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Nd isotopic study of Upper Cambrian conodonts from Korea and implications for early Paleozoic paleogeography

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Abstract

Correlation of the Korean Peninsula with the neighboring South and North China blocks has been one of the most important and long debated issues in East Asian tectonics. The eastward extension of the Chinese collisional belt between the South and North China blocks into the Korean Peninsula is still in dispute. The lower Paleozoic sedimentary rocks in South Korea, the Joseon Supergroup, accumulated in the Okcheon belt which has been proposed as the suture zone or the block boundary between the South and North China blocks in Korea. The Joseon Supergroup comprises five different lithostratigraphic units, and has been proposed to represent two tectonostratigraphic blocks bounded by the Honam Shear Zone (HSZ) in the Okcheon belt; among them, the Yeongweol Unit in the western part of the HSZ is correlated with South China and the Duwibong Unit in the eastern part of the HSZ with North China. To test the above geodynamic interpretation, this study analyzed the Nd isotopic composition of Upper Cambrian conodonts from the Duwibong and Yeongweol units. The difference of the $\varepsilon_{\mathrm{Nd}}$ (T) values between the Upper Cambrian Duwibong and Yeongweol units is about 3ε units. Compared to a wide range of the $\varepsilon_{\mathrm{Nd}}$ (0) values in the modern oceanic basins, this slight difference can be regarded as a variation in a same paleo-watermass. The $\varepsilon_{\mathrm{Nd}}$ (T) values of the two units are consistent with coeval values from North China, and this suggests that the Duwibong and Yeongweol units shared the same oceanic watermass with the North China. Considering current early Paleozoic paleogeographic reconstructions, the Nd isotopic signatures of North China, Duwibong and Yeongweol units may be independent of Laurentia and Baltica and thus can be indicative of another unique oceanic watermass.

In contrast to the previous tectonic interpretations, the same paleoceanographic signatures shown by the Duwibong and Yeongweol units and North China and recent developments suggest that the Yeongweol Unit in the early Paleozoic Joseon Supergroup is not correlated with South China but correlated with North China, and the Korean Peninsula and North China block may have been included in a larger continental block, the Sino-Korean block. The collisional belt between the South and North China blocks may not extend into the Korean Peninsula.

Keywords: Korean Peninsula; Paleozoic; Nd isotope; Conodont; The Sino-Korean block; Paleogeography

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1. Introduction

The Sm–Nd isotopic system is useful for studying the geochemical evolution of the oceans because of the shorter residence time of Nd and Sm within a watermass than the mixing time of the oceans and their tight coupling behavior. The major input of Sm and Nd to oceans is from continental sources via riverine systems (Goldstein and Jacobsen, 1987; Jones et al., 1994). The Nd isotopic composition of present oceans shows a wide range of ε_{Nd} (0) values and each ocean has a characteristic range of values. The Atlantic Ocean has the most negative values (−14 to −7), the Pacific has the most radiogenic values (−2 to −7) and the Indian Ocean shows an intermediate range (−11 to −6). These variations among major oceans suggest that the distribution of Nd isotopes in the marine realm is controlled mainly by the relative release of Nd from old versus young continental materials surrounding each ocean and modified by ocean circulation patterns.

Changes through time in the $^{143}Nd/^{144}Nd$ of seawater reflect not only changes in the isotopic composition of the inputs to the oceans but also changes in ocean circulation patterns. Recent studies illustrate that the $^{143}Nd/^{144}Nd$ of marine authigenic minerals, such as phosphorites, biophosphates and metaliferous sediments, may be used to estimate $^{143}Nd/^{144}Nd$ of paleoseawater. Biophosphates such as conodonts and fish teeth are the best available material for obtaining $^{143}Nd/^{144}Nd$ of paleoseawaters. They are well preserved over all the geologic times

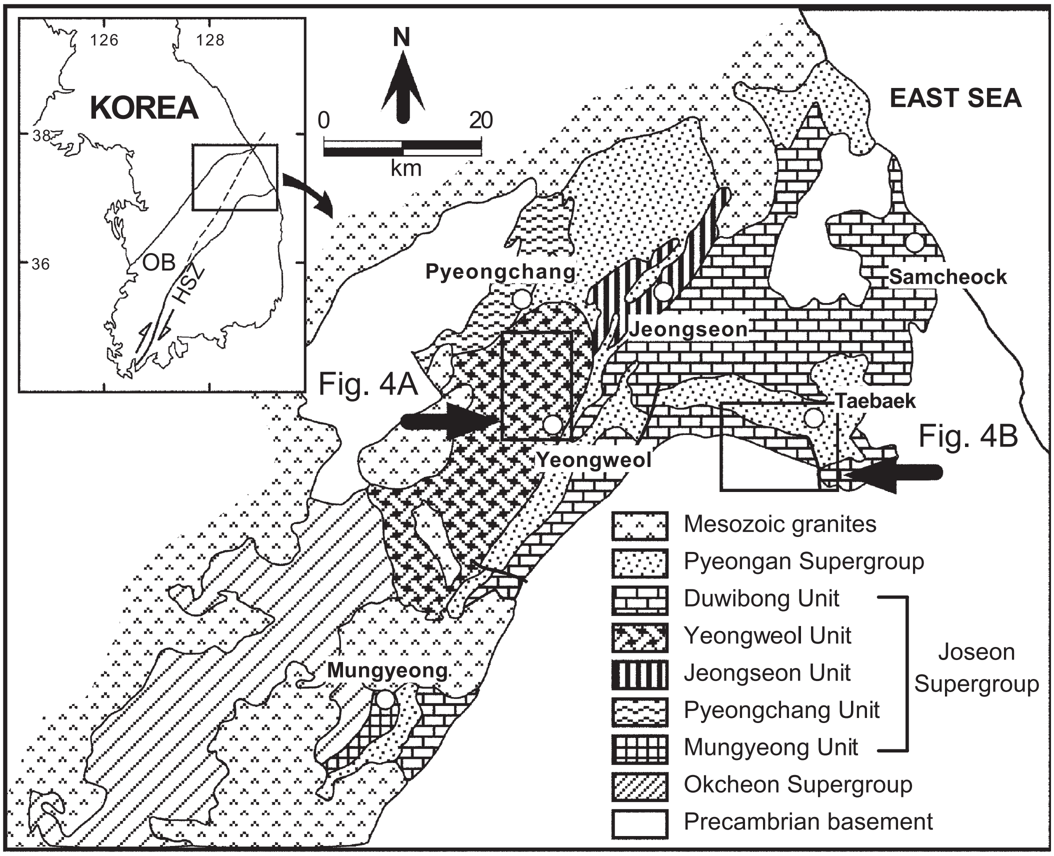

Fig. 1. Index map showing simplified geology and the distribution of the early Paleozoic Joseon Supergroup. Five units of the Joseon Supergroup are shown in the map. The Joseon Supergroup rests unconformably on the Precambrian rocks and is disconformably overlain by the late Paleozoic Pyeongan Supergroup. OB: Okcheon belt; HSZ: Honam Shear Zone. In the inset HSZ is represented by a dotted line in the NE Okcheon belt.

and can give much better age than non-biogenic minerals. Staudigel et al. (1985) and Grandjean et al. (1987) analyzed the Nd isotopic composition of fish teeth debris, and found that although the REE pattern may be affected by diagenesis, $^{143}Nd/^{144}Nd$ ratios preserve the values of bottom waters at the time of deposition. These studies indicate that the Nd signatures of biogenic minerals represent isotopic composition of contemporaneous water masses and is not a product of later diagenetic overprint.

The lower Paleozoic sedimentary rocks in South Korea, the Joseon Supergroup, consist mostly of carbonate sediments with interbedded siliciclastic sediments. The Joseon Supergroup comprises five different lithostratigraphic sequences, the Duwibong, Yeongweol, Jeongseon, Pyeongchang, and Mungyeong units (Fig. 1). Among these, Upper Cambrian conodonts occur abundantly in the Duwibong and Yeongweol units, which are now in fault contact. Correlation between the Duwibong and Yeongweol units and correlation of these two units with neighboring tectonic blocks such as South and North China have been one of the most important and debated issues for a long time. Although the collisional belt between the South and North China blocks has been clearly defined in China, the location of its eastward extension in the Korean Peninsula is still controversial. This problem makes it difficult to understand the tectonics of the East Asian continental margin. Previous tectonostratigraphic and paleontological studies (Kobayashi, 1967; Cluzel et al., 1991a,b; Yin and Nie, 1993, 1996) correlated the Yeongweol Unit with South China and the Duwibong Unit with North China. However, the results of recent studies on the sedimentology and paleontology of these sedimentary rocks have made this interpretation questionable (e.g., Kim and Lee, 1999, 2000; Jeong and Lee, 2000). To solve this longstanding problem of Korean geology, it is necessary to combine reliable results of studies on tectonostratigraphy, sedimentology, paleontology, and paleoceanography. The aims of this study are to determine the Nd isotopic signatures for Upper Cambrian conodonts preserved in the Duwibong and Yeongweol units and to characterize the seawater masses in which Cambrian Duwibong and Yeongweol units were deposited. Based on the Nd isotopic signatures, this study attempts to unravel the paleogeography and paleoceanography of the Korean Peninsula during the early Paleozoic.

2. Geology

2.1. Geological setting

The Korean Peninsula is divided into three Precambrian massifs by the Imjingang and Okcheon belts (Fig. 2). From north to south they are the Nangrim, Gyeonggi, and Yeongnam massifs. Although still in dispute, the Imjingang belt has been proposed as an eastward extension of the Chinese collision belt (Cluzel et al., 1991a,b; Yin and Nie, 1993, 1996; Cho et al., 1995; Chang, 1996, Ree et al., 1996), and the Honam Shear Zone (HSZ) in the Okcheon belt (Fig. 1) has been interpreted as the suture zone between the South and North China blocks (Yin and Nie, 1993, 1996) or the block boundary (Cluzel et al., 1991a,b). These studies suggest that the Gyeonggi massif in central Korea belongs to the South China block and the Nangrim and Yeongnam massifs to the North China block. According to these studies, the Okcheon belt would consist of rocks belonging to both the Gyeonggi and Yeongnam massifs.

In the above tectonic framework, the lower Paleozoic Joseon Supergroup would be divided by the HSZ (Fig. 1). The Joseon Supergroup in the eastern part of the HSZ (e.g. Duwibong Unit) belongs to the Yeong-

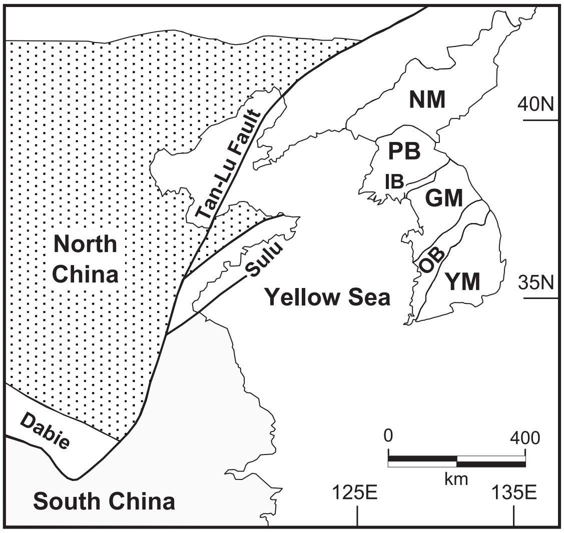

Fig. 2. Simplified geologic map of northeastern Asia (modified after Ree et al., 1996). NM—Nangrim massif, PB—Pyeongnam basin, IB—Imjingang belt, GM—Gyeonggi massif, OB—Okcheon belt, and YM—Yeongnam massif.

nam massif and thus, is correlated with North China; whereas, the Joseon Supergroup in the western part of the HSZ (e.g. Yeongweol Unit) belongs to the Gyeonggi massif and is correlated with South China. This interpretation has been based on biogeographical studies of the Cambrian fossils (Kobayashi, 1967). The Cambrian trilobite faunas of the Yeongweol Unit have been correlated with the Jiangnan faunal province of South China which is dominated by pelagic or offshore faunas indicating deep oceanic environments, whereas those of the Duwibong Unit have been correlated with the Hwangho faunal province of North China which is mainly composed of indigenous faunas indicating shallow marine environments. These faunal contrasts form the basis of interpretations in subsequent studies which put an eastern extension of the South and North China collision belt in the Korean Peninsula. Cluzel et al. (1990) stated that the Jeongseon Unit (Fig. 1) probably represents a lateral facies of the Yeongweol Unit and that the occurrence of early Middle Silurian conodonts (Lee, 1980) from this Unit supports a correlation of it with South China rather than with North China, where Silurian deposits are almost absent.

However, there exists some recent paleontological evidence that questions the above tectonostratigraphic interpretation. Choi (1994, 1998) and Choi et al. (2003) showed the increasing faunal similarities of the Early Ordovician trilobite faunas between the Duwibong and Yeongweol units and between these two faunas and North China fauna. In addition, Ordovician conodont faunas from these two units show close similarities with fauna of the North Chinese Province (Lee and Lee, 1986, 1990; Kim, 1988; Lee, 1990; Seo, 1990; Choi, 1993). To resolve the different interpretations on faunal affinities between the Cambrian and the Ordovician, Jeong and Lee (2000) studied Upper Cambrian conodonts from both units and found that conodont faunas from the two units display higher bioprovincial affinities with North China than with South China.

2.2. Stratigraphy

The Joseon Supergroup rests unconformably on Precambrian rocks and is disconformably overlain by the upper Paleozoic Pyeongan Supergroup (Fig. 1).

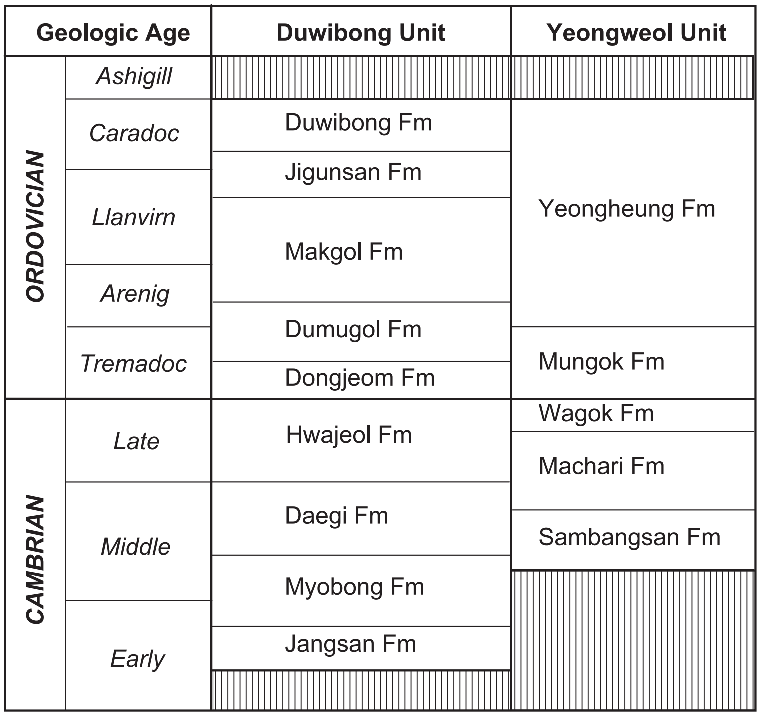

Fig. 3. Stratigraphic subdivision of the Duwibong and Yeongweol units of the Joseon Supergroup (modified after Cheong, 1969; Lee, 1987).

Among five lithostratigraphic units, the Duwibong and Yeongweol units are fossiliferous and relatively well studied. The relationships among these five units are yet not fully understood.

In the Duwibong Unit, the Late Cambrian Hwajeol Formation was selected for this study (Fig. 3). It is about 200–260 m thick, and mainly consists of limestone, intraformational conglomerate, shale, and fine sandstone. The Hwajeol Formation conformably overlies the Middle Cambrian Daegi Formation which is mostly composed of milky white massive limestone with interbedded oolitic limestone and dolomitic limestone, and is overlain by the Early Ordovician Dongjeom Formation which is composed of fine to coarse grained, well sorted, and well rounded grains and is a mineralogically mature sandstone (Son and Cheong, 1965; Cheong, 1969; Kim and Lee, 2000). The Hwajeol Formation is interpreted to have been deposited in a shallow marine setting (Woo and Park, 1989). In the Yeongweol Unit selected was the Machari Formation of latest Middle to Late Cambrian age (Fig. 3). It is about 200 m thick, and comprises thick-bedded limestone, dark gray laminated shale and rhythmic alternations of light gray dolomitic limestone and laminated black shlae. The Machari Formation conformably overlies the early Middle Cambrian Sambangsan Formation which is composed of purple to green shale and sandy shale and greenish gray massive to thick-bedded sandstone (Choi, 1997), and is overlain by the latest Cambrian Wagok Formation which is composed of light gray to gray massive dolostone (Lee, 1987). The Machari Formation is interpreted to have been deposited in a deep shelf to pelagic environment (Chung and Lee, 1992; Lee, 1995).

3. Method

Carbonate rock samples were collected for conodont separation from two measured sections of the Hwajeol Formation in the Duwibong Unit (Fig. 4A) and from four measured sections of the Machari Formation in the Yeongweol Unit (Fig. 4B). Each rock sample (about 1–3 kg) was dissolved using a 15% acetic acid solution and the insoluble residue was dried at 45 °C in the electric oven. Once dried, samples were hand-picked with a fine-tipped brush under a binocular microscope.

Isotopic analyses including chemical separation and mass spectrometry were performed at the Korea Basic Science Institute. All analytical work was done in a clean room with laminar flow benches. Acids and water used were double-distilled with a quartz still or teflon two-bottle method. Separated conodont samples were sonicated in dilute (0.06 N) HCl and water for 10 min to remove any adhering non-apatite materials. Cleaned samples were mixed with weighed ^{150}Nd-^{149}Sm spikes and dissolved in mixed acid ($HF/HClO_4/HNO_3$=5:1:1) in sealed FEP vessels overnight two times. Dissolved samples were evaporated to dryness and redissolved in 2.5 N HCl. About 0.5 ml of centrifuged sample solution was loaded onto a cation resin bed (DOWEX AG50W-X8, H^+ form, 200–400 #) charged into a quartz column (5 mm in diameter×190 mm in length). Rare earth element (REE) fractions were collected with 2.5 N and 6 N HCl. Then, the REE fraction was dissolved with 0.06 ml of 0.06 N HCl and loaded on a polyethylene column (4.1 mm in diameter×40 mm in length) charged with 0.5 ml of DOWEX AG50W-X8 resin ($NH4^+$ form, 200–400 #). Sm and Nd fractions were collected with 0.2 M HIBA (α-hydroxy iso butyric acid, pH=4.5). All the isotopic ratio measurements were made on a VG 54–30 mass spectrometer equipped with nine Faraday collectors. ^{143}Nd/^{144}Nd ratios were corrected for instrumental fractionation by normalizing ^{146}Nd/^{142}Nd=0.636151. These ratios were further corrected for contributions from added spikes. Replicate analyses of La Jolla Nd standard gave ^{143}Nd/^{144}Nd=0.511833±0.000005 (N=12, $2\sigma_m$). Final ^{143}Nd/^{144}Nd ratios of samples are reported relative to ^{143}Nd/^{144}Nd=0.511860 for the La Jolla Nd standard. Sm and Nd concentrations were measured by an isotope dilution technique. Errors of ^{147}Sm/^{144}Nd ratios checked by duplicate analyses are estimated less than 1%. Total blank levels were below 20 pg for Sm and 90 pg for Nd.

4. Results

Sixteen samples of conodonts and one brachiopod sample were analyzed for the determination of Nd isotopic composition. Lithofacies and biozones of conodont-bearing samples are summarized in Table 1, which are presented in ascending order from DCH40 to DCH03 in the Duwibong Unit and YCM34 to

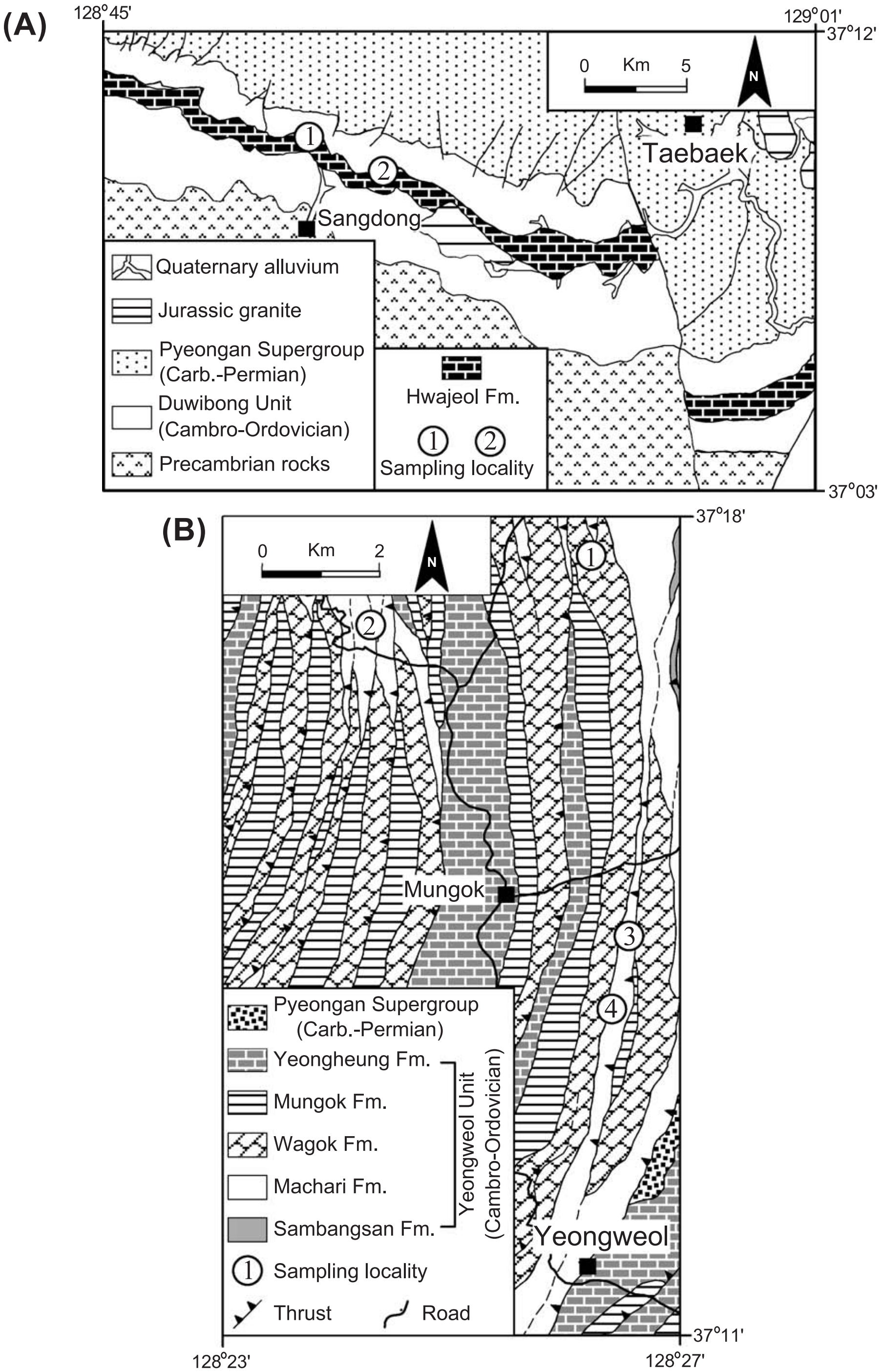

Fig. 4. (A) Geological map showing the localities of the measured sections of the Hwajeol Formation in the Duwibong Unit. The studied sections are ① Teoggol and ② Sesong. (B) Geological map showing the localities of the measured sections of the Machari Formation in the Yeongweol Unit. The studied sections are ① Eodungol, ② Marji, ③ Deogwoo, and ④ Bundeogchi.

Table 1
Conodont-bearing sample information

Fm.	Sample no.	Lithofacies	Biozone
Hwajeol Fm. (Duwibong unit)	DCH03	argillaceous limestone	*Cambrooistodus cambricus*
	DCH13	nodular limestone	*Eoconodontus notchpeakensis*
	DCH20	nodular limestone	*Proconodontus*
	DCH25	argillaceous limestone	*Proconodontus*
	DCH28	dark gray laminated limestone	*Proconodontus*
	DCH31	nodular limestone	*Proconodontus*
	DCH39	nodular limestone	*Proconodontus*
	DCH40	nodular limestone	not zoned
Machari Fm. (Yeongweol unit)	YCM08	thin-bedded dolomitic limestone	*Pseudoyuepingia asaphoides*
	YCM09	thin-bedded dolomitic limestone	*Pseudoyuepingia asaphoides*
	YCM14	shale-parted dolomitic limestone	*Irvingella antigena*
	YCM17	shale-parted limestone	*Oncagnostus machariensis*
	YCM19	thin-bedded limestone with shale layer	*Eugonocare longifrons*
	YCM23	thin-bedded limestone with shale layer	*Hancrania brevilimbata*
	YCM27	light gray massive limestone	not zoned
	YCM34	bioclastic grainstone to packstone	*Tonkinella*

YCM08 in the Yeongweol Unit. Biozones for the samples in the Hwajeol Formation follow the conodont zones of Lee and Lee (1988) whereas those of the Machari Formation follow the trilobite zones of Lee (1995). This results from insufficient research and consequently rough biostratigraphic zonation (Lee et al., 1991) of conodont faunas in the Machari Formation compared to that of the trilobite faunas. Jeong and Lee (2000) correlated the Upper Cambrian conodont zones between the Duwibong Unit (Hwajeol Formation) and Yeongweol Unit (Machari Formation) as well as between them and those of North China and North America. The conodont color alteration index (CAI) in the Hwajeol Formation ranges from 5 to 7, whereas CAI of the Machari Formation is lower, ranging from 5 to 6. The CAI values indicate that both the Hwajeol and Machari formations experienced the maximum burial temperatures of more than 300 °C (Rejebian et al., 1987).

Nd isotopic compositions of 17 conodont and brachiopod samples are shown in Table 2. Three of the samples, YCM08, YCM09, and YCM17 from the Machari Formation, failed to yield the Nd isotopic composition due to the low concentrations of Sm and Nd in these samples. One sample, YCM17br, consists of inarticulate brachiopods from the same numbered conodont sample. This sample was included in this study to compare the latent effect of different sample types on the Nd isotopic composition. The value from the brachiopods coincides well with those from conodont samples from the Machari Formation. The ^{143}Nd/^{144}Nd values of the analyzed samples range from 0.510941 to 0.511262 and ε_{Nd} (0) values from -17.69 to -13.85. Errors associated with the ε_{Nd} (0) values are within 1ε unit.

The $f_{Sm/Nd}$ range from -0.24 to -0.40 and most samples have higher $f_{Sm/Nd}$ ratios than the continental crustal average of -0.4 (Goldstein et al., 1984), suggesting some degree of fractionation from the crustal source. The T_{DM} (single stage Nd model age) values range from 1.99 to 2.62 Ga, and the T_{2DM} (two stage Nd model age) values range from 1.91 to 2.28 Ga. The higher $f_{Sm/Nd}$ ratios suggest that the T_{2DM} is appropriate for estimating the mean age of source materials (Keto and Jacobsen, 1987).

5. Discussion

The effect of thermal alteration in conodonts on the Nd isotopes is not well defined. Keto and Jacobsen (1987) suggested that CAI values up to and including 5 are acceptable for Nd analysis. In the data set of this study, however, all samples have consistent values even though conodonts have rather higher CAI values than 5, which probably suggests that the Nd isotopic composition in this study retains an original isotopic signature of contemporaneous seawater. Hence, this study could not address the CAI issue further. Testing the effects of CAI changes on Sr isotopes is easier

Table 2
Nd isotopic analytical results of the conodonts in the Hwajeol and Machari formations

Sample	^{143}Nd/^{144}Nd^{a}	2σ	^{147}Sm/^{144}Nd	$f_{s}^{Sm/Nd b}$	ε_{Nd} (0)^{c}	ε_{Nd} (515Ma)^{d}	Error^{e}	T_{DM} (Ga)^{f}	T_{2DM} (Ga)^{g}
Hwajeol Formation (Duwibong unit)									
DCH03	0.511262	0.000006	0.1487	−0.24	−11.43	−8.27	0.12	2.56	1.91
DCH13	0.511169	0.000007	0.1226	−0.38	−13.25	−8.37	0.14	1.99	1.92
DCH20	0.511170	0.000042	0.1329	−0.32	−13.23	−9.03	0.82	2.24	1.97
DCH25	0.511170	0.000011	0.1371	−0.30	−13.23	−9.30	0.21	2.36	1.99
DCH28	0.511176	0.000019	0.1249	−0.37	−13.11	−8.38	0.37	2.03	1.92
DCH31	0.511138	0.000010	0.1296	−0.34	−13.85	−9.43	0.20	2.21	2.00
DCH39	0.511211	0.000023	0.1472	−0.25	−12.43	−9.17	0.45	2.62	1.98
DCH40	0.511189	0.000018	0.1323	−0.33	−12.86	−8.62	0.35	2.18	1.94
Mean				−0.32	−12.92	−8.82	0.33	2.27	1.95
Machari Formation (Yeongweol unit)									
YCM08			0.1379						
YCM09			0.1337						
YCM14	0.511053	0.000019	0.1351	−0.31	−15.51	−11.45	0.37	2.52	2.16
YCM17									
YCM17br^{h}	0.511024	0.000010	0.1323	−0.33	−16.07	−11.84	0.20	2.49	2.19
YCM19	0.510943	0.000025	0.1189	−0.40	−17.65	−12.53	0.49	2.27	2.25
YCM23	0.510996	0.000027	0.1292	−0.34	−16.62	−12.18	0.53	2.45	2.22
YCM27	0.510941	0.000015	0.1245	−0.37	−17.69	−12.94	0.29	2.41	2.28
YCM34	0.511048	0.000008	0.1203	−0.39	−15.61	−10.58	0.16	2.13	2.09
Mean				−0.36	−16.53	−11.92	0.34	2.38	2.20

Total procedural blanks were around 20 pg for Sm, and 80 pg for Nd.

[a] Data normalized to ^{146}Nd/^{142}Nd=0.636151 and relative to La Jolla Nd value of 0.511860.

[b] $f_{s}^{Sm/Nd}=(^{147}Sm/^{144}Nd_{sample})/0.1967-1$.

[c] $\varepsilon_{Nd}(0)=[(^{143}Nd/^{144}Nd)_{sample}/0.511847-1]\times 10^{4}$.

[d] $\varepsilon_{Nd}(515Ma)=\varepsilon_{Nd}(0)-25.13\times f_{S}^{Sm/Nd}\times 0.515$.

[e] Reported errors are two standard deviations from the mean.

[f] $T_{DM}=1/\lambda\times\ln\{1+[(^{143}Nd/^{144}Nd)_{sample}-0.512359]/[(^{147}Sm/^{144}Nd)_{sample}-0.2136]\}$, $\lambda=6.54\times 10^{-12}/y$.

[g] $T_{2DM}=T_{DM}-(T_{DM}-T_{STRAT})[f_{cc}-f_{s}/f_{cc}-f_{DM}]$, T_{STRAT}=520Ma; f_{cc}=−0.4 ; f_{DM}=0.08592.

[h] YCM17br: brachiopod.

since the Sr ratios are assumed to be the same throughout the seawaters. In the case of the Nd isotope, it would be difficult to discriminate whether changes in the Nd isotopic compositions were associated with variable CAIs or with different water-masses. To test the effect of CAI requires a sedimentary basin that is known to have homogeneous water mass and that yields conodonts with various CAI values, however, it would be very difficult to obtain such a data set in reality.

Each sample analyzed for Nd isotopes contains various conodont taxa. Based on the variations in the ^{87}Sr/^{86}Sr ratios, Bertram et al. (1992) interpreted that using a different taxon was a possible source of error. They claimed that since there is a linear relationship between Nd concentration and ^{87}Sr/^{86}Sr ratios, analysis of Nd isotopes from different taxa may cause an error. However, for the conodonts from the same horizon they reported $\varepsilon_{Nd}(T)$ values of −6.13, −5.89, −7.08 for *Ozarkodina*, *Panderodus*, and *Dentacodina*, respectively. These are consistent values within a statistical error, therefore, these values can be treated as identical. Wright (1995), for the conodonts from the same whole rock sample, reported $\varepsilon_{Nd}(T)$ values of −5.89 and −6.35 for *Panderodus gracilis* and *Drepanoistodus suberectus*, respectively. These values are also within a statistical error. These results suggest that the intra or inter-taxon isotopic variation can be negligible in the Nd isotopic system.

The stratigraphic age of the Hwajeol and Machari formations is estimated at 515 Ma according to the Harland et al.'s (1990) time scale. Because the Harland et al.'s (1990) time scale, one of the widely adopted time scales, is based on relatively sparse calibrating points, the ages that are assigned to biozones or stages represent only linear interpolations from such calibration points. In general, most of the geologic time scales are the condensed time scale and the assignment of absolute ages to the samples results in uncertainties of the 10^6–10^7 year range. However, ε_{Nd} (T) values in this study show very small dispersion, less than 0.1ε unit, to the ±5 Ma variation of stratigraphic age. Staudigel et al. (1985) reported the ε_{Nd} (T) values of the 1.5–55 Ma old fish teeth and showed that those values are very close to the range of ε_{Nd} (0) in recent ferromanganese sediments and seawaters for the respective ocean. It suggests that Nd isotopic composition of a seawater mass does not easily change in such a short time interval. The error due to uncertainties in designation of absolute ages to the Hwajeol and Machari formations may be negligible.

The ε_{Nd} (T) values of the Hwajeol Formation range from -8.27 to -9.43 (average of -8.82) and those of the Machari Formation range from -10.58 to -12.54 (average of -11.92) (Table 2). The Machari Formation has more negative ε_{Nd} (T) values, about 3ε units, and thus older crustal source, about 0.25 Ga, than the Hwajeol Formation. Although the difference is small, it is consistently present in all samples. The Nd isotopic values of the literature cited in this study for comparison were renormalized to a ^{146}Nd/^{142}Nd value of 0.636151 and corrected using the values listed in Table 2. Where possible, the various time scales used in the previous studies were recalibrated to the Harland et al.'s (1990) time scale.

To test the paleogeography of the Yeongweol and Duwibong units using the Nd isotopic signatures, it is necessary to match the individual Nd isotopic data set with global ones. Most of the Nd isotopic studies for Paleozoic seawater were reported from Laurentia and Baltica. There are several Nd isotopic data for the ancient seawater during the Late Cambrian–Early Ordovician interval (Keto and Jacobsen, 1987, 1988; Chen et al., 1988; Kwon et al., 1991; Wright, 1995; Felitsyn et al., 1998) and these data are from analyzed results of various sample types such as brachiopods, conodonts, hyolithids, trilobites, and carbonates. The effect of different sample types on the Nd isotopic composition is not well defined. One should consider the latent effect of different sample types on the Nd isotopic composition. The Nd isotopic data from North China (Chen et al., 1988; *Cordylodus proavus* zone) show two different groups of ε_{Nd} values depending on the fauna used. The trilobites, hyolithids, and brachiopods have higher values than the conodonts. Chen et al. (1988) stated that the difference of ε_{Nd} (T) values may be affected by ecological factors. However, the Nd isotopic data of trilobites, hyolithids and brachiopods may have been affected by post-depositional changes. There is an example to show skepticism about the Nd signals determined from brachiopods. In the Keto and Jacobsen's (1987) data set, two brachiopod samples from Wisconsin, USA, with ages within an error range of the estimated ages show very different isotopic signatures, one with approximately -19, the other with approximately -14. In addition, Late Cambrian–Early Ordovician seawater values from inarticulate brachiopods determined by Keto and Jacobsen (1987) for Laurentia were more radiogenic than those from conodonts determined by Wright (1995). It seems that brachiopods are susceptible to post-depositional changes that will adversely affect the Nd isotopic signals. Similarly, trilobites, hyolithids, and acrotretids have higher ε_{Nd} (T) values than the conodonts in the Chen et al.'s (1988) data set. In this study, the value from brachiopods (YCM17br; *Oncagnostus machariensis* zone) is consistent with values from conodonts from the same rock specimen in the Machari Formation. Wright (1995) also reported that ε_{Nd} (T) value determined from inarticulate brachiopods in the Llanvirnian Table Head Group is consistent with other regional Laurentian seawater values of conodonts. The ε_{Nd} (515 Ma) value of -9.94 from conodonts (Kwon et al., 1991) in the Hwajeol Formation is consistent with values of the Hwajeol Formation in this study. Present-day Nd isotopic values on various sample types such as seawater, ferromanganese sediments, and biogenic phosphates from major oceans are within very close range of ε_{Nd} (0) for the respective ocean. These results indicate that Nd isotopic signatures determined from different, but relatively stable, sample types may be compatible. Nd isotopic variation depending on different faunal types may be generally insignificant if they are not severely altered. In the following discussion, however, the data analyzed from conodonts are selected to minimize the possible latent error. As discussed above, it is probable that conodonts are mineralogically more stable than other faunal types.

6. Nd isotope composition

Table 3 lists the Nd isotopic data determined from Cambro-Ordovician conodonts, which are compiled to examine the paleogeography and paleoceanography of the Duwibong and Yeongweol units.

The $\varepsilon_{\mathrm{Nd}}$ (T) values of Laurentia range from -12 to -23, whereas those of Baltica range from -5.5 to -9 (Keto and Jacobsen, 1987; Wright, 1995; Felitsyn et al., 1998) during the Late Cambrain–Early Ordovician interval (Fig. 5B). The conodont $\varepsilon_{\mathrm{Nd}}$ (510 Ma; *Cordylodus proavus* zone) data, avg. -8.15, from the Cambro-Ordovician boundary in the Jinlin Province, North China are similar to, but slightly different from, those of the Hwajeol (515 Ma) and Machari (515 Ma) formations. The $\varepsilon_{\mathrm{Nd}}$ (490 Ma) value of -11.90 from conodonts in the Early Ordovician Dumugol Formation in the Duwibong Unit has a slightly more negative signature than those of the Hwajeol Formation, but is very similar to those of the Machari Formation in the Yeongweol Unit. Most of the paleogeographic studies (e.g. Scotese et al., 1979, Lin et al., 1985; Burrett et al., 1990; Scotese and McKerrow, 1991; McKerrow et al., 1992; Metcalfe and Nicoll, 1994; Metcalfe, 1996) described that Asian terranes, including the Korean Peninsula, were located on the northwestern margin of Gondwanaland in the early Paleozoic. In these paleogeographic reconstrucitons, the South and North China blocks are located in tropical–subtropical positions at low latitude compared to Baltica which was situated at high latitude >30°S and show a large geographic and oceanographic separation from Laurentia and Baltica. Although the $\varepsilon_{\mathrm{Nd}}$ (T) values from the Hwajeol Formation and North China are similar to those from Baltica, the Nd isotopic signatures may be independent and different features.

Table 3
Nd isotopic data for conodonts from western Gondwanaland

Location	Age(Ma)[a]	ε_{Nd} (0)	ε_{Nd} (T)	Error	$T_{2\mathrm{DM}}$ (Ga)
Duwibong unit	515[b]	−12.92	−8.82	0.33	1.95
	490[c]	−11.33	−11.90	0.55	2.09
Yeongweol unit	515[d]	−16.62	−11.94	0.37	2.2
North China	510[e]	−12.64	−8.15	2.25	1.89
South China	472[f]	−16.08	−13.80	0.27	2.31
	447[g]	−15.10	−11.38	0.51	2.10
Armorica	482[h]	−10.22	−5.61	0.29	1.67
	477[i]	−11.55	−9.68	0.76	1.99

Calculation methods are the same as those of Table 1.

[a] After Harland et al.'s (1990) time scale.

[b] Hwajeol Formation in the Duwibong unit (this study).

[c] Early Arenig Dumugol Formation (Kwon et al., 1991).

[d] Machari Formation in the Yeongweol unit (this study).

[e] Cambro-Ordovician Boundary in the Jinlin Province (Chen et al., 1988; *Cordylodus proavus* zone), average value of two samples.

[f] Llanvirnian Kunitan Formation (Wright, 1995; *Pygodus serrus* zone).

[g] Caradocian Baota Formation (Wright, 1995).

[h] Early Arenig Seydisehir Formation in Turkey (Wright, 1995).

[i] Late Arenig Sobova Limestone in Turkey (Wright, 1995; *Didymograptus hirundo* zone).

The $\varepsilon_{\mathrm{Nd}}$ (T) values of the Hwajeol and Machari formations are slightly different from that of the North China. The stratigraphic ages of these data differ about 5 Ma. It is obvious that Nd isotopic composition of a seawater mass does not easily change in such a short time interval as demonstrated by Staudigel et al. (1985). The $\varepsilon_{\mathrm{Nd}}$ (T) values from North China, Hwajeol Formation and Machari Formation range from -8.15 to -11.92 and such a variation can occur in a single seawater mass. Considering a wide range of the $\varepsilon_{\mathrm{Nd}}$ (0) values in modern seawater (Fig. 5C), the small range of $\varepsilon_{\mathrm{Nd}}$ (T) may be regarded as a variation within a well-circulated seawater mass. Based on similar $\varepsilon_{\mathrm{Nd}}$ (T) values, it is possible to interpret the mean ages of crustal inputs to the respective basins to have been similar and/or that there was a strong oceanic gyre across the ocean. Unfortunately, there is no Nd isotopic data of conodonts from South China in the Late Cambrian–Early Ordovician interval. This hampers the paleoceanographic correlation between South China and other terranes. There are only two conodont data from South China (Table 3), one in the Llanvirnian and the other in the Caradocian. It is, therefore, difficult to directly compare the data of South China with those of the Hwajeol and Machari fomations and North China. However, the close $\varepsilon_{\mathrm{Nd}}$ (T) values of the Hwajeol and Machari fomations and North China indicate that the Duwibong and Yeongweol units shared a well circulated paleo-watermass with North China.

7. Tectonostratigraphic correlation

Despite a good deal of studies in various fields for a long time, the correlation of the Korean Peninsula with neighboring South and North China blocks is still in

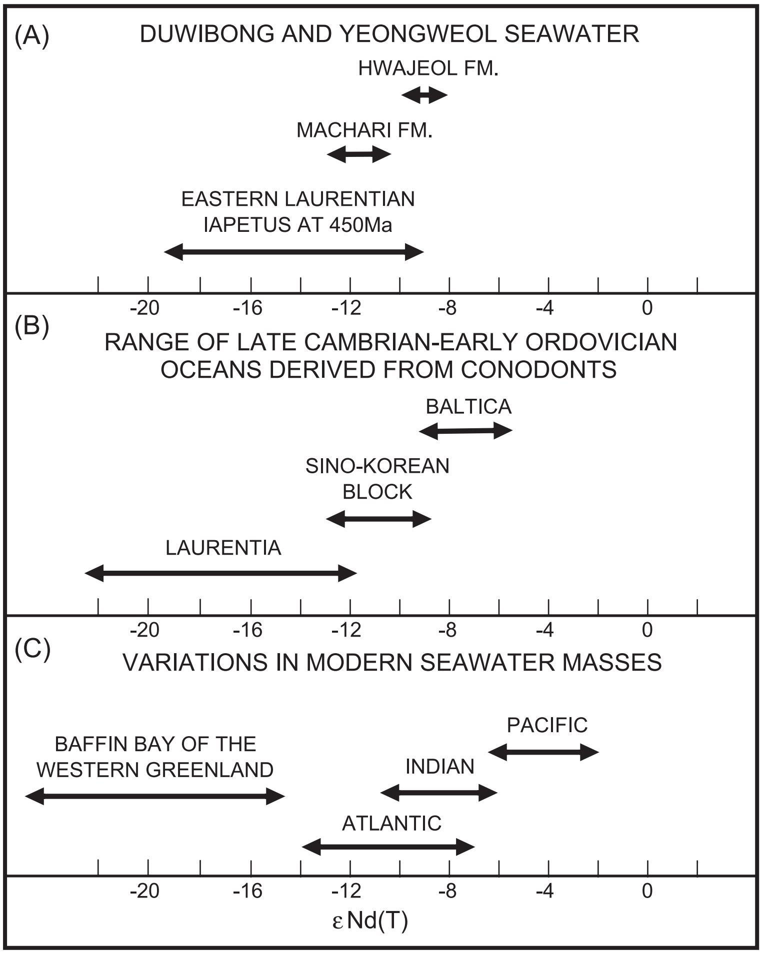

Fig. 5. This figure shows that the difference of ε_{Nd} (T) values between the Hwajeol and Machari formations falls within the ε_{Nd} range observed from a Nd-isotopically distinct and a well-circulated watermass (A, C) and that the Sino-Korean sea comprised an unique oceanic watermass in the early Paleozoic (B). The Nd isotopic data of conodonts are from Keto and Jacobsen (1987, 1988), Chen et al. (1988), Kwon et al. (1991), Wright (1995), Felitsyn et al. (1998), and this study.

dispute. As mentioned above, the previous tectonic interpretations (Cluzel et al., 1991a,b; Yin and Nie, 1993, 1996) correlated the Duwibong Unit with North China, whereas the Yeongweol Unit was correlated with South China based on the Cambrian trilobite faunal contrasts (Kobayashi, 1967) and the presence of Silurian strata (Lee, 1980). However, this interpretation has been questioned by recent studies on the sedimentology and biogeography of these rocks. Choi (1994, 1998) and Choi et al. (2003) reported close faunal similarities of the Tremadocian trilobite faunas between the Duwibong and Yeongweol units and between the two faunas and North China fauna. The Cambrian trilobite faunal contrast between the Duwibong and Yeongweol units can be attributed to a difference in sedimentary environments: the Hwajeol Formation in the Duwibong Unit was deposited in a shallow inner shelf setting, whereas The Machari Formation in the Yeongweol Unit was laid down in a deeper outer shelf setting. The Early Ordovician trilobite faunal similarity may have resulted from the change of depositional environment from the Cambrian deep water to the Tremadocian shallow marine setting in the Yeongweol Unit. Ordovician conodont faunas from the two units also show high similarites with that of North China (Lee and Lee, 1986, 1990;

Kim, 1988; Lee, 1990; Seo, 1990; Choi, 1993) which is included in the Midcontinent Realm, representing a low to mid-latitude, warm water fauna rather than that of South China which is referable to the North Atlantic Realm and represents a high latitude and/or cold water fauna (Charpentier, 1984; Bergstöm, 1990; Wang et al., 1996). Recently, Jeong and Lee (2000) analyzed quantitatively the degree of the provincialism of Upper Cambrian conodonts of the Duwibong and Yeongweol units and South and North China to resolve the Cambrian and Ordovician trilobite faunal affinity disparity. The quantitative analysis showed high faunal similarity between the Duwibong and Yeongweol units, and both conodont faunas of the two units have relatively higher bioprovincial affinities with that of North China than with that of South China. It seems possible trilobites and conodonts might have exhibited different degrees of provincialism at different periods and that the extent of their response to different sedimentary environments and their ecological modes might have differed.

Recent research on glauconite also supports this biogeographic correlation. Just above the Cambro-Ordovician boundary, a glauconite occurrence was reported from the Lower Ordovician Mungok Formation in the Yeongweol Unit (Lee and Paik, 1997) and from the Yeli Formation, Jilin Province, North China (Chen et al., 1988). The glauconites in the two formations are observed in the same conodont biozone, the *Cordylodus intermedius* zone (Chen et al., 1988; Choi, 1993). Kim and Lee (1999, 2000) reported glauconitic facies from the Lower Ordovician Dongjeom Formation in the Duwibong Unit, and stated that the occurrences of the glauconites in the correlative horizons in Duwibong and Yeongweol units and North China may indicate that the host sediments were under the influence of a coeval transgressive event in the same oceanic watermass. The similar Paleozoic stratigraphic sequences of North China and Korea and the unconformity between Late Ordovician and Late Carboniferous strata in both Korea and North China also support this correlation (Kim et al., 2001). Even if the presence of Silurian strata in the Jeongseon Unit of the Joseon Supergroup may weaken this correlation, Silurian and Devonian strata are also distributed in the northern and western flanks of the Sino-Korean platform (Zhao et al., 1993; Yin and Nie, 1996). Based on the compiled Pb and Nd isotope data for basement rocks from both the Yeongnam and Gyeonggi massifs, Cheong et al. (2000) suggest that the two Korean Precambrian massifs, the Yeongnam and Gyeonggi massifs, experienced a similar geologic history and belong to the same continental block, precluding the existence of a suture zone between the two massifs, and contradicting the conventional idea that the Yeongnam and Gyeonggi massifs are separate continental blocks correlated to the North and South China blocks, respectively. This interpretation is supported by the failed intracontinental rift setting of the Okcheon belt (Chough, 1981; Cluzel et al., 1991a) and the recent discovery of a late Precambrian metavolcanic rock in the Okcheon belt (Lee et al., 1998).

The similar Nd isotopic signatures among the Duwibong and Yeongweol units and North China and all the above lines of evidence strongly suggest that the Yeongweol Unit in the Joseon Supergroup is not correlated with South China but correlated with North China, and that the Korean Peninsula may have been included in a larger continental block including North China and the Korean Peninsula, the Sino-Korean block. This interpretation further implies that the collisional belt between the South and North China blocks may not extend into the Korean Peninsula. Recently, a similar tectonostratigraphic interpretation was proposed by Chang and Park (2001) and Ishiwatari and Tsujimori (2003).

However, the high-grade metamorphic textures preserved in east-trending folds and thrusts in the Imjingang belt (Cho et al., 1995; Ree et al., 1996; Chough et al., 2000) and the Gyeonggi shear zone in the northwestern portion of the Gyeonggi massif (Kim et al., 2000) are interpreted to be a result of the Permo-Triassic continental collision between the South and North China blocks, implying that the Imjingang belt is a possible condidate for the suture zone. These authors claimed that the HSZ is not a tectonic boundary between the South and North China blocks but an aggregate of narrow ductile shear zone formed by northwestward subduction of the Izanagi Plate during the Jurassic, and proposed that the collision between the Gyeonggi and Yeongnam massifs occurred along the new tectonic boundary, the South Korean Tetonic Line, during the early Triassic. Futhermore, they divided the Okcheon belt into two zones, the Okcheon Basin, belonging to the Gyeonggi massif, to the southwest and Taebaeksan Basin, belonging to the Yeongnam massif, to the northeast, and stated that the early Paleozoic Joseon Supergroup including all five units were deposited in a single basin, the Taebaeksan Basin. Therefore, further studies are required to resolve the complicated tectonic correlation of the Korean Peninsula, which provides a key for understanding the East Asian margin tectonics.

8. Paleogeography and paleoceanography

The evolution of Cambro-Ordovician paleogeography of the Chinese blocks can give us information for examination of the paleogeography and paleoceanography of the Korean Peninsula. There are two different opinions about the locations of the South and North China blocks in the early Paleozoic. Earlier studies of Burrett and Stait (1985), Lin et al. (1985) and Nie (1991) located the North China block in the Southern Hemisphere and the South China block in the Northern Hemisphere. Recent studies of Burrett et al. (1990), Metcalfe (1996), Zhao et al. (1996), and Cocks and Torsvik (2002), on the other hand, placed the two blocks in opposite positions to the above models. The available paleomagnetic data for the major Gondwana blocks indicate an anticlockwise movement of Gondwana during Cambrian time (Burrett et al., 1990; Kirschvink et al., 1997). If Asian terranes were included in Gondwana, the South and North China blocks would also have rotated anticlockwise. There are close faunal similarities in the Cambrian between North and South China, whereas in the Ordovician there are strong faunal differences (Burrett and Richardson, 1980; Burrett et al., 1990). The faunal differences are not only conspicuous in trilobites and cephalopods but also in conodonts (Burrett et al., 1990; Wang et al., 1996; Kobayashi, 1969). In particular, the Ordovician conodont fauna of South China shows strong faunal affinity with that of North Atlantic Realm representing a high latitude and cold water fauna, whereas Ordovician conodont fauna of North China are included in the Midcontinent Realm indicating a low to mid-latitude warm water fauna (Bergstöm, 1990; Wang et al., 1996). Scotese and McKerrow (1991) stated that the occurrence of the Early Ordovician cold, shallow-water trilobite *Neseuretus* in South China indicates biogeographic connections with Arabia and south-central Europe. There is a distinctive difference in the endemic trilobite taxa between the South and North China, implying a faunal separation between the two Chinese terranes during the Ordovician (Fortey and Cocks, 2003). The paleontological evidence supports the paleogeographic reconstructions of Burrett et al. (1990), Metcalfe (1996), Zhao et al. (1996), and Cocks and Torsvik (2002), and reflects the southward movement of the South China block accompanying the counterclockwiese rotation of the Gondwana during the early Paleozoic.

Metcalfe (1996) combined paleogeographic, tectonostratigraphic and paleomagnetic data, and presented the most reasonable positions of Asian terranes on the Indian–Australian margin of the Gondwanaland. He used the Scotese and McKerrow's (1991) global framework and described the part of Asian terranes in more detail. This model does not use the term, Paleotethys of Scotese and McKerrow (1991), which was used for the ocean separating Kazakhstan and Baltica from the western margin of Gondwana including the Asian terranes. In this model, the Paleotethys represents the ocean that was opened by Devonian clockwise rifting of the South and North China, Tarim and Indochina terranes from Gondwanaland. Most paleogeographic reconstructions do not describe the exact paleoposition of the Korean Peninsula. Fig. 6 is a paleogeographic map for the Late Cambrian–Early Ordovician of Metcalfe (1996) and shows the inferred location of the Korean Peninsula on the basis of the result of this study that the Korean Peninsula belongs to the Sino-Korean block including both North China and the Korean Peninsula. In this reconstruction, the Korean Peninsula is located at the low latitudinal position of the Northern Hemisphere in the vicinity of the paleoequator and is oriented toward the main Gondwanaland. The Sino-Korean block, therefore, is thought to be within an area frequently affected by storm systems such as tropical cyclones and winter storms, mostly occurring along the eastern sides of landmasses (Marsaglia and Klein, 1983). This location is supported by the observation that both the Duwibong and Yeongweol units contain the evidence of storm-influenced deposits (Lee, 1988; Paik and Lee, 1989; Lee and Kim, 1992; Yoo and Lee, 1997; Lee et al., 2001; Lee and Lee, 2003).

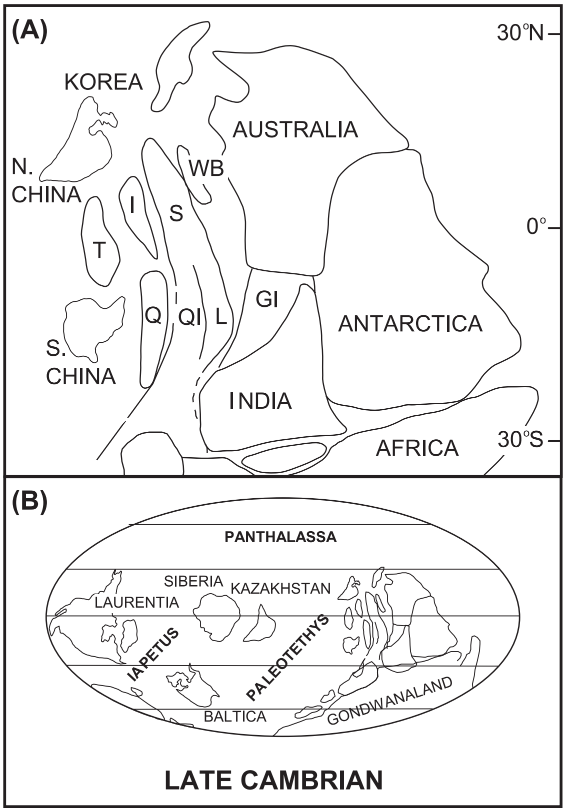

Fig. 6. (A) Reconstruction of northeastern Gondwana for the Late Cambrian–Early Ordovician, showing the postulated positions of the East and Southeast Asian terranes (modified after Metcalfe, 1996). The estimated location of the Korean Peninsula is delineated. Abbreviations: T—Tarim, I—Indochina, Q—Qaidam, QI—Qiangtang, L—Lhasa, S—Sibumasu, WB—West Burma, GI—Greater India. (B) Paleogeographic map for the Late Cambrian–Early Ordovician compiled from Scotese and McKerrow (1991) and Metcalfe (1996).

The early Arenig $\varepsilon_{\mathrm{Nd}}$ (490 Ma) value of −11.90 from the Dumugol Formation in the Duwibong Unit is different from the coeval value (482 Ma, −5.6) of the Armorican microplate, which was located on the southeastern marginal Gondwanaland and bordered 'southern Paleotethys' of Scotese and McKerrow (1991) (Table 3). Wright (1995) reported that Avalonia, a microcontinental block, which was adjacent to the northwestern margin of Africa and the Armorican plate during the Cambrian and rifted away from Gondwana in the Ordovician (Scotese and McKerrow, 1991; McKerrow et al., 1992; Fortey and Cocks, 2003), has Nd isotopic signatures identical with those from the Amorica during the Llandeilo–Caradoc. It is likely that there was a strong circulation in the 'southern Paleotethys'. This interpretation and the consistent Nd isotopic signatures of the Duwibong and Yeongweol units and North China in this study suggest that the Duwibong seawater, and probably the Yeongweol and North Chinese seawaters, were not affected by the 'southern Paleotethys' gyre but comprised another unique oceanic watermass, i.e., a part of 'northern Paleotethys' of Scotese and McKerrow (1991), in the early Paleozoic. The Llanvirnian value (472 Ma, −13.80; *Pygodus serrus* zone) from South China is different from the Arenigian values (477–482 Ma, −9.7 to −5.6) of the Armorican microplate (Table 3), which suggests that although South China experienced southward movement during the Early Ordovician, the South Chinese seawater might have not been affected by the 'southern Paleotethys' gyre. Although direct comparison is inappropriate because of an age difference of 18 Ma, the Llanvirnian value from South China is similar to the early Arenigian $\varepsilon_{\mathrm{Nd}}$ value (490 Ma; −11.90) from the Dumugol Formation in the Duwibong Unit. It is possible that South China might have been under the influence of the 'northern Paleotethys' gyre together with North China and Korean Peninsula in Ordovician time. If the paleogeographic map modified after Metcalfe (1996) is accepted, the northwest Gondwana margin may have been covered with epeiric seas bounded by several microcontinents, thus interrupting a large-scale ocean circulation. Furthermore, the Ordovician bioprovincial similarities between the Korean Peninsula and North China but the contrasts between the South and North China, as discussed above, suggest that South Chinese seawater must have been another separate watermass from the Sino-Korean seawater during the Ordovician. Therefore, the similar $\varepsilon_{\mathrm{Nd}}$ (T) values between the South China and the Duwibong seawater may reflect that the average age of the input materials into the each local epeiric watermass might have been not so much different. To reveal the paleoceanographic relation between the South China and the Sino-Korean platforms, more Nd isotopic data and further studies are needed.

The difference of the $\varepsilon_{\mathrm{Nd}}$ (T) values of about 3ε units between the Hwajeol and Machari formations can be explained as follows. This discussion starts at the provisional conclusion that both the Duwibong and

Yeongweol units were part of the Sino-Korean block. As observed in modern seawater (Fig. 5C), the Nd isotopic composition of a given ocean can show a wide range of ε_{Nd} (0) values. The $^{143}Nd/^{144}Nd$ ratios of seawater can vary significantly not only among the major ocean basins but also within each basin. In restricted ocean basins, the variation can go to extremes. Stordal and Wasserburg (1986) showed that Baffin Bay water of the western Greenland has the ε_{Nd} (0) range from -9.0 to -26, the largest variation in ε_{Nd} (0) values in modern seawater masses (Fig. 5C). Holmden et al. (1998) analyzed Nd isotopic signatures from conodonts of 454 Ma (*Amorphognathus tvaerensis* zone) in the eastern Laurentian Iapetus and showed that the epeiric seas have large differences in ε_{Nd} (T) values (from -19 to -7; Fig. 5A). Holmden et al. (1998) interpreted this variation to result from restricted circulation within epeiric seas and between epicontinental and oceanic environments. They identified three aquafacies in the eastern Laurentian Iapetus based on the ε_{Nd} ranges. It is notable that the difference of ε_{Nd} (T) values between the Hwajeol and Machari formations falls within the variation in an aquafacies in the eastern Laurentian Iapetus. The difference of the ε_{Nd} (T) values between the Hwajeol and Machari formations, thus, does not necessarily mean different watermasses in terms of Nd isotopes, and does not mean restricted or very weak circulation. Secondly, the different sedimentary environments of the Hwajeol and Machari formations can be regarded as a possible factor. It is expected that if the sedimentary environment of the Machari Formation represents deeper water than that of the Hwajeol Formation, the watermass for the Machari Formation may have interacted more intensively with open ocean. One sample, YCM34 (*Tonkinella* zone), from the lowest Machari Formation has the lithology of bioclastic grainstone to packstone, which suggests that the depositional setting was inner shallow carbonate platform. The ε_{Nd} (T) value from YCM34 (Table 2) does not show a large variation compared to the values of the other samples from an outer platform-slope setting. This suggests that there was a more or less strong circulation between the inner and outer carbonate platform during the deposition of the Machari Formation. However, it is not clear if the watermass of the Hwajeol Formation was restricted from the open ocean. The difference in depositional setting may not be a direct cause of ε_{Nd} (T) variation between the Hwajeol and Machari formations. Therefore, the slight difference of Nd isotopic compositions between the Hwajeol and Machari formations probably reflects the difference in the ages of local continental drainage.

9. Conclusions

To reveal the paleogeography and paleoceanography of the Korean Peninsula during the early Paleozoic, this study analyzed the Nd isotopic composition of the Upper Cambrian conodonts of the Duwibong and Yeongweol units. The difference of the ε_{Nd} (T) values between the Upper Cambrian Duwibong and Yeongweol units is about 3ε units. Compared to a wide range of the ε_{Nd} (0) values in the modern oceanic basins, the slight difference can be regarded as a variation in a same paleo-watermass and it probably reflects the difference in the ages of local continental source materials drained into the Duwibong and Yeongweol paleo-seawaters.

The conodont ε_{Nd} (510 Ma; *Cordylodus proavus* zone) values from the North China block are consistent with those from Upper Cambrian Duwibong and Yeongweol seawater, and this suggests that the Duwibong and Yeongweol units shared a well circulated paleo-watermass with North China. Considering the available early Paleozoic paleogeographic reconstructions, the ε_{Nd} (T) range, from -8.15 to -11.92, of North China, Duwibong and Yeongweol units indicates that the Nd isotopic signatures are independent of Laurentia and Baltica and thus forms a unique feature. Futhermore, the Nd isotopic signature of the Ordovician Duwibong Unit is different from coeval values of ‘southern Paleotethys’ of Scotese and McKerrow (1991) and this may indicate that the Duwibong, Yeongweol and North Chinese seawater comprised another unique oceanic watermass, i. e., a part of ‘northern Paleotethys’, in the early Paleozoic.

Using the Nd isotopic analysis, this study revealed the same paleoceanography of Duwibong and Yeongweol units and North China in the Late Cambrian. In contrast to the previous tectonic interpretations, this result and available other studies discussed in this study suggest that the Yeongweol Unit in the early Paleozoic Joseon Supergroup should not be correlated with South China but with North China, and that the

Korean Peninsula and North China block may have been included in a larger continental block, the Sino-Korean block. However, there are still some different claims that the collisional belt between the South and North China blocks may extend into the Korean Peninsula and that the Imjingang belt might be a possible candidate for the suture zone. Therefore, more work is needed to resolve the long-standing problem of the tectonic correlation of the Korean Peninsula with the neighboring South and North China blocks.

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