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Postglacial Sea-Level Change of the Korean Southern Sea Shelf

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ABSTRACT

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Molluscan shells were sampled from 31 localities in the South Sea shelf (26 in the southeastern continental shelf and 5 in the southwest sea) to understand the sea-level changes and molluscan thanatocoenoses after the last glacial maximum (LGM). At the southeastern continental shelf, 13,074 shell remains were classified into 119 genera and 170 species (Bivalvia: 73 genera and 105 species; Gastropoda: 43 genera and 60 species; Scaphopoda: 3 genera and 5 species). Cluster analyses were used to group the species into 12 assemblages (*Glycymeris–Ventricoloidea–Phacosoma* [GVPA], *Glycymeris–Paphia–Pitar* [GPPA], *Glycymeris–Cryptopecten* [GCA], *Glycymeris–Ventricoloidea–Cryptopecten* [GVCA], *Pecten–Pitar, Ostrea–Limopsis, Dentalium, Nuculana–Cranulilimopsis, Lucinoma–Glycymeris, Pecten–Acila–Siphonalia, Glycymeris,* and *Buccium*), among which the *Glycymeris* fauna (GVPA, GPPA, GCA, GVCA) occurred at 11 stations, mainly around Tsushima Island on the South Korean shelf. Radiocarbon dates between late Pleistocene and Holocene were determined for 47 dominant and specific species, which were sampled from 24 stations of the South Sea. Fortunately, the habitats of the molluscan species were depth sensitive, allowing for the discrimination of samples into depth-limited age groups. These groups suggested that the sea level fell by about 150–160 m about 15,000 years ago (during LGM), allowing a land bridge to form between the Korean peninsula and Japan. Subsequently the sea rose approximately 60 m about 9000 years ago. Sea level remained at 50–60 m until about 4000–5000 years ago. About 3000–4000 years ago sea level rose to about 10–20 m (below present) and has remained there to the present. *Glycymeris* fauna were created on the southeastern shelf about 6000 years ago, whereas *Arca* fauna prospered in the southwestern sea area about 2000–3000 years ago when the sea level was 10–20 m below present.

ADDITIONAL INDEX WORD: *Molluscan shell*.

INTRODUCTION

Paleontological approaches have been very useful for understanding changes in environmental conditions through geologic time. Phylum Mollusca is a large fauna mainly comprised of shellfish and arthropods. Mollusca are divided into seven classes: Aplacophora, Polyplacophora, Monoplacophora, Gastropoda, Cephalopoda, Scaphopoda, and Bivalvia. The fossils of Gastropoda, Bivalvia, and Scaphopoda are the main components of shellfish discovered in sedimentary strata from various regions and time. Therefore, paleontologists have used fossils of Gastropoda, Bivalvia, and Scaphopoda to study paleoenvironment, paleogeography, biostratigraphy, paleoecology, and evolution biology.

Age determination of fossil material using radiocarbon decay, along with oxygen and carbon isotope ratios, has provided time and temperature information for understanding the formation timing of sedimentary strata, sea temperature, and sea-level changes, paleogeography, and paleocurrents.

Quaternary deposits are widely distributed on the continental shelf of the Korean peninsula. Mollusc shells are plentiful in the coarse-grained relict sediments of the southern continental shelf. Recent species well suited for the present ocean environments (deep water) are mixed with fossil species that inhabited past ocean environments when the sea level was lower (LEE, 1997a, 1997b, 1998; YOON *et al.,* 1994). Late Pliocene–Pleistocene fossil species such as *Mizuhopecten tokyoensis hokurikuensis, Amussiopecten praesignis,* and *Turritella saishuensis* have been reported in the front sea area on the continental shelf of Geoje Island and Ulsan, Korea (LEE, 1997b, 1998). Molluscan species collected from this study area provided a very useful tool for understanding the paleoenvironment on the continental shelf of the South Sea.

About 15,000 years ago, Korean shorelines were displaced seaward by more than 100 km as sea level dropped because of widespread glaciation. Between 15,000 years ago and the present, sea level has been rising in response to deglaciation. Coarse sediment (sand and gravel) blankets the outer shelf where water depths are deep and bottom and physical energy is minimal. These coarse-grained deposits on the outer two-thirds of the Korean shelf are not consistent with the present low-energy conditions. Such material was termed relict sediment by EMERY (1952) because it accumulated at an early time and under very different depositional conditions (PINET, 2000). Thus, sediment on the outer Korean shelf could be classified as relict because it was deposited under signifi-

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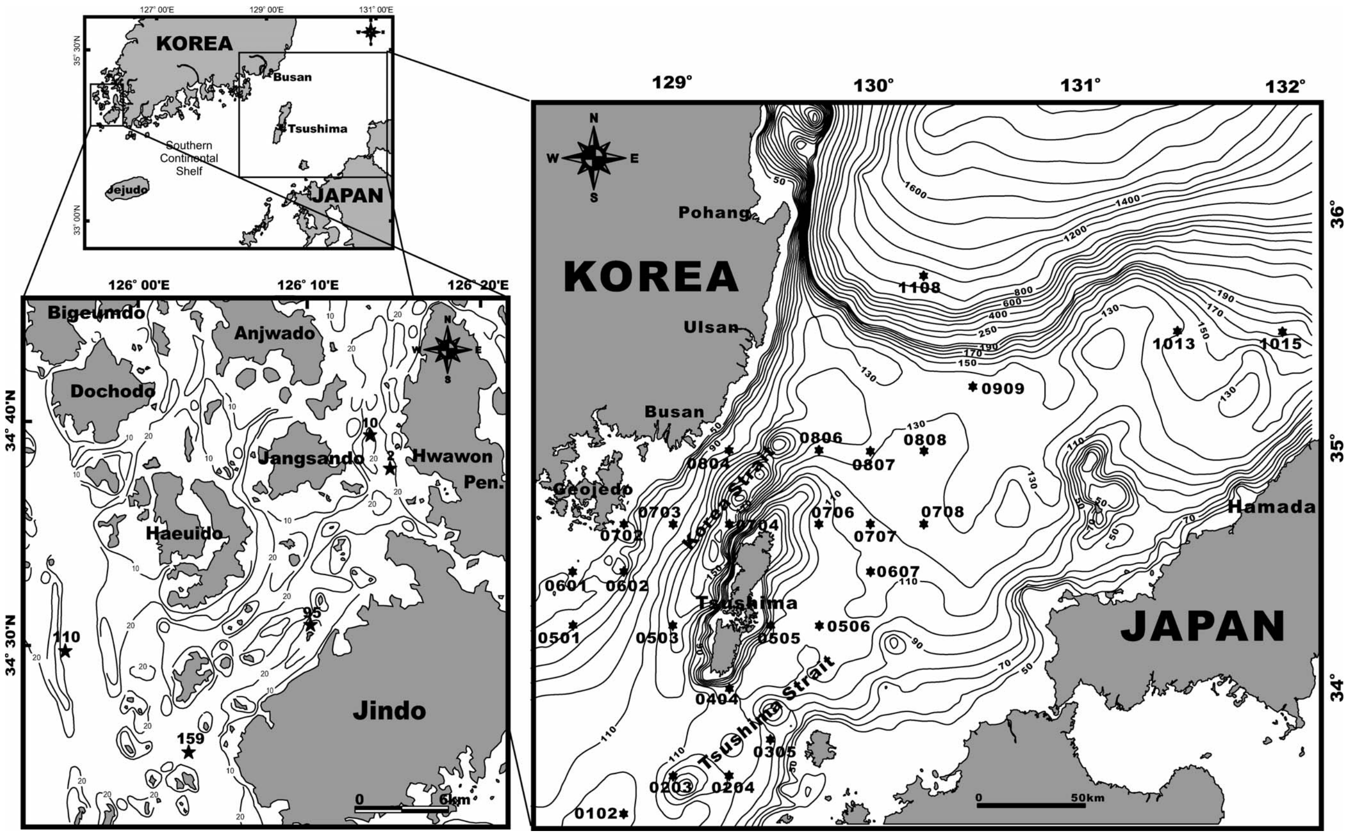

Figure 1. Bathymetric map showing the sample correction for 31 localities in the South Sea shelf (26 in the southeastern continental shelf and 5 in the southwest sea) of Korea.

cantly different environmental conditions. Although "relict sediment" is a valuable term used to describe sediment that has been displaced from its original environment of deposition, "palimpsest sediment" is a convenient term for the mixture of relict and modern materials (SWIFT, STANLEY, and CURRAY, 1971).

The Korean southern shelf has produced faunas or floras from relict and palimpsest sediment. After the last glacial maximum (LGM), the current speed increased continuously as sea level rose around Korea Strait. High current speeds facilitated the reworking/mixing of sediments. Shell valves in palimpsest sediment must have had an autochthonous history to provide valid chronological data for a sea-level curve.

The depth of the sea level lowstand on the continental shelf during the LGM needs to be determined to understand the paleoenvironment of the South Sea continental shelf (Figure 1). The characteristics of this environment include the nature of the land bridge between the Korean peninsula and Japan, the flow of the paleo-Tsushima Current centering around the Korea Strait, and the desalination of the East Sea. PARK *et al.* (2000) and SUK (1989) have conducted radiocarbon age determination of the shell remains from the sea around Tsushima and concluded that the last glacial sea level was approximately 130 m below the present. These results contradict the research results reported for the East Sea desalination at the last glacial period (FENG, 1983; KIM *et al.,* 2000), which indicated the formation of a land bridge between Korea and Japan and disputed the inflow of the Tsushima Current.

The purpose of this study was to understand the variation of sea level and paleoenvironment after the last glacial period. Our main tools were ^{14}C radiocarbon age determinations of the dominant and character species, and interpretation of species distribution and assemblage composition of the shell remains produced from the surface sediments of the Korean South Sea shelf.

STUDY AREA SETTING

The South Sea coast of Korea is a typical Ria-type coast with intricate coastlines and multiple inner bays, and was formed by rising sea level after the last glacial period. Sedimentary deposits primarily consist of recent fine-grained sediments known to be delivered from seas influenced by river sources or tidal currents (CHOUGH, 1983). The present study area (Figure 1) is divided into two sea areas, one of the southeastern continental shelf centering around Tsushima, and the other around Jindo on the southwest coast. The southeastern continental shelf of Korea, the sea area between southeast Korea and southwest Japan, is the gateway where the Tsushima Current, a tributary of the warm Tsushima–Kuroshio Current, flows into the East Sea. At the East Sea, an influx has formed a very steep landform sloping to great depths. The Tsushima islands are located at the center of the continental shelf, whereas the Korea Strait is at the northwest of the island and the Tsushima Strait is at the southeast of the island. The Tsushima sea area is separated into two regions. The Kyusyu coast sea area of Japan has depths of less than 70 m over a gentle undulating surface; the Tsushima coast sea area is distinguished by the relative absence of undulation, where discontinuous and shallow troughs are present between the Tsushima islands (Ujiie, 1973). In the Korea Strait, the Tsushima trough (230 m depth; Park *et al.,* 2000) slopes upward toward the coast of the Korea peninsula. The Tsushima trough is the deepest area in the South Sea continental shelf. During the last glacial epoch, shellfish inhabited the littoral zone in this area (Habe and Kosuge, 1970).

Many tectonic lines with NE-SW and NNE-SSW orientations occur in the southeastern continental shelf (Katsura and Nagano, 1976). These faults are known to be main factors forming the Korea Strait (Ministry of Science and Technology, 1994).

The southwestern sea area of the Korean peninsula is an archipelago with the islands of Hauido, Jangsando, and Anjwado surrounding the island of Jindo. It is a complicated sea area with interlacing networks of large and small channels with rapid, semidiurnal tidal currents. During mean spring tide, the maximum flood and ebb currents are 1.9–3.7 and 1.6–3.9 knots, respectively (Office of Hydrographic Affairs, 1996). Sedimentary deposits are composed of coarse-grained sand and gravel. Numerous shellfish remains, such as *Arca boucardi* (from the last lowstand), have been found in surface sediments (Lee, 1997a).

METHODS

Surface sediments were collected from 31 localities, 26 in the southeastern continental shelf and 5 in the southwest sea area (Figure 1). Samples were taken with the use of a grab sampler (Van Veen type) and frame dredge (5-minute drags). During drags, an echo sounder (Furuno, model JFV-200) was used to verify and maintain constant depth. Drags were made at constant slow speeds between 1 and 2 knots.

The species of modern shell remains were identified in reference to illustrations and reference plates (Gakken, 1975; Habe, 1977; Habe and Kosuge, 1967; Min Shell House, 2001) and those of the Pliocene–Pleistocene fossils were identified from descriptions in Habe and Kosuge (1970) and Okamoto and Honza (1978). Sediment samples were initially prepared for size analysis by completely eliminating organic materials and carbonates through the sequential addition of 10% hydrogen peroxide and 0.1 N hydrochloric acid. Grain size fractions were determined using sieve analysis for the coarse fraction and a Sedigraph 5100 automatic grain size analyzer for the fine fraction. ^{14}C radiocarbon ages were determined by accelerator mass spectrometry (AMS) and liquid scintillation counter (LSC). AMS was done on small samples of less than 7 g at the radioactivity laboratory at Waikato

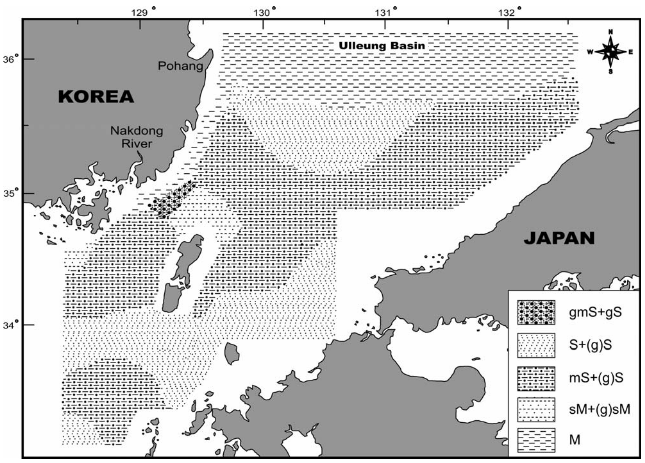

Figure 2. Distribution map of surface sediment type in the southeastern continental shelf of Korea (modified by the Ministry of Science and Technology, 1993). S, sand; gS, gravelly sand; gmS, gravelly muddy sand; (g)S, slightly gravelly sand; mS, muddy sand; sM, sandy mud; M, mud.

University of New Zealand. LSC was done at Chonnam University of Korea on larger samples of more than 14 g. Samples for age analysis were selected from the dominant and characteristic species of shell remains produced from each locality. The degree of shell reworking/mixing was assessed by comparison of present water depth with known habitat depths for the species and preservation state of the shell.

RESULTS

Distribution of Surface Sediments

On the southeastern continental shelf of the study area, surface sediments were composed of various materials (Figure 2). Coarse-fractioned samples had large quantities of shell material producing large carbonate contents (20~70%). Muddy sediments formed a band distribution along the continental slope at the northern part of the study area, southern Ulleung Basin, and the sea coast between Busan and Pohang. Muddy sand or slightly gravelly muddy sand facies appeared in the southwestern sea area of Tsushima and the southern sea area of the East Sea. Sand or slightly gravelly sand facies were distributed at a depth of 100~200 m in the central area of the southern sea area of the East Sea and the southern sea area of Tsushima. Sandy mud or slightly gravelly sandy mud facies had a restrictive distribution in the north sea area of Tsushima and local areas. Gravelly sand or gravelly muddy sand facies occurred in a northeast~southwest trending band following the Tsushima trough between Korea and Japan (Ministry of Science and Technology, 1993). The fine-grained muddy sediments that occurred on the continental slope areas at the East Sea entrance, the southern Ulleung Basin, and the sea coast between Busan and Pohang were derived from the Nakdong River (Park *et al.,* 1999). The coarse-grained fractions that occurred on the continental shelf are believed to be relict sediments (Emery, 1952) or palimpsest (Swift, Stanley, and

CURRAY, 1971) formed during the last postglacial transgression (CHOI and PARK, 1993; LEE, 1997b). These relict and palimpsest sediments contained abundant shell remains.

Twenty six sample localities of southeastern sea area produced relict or palimpsest sediments. Loc. no. 1108 (Appendix 1) was the only locality that did not produce relict or palimpsest sediments.

Surface sediments of the southwestern sea area were primarily composed of muddy gravel–gravel facies and silty sand–sand facies, and these relict sediments contained plentiful shell remains (LEE, 1997a). The surface sediments of the five sample collection localities were composed of slightly gravelly sand–gravel facies.

Species Composition

Shell valves from the five localities in the southwestern sea area produced *Arca* assemblages dominated by *A. boucardi,* which is an "attaching species" that lives fastened to rock and gravels of the littoral zone. The 13,074 samples from the 26 localities in the southeastern shelf produced 119 genera and 170 species (Bivalvia: 73 genera and 105 species; Gastropoda: 43 genera and 60 species; Scaphopoda: 3 genera and 5 species) (Appendix 2). The species composition of each locality is summarized in Table 1. Six of the 26 localities in the southeastern shelf (loc. nos. 0203, 0204, 0305, 0404, 0708, and 1015) had very sparse population yields but the other 20 localities had high yield frequency. Loc. no. 0102 had the highest frequency with a total population of 2962. Loc. no. 0808 had the highest species yield with 43 species.

Among the component species, attaching species of the rocky littoral zone and sandy muddy infaunal species of the shallow sea were found in much deeper environments than normal. The oldest samples were *Mizuhopecten yessoensis* and *M. tokyoensis hokurikuensis* produced from loc. nos. 0807 and 0806. *Mizuhopecten yessoensis* and *M. tokyoensis hokurikuensis* are known from the late Pliocene–Pleistocene of the Seogwipo Formation in Jeju Island of Korea (YOON, 1988).

Assemblage

To understand the similarity between the component species at each locality we conducted the cluster analysis with the Bray–Curtis similarity index (SI) (Figure 3). Species composition showed the greatest similarity between loc. nos. 0707 and 0807 (SI 0.8235). Eleven localities from loc. nos. 0102 to 0706 had SIs of 0.2451, whereas the other localities were categorized into smaller groups. The big group was subdivided into four smaller groups of loc. nos. 0102 and 0808; 0501 and 0703; 0506, 0806, and 0909; and 0602, 0707, 0807, and 0706. Species composition of the dominant species between the localities is compared in Table 2.

Locality nos. 0102 and 0808 had a SI of 0.5944 and formed the *Glycymeris–Ventricoloidea–Phacosoma* assemblage (GVPA). *Glycymeris rotunda* constituted 59.07% of the assemblage and was accompanied by *Ventricoloidea foveolata, Phacosoma japonicum,* and *Cryptopecten vesiculosus.*

Locality nos. 0501 and 0703 had a SI of 0.4953. *Glycymeris rotunda* constituted 15.91% of the assemblage. *Cyclocardia* sp. occurred at loc. no. 0703 with a yield frequency of 10.34% but did not occur at loc. no. 0501. This difference in species composition between the two localities (loc. nos. 0501 and 0703) formed the *Glycymeris–Paphia–Pitar* assemblage (GPPA) with accompanying species of *Paphia amabilis, Pitar noguchii, Nemocardium samarangae,* and *C. vesiculosus.*

Locality nos. 0506, 0806, and 0909 had a SI of 0.4932 and formed the *Glycymeris–Cryptopecten* assemblage (GCA). *Glycymeris rotunda* constituted 50.44% of the assemblage and *C. vesiculosus* was the main accompanying species.

Locality nos. 0602, 0706, 0707, and 0807 had a SI of 0.6653. *Glycymeris rotunda* and *V. foveolata* had yield frequencies of 42.74% and 27.03% respectively. They formed the main components of the *Glycymeris–Ventricoloidea–Cryptopecten* assemblage (GVCA). *Cryptopecten vesiculosus, Phacosoma japonicum,* and *Pecten albicans* were accompanying species. These four main groups (GVPA, GPPA, GCA, and GVCA) had *G. rotunda* as the representative species but had different distributions of the accompanying species.

Locality nos. 0601 and 0607 had a SI of 0.3758 and dominant species of *C. vesiculosus, Pecten albicans,* and *Pitar noguchii* that formed the *Pecten–Pitar* assemblage (PPA). *Pecten albicans* and *Pitar noguchii* were the dominant species but there were different yield frequencies of *C. vesiculosus* between the two localities.

Locality no. 0804 formed the *Ostrea–Limopsis* assemblage (OLA) dominated by *Ostrea* sp. (44%) and *Limopsis tajimae* (34%). Locality no. 1013 was a *Dentalium* assemblage (DA) dominated by *Dentalium octangulatum* (78.5%). Locality no. 0704 was a *Nuculana–Crenulilimopsis* assemblage (NCA) dominated by *Nuculana pernula pernuloides* (37%) and *Crenulilimopsis oblonga* (25%). Locality no. 0505 was a *Glycymeris* assemblage (GPA) dominated by *Glycymeris pilsbryi* (68.4%). Locality no. 0503 was a *Lucinoma–Glycymeris* assemblage (LGA) dominated by *Lucinoma acutilineata* (42.7%) and *Glycymeris rotunda* (28.0%). Locality no. 0702 was a *Pecten–Acila–Siphonalia* assemblage (PASA) dominated by *Pecten albicans* (43.9%), *Acila mirabilis* (10.1%), and *Siphonalia fusoides* (8.5%). Locality no. 1108 was a *Buccium* assemblage (BA) 100% dominated by *Buccium tsubai.* The other localities 0203, 0204, 0305, 0404, 0708, and 1015, could not be grouped into assemblages because of low yield frequencies.

Twelve assemblages (GVPA, GPPA, GCA, GVCA, PPA, OLA, DA, NCA, LGA, PASA, GPA, and BA) were established on the basis of the similarity between the component species of the localities. *Glycymeris rotunda* was the most prevalent species among the 12 dominant species constituting the shell assemblages in the study area.

Radiocarbon Age and Sea-Level Changes

Table 3 presents the radiocarbon ages of the dominant and characteristic species of the shell remains produced from the 24 localities at the southwestern sea area and the southeastern continental shelf.

Southeastern Continental Shelf

Radiocarbon dates were determined for 42 dominant and characteristic species of the shell remains produced from 19 localities ranging in depth from 62 m to 194 m below sea level

Table 1. *Molluscan species composition of 26 localities of the southeastern continental shelf of Korea.*

		Species Composition						
Loc. No.	Depth (m)	Tot. Indiv.	Gen. No.	Spec. No.	Dominant Species (%)	Associated Species	Assoc.	Remarks
0102	170	2962	29	30	*Glycymeris rotunda* (59.8)	*Phacosoma japonica, Ventricoloidea foveolata, Lucinoma annulata*	GVPA	
0203	120	40	15	15	*Glycymeris rotunda*	*Glycymeris rotunda, Cryptopecten vesiculosus, Pecten albicans*		
0204	98	3	3	3		*Glycymeris rotunda, Cryptopecten vesiculosus, Pecten albicans*		
0305	90	30	13	13		*Paphia amabilis, Macoma tokyoensis*		
0404	100	15	2	2		*Glycymeris* sp., *Pecten albicans*		
0501	675	34	35		*Glycymeris rotunda* (15.4%), *Pitar noguchii* (13.6%)	*Neomocardium samarangae* (10.2%), *Cryptopecten vesiculosus, Pecten albicans, Megacardita coreensis, M. ferruginosa*	GPPA	
0503	136	239	18	18	*Lucinoma acutilineata* (42.7%), *Glycymeris rotunda* (28.0%)	*Nemocardium samarangae*	LGA	
0505	104	95	15	15	*Glycymeris pilsbryi* (68.4%)		GpA	
0506	103	190	22	22	*Glycymeris rotunda* (50.5%)	*Cryptopecten vesiculosus, Pitar noguchii*	GCA	
0601	62	159	24	25	*Pecten albicans* (32.1%)	*Glycymeris rotunda, Pitar noguchii, Macoma incongrua*	PPA	Associated littoral species: *Arca boucardi*
0602	86	619	16	16	*Glycymeris rotunda* (38.9%), *Ventricoloidea foveolata* (28.9%)	*Pecten albicans, Phacosoma japonicum*	GVCA	
0607	113	143	22	23	*Cryptopecten vesiculosus* (23.1%), *Pitar noguchii* (15.4%), *Pecten albicans* (13.3%)	*Ostrea* sp., *Nemocardium samarangae*	PPA	
0702	68	692	36	36	*Pecten albicans* (43.9%)	*Acila milabilis, Siphonalia fusoides*	PASA	Associated littoral species: *Arca boucardi, Scapharca broughtonii*
0703	95	708	32	34	*Cyclocardia* sp. (20%), *Glycymeris rotunda* (16%), *Paphia amabilis* (12%)		GPPA	Associated littoral species: *Trapezium liratum*
0704	194	1808	24	24	*Nuculana pernula pernuloides* (37%), *Crenulilimopsis oblonga* (25%)	*Limopsis tajimae tajimae, Nemocardium samarangae*	NCA	Associated littoral species: *Arca boucardi, Scapharca broughtonii, Callithaca adamsi, Trapezium liratum, Macoma calcrea, Mya truncata*
0706	103	624	20	21	*Ventricoloidea foveolata* (30%), *Glycymeris rotunda* (29%), *Cryptopecten alli* (17%)	*Pecten albicans, Ostrea* sp.	GVCA	Associated littoral species: *Arca boucardi, Trapezium liratum*
0707	121	723	25	26	*Glycymeris rotunda* (48%), *Ventricoloidea foveolota* (21%)	*Lucinoma annulata, Crytopecten alli*	GVCA	
0708	121	3				*Glycymeris rotunda, Anomia* sp., *Fissidentalium* sp.		
0804	102	47	9	9	*Ostrea* sp. (44%), *Limopsis tajimae* (34%)		OLA	
0806	124	239	18	18	*Glycymeris rotunda* (60.3%)	*Ventricoloidea foveolata* (15.1%)	GCA	Associated late Pliocene species: *Mizuhopecten tokyoensis hokurikuensis*
0807	127	446	20	21	*Glycymeris rotunda* (67.5%)	*Ventricoloidea foveolata* (35.7%)	GVCA	Associated late Pliocene species: *Mizuhopecten yessoensis*
0808	120	1792	39	43	*Glycymeris rotunda* (57.81%)	*Ventricoloidea foveolata* (12.11%)	GVPA	
0909	131	380	34	35	*Glycymeris rotunda* (42.9%)	*Plicatula muricata, Cryptopecten vesiculosus*	GCA	
1013	139	79	7	7	*Dentalium octangulatum* (78.5%)		DA	
1015	171	7	3	3		*Acila divaricata*		
1108	####	56	1	1	*Buccium tsubai* (100%)		BA	

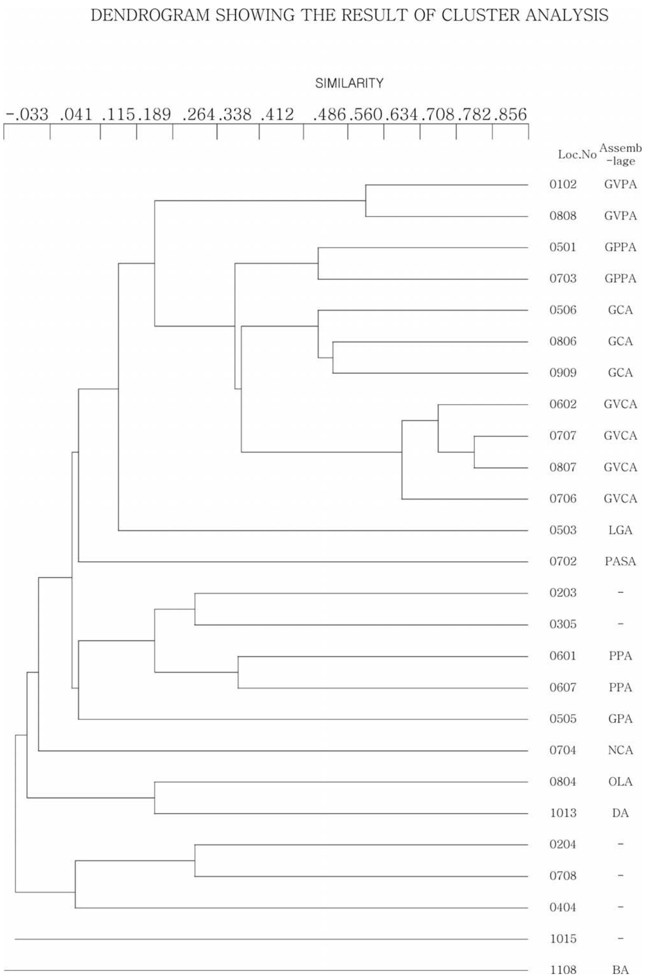

Figure 3. Dendrogram resulting from cluster analysis on the basis of the Bray–Curtis similarity index (SI) between each sampling locality of the southeastern continental shelf of Korea. The most similar species composition occurred between loc. nos. 0707 and 0807 (SI 0.8235). Eleven localities from loc. nos. 0102 to 0706 had SIs of 0.2451; the other localities were categorized into smaller groups. GVPA, *Glycymeris–Ventricoloidea–Phacosoma* assemblage; GPPA, *Glycymeris–Paphia–Pitar* assemblage; GCA, *Glycymeris–Cryptopecten* assemblage; GVCA, *Glycymeris–Ventricoloidea–Cryptopecten* assemblage; LGA, *Lucinoma–Glycymeris* assemblage; PASA, *Pecten–Acila–Siphonalia* assemblage; PPA, *Pecten–Pitar* assemblage; GPA, *Glycymeris* assemblage; NCA, *Nuculana–Crenulilimopsis* assemblage; OLA, *Ostrea–Limopsis* assemblage; DA, *Dentalium* assemblage; BA, *Buccium* assemblage.

(Figure 4). The results showed variations in age related to each locality, depth, and species. Dates were from 15,694 ± 328 YBP (loc. no. 0704, *Macoma calcarea*) to recent (loc. no. 0909, *Glycymeris rotunda*).

Southwestern Sea Area

Radiocarbon dates were determined on *A. boucardi* from five localities ranging from 21 m to 29 m below sea level, and ranging in age from 3635 ± 60 YBP to 742 ± 57 YBP.

The radiocarbon dates of 47 individuals from the above two sea areas are illustrated in Figure 4. The oldest date of

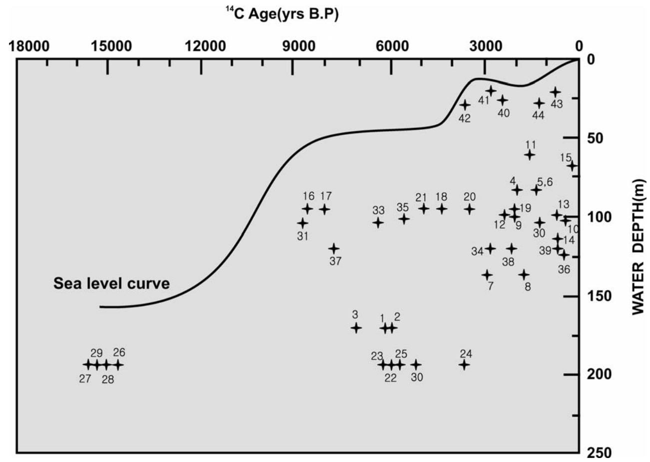

Figure 4. Regional sea-level curve for the South Sea in Korea. Numbered crosses show the radiocarbon ages, depths of localities numbered, and species names as in Table 3. The sea-level position was inferred from the depth ranges of the samples, considering the tidal range (*ca.* 2 m) in this area.

15,694 ± 328 YBP came from *Macoma calcrea,* which was recovered from a depth of 194 m (loc. no. 0704). Loc. no. 0704 also produced *Scapharca broughtonii* (14,616 ± 364 YBP), *Callithaca adamsi* (15,072 ± 291 YBP), and *Mya truncate* (15,412 ± 338 YBP), which are shallow sea species. *Scapharca broughtonii* inhabits depths between 10 m and 50 m, *Macoma calcrea* the littoral zone, and *Callithaca adamsi* and *Mya truncata* inhabit the surface from the littoral zone to depths of 20 m. The maximum depth for these species is 20–50 m. Loc. no. 0704 occurred at a depth of 194 m, which is about 159 m below the average habitat depth of 35 m. This discrepancy indicates that about 15,000 years ago, the depth of the South Sea shelf was approximately 150–160 m below present sea level.

Megacardita corensis (8028 ± 69 YBP) and *Cyclocardia* sp. (8643 ± 72 YBP) inhabited depths of 20–50 m, and *Cryptopecten vesiculosus (*8779 ± 63 YBP) occurred at a depth of 50 m. Since these species commonly occur about 50 m below sea level, the depth of water 8000–9000 years ago was approximately 50–60 m. Shells of *A. boucardi* were recovered from a depth of 20–29 m below sea level, with dates between 742 ± 57 YBP and 3635 ± 60 YBP. The habitat for this species is generally between the littoral zone and about 10 m in depth, suggesting that the depth of water around 3000 years ago was approximately 10–20 m.

To summarize the sea level changes on the South Sea coast between 15,000 years ago and the present, the sea level of the South Sea area fell by about 150–160 m below the present sea level during LGM, subsequently rapidly rose to about 60 m below present sea level about 9000 years ago, remained at 50–60 m below present sea level until 4000–5000 years ago, and rose to 10–20 m below present level about 3000–4000 years ago.

Table 2. *Comparative table of associated species composition among molluscans.*

Assemblage	Species	Loc. No.				Sum	%	Avg.
		0102		0808				
GVPA	*Glycymeris rotunda*	1772		1036		2808	59.07	1404
	Ventricoloidea foveolata	351		217		568	11.95	284
	Phacosoma japonicum	412		27		439	9.23	220
	Cryptopecten vesiculosus	13		227		240	5.05	120
		0501		0703				
GPPA	*Glycymeris rotunda*	140		116		220	15.91	110
	C. sp.			143		143	10.34	143
	Paphia amabilis	49		88		137	9.91	69
	Pitar (Pitarina) naguchii	92		37		129	9.33	65
	Nemocardium samarangae	69		35		104	7.52	52
	Cryptopecten vesiculosus	49		44		93	6.72	47
	Pecten (Notovola) albicans	56		16		72	5.21	36
		0506	0806	0909				
GCA	*Clycymeris rotunda*	96	144	163		403	50.44	134
	Gryptopecten vesiculosus	23	6	47		76	9.51	25
		0602	0706	0707	0807			
GVCA	*Glycymeris rotunda*	241	184	346	301	1072	42.74	268
	Ventricoloidea foveolata	179	186	154	159	678	27.03	170
	Cryptopecten vesiculosus	9	125	39	6	179	7.14	45
	Phacosoma japonicum	85	7	36	32	160	6.38	40

DISCUSSION

Surface sediment of the South Sea shelf of the Korean peninsula is a mixture of recent fine-grained muddy sediments and coarse-grained relict and palimpsest sediments with shell material. *Mizuhopecten yessoensis* and *M. tokyoensis hokurikuensis* retrieved from locality nos. 0806 and 0807 were fossil species known to occur during the late Pliocene–Pleistocene. Late Pleistocene fossils such as *Amussiopecten praesignis* and *M. tokyoensis hokurikuensis* were reported in water depths of 100~150 m southwest of Yamaguchi Prefecture, Japan (Okamoto and Honza, 1978; Okamoto and Ibaraki, 1988). Moreover, *M. tokyoensis hokurikuensis* and *Turritella saishuensis* were reported from depths of 150 m northeast of Busan and around Geoje Island in Korea (Lee, 1997b, 1998). These fossil species are representative component species of the Seogwipo fauna from the late Pliocene Seogwipo Formation in Jeju, Korea (Yoon, 1988). They are also known as principal component species of the Omma-Manganji and Kakegawa fauna in Japan. In our study area, *M. tokyoensis hokurikuensis* and *M. yessoensis* occurred at locality nos. 0806 and 0807. These species appeared north of Tsushima between the Korean peninsula and Japan, making a distributional band in the direction from the southwest to the northeast. The limited and directional distribution toward the northeast correlates with the tectonic movement of the southeastern continental shelf where the northeastern tectonic lines develop.

Fossil species on the South Sea shelf of the Korean peninsula have habitat requirements that may suggest a history of sea level rise in this area. The late Pliocene sedimentary strata comprising shell layers during LGM are exposed on the submarine surface of the continental shelf.

Twelve shell assemblages including GVPA were discriminated from the southeastern continental shelf. Among the assemblages, GVPA, GPPA, GCA, and GVCA appearing in the 11 localities with *Glycymeris rotunda* were the main species categorized (Table 2). These assemblages were distributed along the southeastern continental shelf. Radiocarbon data indicated that *Glycymeris rotunda* had a temporal range from 6461 ± 135 YBP to modern times. The assemblages appeared as *Glycymeris* fauna inhabiting a confined region during the particular period. The main species of *Glycymeris* fauna was *Glycymeris rotunda* with *Cryptopecten vesiculosus, Nemocardium samarangae, Pitar noguchii, Phacosoma japonicum, Ventricoloidea foveolata,* and *Paphia amabilis* as accompanying species. These are typical fauna after the last glacial period created about 6000 years ago in the area around the southeastern continental shelf and have been preserved to the present. According to Katsura and Nagano (1982), there was a channel-like seaway linking the western North Pacific and the East Sea at the west of Tsushima when the sea level was 130 m below present, at the last glacial period. The peripheral zone of the channel-like seaway was affected first by the rising sea. At the same time, the southern sea area (loc. nos. 0102 and 0706) became a good habitat for *Glycymeris* fauna along with the rising sea level. In the southwestern sea area, *A. boucardi* of the *Arca* fauna inhabited depths between the rocky littoral zone and about 10 m below sea level about 3000 years ago.

Determination of the depression depth of the sea level lowstand at the South Sea shelf during LMG is an important step to developing an understanding of the paleoenvironment, especially the land bridge between the Korean peninsula and Japan, the flow of paleo-Tsushima Current, and the desalination of the East Sea. Feng (1983); Park *et al.* (2000), and Suk (1989) investigated the sea-level change of the

Table 3. *Radiocarbon data from the southwestern and southeastern continental shelf. Ages were determined by LSC and AMS.*

Area	Occurrence Locality			Species Name	Pr.	Habitat		Conventional Age (YBP)	Method	Ref. No.
	No.	W.D. (m)	S.F.			Type	Substrate, W.D. (m)			
SCS	102	170	zS	*Glycymeris rotunda*	f.	inf.	M. 60–300	6161 ± 131	LSC	1
				Phacosoma japonicum	f.	inf.	S, ⟨50	5946 ± 131	LSC	2
				Ventricoloidea foveolata	f.	inf.	sM. 50–200	7127 ± 141	LSC.	3
	0501	84	(g)mS	*Glycymeris rotunda*	f.	inf.	M. 60–300	1974 ± 103	LSC	4
				Pitar noguchii	f.	inf.	S, 10–100	1353 ± 40	AMS	5
				Nemocardium samarangae	f.	inf.	sM, 50–200	1353 ± 40	AMS	6
	0503	136	(g)mS	*Lucinoma acutilineata*	f.∼sl.	inf.	M, 100–700	2911 ± 41	LSC	7
				Glycymeris rotunda	f.	inf.	M. 60–300	1757 ± 101	LSC	8
	0505	104	(g)mS	*Glycymeris pilsbry*	f.	inf.	M. 60–300	2066 ± 44	AMS	9
	0506	103	gmS	*Glycymeris cf. rotunda*	f.	inf.	M. 60–300	472 ± 42	LSC	10
	0601	62	sC	*Pecten albicans*	f.	inf.	sM. ⟨30	1581 ± 101	LSC	11
	0602	86	(g)mS	*Glycymeris rotunda*	f.	inf.	M. 60–300	2389 ± 105	LSC	12
				Ventricoloidea foveolata	f.	inf.	sM. 50–200	712 ± 96	LSC	13
	0607	113	zS	*Cryptopecten vesiculosus*	f.	epi.	sG. 50–300	644 ± 44	AMS	14
	0702	68	mS	*Pecten albicans*	f.	inf.	sm. ⟨30	210 ± 100	LSC	15
	0703	95	(g)mS	*Cyclocardia* sp.				8643 ± 72	AMS	16
				Megacardita corensis	sl.	inf.	S. ⟨50	8029 ± 69	AMS	17
				Phaphia amabilis	f.	inf.	S. ⟨50	4395 ± 126	LSC	18
				Ventricoloidea foveolata	f.	inf.	sM. 50–200	2053 ± 110	LSC	19
				Ostrea sp.	sl.	epi.		3490 ± 125	LSC	20
				Glycymeris rotunda	f.	inf.	M. 60–300	4921 ± 166	LSC	21
	0704	194	(g)sM	*Trapezium bicarinatum*	sl.	epi.	Rb.	5999 ± 61	AMS	22
				Limopsis tajimae tajimae	sl.	inf.	M. 100–700	6245 ± 63	AMS	23
				Crenulilimopsis oblonga	f.	inf.	S. 20–2000	3655 ± 60	AMS	24
				Arca boucardi	sl.	epi.	Rb.	5725 ± 65	AMS	25
				Scapharca broughtonii	sl.	inf.	mS. ⟨50	14,616 ± 364	LSC	26
				Macoma calcarea	sl.	inf.	mS. ⟨20	15,694 ± 328	LSC	27
				Callithaca adamsi	sl.	inf.	S. ⟨20	15,072 ± 291	LSC	28
				Mya truncata	sl.	inf.	M. ⟨30	15,412 ± 338	LSC	29
				Lucinoma annulata	sl.	inf.	M. 10–50	5219 ± 132	LSC	30
	0706	103	sZ	*Cryptopecten vesiculosus*	f.	epi.	sG. 50–300	8779 ± 63	AMS	31
				Ventricoloidea foveolata	f.	inf.	sM. 50–200	1258 ± 118	LSC	32
				Glycymeris rotunda	f.	inf.	M. 60–300	6461 ± 135	LSC	33
	0707	119	zS	*Glycymeris rotunda*	f.	inf.	M. 60–300	2827 ± 140	LSC	34
	0804	102	gmS	*Limopsis tajimae tajimae*	f.	inf.	M. 100–700	5592 ± 64	AMS	35
	0806	124	zS	*Glycymeris rotunda*	f.	inf.	M. 60–300	489 ± 101	LSC	36
	0807	127	mS	*Glycymeris rotunda*	f.	inf.	M. 60–300	Modern	LSC	
	0808	120	mS	*Trapezium bicarinatum*	sl.	epi.	Rb.	7851 ± 61	AMS	37
				Cryptopecten vesiculosus	f.	epi.	sG. 50–300	2194 ± 57	AMS	38
				Glycymeris rotunda	f.	inf.	M. 60–300	676 ± 97	LSC	39
	0909	131	S	*Glycymeris rotunda*	f.	inf.	M. 60–300	Modern	AMS	
	1108	1,130	C	*Buccium tsubai*	f.	inf.		564 ± 57	AMS	
WCS	2	26	(g)S	*Arca boucardi*	f.	Epi	G. Rb. <20m	2430 ± 66	AMS	40
	10	20	(g)S	*Arca boucardi*	f.	Epi	G. Rb. <20m	2818 ± 60	AMS	41
	95	29	G	*Arca boucardi*	f.∼sl.	Epi	G. Rb. <20m	3635 ± 60	AMS	42
	110	21	(g)S	*Arca boucardi*	f.	Epi	G. Rb. <20m	742 ± 57	AMS	43
	159	28	G	*Arca boucardi*	f.∼sl.	Epi	G. Rb. <20m	1187 ± 61	AMS	44

South Sea area after the last glacial period. Results of these investigations have revealed discrepancies in depression depths of the last glacially induced lowstand about 15,000 years ago (Figure 5). FENG (1983) considered the sea-level depression during LMG to be about 160 m below the present sea level, compared with 130 m according to SUK (1989) and PARK *et al.* (2000). In addition, PARK *et al.* (2000) insisted on the formation of a channel to the west of Tsushima during LGM and the inflow of the paleo-Tsushima Current to the East Sea, whereas KIM *et al.* (2000), on the other hand, asserted the desalination of the East Sea on the basis of the results of oxygen and carbon isotope analyses from Ulleung Basin cores.

The East Sea is a back-arc basin with an average depth of 1680 m and a semi-isolated marginal sea connected with the Okhotsk Sea, East China Sea, and North Pacific by shallow straits (Korea Strait, 130 m; Tsugaru Strait, 130 m; Soya Strait, 55 m; Tatarskiy Strait, 15 m). The Tsushima Current flows into the East Sea through the Korea Strait and flows out mainly through the Tsugaru and Soya straits.

Significantly lower sea levels during the last glacial epoch formed a land bridge between Korea and Japan with Tsushima in the middle. However, opinions disagree over this issue, as with the inflow of the paleo-Tsushima Current to the East Sea (GORBARENKO, 1983). SUK (1989) harvested 24 shell remains and PARK *et al.* (2000) harvested 17 drill sam-

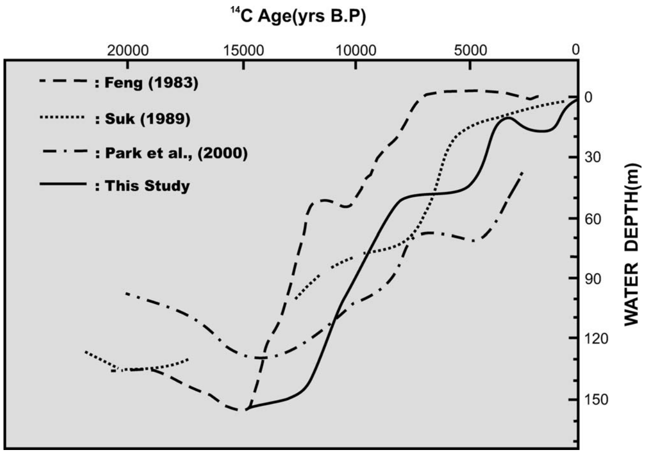

Figure 5. Comparison of sea-level curve for the South Sea in Korea.

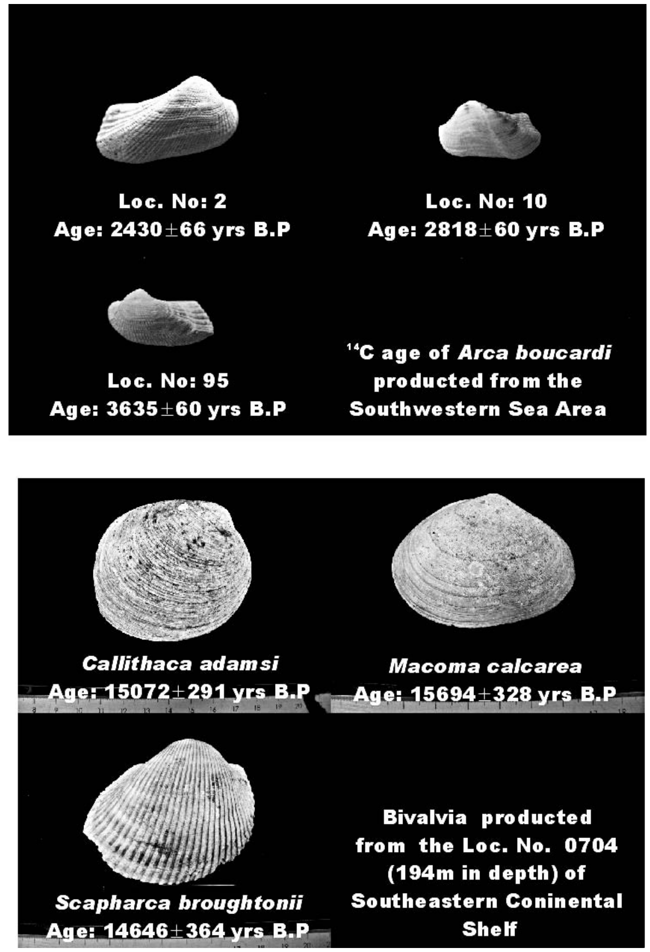

Figure 6. Photograph of preservation state of molluscan shell in southwestern and southeastern continental shelves of Korea.

ples for age determination by AMS. Feng (1983) also utilized shell remains, but did not discuss issues of time-averaging and autochthonous formation. There is partial disparity in the classification of shells and depth-related habitats. These factors can cause different interpretations of the radiocarbon age data about shells.

In this study, the sea level of the South Sea area was determined from radiocarbon data of the littoral species (*Scapharca broughtonii, Macoma calcarea, Callithaca adamsi,* and *Mya truncate*: loc. no. 0704). This suggests that sea level fell by about 150–160 m below present sea level during the LGM.

These specimens had large valves and were well preserved, in the exterior margin (Figure 6). In the marine environment, prolonged posthumous exposure on submarine surfaces degrades the shell material through the serial process of reorientation and transportation, disarticulation, fragmentation, and corrosion. Characteristic aspects of the sequential process are revealed in the pattern of hard part degradation (Brett and Baird, 1986; Martin, 1999). Shells experience separation of attached valves within several weeks after death (Schafer, 1972). Corrosion primarily occurs in the high-energy environment, with coarse, poorly sorted deposits (Driscoll and Weltin, 1973). Littoral zone species like *Scapharca broughtonii* (which was produced in the present research area) are parautochthonous and are more affected by corrosion by refloating or reworking of the seawater flow, rather than transportational fragmentation. These parautochthonous materials were considered to have formed in the littoral zone–shallow sea environments. Seismic investigation at loc. no. 0704 indicated a former beach environment (Park *et al.,* 2000), and this result was consistent with the present research results.

Radiocarbon data (Table 3) illustrated a variety of ^{14}C radiocarbon dates among the species within the same locality (loc. nos. 0703 or 0704). At loc. no. 0704, for example, *Crenulilimopsis oblonga* was dated at 3655 ± 60 YBP, whereas *Macoma calcarea* had an age of 15,694 ± 328 YBP, giving an age difference between the two species of about 11,939 years. At loc. no. 0703, *Ventricoloidea foveolata* had an age of 2053 ± 110 YBP and *Cyclocardia* sp. was dated at 8643 ± 72 YBP, yielding a difference of about 6590 years. At loc. no. 0706, *Ventricoloidea foveolata* was dated at 1258 ± 118 YBP and *Cryptopecten vesiculosus* at 8779 ± 63 YBP, yielding a difference of about 7521 years. At loc. no. 0808, *Glycymeris rotunda* yielded a date of 676 ± 97 YBP and *Trapezium bicarinatum* had a date of 7851 ± 61 YBP, producing a difference of about 7175 years. Thus, the age differences between the species sampled from the same locality ranged from 6590 years to 11,939 years.

According to Walker and Bambach (1971), “time-averaging” is defined as “accumulate from the local community during the time required to deposit the containing sediment.” It is interpreted broadly to mean not only the age differences but also ecological combination of unique species or accumulation of their remains. Fujiwara and Kamataki (2003) explained that the mixture of fossil species having different ages in one stratum is an example of the phenomenon of time averaging. This phenomenon appears in shell samples of ages ranging from several decades to more than 3500 years in the littoral zone (Flessa, Meldahl, and Cutler, 1990) and from several hundred years to about 1500 years in cheniers of the Yellow River delta, China (Saito *et al.,* 1999). The phenomenon inhibits the accurate judgment of sedimentation time because shells are occasionally delivered (or remain) to an area after death and are subsequently found as buried fossils in different environments from their native habitat. This can occur when shells are buried after death but exhumed by erosion and later transported to a new site. Radiocarbon age differences in species produced at the same locality and the ecological blending of the littoral zone species in the present research are considered to reflect the phenomenon of time averaging. However, instead of using an "average time" to describe the surface of the continental shelf, we sorted the shells into depth-sensitive habitats and have found that shells with similar depth constraints had similar dates. This allowed us to reconstruct water-depth estimates on the shelf at different periods of time between 15,000 years ago and the present.

CONCLUSIONS

Our coupled age and habitat data indicated that the sea level of the South Sea area was about 150–160 m below present sea level about 15,000 years ago. This drop allowed a land bridge to form between the Korea peninsula and Japan, which remained above sea level for about 6000 years. The sea level rose to approximately 60 m (below present sea level) about 9000 years ago, remained at this depth until about 4000–5000 years ago, and then rose to 10–20 m below the present level about 3000–4000 years ago.

Glycymeris fauna were created in the sea area of the southeastern continental shelf about 6000 years ago, while *Arca* fauna prospered in the southwestern sea area about 2000–3000 years ago when the sea level was 10–20 m below present sea level.

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LITERATURE CITED

Brett, C.E. and Baird, G.C., 1986. Comparative taphonomy: a key to paleoenvironmental interpretation based on preservation. *Palaios,* 1(3), 207–227.

Choi, J.Y. and Park, Y.A., 1993. Distribution and textural characters of the bottom sediments on the continental shelves, Korea. *The Journal of the Oceanological Society of Korea,* 28(4), 259–271.

Chough, S.K., 1983. *Marine Geology of Korean Seas.* Boston, Massachusetts: International Human Resources Development Corporation, 157p.

Driscoll, E.G. and Weltin, T.P., 1973. Sedimentary parameters as factors in abrasive shell reduction. *Paleogeography Paleoclimatology Paleoecology,* 13, 275–288.

Emery, K.O., 1952. Continental shelf sediments off southern California. *Geological Society of America Bulletin,* 63, 1105–1108.

Feng, Y., 1983. Since 40 Ka sea-level change and lowest sea level. *East China Sea* 1, 36–42.

Flessa, K.W.; Meldahl, K.H., and Cutler, A.H., 1990. Quantitative estimates of stratigraphic disorder and time-averaging in a shallow marine habit. *Geological Society of America.* Abstracts with Programs, 22, A83.

Folk, R.L., 1968. *Petrology of Sedimentary Rocks*. Austin, Texas: Hemphill's, 170 p.

Fujiwara, O. and Kamataki, T., 2003. Significance of sedimentological time-averaging for estimation of depositional age by 14C dating on molluscan shells. *The Quaternary Research,* 42(1), 41–48.

Gakken, 1975. *Illustrated Nature Encyclopedia the Mollusks of Japan.* Tokyo: Gakken Co., 294p [In Japanese].

Gorbarenko, S.A., 1983. Paleogeographic conditions in the central part of the of Japan during Holocene and late Pleistocene time on the basis of $^{18}O/^{16}O$ ratios in foraminiferal tests. *Oceanology,* 23, 224–227.

Habe, T., 1977. *Systematics of Mollusca in Japan. Bivalvia and Scaphopoda.* Tokyo: Hokuryukan, 372p, 72 pls [In Japanese].

Habe, T. and Kosuge, S., 1967. *Standard coloured illustrations 3. Shells.* Tokyo: Hoikusha, 223p, 64pls [In Japanese].

Habe, T. and Kosuge, S., 1970. The ^{14}C age estimation of shell fossils taken from the Tsushima trough and its geological significance. *Memoirs of the National Science Museum, Tokyo,* 3, 75–82 [In Japanese with English summary].

Katsura, T. and Nagano, M., 1976. Geomorphology and tectonics movement of the sea floor, Northwest off Kyushu, Japan. *The Journal of the Oceanographical Society of Japan,* 32(3), 139–150.

Katsura, T. and Nagano, M., 1982. Geomorphology of Goto shelf channels off northern Kyushu, Japan. *Report of Hydrographic Researches,* 17, 71–92.

Kim, J.M.; Kennett, J.P.; Park, B.K.; Kim, D.C.; Kim, Y.K., and Roark, E.B., 2000. Paleoceanographic change during the last deglaciation, East Sea of Korea. *Paleoceanography,* 15(2), 254–266.

Lee, Y.G., 1997a. Characteristic of molluscan thanatocoenoses distributed around Hwawon Peninsula in Southwestern Coast, Korea. *Journal of the Paleontological Society of Korea,* 13(1), 1–20.

Lee, Y.G., 1997b. The Quaternary paleoenvironment and molluscan thanatocoenoses characteristics in the continental shelf off Ulsan, southeastern Korea. *Journal of the Paleontological Society of Korea,* 13(2), 103–118.

Lee, Y.G., 1998. The late Quaternary paleoenvironment and tidal flat shell thanatocoenoses in the continental shelf off Geoje-Pusan, southern Korea. *Journal of the Paleontological Society of Korea,* 14(2), 165–178.

Martin, R.E., 1999. *Taphonomy: A Processes Approach.* Cambridge, U.K.: Press Syndicate of the University of Cambridge, 508p.

Min Shell House, 2001. *Korean Mollusks with Color Illustration.* Busan: Hanguel Co., 332p [In Korean].

Ministry of Science and Technology, 1993. *A Study on the Atlas of Marine Resources in the Adjacent Seas to Korea—Korea Strait (Second Year).* 392p.

Ministry of Science and Technology, 1994. *A Study on the Atlas of Marine Resources in the Adjacent Seas to Korea—Korea Strait (Third Year),* 715p.

Office of Hydrographic Affairs, 1996. *Tidal Current Charts (Mokp'o Hang and Approaches).* Republic of Korea, Pub. 630, 1–22.

Okamoto, K. and Honza, E., 1978. The "Pliocene" fossil molluscan assemblage including Ammussiopecten by GH77-2 cruise in the southwestern Japan Sea. *The Journal Geological Society of Japan,* 84(10), 625–628 [In Japanese].

Okamoto, K. and Ibaraki, M., 1988. Early Pleistocene mollusca from the southwestern area of the sea of Japan (or the northeastern Tsushima Strait). *Journal of the Paleontological Society of Korea,* 4, 30–36.

Park, S.C.; Yoo, D.G.; Lee, K.W., and Lee, H.H., 1999. Accumulation of recent muds associated with coastal circulations, southeastern Korean sea (Korea Strait). *Continental Shelf Research,* 19, 589–608.

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

Pinet, P.R., 2000. *Invitation to Oceanography.* Sudbury, Massachusetts: Jones and Bartlett Publishers, 555p.

Saito, Y.; Wei, H.; Zhou, Y.; Nishimura, A.; Sato, Y., and Yokota, S., 1999. Natural and anthropogenic changes of the Huanghe (Yellow River) delta, China. *In*: Saito, Y.; Ikehara, K., and Katayama, H. (eds.), *Land–Sea Link in Asia: "Prof. Kenneth O. Emery Commemorative International Workshop."* Proceedings of an International Workshop on Sediment Transport and Storage in Coastal Sea–Ocean System. Science Technology Agency of Japan and Geological Survey of Japan, pp. 33–38.

Schafer, W., 1972. *Ecology and Paleoecology of Marine Environments.* Oertel, I., trans., Craig, G.Y., ed. Chicago: University of Chicago Press, 568p.

Suk, B.C., 1989. Sedimentology and history of sea level changes in the East China Sea and adjacent seas. *In*: Taira, A. and Masuda, F. (eds.), *Sedimentary Facies in the Active Plate Margins.* Tokyo: Terra Scientific Publishing Company, pp. 215–221.

Swift, D.J.P.; Stanley, D.J., and Curray, J.R., 1971. Relict sediments on continental shelves: a reconsideration. *Journal of Geology,* 79, 322–346.

Ujiie, H., 1973. Sedimentation of planktonic foraminiferal shells in the Tsushima and Korea Straits between Japan and Korea. *Micropaleontology,* 19(4), 444–460.

Walker, K.R. and Bambach, R.K., 1971. The significance of fossil assemblages from fine-grained sediments: time-averaged communities. *Geological Society of America,* Abstracts with Programs, 3, 783–784.

Yoon, S., 1988. The Seoguipo Molluscan Fauna of Jeju Island, Korea. *Saito Ho-on Kai Special Publication* (Prof. T. Kotaka Commem. Vol.), 539–545.

Yoon, S.; Park, Y.A.; Choi, J.Y., and Kim, Y.D., 1994. Study of the surface sediments, shell assemblages and sedimentary environments of southeastern continental shelf of the Korean Peninsula. *Journal of the Paleontological Society of Korea,* 10(1), 154–169.

Appendix 1. *Sediment composition of the surface sediment (26 sample correction localities) of the southeastern continental shelf of Korea. S, sand; (g)S, slightly gravelly sand; gmS, gravelly muddy sand; (g)mS, slightly gravelly muddy sand; mS, muddy sand; zS, silty sand; (g)sM, slightly gravelly sandy mud; sZ, sandy silt; sC, sandy clay; C, clay.*

		Composition (%)						Locality	
Locality No.	Depth (m)	Gravel	Sand	Silt	Clay	Facies (by Folk, 1968)	Mz (ø)	Latitude (N)	Longitude (E)
0102	170	—	73.9	18.87	7.23	zS	3.69	33°15′00″	128°45′00″
0203	120	5.74	83.41	10.36	0.49	gmS	1.85	33°30′00″	129°00′00″
0204	98	0.87	92.2	6.24	0.69	(g)S	2.76	33°30′00″	129°15′00″
0305	90	0.36	93.82	4.85	0.97	(g)S	1.99	33°45′00″	129°30′00″
0404	100	4.00	88.24	5.94	1.82	(g)S	1.86	34°00′00″	129°15′00″
0501	84	1.43	72.06	10.1	16.41	(g)mS	2.95	34°15′00″	128°30′00″
0503	136	0.18	78.38	8.3	13.15	(g)mS	3.46	34°15′00″	129°00′00″
0505	104	1.43	72.91	18.74	6.91	(g)mS	3.08	34°15′00″	129°30′00″
0506	103	7.21	79.24	10.92	2.63	gmS	1.88	34°15′00″	129°45′00″
0601	62	—	15.73	27.68	56.59	sC	8.00	34°30′00″	128°30′00″
0602	86	0.49	59.28	13.69	26.54	(g)mS	4.46	34°30′00″	128°45′00″
0607	113	—	70.63	20.1	9.27	zS	3.73	34°30′00″	130°00′00″
0702	68	—	62.56	14.6	22.83	mS	4.85	34°45′00″	128°45′00″
0703	95	0.89	61.36	33.83	3.92	(g)mS	3.92	34°45′00″	129°00′00″
0704	194	0.23	33.69	36.75	29.33	(g)sM	6.10	34°45′00″	129°15′00″
0706	103	—	39.65	40.65	19.7	sZ	5.59	34°45′00″	129°45′00″
0707	119	—	54.93	30.92	14.15	zS	4.95	34°45′00″	130°00′00″
0708	121	—	76.6	14.96	8.44	mS	4.02	34°45′00″	130°15′00″
0804	102	12.28	73.03	6.73	7.96	gmS	1.94	35°00′00″	129°15′00″
0806	124	—	61.05	26.6	12.35	zS	4.47	35°00′00″	129°45′00″
0807	127	—	71.89	17.83	10.29	mS	4.02	35°00′00″	130°00′00″
0808	120	—	70.98	16.85	12.17	mS	4.04	35°00′00″	130°15′00″
0909	131	—	95.04	1097	2.98	S	2.95	35°15′00″	130°30′00″
1013	139	—	66.06	23.01	10.93	zS	4.66	35°30′00″	131°30′00″
1015	171	—	60.39	21.73	17.88	mS	5.06	35°30′00″	132°00′00″
1108	1130	—	0.36	13.08	86.56	C	9.52	35°45′00″	130°15′00″

Appendix 2. *Molluscan species list produced from the surface sediment of the southeastern continental shelf of Korea.*

Species	Loc. No.																									
	0102	0203	0204	0305	0404	0501	0503	0505	0506	0601	0602	0607	0702	0703	0704	0706	0707	0708	0804	0806	0807	0808	0909	1013	1015	1108
Lamellinucula tokyoensis													1	7												
Acila mirabilis													70				10									
A. insignis	9															2						2				
A. divaricata							3																			
Nuculana yokoyamai		1				1								1										1		
N. pernula pernuloides													3	3	676											
Yoldia cf. notabilis yokoyama																	19									
Y. johanni																					2					
Saccella confusa	1																2									
S. cf. gordonis		1				2																				
Arca plicatum						3			3														1			
A. boucardi						5				3			1		11	3						1				
Samacar strabo pacifica									7														1			
Hawaiarca uwaensis									1														1			
Nipponarca bistrigata													9	8												
Barbatia sp.													13										2			
Porterius dalli														4						1						
Scapharca broughtonii	1												5		9											
Glycymeris rotunda	1772	13	1			104	67		96	14	241	5	12	116		184	346	1	1	144	301	1036	163			
G. pilsbryi								65																		
G. sp.					14																					
Crenulilimopsis oblonga		3		3		19							14		459											
Entalinopsis intercostatus		1																								
Limopsis tajimae tajimae													1		176				16	1				9		
L. cumingii						9			1	1																
Modiolus sp.								1							11								1			
Plicata muricata																							36			
Polynemamussium alaskense															53								2			
Chlamys jousseaumei	3			1		3			8	1		4			36	18	4				1	4	6	1		
C. farreri farreri													13				1									
C. sp.																				1						
Cryptopecten vesiculosus	13	1		1		49		7	23	1	9	33	9	44		125	39			6	6	227	47			
Pecten (Notovola) albicans	17	1	1	5	1	56	4	1		51	56	19	304	16		28	13			5	4	34	5			
Patinopecten sp.															2											
Mizuhopecten yessoensis																					1					
M. tokyoensis hokurikuensis																				1			1			
Sponylus sp.									2																	
Plicatula muricata									5																	
Lima fujatai						5																		9		
L. zushiensis												2														
L. sp.				1				1																		
Limaria hakodatensis						2																				
L. sp.												2														
Limatula japonica												1											1			
Anomia sp.													2	2			4	1								
A. chinensis															20											
Monia sp.																						1				
Ostrea sp.									3	2		10		41	3	21	14		20	1	3	47				
Crassostrea sp.																							11			
Tridonta bennetti																						2				

Appendix 2. *Continued.*

Species	Loc. No.																									
	0102	0203	0204	0305	0404	0501	0503	0505	0506	0601	0602	0607	0702	0703	0704	0706	0707	0708	0804	0806	0807	0808	0909	1013	1015	1108
Indocrassatella oblongata														12												
Crassatellites cf. nanus						8					7		2		59	1										
Nipponocrassatella cf. nana																						9				
Cardita leana						3								28												
Megacardita coreensis	18					52		5		2	3	3	16	13					1	1		12	12			
M. ferruginosa						57			1	5						14										
Trapezium bicarinatum														4	68	1						3				
Felaniella usta		1														1						7	1			
Glans sp.								1	9												7					
Cyclocardia ferruginea	4					2			2	5								1		1		10				
C. sp.													21	143	4	4										
Meiocardia tetragona	5					5			3		1	5		12		3	3					2				
Thyasira tokunagai													4													
Anodontia stearnsiana										4																
Lucinoma acutilineata	6						102						13		59											
L. annulata	150	4	1											1			29				6	12				
Nemocardium samarangae	57	1				69	22	1	3		2	7		35	92	4	8		5	2	1	25		3		
Clinocardium buellowi	16	1																								
C. sp.						9	1			3	1		43						1			1				
Frigidocardium torresi								1	3			6														
Mactrinula dolabrata	8																									
Pitar (Pitarina) noguchii	11			1		92		7	15	12	9	22	2	37		13	12			1	1	35				
Cyclosunetta sp.																							13			
Callithaca (Potocallithaca) adamsi															24											
Phacosoma japonicum	412	3		2		5	7	2	1	2	85	1		3		7	36			27	32	27	5			
Ventricoloidea foveolata	351	5				23				5	179	6		23		186	154			36	159	217				
Paphia amabilis	78	3		7		49	1		1	5	16	8		88		5	13		1	5	9	32	4			
P. sp.													3													
Lutraria maxima																	1									
L. sieboldii																						4				
L. sp.				1								1														
Solecurtus divaricatus														3			1					1				
S. d. dunkeri																						4				
Moerella iridescens																				1	5	12				
Angulus vestalioides	2					2																				
Macoma calcrea															6											
M. cf. sectior													12				6									
M. tokyoensis	7	1		5																2						
M. incongrua							1			16																
M. sp.	2																									
Cyclina sinensis										1																
Solecurtus divaricatus divaticatus	2				6						1	2														
Solen gordonis																						2				
S. krusensterni										1																
S. sp.									1			2					1									
Anisocorbula venusta				1		4			1	2		1	33	19	19	4							2			
A. scaphoides																							3			
Mya truncata															3											
Myadora fluctuosa	1			1		4							2	7									8			

Appendix 2. *Continued.*

Species	Loc. No. 0102	0203	0204	0305	0404	0501	0503	0505	0506	0601	0602	0607	0702	0703	0704	0706	0707	0708	0804	0806	0807	0808	0909	1013	1015	1108
Myadropsis brevispinosus																							2			
Pandora wardiana						2																4				
Panopea japonica				1																						
Cuspidaria nobilis																					1	1				
Entalinopsis intercostatus																					1					
Fissidentalium vernedei	5					3														1		1				
Fissidentalium sp.							1			2	2		4	12				1								
Dentalium octangulatum													3	11		1						1				
D. sp.																						2		62		
Collisella dorsuosa																							1			
Puncturella sp.													1		4	1										
Capulus sp.																							1			
Calyptraea yokoyamai						4																		6		
Tristichotrochus sp.						1																				
Neohaustator tsushimaensis							13																			
Ergaea walshic									1																	
Xenophora japonica																							4			
X. sp.																							4			
Onustus exutus	2						2																			
Euspira sp.															6											
Polinices vestitus	1									3		1														
Cryptonatica janthostomoides							1																			
Sinum javanicum							1																			
Natica sp.							5																			
Buccinum striatissimum																									5	
B. tsubai																										56
B. cf. opisthoplectum																								2		
Neptunea intersculpa																									1	
Hemifusus tuba																								1		
Fusinus perplexas ferrugineus						1								1												
F. sp.												1														
Glassaulax sp.													9				1									
Zeuxis concinnus																										
Ranularia cf. dunkeri																							1			
Ocenebra eurypteron													1	2			1									
Columbarium pagoda costatum														1			1					1				
C. sp.																						1				
Boreotrophon pacifica																									1	
B. candelabrun							1																			
Onustus exutus																						1				
Pteropurpura plorator																						1				
P. adunca										1																
P. sp.															5											
Phalium areola	1																									
Tonna luteostoma								3																		
T. sp.																				1			1			
Columbarium pagoda costatum																										
C. sp.																							1			
Murexul multispinosus																							1			
Siphonalia fusoides													59	3												

Appendix 2. *Continued.*

Species	Loc. No.																									
	0102	0203	0204	0305	0404	0501	0503	0505	0506	0601	0602	0607	0702	0703	0704	0706	0707	0708	0804	0806	0807	0808	0909	1013	1015	1108
S. filosa														6												
S. spadicea						14	6			13	6	1									3	3	6	1		
S. sp.											1											1	2			
Neptunea arthritica arthritica															3											
Zeuxis sp.	6												1													
Fusinus perplexux ferrugineus													1	1												
F. sp.																								2		
Olivella sp.																								2		
Fulgoraria noguchii															4											
F. rupesyris hammillei													1													
F. sp.						2																	1			
Paradrilla patruelis																							1			
P. sp.																							1			
Comitas kirai													2													
Pristiterebra bifrons																							1			
Brevimyurella japonica														1												
Myurella sp.																							1			
Pristeterebra bifrons							1																			
Myurella sp.	1																									
Total species number	30	15	3	13	2	35	18	12	22	25	16	23	36	35	24	21	26	3	9	18	21	43	35	7	3	1
Total individual number	2962	40	3	30	15	675	239	95	190	159	619	143	692	708	1808	624	723	3	47	239	449	1792	380	79	7	56