지구물리 제5권 제4 호, p. 271-281 (2002년 12월)

Seismic Stratigraphy and Depositional History of Late Quaternary Deposits on the Korea Strait Inner Shelf, Korea

D.G. Yoo, H.Y. Lee, S.P. Kim, K.O. Kim, N.H. Koo and Y.G. Kim

Petroleum and Marine Research Division, Korea Institute of Geoscience and Mineral Resources (KIGAM), Taejon 305-350, Korea

ABSTRACT

Interpretation of high-resolution seismic profiles collected from the inner shelf of the Korea Strait reveals that the shelf sequence in this area consists of three sedimentary units (I, II, and III in a descending order) formed after the last glacial maximum. Lower two units (II and III) represent the transgressive systems tract formed during the Holocene transgression. Unit III above the sequence boundary is interpreted to be the transgressive estuarine deposit, whereas Unit II above the ravinement surface forms a thin transgressive sand which consists of the sediment produced through shoreface erosion and winnowing during the transgression. Unit I above the maximum flooding surface is the highstand systems tract consisting mainly of recent muds derived from the Nakdong River.

Key words: Late Quaternary, Seismic stratigraphy, Holocene transgression, Korea Strait inner shelf

D.G. Yoo, H.Y. Lee, S.P. Kim, K.O. Kim, N.H. Koo, and Y.G. Kim, 2002, Seismic Stratigraphy and Depositional History of Late Quaternary Deposits on the Korea Strait Inner Shelf, Korea. Journal of the Korean Geophysical Society, v. 5, n. 4, p. 271-281

요 약: 대한해협 내대륙붕에서 취득된 고해상 탄성파 탐사자료의 해석에 의하면 연구해역 내대륙붕에 분포하는 퇴적층은 마지막 빙하기 이후에 형성된 3개의 퇴적단위(I, II, III)로 구성된다. 하위에 놓이는 두 퇴적단위는 홀로세 해침동안 형성된 해침계열에 속한다. 시퀀스 경계면 위에 놓이는 퇴적단위 III은 해침과정 중 하구 환경 하에서 퇴적된 것으로 해석되는 반면 침식면 위에 놓이는 퇴적단위 II는 해침과정 중 침식 및 제동에 의해 형성된 박층의 해침모래에 속한다. 최대해침면 상부에 놓이는 퇴적단위 I은 고해수면계열에 해당되며 주로 낙동강에서 유입된 현생 니질퇴적물로 구성된다.

주요어: 후기 제4기, 탄성파 층서, 홀로세해침, 대한해협 내대륙붕

(D.G. Yoo, H.Y. Lee, S.P. Kim, K.O. Kim, N.H. Koo and Y.G. Kim, Petroleum and Marine Research Division, Korea Institute of Geoscience and Mineral Resources (KIGAM), Taejon 305-350, Korea, E-mail: dgyoo@kigam.re.kr)

1. Introduction

The field of seismic stratigraphy as a tool in depicting depositional history has received much attention since the publication of the Exxon Production Research Group (e.g. Mitchum *et al.*, 1977). Identification of seismic sequences and nature of acoustic characters allow us information for the interpretation of depositional history and sedimentation patterns of shelf deposits. The basic concept has been applied to the study of late Quaternary sediments based on the interpretation of high-resolution seismic profiles, and a number of results yield a detailed identification of shallow sedimentary units and depositional history in response to sea-level changes (Hernandez-Molina *et al.*, 1994; Okyar *et al.*, 1994; Saito, 1994; Trincardi *et al.*, 1994; Tesson *et al.*, 2000).

The Korea Strait located between the southeastern tip of the Korean Peninsula and Tsushima Island is a sea way through which the Warm Tsushima Current flows into the East Sea (Fig. 1). Various aspects of the late Quaternary sedimentation in the Korea Strait have been addressed previously by several authors (Park and Choi, 1986; Park and Yoo, 1992; Yoo *et al*., 1996; Park *et al*., 1999; Lee and Chung, 2000). According to them, the shelf serves as the principal depocenter of clastic sediments derived from the Nakdong River in the late Quaternary. As the shelf was flooded since the last glacial maximum (LGM), the study area has undergone a whole suite of dramatic environmental changes resulting from progressively landward migration of shoreline (Park and Choi, 1986; Yoo *et al*., 1996; Lee and Chung, 2000; Yoo and Park, 2000). As a result, various sedimentary units may have been created and left in the modern Korea Strait shelf. Especially, the Korea Strait inner shelf is an area of thick accumulation of late Quaternary sediments since the mid- to late stage of Holocene transgression (Park *et al*., 2000). Such shelf sediments associated with the sea-level changes are widely interpreted within the framework of sequence stratigraphic concepts (e.g., Posamentier *et al*., 1988),

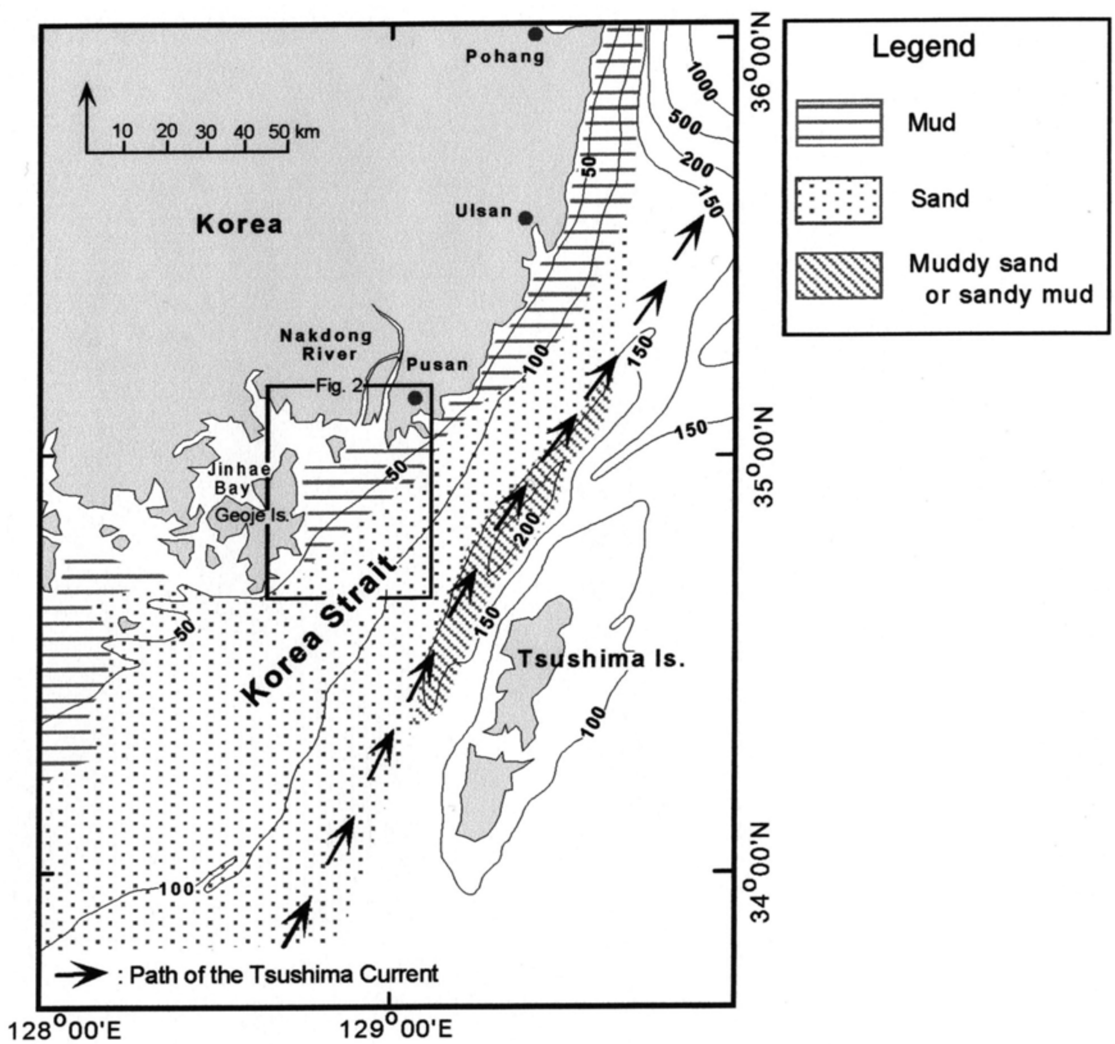

Fig. 1. Index map showing the bathymetry and sediment distribution.

using high-resolution seismic profiles (Tesson *et al.*, 2000; Hernandez-Molina *et al.*, 1994; Okyar *et al.*, 1994; Saito, 1994; Trincardi *et al.*, 1994; Morton and Suter, 1996; Tortora, 1996; Yoo *et al.*, 2002). In this paper, we discuss the internal structure and depositional pattern of inner shelf deposits in order to reconstruct Holocene sequence stratigraphy and depositional history.

2. Description of Study Area

The Korea Strait is a narrow shelf located between the southeastern Korean Peninsula and Tsushima Island (Fig. 1). The shelf can be divided into three regions: inner (shallower than 80 m depth), mid- (80 - 120 m depth), and outer shelves (deeper than 120 m depth). The inner shelf is flat and smooth in response to deposition of recent mud derived from the Nakdong River. In contrast, the mid-shelf occupies the central part of the Korea Strait and forms a relatively flat platform covered by sandy sediments containing large amounts of gravels and shell debris (Yoo *et al.*, 1996). The fine-grained sediment of the inner shelf consists of the highstand systems tract, whereas the mid-shelf sand belongs to the transgressive systems tract formed during the post glacial transgression (Fig.1). The outer shelf is occupied by the NE-SW trending trough which is as deep as 230 m. The outer shelf sediment consists of sandy mud or muddy sand forming a lowstand systems tract (Fig. 1; Yoo and Park, 2000).

Oceanic circulation in this region is dominated by the northeastward-flowing Tsushima Current. The speed of the Tsushima Current is about 30-90 cm/s, being strongest in summer and weakest in winter (Korea Hydrographic Office 1982). Tidal currents generally flow northeastward during ebb and southwestward during flood with a maximum velocity of 90 cm/s (Korea Hydrographic Office 1982). A coastal current flowing northeastward along the southeastern coast of the Korean Peninsula is also reported (Kim *et al.* 1986). The Nakdong River, which is the second largest fluvial system in Korea, is a major source of terrigenous sediment to the Korea Strait; its drainage basin occupies an area of 23,656 Km^2(Korea Ministry of Construction, 1974). This river discharges about 63 billion tons of fresh water and contributes annually 10 million tons of sediment which are mainly concentrated during the rainy season from July to August (Kim *et al.*, 1986).

3. Data Acquisition and Processing

High-resolution (3.5 kHz and air-gun) seismic reflection profiles used in this study were acquired by the Korea Institute of Geoscience and Mineral Resources (KIGAM) (Fig. 2). 3.5 kHz subbottom profiles were collected using a GeoAcoustics 3.5 kHz subbottom profiling system (model 137D transducer, 5430A transmitter, 5210A receiver, EPC 9800 thermal graphic recorder). Air-gun data were also acquired using a PC-based system of KIGAM (Lee *et al.*, 1996). The layout of the survey is shown in Fig. 3. The energy source was a 30 in^3 air gun and the receiver was a 30 m long 6 channel streamer cable with a group interval of 5 m. The offset distance between the source and the first channel was 20 m and the shooting interval was 12.5 m (about 5 sec). The data were digitally recorded with a sample interval of 0.2 ms and a record length of 2 s using KDAPS (KIGAM data acquisition and processing system) PC-based system where an A/D converter and analog filter board were installed. Ship-board navigation was controlled using a Differential Global Positioning System (DGPS). Ship speed was maintained about 5-6 knots.

To improve data quality, the data were processed by KDAPS system. The processing flow involved gain recovery, deconvolution, filtering, normal move-out and CMP (common mid-point) gathering. After data processing, seismic data which have a trace spacing of 2.5 m and 1 fold were plotted with a variable area method.

4. Results and Discussion

4.1. Seismic Units with Bounding Surfaces

We divide the inner shelf sequence above the older sedimentary strata into three seismic units (Unit III, II, and I in an ascending order) based on air-gun seismic profiles (Figs. 4-6). Three units are separated

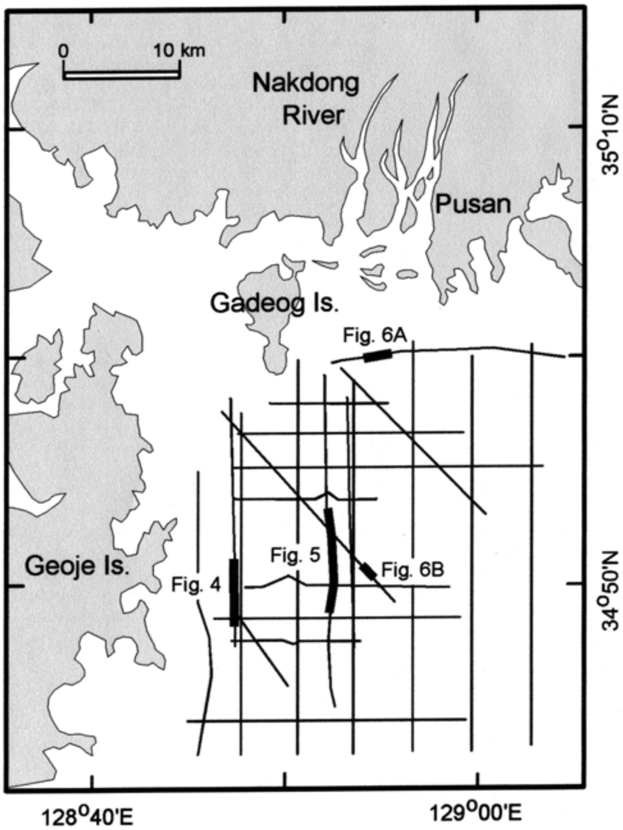

Fig. 2. Track lines of seismic surveys. Heavy lines denote selected profiles shown in Figs. 4 -6.

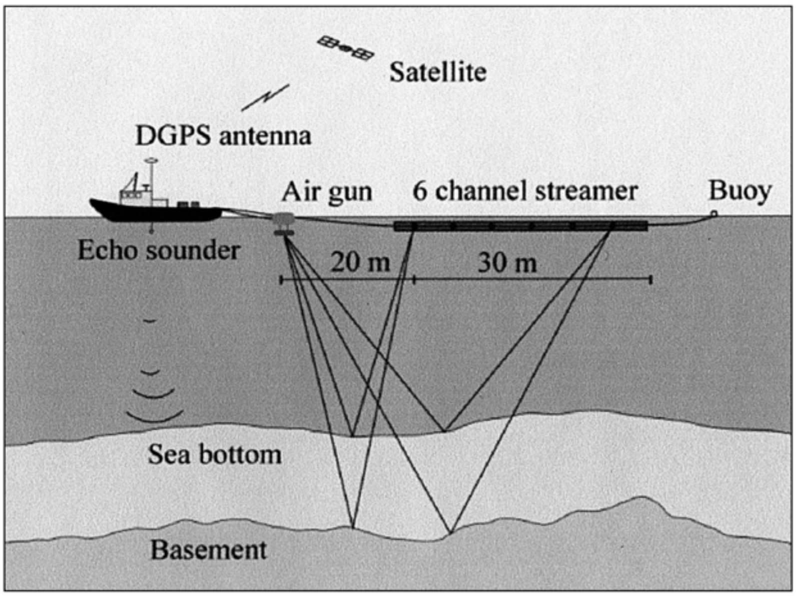

Fig. 3. Layout of 6-channel high-resolution seismic survey.

by two bounding surfaces (R1 and R2). R1 is the first subbottom reflector within the sedimentary sequence, and can be traced over most of the inner shelf. It is well defined by a non-erosional surface with continuous reflection on seismic profiles (Figs. 4 and 5). It occurs at depths of about 10 - 30 m below the sea floor and crops out at the seaward termination of Unit I (Figs. 4 and 5). In contrast, R2 separating Unit III from the overlying Unit II is defined by an erosional truncation cuttting the internal reflector of underlying unit. Acoustically, it locally pinches out on the upper surface of older sedimentary strata (Fig. 6A). The basal surface of Unit III shows an irregular, erosional unconformity (Fig. 5).

The lower unit (III) directly overlying the older sedimentary strata is found on the inner shelf near the eastern part of Geoje Island. Internally, it shows the transparent or semi-transparent subbottom with some weakly stratified reflections (Figs. 4 and 6). Locally, its upper part contains irregular subbottom reflectors and obliquely inclined beddings. On the eastern part of Geoje Island with a deep erosional part of the acoustic basement, it shows small-scale progradation or coastal onlap patterns with faintly stratified reflections. It also contains the acoustically turbid layer, which masks the underlying internal structures (Figs. 5 and 6). This turbid layer indicates

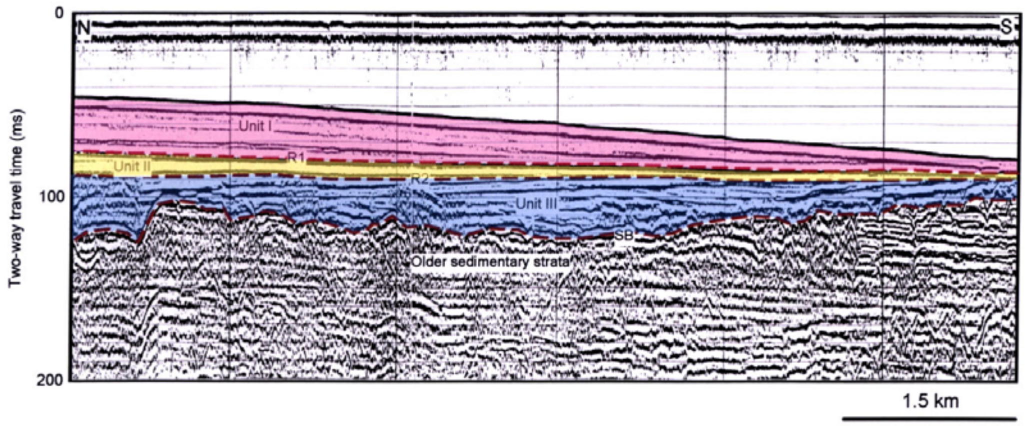

Fig. 4. High-resolution air-gun profile (for location, see Fig. 2), showing three sedimentary units (I, II, and III) separated by two bounding surfaces (R1 and R2). SB; sequence boundary.

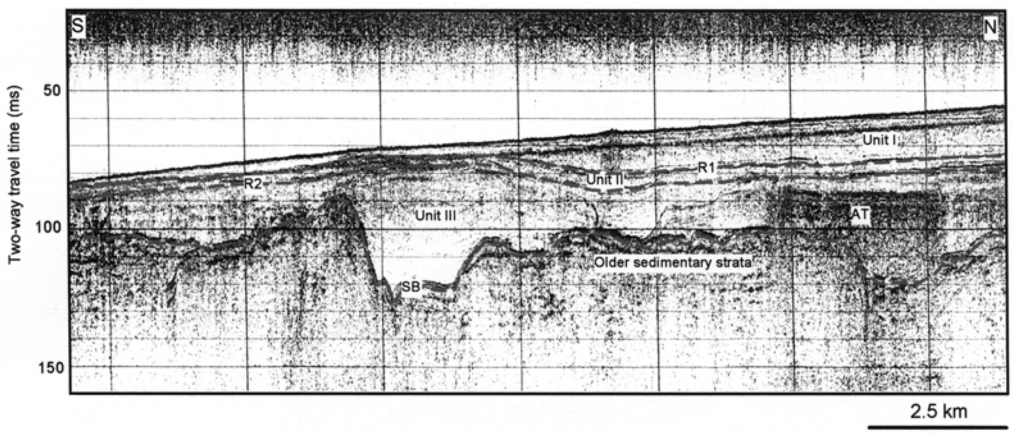

Fig. 5. High resolution air-gun profile (for location, see Fig. 2), showing three sedimentary units (I, II, and III).

the presence of gas bubbles within sediment column which scatter and attenuate the acoustic energy (Min, 1994).

Unit II shows a semi-transparent subbottom with faintly stratified reflectors (Fig. 5). Locally, it contains some hummocky reflections with a low amplitude. Unit II is less than a few meters thick. Externally, it is shaped in a sheet type with a slightly increase in thickness landward.

The upper unit (I) forms a stratal wedge that thins seaward from a maximum thickness of 30 m near the river mouth. Closer inspection of seismic profiles, Unit I acoustically shows a well-stratified to transparent subbottom with a variable amplitude (Figs. 5 and 6). In the landward portion, it is defined by a distinct and laterally persistent internal reflectors (Fig. 6A). The internal reflectors are concordant with the sea floor and show parallel to slightly progradational configurations. Toward the offshore, internal reflectors become progressively weak with low continuity. For most part of the inner shelf, Unit I shows a transparent or semi-transparent subbottom with no internal reflectors (Fig. 6B). In some places, the acoustically turbid layer masks the underlying structures, as in the case of Unit III. This feature is isolated or wide-spread over a distance of several kilometers. Externally, Unit I shows a wedge shape, decreasing in thickness seaward. It downlaps on the underlying surface at water depths of about 70-80 m.

4.2. Distribution of Seismic Units

The sedimentary sequence above the older sedimentary strata ranges from 5 m to 50 m in thickness; the thickest section occurs near the eastern part of Geoje Island, associated with the deep erosional depression of older sedimentary strata (Fig. 7A). The sediment thickness is less than 10 m near Pusan where the basement rock is partly exposed on the sea floor. However, the thickness increases

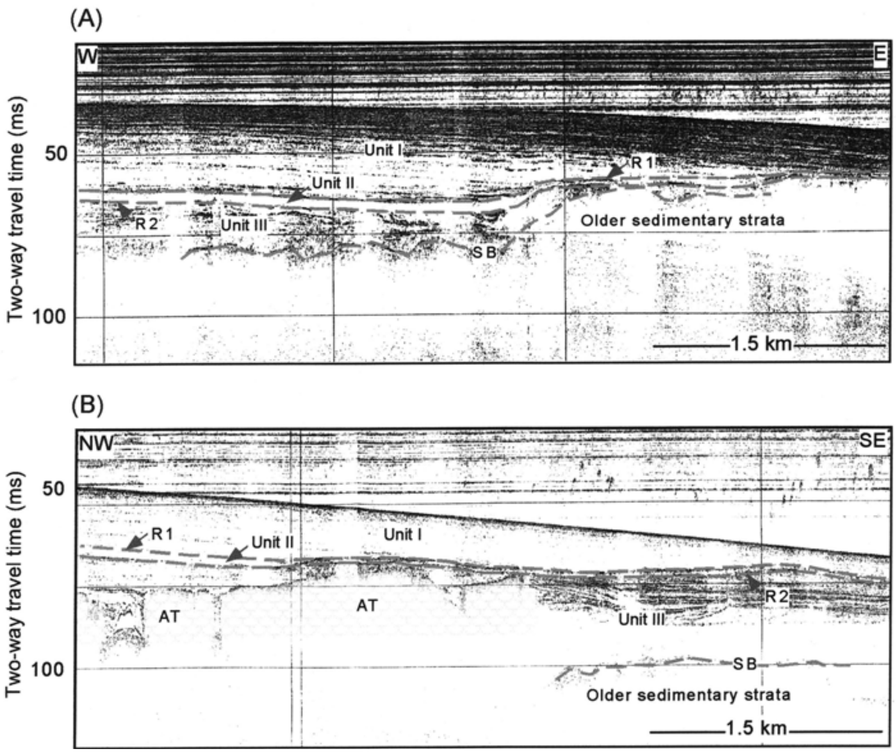

Fig. 6. High-resolution (3.5 kHz) seismic profiles (for location, see Fig. 2), illustrating three sedimentary units (I, II, and III). Note that Unit I near the river mouth shows well-stratified reflections (A), whereas toward the offshore the internal reflections become progressively weak and then Unit I is characterized by a transparent subbottom with no internal reflectors (B).

again northeastward. Generally, the total thickness of sediment decreases progressively seaward, showing a wedge shape.

Unit I is commonly 10 - 20 m thick (Fig. 7B). Two different depocenters of this unit occur around Gadeog Island: one with a thickness of more than 25 m is located on the inner shelf between Geoje and Gadeog islands, whereas the other with a maximum thickness of 20 m occurs on the eastern part of Gadeog Island (Fig. 7B). Toward the offshore, the thickness of this unit decreases progressively. Although it is less than a few meters thick or absent on the inner shelf near Pusan, it extends northeastward along the coast where the thickness increases up to 10 m (Fig. 7B). Figure 7C is the isopach map of both units II and III. The thickness ranges from 5 m to 25 m, and the depocenter is located near the eastern part of Geoje Island. In most case, Unit II is about 5 m thick, but its thickness increases slightly landward. In contrast, Unit III has variable thickness and the depocenter up to 20 m thick is located on the eastern part of Geoje Island where the older sedimentary strata is deeply depressed. However, the overall thickness of Unit III is about 5 - 10 m.

4.3. Late Quaternary Depositional History

On the basis of seismic profiles, two bounding

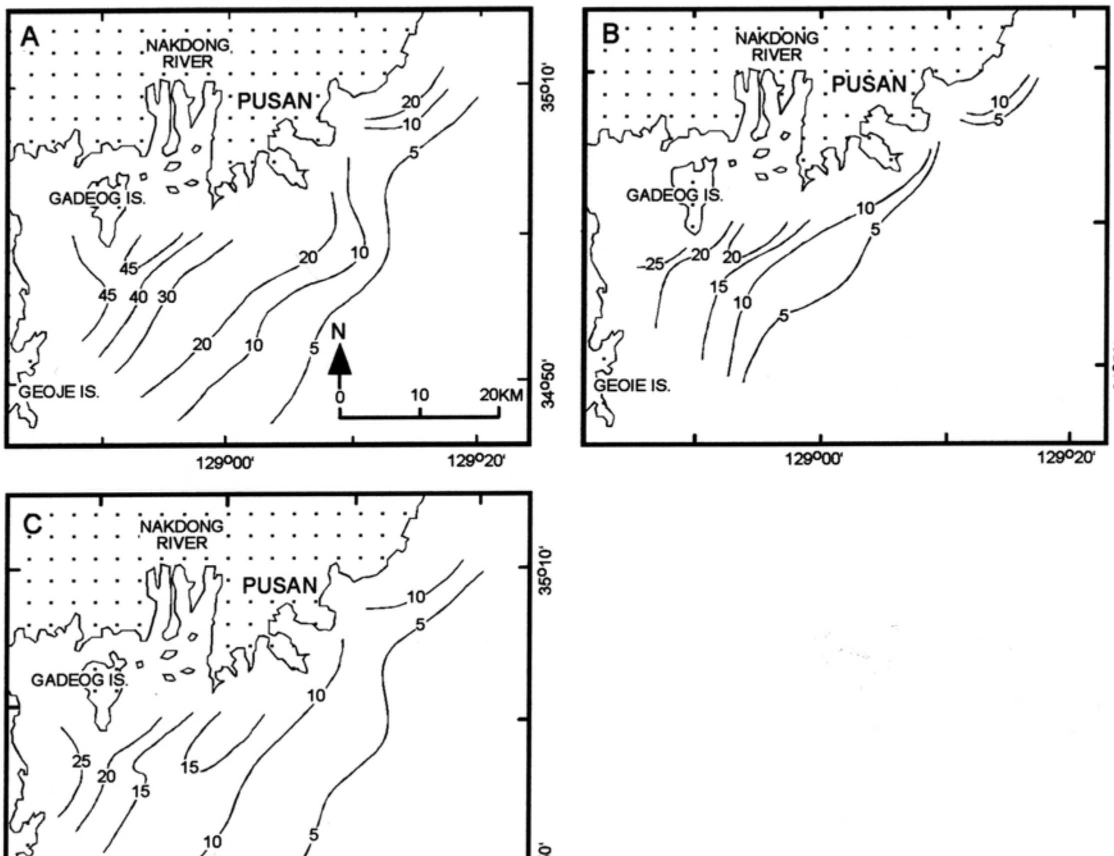

Fig. 7. Isopach map of the inner shelf sediments; (A) total, (B) highstand systems tract (Unit I), and (C) transgressive systems tract (units II and III).

surfaces (R1 and R2) were identified within the sedimentary sequence above older sedimentary strata (Figs. 4-6). We interpreted that the second bounding surface (R2) belongs to a ravinement surface formed by shoreface erosion that shifted landward during transgression (Demarest and Craft, 1987; Trincardi *et al.*, 1994). On seismic profiles, R2 between Unit II and Unit III is defined by an erosional surface with strong, continuous reflectivity, possibly developed under the high-energy condition such as coastal environment. On the other hand, R1 is defined by a non-erosional surface on seismic profiles (Fig. 5). It can be also traced over the most part of the inner shelf. The occurrence of same type of R1 has been reported on shelf regions of the world by a number of workers (Hernandez-Molina *et al.*, 1994; Okyar *et al.*,1994; Saito, 1994; Trincardi *et al.*, 1994) and they interpreted this surface as maximum flooding surface. R1 in this area is interpreted as a maximum flooding surface that marks the transition from a retrogradational phase to a progradational phase. Therefore, R1 is an isochronous surface created when shoreline reached its maximum landward excursion, whereas R2 is a time-transgressive, erosional surface formed by shoreface erosion that shifted landward during postglacial transgression. Consequently, units II and III between the maximum flooding surface and the sequence boundary belong to the transgressive systems tract mainly formed during the postglacial transgression, while Unit I directly overlying the maximum flooding surface is the highstand systems tract formed during the recent highstand of sea level.

The last glacial maximum reached the Korea Strait between 15,000 and 16,000 years ago, when sea level was about 130 m lower than at present (Fig. 8A; Suk, 1989; Min, 1994; Park *et al.*, 2000). At that time, the shoreline was loacted about 60 km southeast of its present position, and much of the study area was subaerially exposed, resulting in the formation of the sequence boundary that cut the underlying older sedimentary strata. This sequence boundary, showing an erosional unconformity, marks the basal surface of Holocene deposits and thus the overlying shelf sequence in the inner shelf is considered to be late Quaternary deposits accumulated since the last glacial maximum. In the Korea Strait, the postglacial transgression began about 15,000 - 16,000 yr BP (Suk, 1989; Min, 1994) and the shoreline migrated landward across the shelf. Around 11,000-10,000 yr BP, the shoreline approached the southern part of the study area approximately 70-80 m in water depth below the present sea level (Korea Institute of Geoscience and Mineral Resources, 2000). As sea level rose further, the coastline migrated northward and then an estuarine environment probably developed around the inner shelf between Geoje Island and the present river mouth as reported by Yoo and Park (2000). Under that condition, the sediments derived from the paleo-Nakdong River were trapped in this estuary forming Unit III as estuarine deposits (Fig. 8). The estuary is likely to trap the river-derived sediments until the shoreline is displaced further landward, resulting in backstepping or retrograding arrangements. Sea level continued to rise and the shoreline migrates further landward. The near-surface sediment was reworked and eroded by shoreface erosion, forming a ravinement surface. This surface was draped by a thin lag of sandy sediments forming Unit II as a relict sand.

The rising sea level decelerated after about 7000 yr B.P. and sea level reached the present position approximately 6000 yrs B.P. (Suk, 1989; Min, 1994). This age is in good agreement with the occurrence of maximum flooding surface, reflecting environmental changes from retrogradational phase forming transgressive deposits (units II and III) to a progradational phase consisting of highstand deposits. Since that time, the inner shelf began to receive large amount of fine-grained sediments from the Nakdong River (Fig. 8). Formation of Unit I consisting of the highstand systems tract initiated and most river-derived sediments have been deposited at and immediately beyond the river mouth, forming a subaqueous prodelta and shelf deposits. This unit extends seaward from the present river mouth and pinches out at water depths of about 70-80 m.

5. Conclusions

Analyses of high-resolution seismic profiles collected from the Korea Strait inner shelf lead us to the following conclusions.

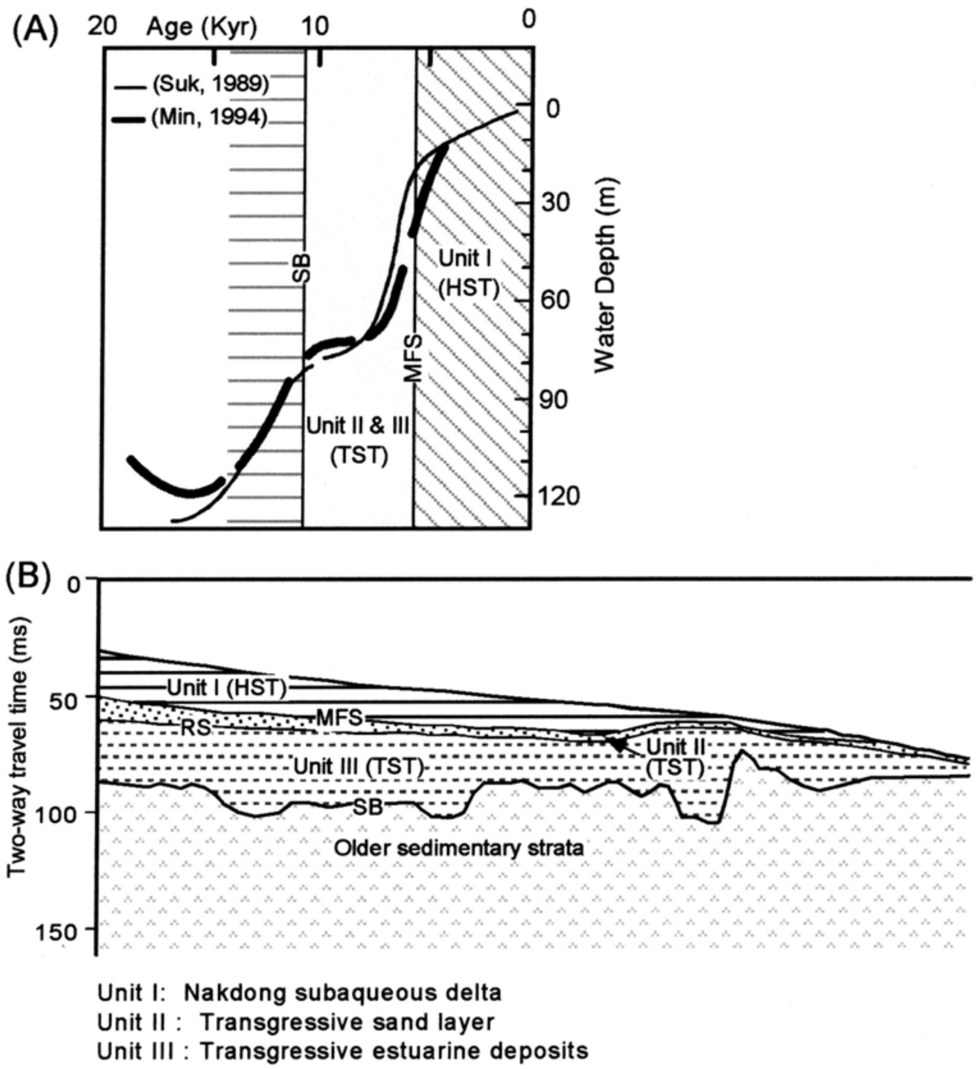

Fig. 8. Sea-level curve in the Korea Strait (A), and proposed stratigraphic architecture for the Korea Strait inner shelf (B).

(1) The inner shelf deposits above the sequence boundary form a high-frequency sequence consisting of three sedimentary units (Unit I, II, and III) separated by two bounding surfaces (maximum flooding surface and ravinement surface). A maximum flooding surface separating Unit II from the overlying Unit I is a non-erosional surface created when the shoreline has reached at its maximum landward excursion, whereas a ravinement surface is an erosional surface related to shore retreat during the post glacial transgression. Three units constitute the transgressive and highstand systems tracts formed since the last glacial maximum.

(2) Upper unit (I) above the maximum flooding surface represents the highstand systems tract formed during the recent highstand of sea level and forms a subaqueous prodelta. Lower two units (II and III) constitute the transgressive systems tract. Lower unit (III) above the sequence boundary is regarded as the transgressive estuarine deposits formed during the late stage of transgression, whereas middle unit (II) between the maximum flooding surface and the ravinement surface forms a thin transgressive sand layer which consists of the sediment produced through the shoreface erosion during the transgression.

Acknowledgements

This work was supported by the National Research Laboratory programme from the Korea Institute of Science & Technology Evaluation and Planning (KISTEP), and in part by the Korea Research Council of Public Science and Technology. We would like to thank the officers and crew of the R/V Tamhae II for their effort in seismic survey. Dr. S.L. Nam gave many helpful suggestions to improve the draft of the text. We thank Dr. M.C. Suh and an anonymous reviewer for constructive reviews that improved the manuscript.

References

Demarest, J.M., and Kraft, J.C., 1987, Stratigraphic record of Quaternary sea levels: implications for more ancient strata, inNummedal, D., Pilkey, O.H., and Howard, J.D., eds., Sea-level Fluctuation and Coastal Evolution: SEPM, Special Publication, 41, 223-239.

Hernandez-Molina, F.J., Somoza, L., Rey, J., and Pomar, L., 1994, Late Pleistocene-Holocene sediments on the Spanish continental shelves: Model for very high resolution sequence stratigraphy: Marine Geology, 120, 129-174.

Kim, M.S., Chu, K.S., and Kim, O.S., 1986, Investigation of some influence of the Nakdong River water on marine environment in the estuarine area using Landsat imagery: Technical Report of Korea Ministry Sciences Technology, 93-147.

Korea Hydrographic Office, 1982, Marine environmental atlas of Korean waters: Research Report, 38 pp.

Korea Ministry of Construction, 1974, Report on the Nakdong Estuary: Industrial site investigation. Research Report, 1-56

Korea Institute of Geoscience and Mineral Resources, 2000, Study on Quaternary Stratigraphy and Environmental Changes. Report of Korea Institute of Geoscience and Mineral Resources, Taejon, Korea 677p.

Lee, C.S., and Chung, Y.H., 2000, Late Quaternary sedimentation in the Kadeok region, Korea: Geo-Marine Letters, 20, 72-79.

Lee, H.Y., Hyun, B.K., and Kong, Y.S., 1996, PC-based acquisition and processing of high-resolution marine seismic data: Geophysics, 61, 1804-1812.

Min, G.H., 1994, Seismic stratigraphy and depositional history of Pliocene- Holocene deposits in the southeastern shelf, Korean Peninsula. Ph.D. Thesis, Seoul National University.

Mitchum, R.M., Vail, P.R., and Sangree, J.B., 1977, Stratigraphic interpretation of seismic reflection patterns in depositional sequence. In: Payton,C.E. (editor), Seismic Stratigraphy-application to Hydrocarbon Exploration, AAPG Memoir, 26, 117-133.

Morton, R.A., and Suter, J.R., 1996, Sequence stratigraphy and composition of late Quaternary shelf-margin deltas, Northern Gulf of Mexico: American Association of Petroleum Geologists, Bulletin, 80, 505-530.

Okyar, M., Ediger, V., and Ergin, M., 1994, Seismic stratigraphy of the southeastern Black Sea shelf from high-resolution seismic records: Marine Geology, 121, 213-230.

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., Yoo, D.G., Lee, K.W., and Lee, H.H., 1999, Accumulation of recent muds associated with coastal circulations, southeastern Korea Sea (Korea Strait): Continental Shelf Research, 19, 589-608.

Park, S.C., Yoo, D.G., Lee, C.W., Lee. E.L., 2000, Last glacial sea-level changes and paleogeography of the Korea (Tsushima) Strait: Geo-Marine Letters, 20, 64-71.

Park, Y.A., and Choi, J.Y., 1986, Factor analysis of the continental shelf sediments of the southeast coast of Korea and its implication of the depositional environments: J. Oceanological Society of Korea, 21, 34-45.

Posamentier, H.W., Jervey, M.T., and Vail, P.R., 1988, Eustatic controls on clastic deposition I - Conceptual framework, *in* Wilgus, C.K., Hastings, B.S., Kendall, C.G. St.C., Posamentier, H.W., Ross, C.A., and Van Wagoner, J.C., eds., Sea-level Changes: An Integrated Approach: SEPM, Special Publication, 42, 109-124.

Saito, Y., 1994, Shelf sequence and characteristic bounding surfaces in a wave-dominated setting: Latest Pleistocene-Holocene examples from Northeast Japan: Marine Geology, 120, 105-127.

Suk, B.C., 1989, Quaternary sedimentation processes, structures and sea level changes in the East China Sea, the Yellow Sea and the Korea-Tsushima Strait Regions. Ph.D. Thesis, University of Tokyo.

Tesson, M., Posamentier, H.W., and Gensous, B., 2000, Stratigraphic organization of late Pleistocene deposits of the western part of the Golfe du Lion Shelf (Languedoc Shelf), western Mediterranean Sea, using high-resolution seismic and core data: American Association of Petroleum Geologists, 84, 119-150.

Tortora, P., 1996, Depositional and erosional coastal processes during the last postglacial sea-level rise:

An example from the central Tyrrhean continental shelf (Italy): J. of Sed. Res., 66, 391-405.

Trincardi, F., Correggiari, A., and Roveri, M., 1994, Late Quaternary transgressive erosion and deposition in modern epicontinental shelf: the Adriatic Semien-closed Basin: Geo-Marine Letters, 14, 41-51.

Yoo, D.G., and Park, S.C., 2000, High-resolution seismic study as a tool for sequence stratigraphic evidence of high-frequency sea-level changes: Latest Pleistocene-Holocene example from the Korea Strait shelf: J. of Sedi. Res., 70, 296-309.

Yoo, D.G., Park, S.C., Shin, W.C., and Kim, W.S., 1996, Near-surface seismic facies at the Korea Strait shelf margin and trough region: Geo-Marine Letters, 16, 49-56.

Yoo, D.G., Lee, C.W., Kim, S.P., Jin, J.H., Kim, J.K., and Han, H.C., 2002, Late Quaternary transgressive and highstand systems tracts in the northern East China Sea mid-shelf: Marine Geology, 187, 313-328.

2002년 9월 14일 원고접수
2002년 12월 23일 원고채택