 구성된다. 이들 퇴적단위들은 저해수면계열, 해침계열, 그리고 고해수면계열을 구성한다. 저해수면 계열은 저해수면 쐐기 퇴적단위(SU1) 와 슬럼프 및 슬라이드를 포함하는 질량류 퇴적단위(SU2)로 구성된다. 해침계열은 고해빈/연안 퇴적단위(SU3), 수로충진 퇴적단위(SU4), 해침 사질 퇴적단위(SU5), 해침사퇴 퇴적단위(SU6)등 4 개의 퇴적단위를 포함한다. 고해수면계열은 내대륙붕 니질 퇴적단위(SU7)로 구성 되며, 해수면이 현 수준에 도달한 지난 6000년 이후동안 낙동강과 섬진강에서 공급된 퇴적물로 구성된다.

주요어 : 후 제4기, 탄성파 층서, 해수면 변화, 대한해협

Introduction

The southeastern continental shelf of Korea (Fig. 1) has been a principal depocenter for clastic sediments throughout the late Quaternary (Park and Yoo, 1988; 1992; Suk, 1989; Min, 1994; Yoo *et al.*, 2004). Sea-level changes and sediment supply have played an important role in forming late Quaternary depositional sequences in this area (Min, 1994; Yoo *et al.*, 1996; Yoo and Park, 1997; Park *et al.*, 1999; Yoo *et al.*, 2003). During the Last Glacial Maximum (LGM), the sea level was about 120 - 130 m lower (Park *et al.*, 2000) and the paleo-shoreline of the southeastern part of Korea was located at the shelf margin near the Korea Trough, exposing much of the shelf in this area (Yoo and Park, 1997; 2000). During the post-glacial transgression, the principal depocenter in the Korea Strait migrated from the shelf margin to the inner shelf, producing various sedimentary units. As such, the southeastern continental shelf of Korea serves as a site for understanding depositional and erosional processes associated with sea-level change. In this paper, we interpreted high-resolution seismic data (Fig. 2) to describe the geometry and acoustic characters of the late Quaternary deposits and discuss the depositional history of the southeastern continental shelf of

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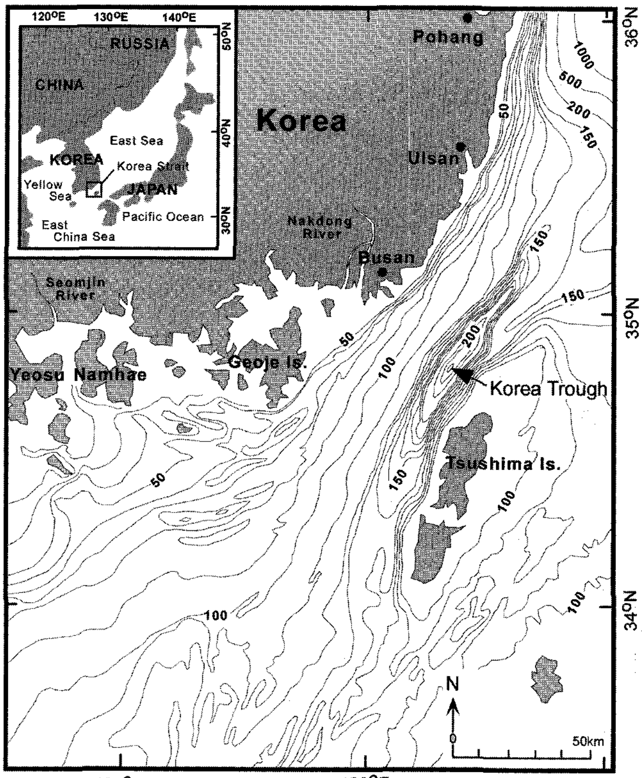

Fig. 1. Location and bathymetric map of the Korea Strait. Contour interval is 10 m.

Korea in response to the sea-level rise since the LGM.

Study Area

The study area encompasses the narrow shelf between the southeastern tip of the Korean Peninsula and the Tsushima Island (Fig. 1). The area can be divided into inner shelf (shallower than 80 m depth), mid-shelf (80 - 120 m depth), and outer shelf (deeper than 120 m depth; Korea Trough) based on bottom sediment and topography (Park and Yoo, 1988). The inner shelf is flat and smooth, covered by recent mud. The mid-shelf in the central part of the Korea Strait forms a relatively flat platform covered by sandy sediments with gravels and shell debris (Park and Yoo, 1992). The outer shelf is located in the NE-SW trending the Korea Trough (Fig. 1). The bottom sediments in the Korea Trough consist of sandy mud and muddy sand.

Two major river systems, the Nakdong and Seomjin rivers, deliver sediments and fresh water to the Korea Strait. The inner shelf is mainly influenced by the discharge of the Nakdong River whose drainages basin occupies an area of about 24,000 km^2 (Kim *et al.*, 1986). This river discharges annually about 6.3×10^{10} tons of fresh water and about 1.0×10^7 tons of sediments into the Korea Strait. The Seomjin River in the west discharges annually about 0.8×10^6 tons of sediments into the south of Namhae Island (Kim *et al.*, 1986). The sediments derived from these rivers are confined to inner shelf of the Korea Strait and mostly transported northeastward by strong shelf currents (Park *et al.*, 1999).

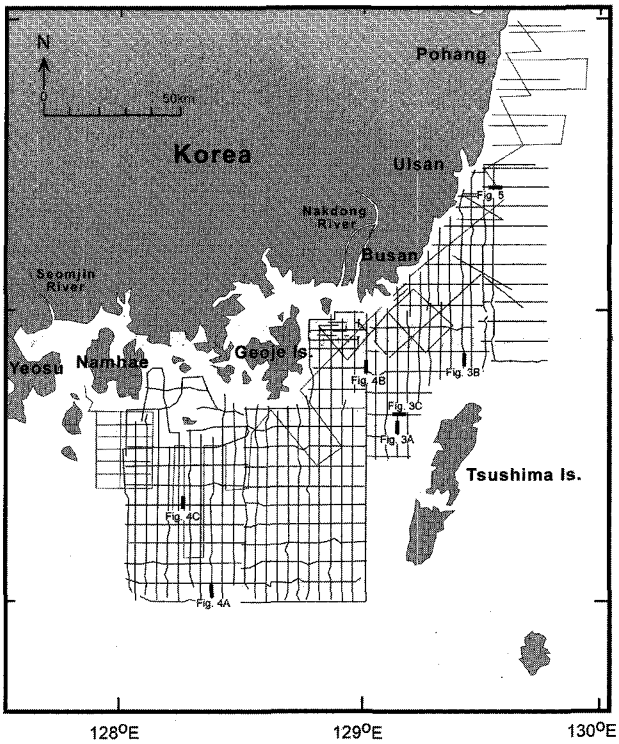

Fig. 2. Map showing the tracklines of sparker seismic profiles. Heavy lines denote the selected profiles shown in Figs. 3 - 5.

Data

This study uses high-resolution Sparker profiles acquired by the Korea Institute of Geosciences and Mineral Resources (KIGAM) (Fig. 2). The single-channel sparker profiles were collected using a 1 - 2 kJ sparker system (model EG&G 231A triggered capacitor bank, 232A power supply, 402-7 sparkarray, Benthos MESH 50/24P hydrostreamer, EPC 4600 graphic recorder). Shipboard navigation was controlled using a Global Positioning System (GPS). Ship,s speed was maintained at about 5 - 6 knots.

Interpretation of Seismic Data

Seven seismic units (SU1 - SU7, from bottom to top) have been identified on the Korea Strait shelf based on acoustic

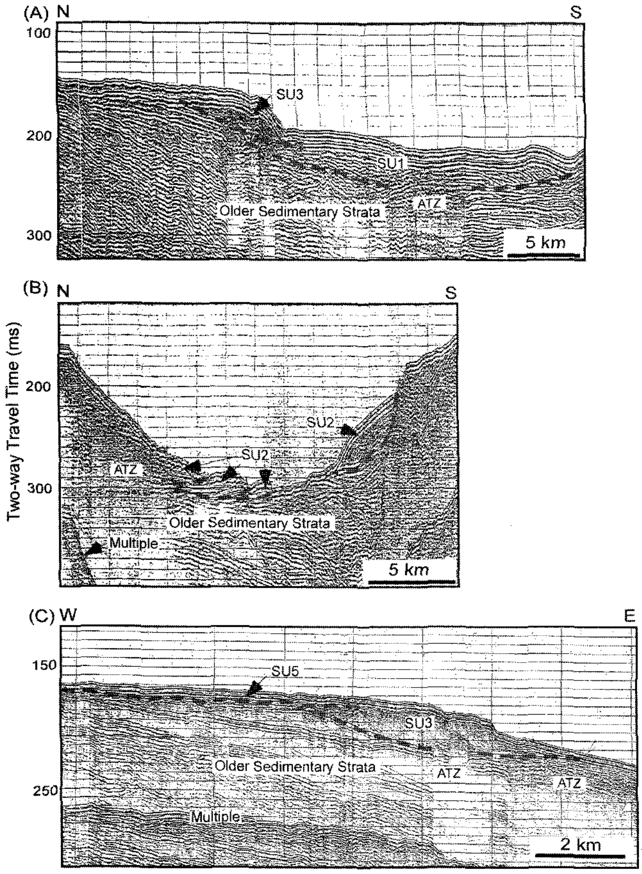

Fig. 3. Sparker seismic profiles from the shelf margin and trough region (for location, see Fig. 2), showing SU1, SU2, SU3 and SU5 overlying the older sedimentary strata. ATZ, acoustically turbid zone.

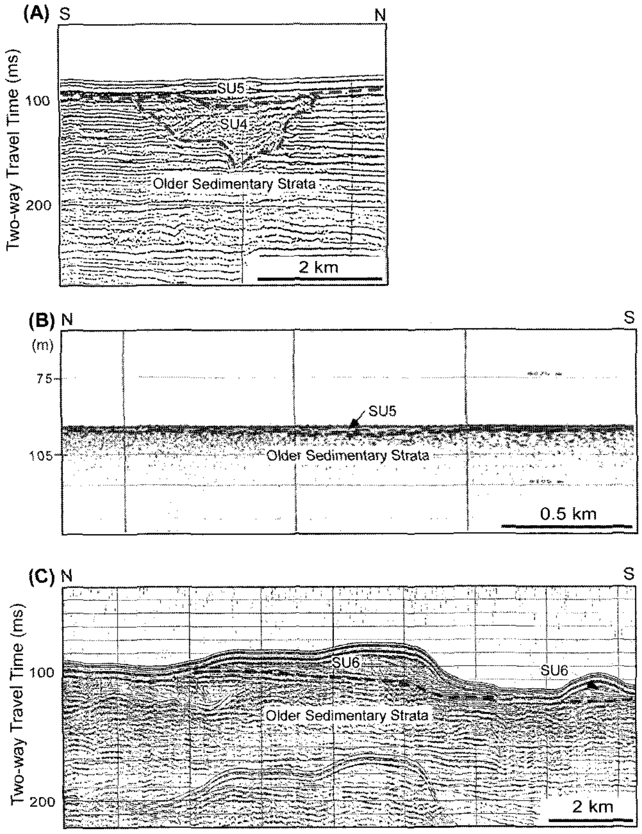

Fig. 4. Sparker seismic profiles from the mid-shelf (for location, see Fig. 2), showing SU4, SU5, SU6 and SU7.

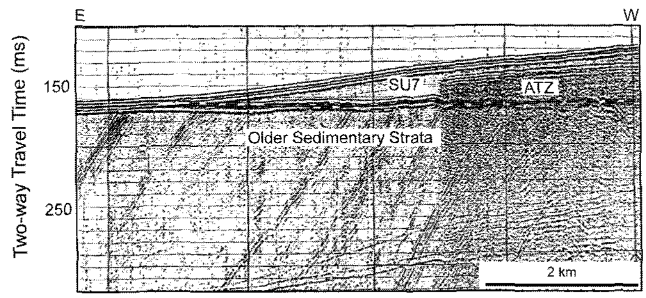

Fig. 5. Sparker seismic from the inner shelf (see Fig. 2), showing SU7. ATZ, acoustically turbid zone.

characters. Representative seismic profiles of these seismic units are shown in Figs. 3 - 5. Figure 6 is a distribution map of seven seismic units in the Korea Strait.

SU1 occupies the southwestern margin of the Korea Trough (Fig. 6). The internal structure of this unit shows seaward-dipping clinoforms (Fig. 3A). The clinoforms are generally characterized by variably alternating sigmoid and oblique reflection patterns. SU1 is a mound or wedge-shaped type externally. SU1 ranges from 10 to 40 m in thickness and its depocenter is located near the southwestern margin of the trough.

SU2 is confined to the base of slope in the central and northern part of the Korea Trough (Fig. 6). It consists of two separate bodies, each of which occupies the slope area of the trough. SU2 in the northern slope shows complex seismic facies indicated by contorted beds with very irregular surface (Fig. 3B). Some sections are broken up into pockets, consisting of discontinuous blocks or slabs of sediments. Thickness of each block is generally 10 - 15 m. SU2 in the southern slope is less deformed than that of the northern slope and shows more laterally continuous bedding plane pattern (Fig. 3B). The upper surface of SU2 in the southern slope is usually smooth and the base of SU2 is characterized by a sharp and erosional boundary. Some failure scarps on the upper and middle slope of the trough indicate a downslope movement of sediment, most likely due to gravitational instability of the shelf margin and slope (Yoo *et al.*, 1996).

SU3 is found only on the shelf margin at water depths of about 120-150 m, forming a narrow belt parallel to the bathymetric contours (Fig. 6). It is characterized by hummocky or chaotic reflection patterns (Fig. 3C) and locally contains inclined reflectors dipping seaward. In cross section, this unit exhibits asymmetrical, bank type with a steep side oriented seaward. SU3 is more than 100 km long and 2 - 4 km wide. The thickness of SU3 is generally 5 - 10 m and reaches up to 15 m in areas near the paleo-river mouth.

SU4 consists of channel-like features, extending from north to south (Figs. 4A and 6). These channel-like features are deeply entrenched into the underlying Pleistocene sedimentary strata (Fig. 4A). SU4 is about 10 m deep and 1-1.5 km wide. SU4 is characterized by divergent and/or prograding reflection patterns with variable amplitude. Some chaotic or hummocky reflection configurations are also present. SU4 is completely buried by SU5 (Fig. 4A).

SU5 covers a wide area of the flat mid-shelf (Fig. 6). It is relatively thin (less than a few meters thick) and laterally discontinuous (Fig. 4A and 4B). Acoustically, it is semi-transparent with some hummocky reflection pattern. It is shaped in a sheet type.

SU6, found on the southern mid-shelf off Geoje and Namhae islands where water depths range from 60 to 100 m, consists of a series of sand ridges (Park *et al.*, 2003) oriented in a NE-SW, ENE-WSW or E-W direction (Fig. 6). These sand ridges are generally 15 - 40 km long and 2 - 4 km wide. The internal structure of this unit shows a low-angle reflectors dipping seaward (Fig. 4C). Some hummocky or chaotic reflection patterns are also seen in this unit. SU6 is a bank type and commonly 5 - 10 m thick; the maximum thickness reaches up to 20 m at the crest.

SU7 is found on the inner shelf along the coast (Fig. 6). It is acoustically characterized by semi-transparent to transparent subbottom reflection patterns with variable amplitude (Fig. 5). The amplitude strength of the internal reflectors become progressively weak toward offshore. It reaches a maximum thickness of more than 25 m near the river mouth. SU7 thins progressively offshore, forming a sedimentary wedge, and pinches out at water depths of about 90 - 100 m (Fig. 5).

Depositional History in Response to Sea-level Changes

The LGM reached the Korea Strait between 15 and 16 ka, when sea level was about 130 m lower than at present (Suk, 1989; Min, 1994; Park *et al.*, 2000). At that time, the shoreline was located about 60 km southeast of its present position and much of the shelf in this area was subaerially exposed (Min, 1994). The paleo-rivers such as the Nakdong and Seomjin rivers extended to the present shelf margin, supplying large amounts of terrigenous sediments to the Korea Trough. These sediments were deposited preferentially around the paleo-river mouth, producing SU1 as a lowstand prograding wedge (Fig. 6). The sediment overburden and steep slope near the central and northern part of the trough caused sediment instability and gravity-induced, mass wasting processes. Seismic sections across the central trough provide evidence for mass-flow deposits, consisting of slumps and slides forming distinct blocks or slabs (Fig. 3B). Within each block of SU2, the original internal layers are partially preserved, but the toe side is plastically deformed because of compressional force resulting from downslope movement. Additionally, the base of both slump and slide blocks shows a sharp erosional boundary, which may result from scour by the flow during downslope movement. Similar features have previously been identified in the study area (Min, 1994; Yoo *et al.*, 1996; Yoo and Park, 1997; Yoo *et al.*, 2003).

Shells within SU3 are dated about 15 ka, indicating the

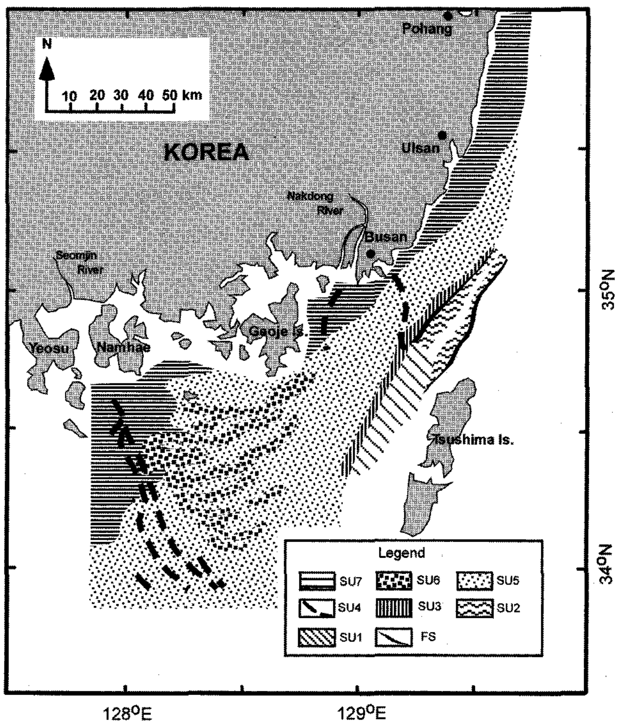

Fig. 6. Distribution of seismic units. Lowstand prograding wedge (SU1), mass flow deposits (SU2), ancient beach/shoreface deposits(SU3), transgressive sand layer (SU5), transgressive sand ridge (SU6), and inner-shelf mud deposits (SU7) are exposed at the sea floor, whereas channel fill deposits (SU4) is completely covered by SU5 or SU6. FS, failure scar.

early stage of the postglacial transgression (Yoo and Park, 2000). The paleo-shoreline was probably located at water depths of about 120 - 130 m at that time. The study area occupied a narrow seaway, connecting the East China Sea to the East Sea (Min, 1994; Yoo *et al.*, 2003). The longshore currents, passing through the constricted seaway, were probably much stronger than today, playing an important role in creating and shaping SU3. The orientation of SU3, parallel to the bathymetry (Fig. 6), supports our interpretation. Thus, we interpret SU3 as an ancient beach/shoreface deposit formed during the early stage of the transgression. The post-glacial transgression in the study area began at about 15 ka and the shoreline migrated northwestward across the shelf (Min, 1994; Park *et al.*, 2000). As the shoreline retreated, fluvial or coastal plain sediments (SU4), preferentially filled paleo-channels. Where the rate of sediment supply was high, the sediments formed onlap patterns on the low-lying area of the underlying sequence. As the transgression continued, the rate of accommodation space generated probably exceeded the rate of sediment supply. As a result, the surface sediments were reworked and redistributed forming a thin sand lag (SU5, Fig. 6). SU5 is interpreted to be the product of reworking and resuspension of shoreface sediments by wave and current action during the Holocene transgression (Ercilla *et al.*, 1994; Saito, 1994; Morton and Suter, 1996; Lee and Yoon, 1997; Yoo *et al.*, 2002). By about 12 ka the shoreline approached the mid-shelf around 80-90 m water depths (Yoo and Park, 2000). The shoreline may have stabilized at the mid-shelf for some time, probably sufficient to form SU6 comprising the transgressive sand ridge. The paleo-channels (Nakdong and Seomjin rivers) may have supplied abundant terrigenous sediments to the mid-shelf. Tidal currents could have become the most important factor for development of sand ridges in the mid-shelf (Park *et al.*, 2003). The rapid rise of sea level in the following stage of transgression has resulted in a substantial reduction of tidal current strength. Consequently, SU6 remained on the mid-shelf as a relict feature (Park *et al.*, 2003).

With the continued rise of sea level, the paleo-river mouth gradually retreated landwards. The sea level in this area reached its present position at approximately 6 ka (Min, 1994; Park *et al.*, 2000; Yoo *et al.*, 2004). Since the end of transgression, sediments from the Nakdong and Seomjin rivers are deposited in the inner shelf, forming SU7 as the inner-shelf mud deposit (Fig. 6).

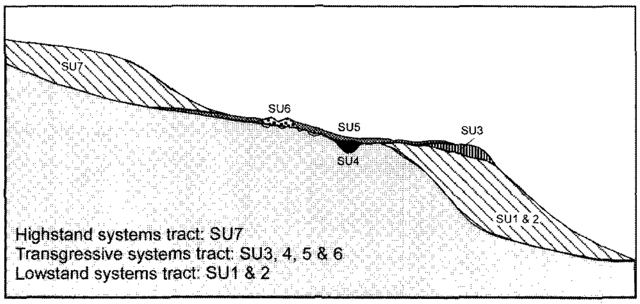

Fig. 7. Proposed stratigraphic architecture for the southeastern continental shelf of Korea.

Conclusions

On the Korea Strait shelf, the late Quaternary deposits comprise seven seismic units formed since the LGM. During the LGM, thick lowstand prograding wedge was deposited on the southwestern part of the trough, whereas the mass flow deposits including slumps and slides possibly transported downslope due to sediment overburden and steep gradient predominate over the central and northern part of the Korea Trough. During the early stage of the transgression, the ancient beach/shoreface deposit formed on the shelf margin at water depths of about 120 - 150 m. As the shelf was flooded, the paleo-channels were filled with fluvial or coastal-plain sediments forming the channel-fill deposit. The surface sediments were reworked and redistributed by shoreface erosion, resulting in a thin lag of transgressive sands. A series of sand ridges on the southern mid-shelf off the Namhae and Geoje islands were formed under the shallow water high-energy environments at a period of stillstand or slow rise during the middle stage of post-glacial transgression. As the sea level reached the present position, the sediments originated from the Nakdong and Seomjin rivers are deposited in the inner shelf, forming the inner-shelf mud deposit.

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