Last glacial sea-level changes and paleogeography of the Korea (Tsushima) Strait

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Abstract The Korea (Tsushima) Strait is an important seaway through which the warm Tsushima Current flows into the East Sea (Japan Sea). A paleogeographic map constrained by a regional sea-level curve developed on the basis of a number of recent ^{14}C radiocarbon dates suggests that the Korea Strait was not closed during the last glacial period. Rather, it was open as a channel-like seaway linking the western North Pacific and the East Sea. Some fraction of the paleo-Tsushima Current inflow presumably continued at that time through the Korea Strait. The activity of the paleo-Tsushima Current is evidenced by the distribution pattern of river-derived lowstand deposits, consisting of a beach/shoreface complex and lowstand deltaic wedges.

Introduction

The warm Tsushima Current flows into the East Sea (Japan Sea) through the Korea (Tsushima) Strait between the southeastern Korean Peninsula and Japan, and flows out mainly through the Tsugaru and Soya Straits in northern Japan (Fig. 1). The Tsushima Current is reported to be a branch of the regional Kuroshio Current, the western boundary current of the subtropical North Pacific circulation (e.g., Lie and Cho 1994). The warm and saline water of the Tsushima Current is considered to be a major source of the surface water supplied to the southern East Sea (e.g., Moriyasu 1972), and is especially important as a major supplier of heat and salt to the marginal East Sea. The Tsushima Current splits into two or three main branches as it passes through the Korea Strait and enters the East Sea. Each branch shows seasonal variability in path and volume transport (Fig. 1; Yoon 1982).

Geographically, the Korea Strait is divided into western and eastern channels (straits) by Tsushima Island. The western channel is as deep as 230 m, whereas the eastern channel is shallower than 120 m (Fig. 2). The western channel has a sill depth of approximately 130–140 m, which is close in magnitude to the eustatic sea-level drop during the last glacial maximum (LGM).

The deep western channel is occupied by the NE-SW-trending Tsushima Trough formed along the Tsushima Fault, one of the major strike-slip faults associated with the opening of the marginal sea during the Miocene (Yoon and Chough 1995; Yoon et al. 1997). Previous studies suggest that, during the LGM (about 18,000–15,000 years B.P.), the East Sea was a completely isolated, inland basin without any connections to the North Pacific warm water, and was dominated by much colder water masses with anaerobic bottom-water conditions (Ichikura and Ujiie 1976; CLIMAP 1981; Oba et al. 1991). Additionally, close to half of the northern East Sea was covered by ice sheets at that time, when the northern hemisphere ice sheets reached their maximum extent. However, it remains controversial whether the East Sea was completely isolated or not during the LGM.

In this study, we analysed a number of sediment cores and seismic (sparker) profiles from the western channel of the Korea Strait in order to examine changes in the sedimentary record since the last glacial. Based on a regional sea-level curve provided by recent radiocarbon dates and sedimentary records on the shelf, we propose that the western channel of the Korea Strait was not completely closed during the last glaciation. Rather, it was open as a channel-like seaway, connecting the western North Pacific and the East Sea.

Radiocarbon dates and regional sea-level curve

Figure 3 shows the new regional sea-level curve for the Korea Strait during the last 40,000 years, based on a

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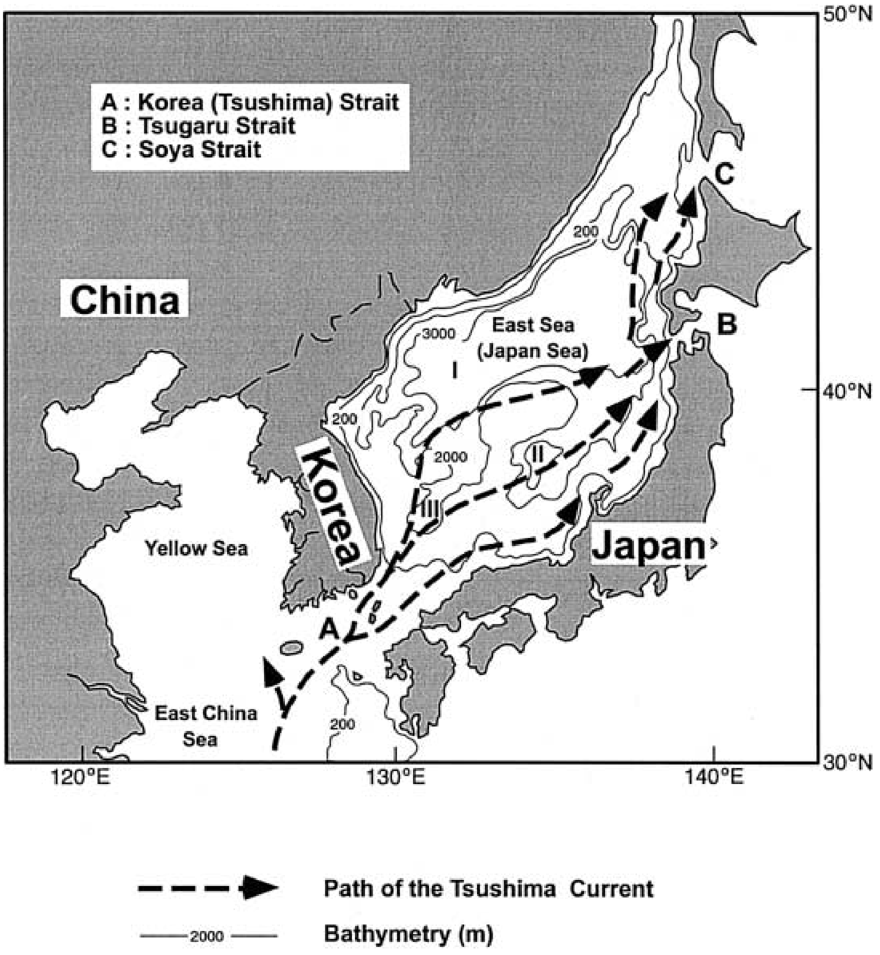

Fig. 1 Geographic location of the Korean Peninsula, showing the Korea (Tsushima) Strait between Korea and Japan, and the Tsugaru and Soya Straits near northern Japan. *Dashed arrows* Present-day path of the warm Tsushima Current. *I* Japan Basin; *II* Yamato Basin; *III* Ulleung (Tsushima) Basin

series of recent radiocarbon dates. Most radiocarbon dates were made on selected, fresh molluscan shells which were sampled from the shelf of the western channel, except for one date made on a peat layer (Table 1). Radiocarbon ages were determined either by accelerator mass spectrometry (AMS) or by conventional scintillation methods. Most shells dated by the radiocarbon method are indicative of intertidal or very shallow water environments, although some species, such as *Siphoualia filosa* and *Acila insignis*, show a relatively wide depth range (~10–80 m). The sea-level curve shown in Fig. 3 is based mainly on the radiocarbon dates of intertidal or very shallow water species in order to minimize the errors caused by such wide depth ranges. Because of the lack of dateable material to determine the age and depth during the last interstadial (around 30,000–35,000 years B.P.) and the recent highstand (the last 5000 years), the complete sea-level curve was not fully reconstructed.

The sea-level position between about 24,000 and 13,000 years B.P. indicates a last lowstand period during the glacial with depths ranging from −90 to −130 m (compared to the present level). A recent study of single-channel (sparker) seismic profiles reveals that the Korea Strait shelf experienced tectonic tilting and subsidence from the Pliocene to middle Pleistocene, but that it has been tectonically stable since the middle Pleistocene (Yoo 1997). Consequently, a depth of about −130 m is inferred to have been the lowest sea-level position during the LGM. When taking some local isostatic adjustments into consideration (see below), the sea-level curve of the present study results in an estimated LGM sea-level lowstand which is virtually identical to that (121 ± 5 m below present level) proposed by Fairbanks (1989). This lowest position of sea level is also supported by a number of marine-built terraces observed on the shelf margin of the western channel of the Korea Strait (Park and Yoo 1988). It has been reported that the lowest glacial position of sea level on the East China shelf was about −150 m, which is about 20 m lower than that of the Korea Strait (Feng 1983). This difference can be explained by the persistent tectonic uplift of the Chinese continent and resultant subsidence of the shelf, as well as by the accumulation of a thick body of sediments causing the isostatic subsidence of the East China shelf (cf. Wang 1993).

Lowstand deposits on the shelf margin

Continuous shallow seismic profiling (sparker) across the western channel of the Korea Strait reveals that the

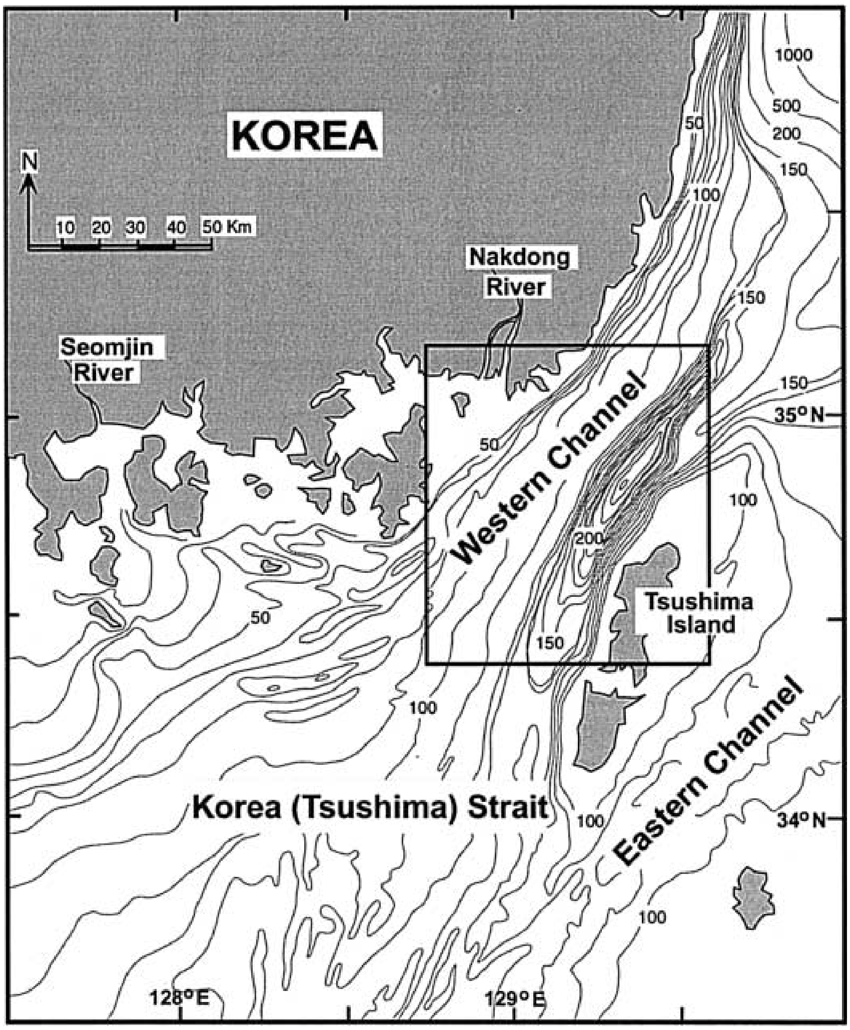

Fig. 2 Detailed bathymetry (m) of the Korea (Tsushima) Strait which can be divided into a western channel as deep as 230 m and an eastern channel shallower than 120 m. *Box* Area of seismic surveys shown in Fig. 4

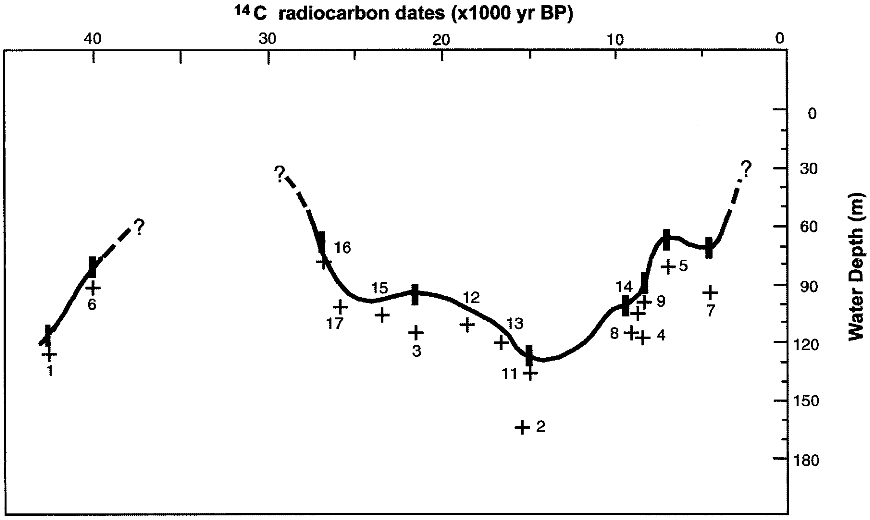

Fig. 3 Regional sea-level curve for the Korea Strait. *Numbered crosses* show the radiocarbon ages and depths of cores numbered likewise in Table 1. *Solid bars* Intertidal or very shallow water samples. The sea-level position was inferred from the depth ranges of the samples, considering the tidal range (ca. 2 m) in this area

lowstand deposits consist of relict coastal deposits (beach/shoreface complex; BSC) and thick deltaic deposits (lowstand deltaic wedge; LDW) at the shelf margin and in the trough region (Figs. 4 and 5). The sediment cores from the shelf margin show that the BSC and LDW consist mainly of gravelly sand and sandy mud, respectively (Fig. 6).

The deposits of the BSC along the present shelf margin (about 120–150 m deep) are about 30 km long and up to 20 m thick (Fig. 4), and are interpreted to

Table 1 Radiocarbon dates from the southern continental shelf of Korea (Korea Strait). Ages of 1–10 were determined by AMS, and the others are conventional radiocarbon ages. Age of 11 is extracted from Yoo and Park (1997). *CAMS* Lowrence Livermore National Laboratory; *R* Institute of Geological & Nuclear Sciences of New Zealand; *I* Teledyne Laboratory; *KIGAM* Korea Institute of Geology, Mining & Materials

Reference No.	Core No.	Water depth (m)	Depth in core (cm)	Material dated	Depth range (m)	^{14}C age (years B.P.)	Lab. No.
1	94-KS-17	124	40–42	*Japeuthria* sp.	Intertidal	42,150 ± 800	CAMS 17315
2	94-KS-09	161	38–40	*Acila (Trunacila) insignis*	Neritic	15,440 ± 60	CAMS 17314
3	94-TS-03	112	70–72	*Megacardita ferrunginosa*	15–20	21,490 ± 120	CAMS 25793
4	94-KS-03	117	17–19	*Siphoualia filosa*	10–80	8610 ± 60	CAMS 25794
5	93-KS-03	77	77–79	*Paphia euglypta*	Subtidal	7280 ± 60	CAMS 25795
6	93-KS-16	88	160–162	*Arca boucardi*	Intertidal	40,100 ± 1100	CAMS 25796
7	93-KS-19	91	138–140	*Megacardita ferrunginosa*	15–20	4770 ± 60	CAMS 25797
8	93-KS-21	114	43–45	*Paphia euglypta*	Subtidal	9010 ± 60	CAMS 25798
9	93-KS-13	100	120–122	*Megacardita koreanea*	Intertidal	8750 ± 60	CAMS 25799
10	94-TS-07	121	58–60	*Megacardita koreanea*	Intertidal	> 50,000	R18942
11	84-B-03	132	31–33	*Megacardita koreanea*	Intertidal	15,080 ± 150	
12	M1	110	80	Shell		18,400 ± 290	KIGAM-26
13	M2	120	114	Shell		16,330 ± 250	I-16500
14	87P5	102	0–10	Shell		8450 ± 640	KIGAM-27
15	90P6	107	80	Shell		23,300 ± 600	I-16681
16	92P15	71	114	Peat	Supratidal	26,800 ± 370	R18539/1
17	89P18	102	35–45	Shell		25,660 ± 810	I-16680

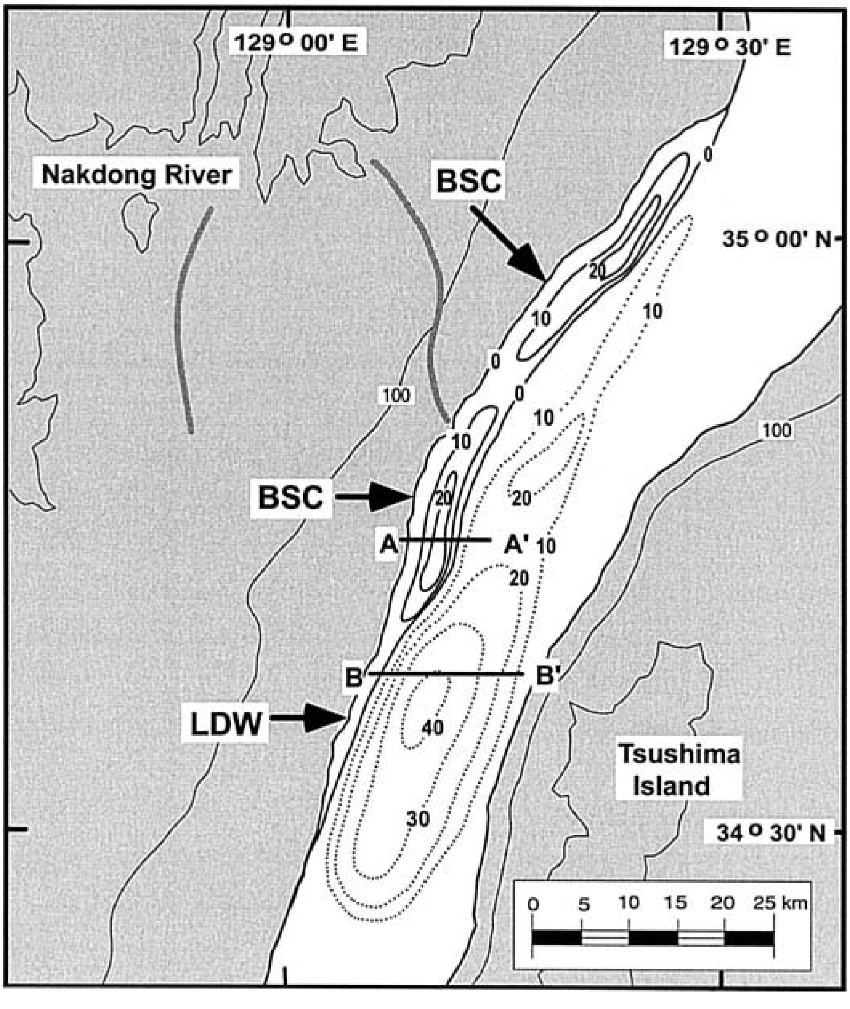

Fig. 4 Map showing the distribution pattern of lowstand deposits (thickness in m, based on a sediment sound velocity of 1600 m/s, Yoo 1997) consisting of a beach/shoreface complex (*BSC*; *solid lines*) and a lowstand deltaic wedge (*LDW*; *dashed lines*), derived mainly from the paleo-Nakdong River during the last glacial period. The landward boundary of these deposits corresponds to a depth of about 120 m. Representative seismic profiles of the *BSC* (*A-A′*) and the *LDW* (*B-B′*) are shown in Fig. 5

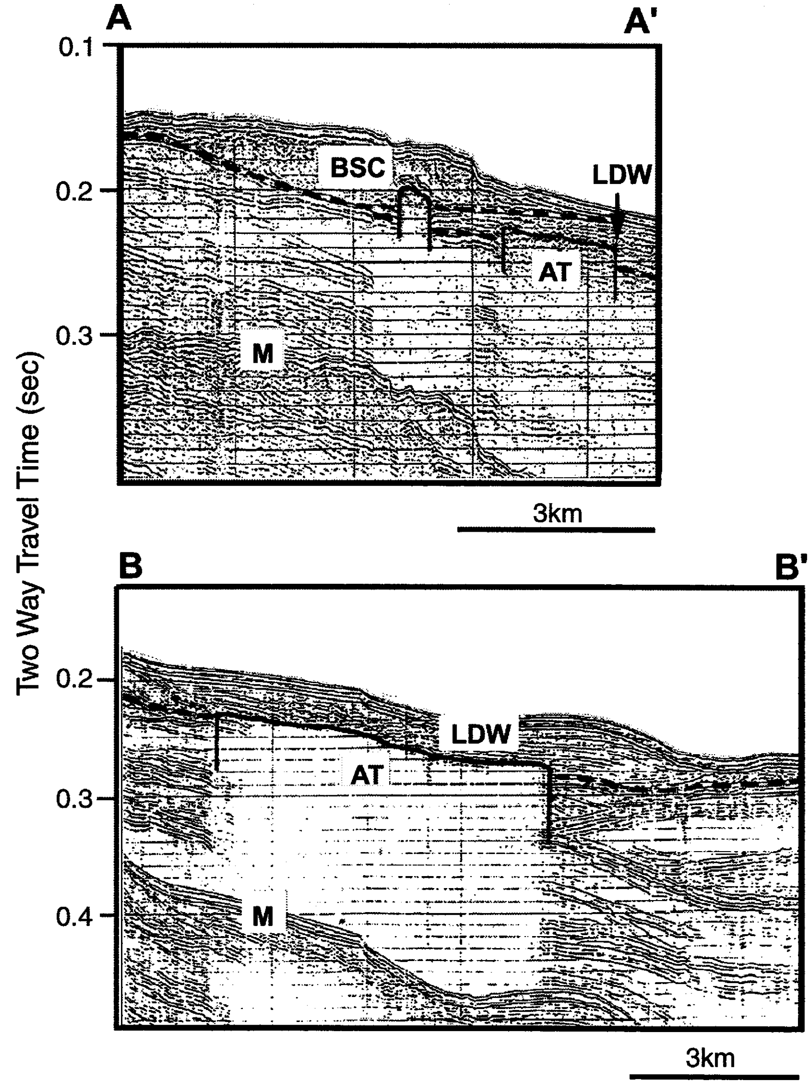

Fig. 5 Representative seismic profiles of the beach/shoreface complex (*BSC*) and the lowstand deltaic wedge (*LDW*; see Fig. 4 for locations of the seismic profiles *A-A′* and *B-B′*). *AT* Acoustic turbidity; *M* Multiple

have formed either during the last stage of regression or at the beginning of the postglacial transgression around 15,000 years B.P. (Yoo and Park 1997). Acoustically, these deposits are defined by hummocky or chaotic reflection patterns (Fig. 5). They usually overlie the erosional transgressive surface of the pre-existing shelf deposits, regionally comprising the lowstand deltaic wedge. The sediments consist of reworked gravelly sand with some molluscan shells (Fig. 6), the latter from intertidal or very shallow water species such as *Megacardita koreanea*. The shells in core 84-B-03, collected at a water depth of 132 m, show an age of 15,080 ± 150 years (Table 1). Interestingly, the distribution pattern of the relict coastal deposits parallels the paleoshoreline (Fig. 4), suggesting the longshore transport of sediments by current activity at that time. Similar shelf-parallel remnants of coastal deposits have been reported from many shelf margins including northeastern Spain (Diaz et al. 1990), the eastern coast of Japan (Saito 1991), and the eastern Tyrrhenian Sea of Italy (Field and Trincardi 1991).

The deposits of the LDW are acoustically defined by well-stratified and seaward-dipping reflections, highlighting the regressive wedge which has prograded seawards from the shelf margin (about 110–120 m deep) to the base of the trough (about 150–200 m deep) during the last glacial lowstand period (Fig. 5). The LDWs have a depocenter attaining a thickness of up to 40 m in the southwestern trough region, and show an elongated distribution pattern in a NE-SW direction, decreasing in thickness northeastwards (Fig. 4). This distribution pattern suggests a strong erosional potential of the paleocurrent to transport a substantial amount of sediment downstream. The sediments of the relict deltaic deposits consist mainly of sandy mud (Fig. 6). Core 94-TS-03 (ref. no. 3, Table 1), collected from the landward part of the lowstand deltaic wedge at a water depth of 112 m, shows a radiocarbon age of 21,490 ± 120 years B.P., while core 94-KS-09 (ref. no. 2, Table 1), retrieved from the seaward part of the wedge at a water depth of 161 m, has an age of 15,440 ± 60 years B.P. These two cores contain various

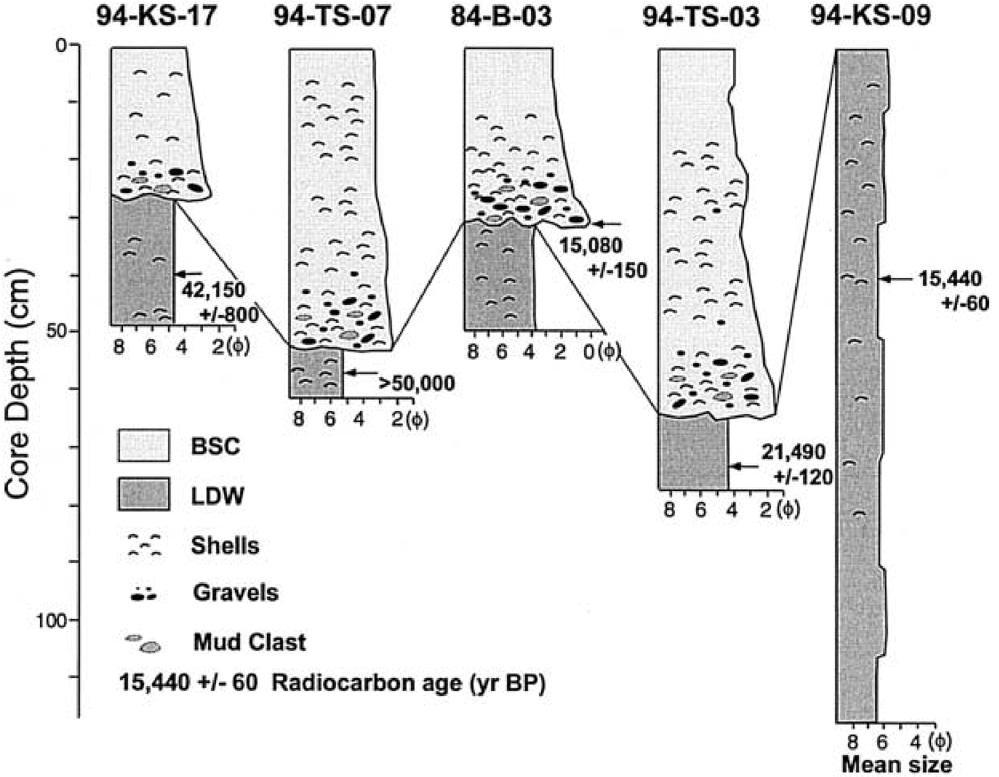

Fig. 6 Description of cores retrieved from the shelf margin of the Korea Strait (for water depths, see Table 1). The sediments of the beach/shoreface complex (*BSC*) consist mainly of gravelly sand, whereas the sediments of the lowstand deltaic wedge (*LDW*) are comprised of sandy mud. Some mud clasts derived from the *LDW* are present in the bottom layer of the *BSC*

diatom species such as *Paralia sulcata*, *Thalassiosira eccentrica*, *Cyclotella striata*, and *Cocconeis placentula* which indicate a littoral or estuarine environment. Core 94-KS-17 with an age of 42,150 ± 800 years B.P. (ref. no. 1, Table 1), and core 94-TS-07 with an age over 50,000 years B.P. (ref. no. 10, Table 1) presumably represent the lowstand sediments deposited before the last interstadial, which is also evidenced by the seismic profiles (Yoo and Park 1997).

According to the sea-level curve of the present study, a depth of between 90 and 130 m below present level is inferred to be the lowstand sea-level position during the last glacial regression (approx. 25,000–15,000 years B.P.). During this lowstand period, subaerial erosion of the pre-existing shelf by rivers (the Nakdong River) produced the paleochannel systems which extend onto the shelf margin across the mid shelf (Park and Yoo 1992). We suspect that these paleochannels played an important role in the transport of sediments across the shelf. The sediments forming the lowstand deltaic deposits on the shelf margin are inferred to have been provided through these paleochannels. The acoustic character of the lowstand deltaic wedge, showing sigmoid-oblique clinoforms (Fig. 5), represents lateral outbuilding or progradation, progressively following the drop in sea level. The same kind of regressive facies associated with relative sea-level fall has also been documented in many other areas. Well-studied examples are the outer shelf of the Gulf of Mexico (Suter and Berryhill 1985), the US Atlantic continental shelf off Cape Fear, North Carolina (Matteucci and Hine 1987), and the Rhône shelf of southern France (Tesson et al. 1990). In the case of the Korea Strait, only the deltaic body fed by the Nakdong River system was identified in the seismic data. Therefore, further research is needed to trace the deltaic body produced by the paleo-Seomjin River system (Fig. 7) which may have reached further south beyond the limit of the present study area.

Paleogeography of the Korea Strait

The sea-level curve delineated in the present study suggests that the Korea Strait had a glacial sill depth of at least 10 m during the LGM. Figure 7 shows a reconstructed paleogeographic map of the Korea Strait when sea level was as low as −130 m. The western channel was a narrow seaway (about 20 km wide) connecting the East China Sea and the East Sea, whereas the eastern channel was completely closed. We suspect that transport of water masses by the paleo-Tsushima Current to the East Sea continued at that time through this western channel, providing warm water to the southern part of the East Sea (north of Japan). The occurrence of marine and brackish-water diatom species in the Korea Strait cores also suggests that, during the last glacial lowstand period, environmental conditions in the western channel were influenced by marine incursion as well as by freshwater discharge from the adjacent land.

A number of cores were collected from the southwestern region of the East Sea (Ulleung or Tsushima Basin) in order to examine the influence of the paleo-

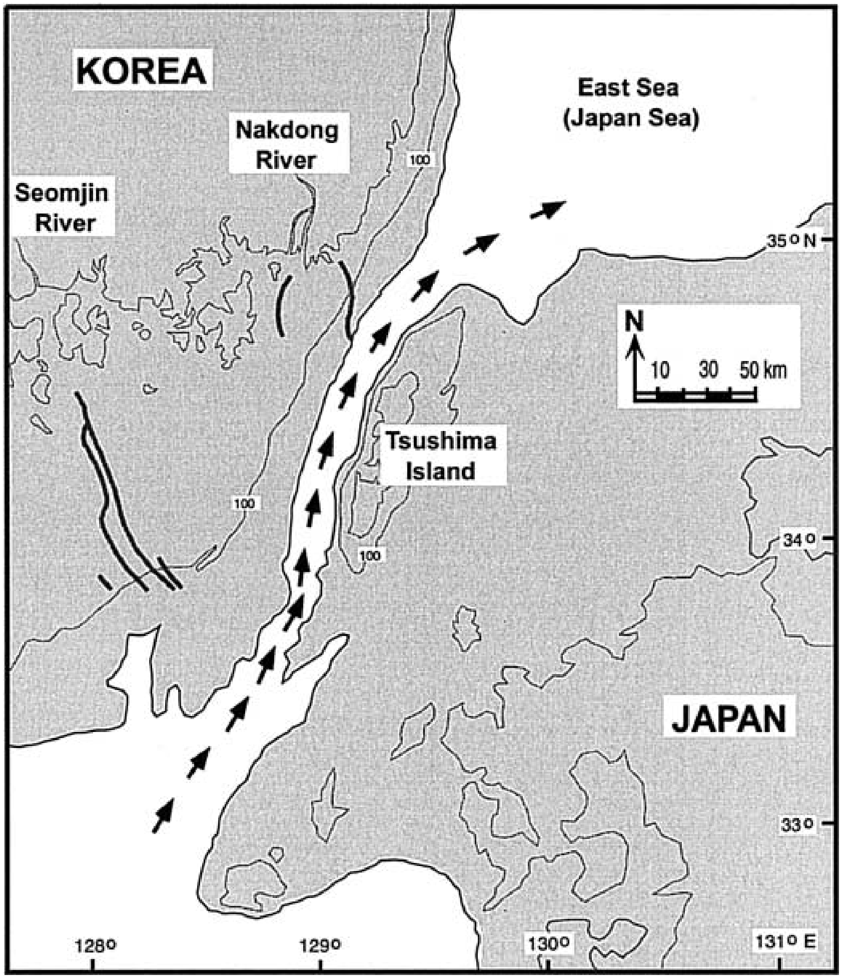

Fig. 7 Reconstructed paleogeographic map of the Korea (Tsushima) Strait during the last glacial maximum when sea level was as low as −130 m. The western channel was a narrow seaway through which some degree of inflow of warm water, presumably the paleo-Tsushima Current (*arrows*), continued at that time. *Thick solid lines* Paleochannel systems identified in high-resolution (sparker) seismic profiles (Yoo 1997)

Tsushima Current on the sedimentary record during the last glaciation. It is difficult, however, to recognize any signature of the hypothesized glacial warm-water influence in the sediments due to the basin-wide occurrence of mass flow deposits such as turbidites, debris flows, and slumps (Chough et al. 1985, 1997). A previous study (Morley et al. 1986) of radiolarians and pollen, in a core retrieved from the southern section of the East Sea (north of Japan), revealed the continuous presence of warm-water species (similar to present-day ones) during the last glacial period, suggesting some degree of inflow of warm water from the North Pacific. Recent studies (Tada 1995; Matsui et al. 1998) document that the shallow sill depth of the Korea Strait during the LGM would have resulted in a 95% reduction in the cross-sectional area of the strait at that time. We propose that the paleo-Tsushima Current influenced at least the southern part of the East Sea (north of Japan) throughout the last glacial period (25,000–15,000 years B.P), although its volume transport through the western channel was much lower than at present.

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