

Stable Oxygen and Carbon Isotope Profiles of the Bivalve Shells collected from Coastal Regions of Korea: Comparison of the Coastal Water Properties

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Two marine bivalve shells were collected from the eastern and western coastal regions of Korea, respectively. Stable oxygen and carbon isotope profiles are constructed using the incremental sampling along the axis of maximum growth to provide the continuous $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records, which register the physical, biological and chemical properties of seawater where the organisms live. Cycles in the $\delta^{18}\text{O}$ profiles are interpreted as annual along with the identification of annual growth bands; the maximum $\delta^{18}\text{O}$ values correspond with the coldest temperature of seawater whereas the minimum $\delta^{18}\text{O}$ values with the warmest temperature. The primary control on the amplitude of the $\delta^{18}\text{O}$ profiles is seasonal variation of seawater temperature. The offset of the baseline between $\delta^{18}\text{O}$ values of the two specimens is attributed to differences in both temperature and seawater $\delta^{18}\text{O}$ values between two localities. The $\delta^{13}\text{C}$ profiles show the similar seasonality of carbon cycling associated with phytoplankton productivity. The offset in the $\delta^{13}\text{C}$ profiles between two specimens may be, as in the case of oxygen isotope profile, attributed to the different $\delta^{13}\text{C}$ value of the seawater DIC (dissolved inorganic carbon) between the western coast and the eastern coast. Relationships between the shell isotopic composition and the coastal water properties of shell growth are readily interpreted from the $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ pair diagram of the shell isotope data, similar to the use of salinity- $\delta^{18}\text{O}$ diagram for identifying water masses. The preliminary stable isotope results of this study suggest that mollusk shell isotope geochemistry may be useful to monitor the properties of water masses in the coastal and inner shelf setting around Korea and improve the interpretation of paleoceanography, provided the fossil mollusks are well preserved.

INTRODUCTION

Since the pioneering work of Urey (1947), the stable oxygen and carbon isotopic composition of calcium carbonate in the skeletons of marine invertebrates has provided important information about the environment in which the organisms lived. The stable oxygen isotopic composition of any given biogenic carbonates reflects both the temperature and oxygen isotopic composition of the ambient seawater from which they were precipitated (Epstein *et al.*, 1953). Carbon isotope profiles also contain considerable information on seasonal water-column dynamics related to the carbon transport and cycling, but biological influences are not as well understood and interpretation is more uncertain. Nevertheless, because mollusks secrete shell carbonate incrementally over the growth season, a time-series of ambient seawater conditions recorded in

the shell chemistry can be investigated by detailed serial sampling of the shell at a closely spaced intervals.

Many previous investigations have explored the relationship between the oxygen and carbon isotope ratios of shell carbonates and the environmental conditions in which the organisms grew. In particular, stable isotope profiles of bivalve shells from a sequential sampling method provide a fine-resolution record of environmental changes during the growth of the mollusks (Killingley and Berger, 1979; Williams *et al.*, 1982; Arthur *et al.*, 1983; Jones *et al.*, 1983; Krantz *et al.*, 1987; Romanek and Grosman, 1989; Weidman *et al.*, 1994; Khim *et al.*, 1996). Those studies have been used to track annual and seasonal marine temperature cycles, to detect seasonal hydrographic event such as upwelling on the continental shelves, and to identify role of symbiotic bacteria in deep-sea bivalves.

Recently, a variety of geological and oceanographic research documents the stable oxygen and carbon isotope data from seawater and shell carbonates (recent and fossil) in Korea (Kang *et al.*, 1994; Park and Lee, 1994; KORDI, 1995; Woo *et al.*, 1995; Woo and Park, 1996). Some studies allow a quantitative assessment of paleotemperature ranges based on the oxygen isotope data obtained from a bulk carbonate of fossil shells (Woo *et al.*, 1995). Such recent investigations enhanced to examine the preliminary properties of paleoseawater in various geologic events, however, the isotope data from the live shells are not enough to understand the present condition of marine system. Thus, more thoroughgoing investigation on the modern environment based on the isotope data of live shells would be necessary for the better paleoenvironmental reconstructions.

This study addresses the potential factors controlling the stable isotopic composition of the shell carbonate of bivalves living in coastal waters of Korea. The two fundamental effects on the oxygen isotope values are seasonal temperature cycles and water-mass properties, both of which are not entirely independent because temperature variation is linked with water mass. Significant variation in water mass properties would be expected from the changes in the shell isotopic composition. The results are discussed with respect to temperature, salinity, and seawater $\delta^{18}\text{O}$ from the coastal region of Korea. These data allow a comparison of the relative effects on the shell isotopic composition of oceanographic processes, in particular property variation (e.g., temperature or salinity) associated with the coastal setting around the Korean Peninsula. The primary objective of the present work is to document the detailed stable oxygen and carbon isotope profiles in order to better examine the relationship between mollusk shell isotopic composition and seasonal temperature, salinity, and seawater $\delta^{18}\text{O}$ variations of the Korean coastal waters.

MATERIALS AND METHODS

A living specimen (YS-1, 65 mm of shell height) of the bivalve, *Cyclina sinensis*, was collected from the subtidal flat in the Namyang Bay, west coast of Korea (Fig. 1 and 2a). This species is common in the sandy-to-muddy sediments of intertidal to subtidal environments and is distributed on the coasts of Korea, Japan, and China (Habe, 1977). Another

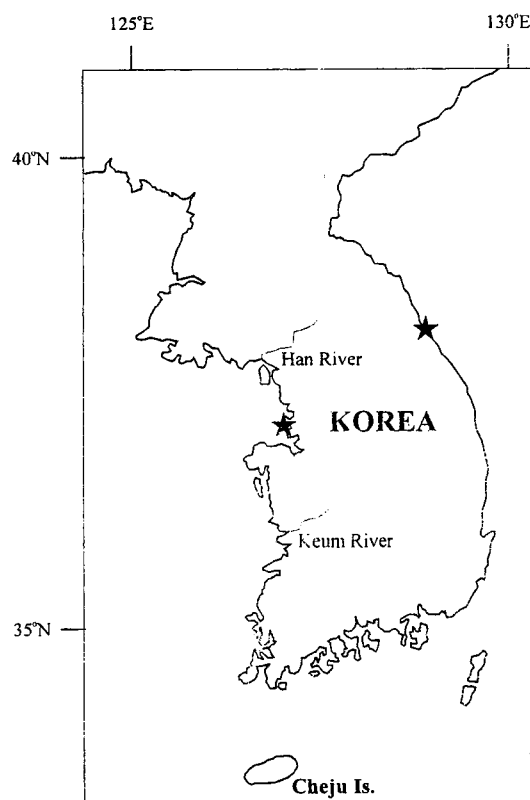


Fig. 1. Collection sites (stars) of bivalve shells in this study. A living bivalve specimen, YS-1 (*Cyclina sinensis*) was collected from the tidal flat in the Namyang Bay, west coast of Korea. Another remnant (dead-form) shell specimen, ES-1 (*Spisula sachaliensis*) was obtained from the beach near the Namdaechun (Yang Yang), east coast of Korea.

specimen (ES-1, 105 mm of shell height), *Spisula sachaliensis*, was also obtained from the coastal beach near the Namdaechun (Yang Yang), east coast of Korea (Fig. 1 and 2b). *S. sachaliensis* is one of the cold species that are dominant in the sandy bottom of shallow water (20 to 30 m in depth) off the eastern coast of Korea (Habe, 1977; Kang and Kim, 1983; Je, 1993). The specimen ES-1 was not alive (*in situ*) at the time of collection, but might be transported from adjacent nearshore or inner shelf by the storm.

The specimens were washed and soaked in a 5% solution of reagent-grade sodium hypochlorite for 24 hours and then rinsed in distilled deionized water to remove organic matter from the external shell layer. A serial shell-sampling was conducted from the outer layer along the axis of maximum growth using a dental drill with a 0.5 mm bur mounted in a handheld drill (Jones *et al.*, 1983; Krantz *et al.*, 1987). X-ray diffraction analyses of powders from each spec-

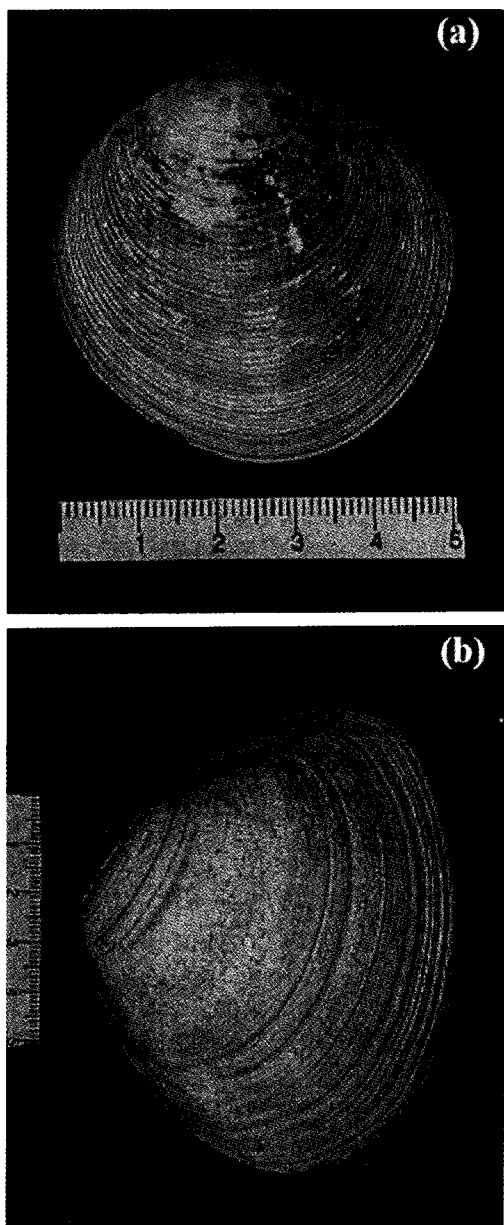


Fig. 2. Photographs of bivalve shells (a) specimen YS-1, *Cyclina sinensis* and (b) specimen ES-1, *Spisula sachaliensis*. The sampling groove of calcium carbonate powders for isotope analyses can be seen in *C. sinensis*. Scales are in centimeters.

imen indicate that shell was composed of aragonite.

Isotopic determinations were made on 18 discrete powder samples secured from 41 to 58 mm and from 68.5 to 87 mm shell height from specimens YS-1 and ES-1, respectively. Individual carbonate powder samples consisted of 2~3 mg of carbonate and were stored in pharmaceutical gelatin capsules, which were sent to mass spectrometer facilities at the University of Maine. After reaction in 100% phosphoric acid at 90°C in an auto-carbonate device,

the liberated CO₂ gas was analyzed with a VG Prism stable isotope mass spectrometer equipped with triple collectors and micro-inlet system. All values are reported in the standard δ notation of permil (‰) relative PDB (Pee Dee Belemnite) reference following the method of Craig (1957) as below:

$$\delta^{18}\text{O} (\text{‰}) = \left[\frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}} - (^{18}\text{O}/^{16}\text{O})_{\text{standard}}}{(^{18}\text{O}/^{16}\text{O})_{\text{standard}}} \right] \times 1000$$

$$\delta^{13}\text{C} (\text{‰}) = \left[\frac{(^{13}\text{C}/^{12}\text{C})_{\text{sample}} - (^{13}\text{C}/^{12}\text{C})_{\text{standard}}}{(^{13}\text{C}/^{12}\text{C})_{\text{standard}}} \right] \times 1000$$

Precision of the analyses, based on the difference among duplicate samples of carbonate powders, averaged 0.1‰ for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$.

RESULTS AND DISCUSSION

Oxygen isotope profiles

The stable oxygen and carbon isotope profiles of two bivalves (specimen YS-1 and specimen ES-1) are illustrated in Fig. 3 and the isotope data are listed in Table 1. Variations in the oxygen isotope profiles of the mollusk shell specimens are interpreted as being controlled primarily by seasonal changes of seawater temperature based on the thermodynamic properties of oxygen isotope (Urey, 1947). "Lighter" or more negative $\delta^{18}\text{O}$ values in the shell oxygen isotope profiles indicate warmer seawater temperature during summer season whereas "heavier" or more positive values indicate colder temperature during winter season.

Certain marine invertebrate organisms possess annual growth increments in their skeletons analogous to annual rings in trees (Rhoads and Lutz, 1980). Just as tree rings record climatic information in terrestrial settings, systematic variations in the size or properties of annual growth increments in the skeletons of marine organisms can provide a record of the environmental or climatic conditions of the marine realm. Annual layering can be usually observed in the majority of bivalve mollusks to determine the age and growth rate (Lutz and Rhoads, 1980; Jones, 1983; Jones *et al.*, 1986). Such growth increments of bivalves are often well preserved in the outer shell layer, exhibiting the cyclic and periodic shell growth patterns. The specimen YS-1 had dark growth bands which were equivalent to the heaviest $\delta^{18}\text{O}$ values (Fig. 3a). Recent sclerochronological analyses of marked and recovered exper-

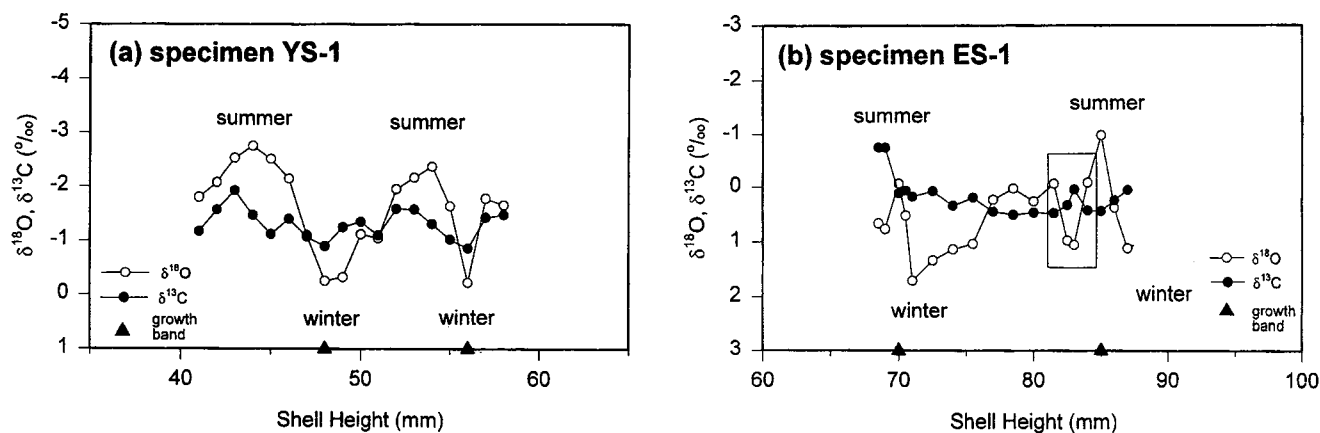


Fig. 3. (a) The oxygen and carbon isotope profiles for specimen YS-1 with $\delta^{18}\text{O}$ scale reversed so that lighter $\delta^{18}\text{O}$ values representing "warm" temperatures are at the top of the vertical scale. The positions of growth bands that are visible on the shell exterior are indicated by solid triangles along the horizontal axis. (b) The oxygen and carbon isotope profiles for specimen ES-1. The inset box represents the possible occurrence of seasonal and intermittent cold water before summer.

Table 1. Summary of stable oxygen and carbon isotope data measured from the mollusk shell specimens YS-1 and ES-1

Specimen YS-1 (<i>C. sinensis</i>)				Specimen ES-1 (<i>S. sachalinensis</i>)			
Sample Number	Shell Height (mm)	$\delta^{18}\text{O}$ (‰)	$\delta^{13}\text{C}$ (‰)	Sample Number	Shell Height (mm)	$\delta^{18}\text{O}$ (‰)	$\delta^{13}\text{C}$ (‰)
1	41	-1.80	-1.17	1	68.5	0.67	-0.75
2	42	-2.07	-1.57	2	69.0	0.77	-0.75
3	43	-2.53	-1.92	3	70.0	-0.06	0.12
4	44	-2.75	-1.47	4	70.5	0.53	0.07
5	45	-2.50	-1.12	5	71.0	1.71	0.18
6	46	-2.14	-1.40	6	72.5	1.34	0.08
7	47	-1.10	-1.07	7	74.0	1.14	0.35
8	48	-0.25	-0.90	8	75.5	1.04	0.20
9	49	-0.32	-1.25	9	77.0	0.24	0.46
10	50	-1.12	-1.35	10	78.5	0.03	0.52
11	51	-1.05	-1.10	11	80.0	0.27	0.48
12	52	-1.95	-1.59	12	81.5	-0.06	0.49
13	53	-2.16	-1.58	13	82.5	0.98	0.34
14	54	-2.37	-1.31	14	83.0	1.06	0.05
15	55	-1.64	-1.03	15	84.0	-0.08	0.44
16	56	-0.22	-0.86	16	85.0	-0.98	0.45
17	57	-1.78	-1.43	17	86.0	0.39	0.25
18	58	-1.66	-1.48	18	87.0	1.12	0.06

iments indicate that the presence of growth cessation marks (annual growth bands) in the species of Veneridae is coincident with the cold winter season (Tanabe and Oba, 1988). Thus, the formation of annual growth bands on the specimen YS-1 can be regarded as annual. In addition, the oxygen isotope profile confirms the visual identification of growth bands, exhibiting an apparent annual cycles. On the other hand, the specimen ES-1 shows that the growth bands appear to coincide closely with the lightest $\delta^{18}\text{O}$ values (Fig. 3b). In this specimen, each annual growth increment seems to be formed during the summer season defined by the $\delta^{18}\text{O}$ record. It was reported that the growth bands of *S.*

sachalinensis were formed annually between August and September during late summer (Kato and Hamai, 1975; Kang and Kim, 1983). However, just because the specimen ES-1 was not obtained as a living one, it needs to verify further with the controlled sampling.

The oxygen isotope profile of specimen YS-1 exhibits the two distinct seasonal cycles over the shell height of sampling interval, which corresponds with the annual pattern of shell growth increment formation (Fig. 3a). Both amplitudes are similar each other with about 2.5‰. From the $\delta^{18}\text{O}$ values and cyclic pattern, two winters and summers can be easily identified with supplementary diagnosis of

annual growth bands. Among them, two winters are almost consistent in $\delta^{18}\text{O}$ values, but the summer $\delta^{18}\text{O}$ values are a little different due to the interannual variability. During the winter months, the coastal water with the lowest temperature is well mixed to the bottom, whereas different thermal maximum conditions can be achieved in the summer seasons. The most positive $\delta^{18}\text{O}$ value in the record is -0.22‰ and the most negative is -2.75‰ (Table 1). A profile mean of -1.63 (s.d., ± 0.80) ‰ was calculated.

Based on the oxygen isotope profile of specimen YS-1, this species seems to record the seasonal variation of hydrographic properties (e.g., temperature) in the ambient coastal water of tidal flat setting. Seasonal variation of seawater temperature calculated from the change of $\delta^{18}\text{O}$ values on the basis of the oxygen isotopic fractionation (-0.23‰C/‰ ; Grossman and Ku, 1986) records the range of approximately 11°C . Due to the lack of seawater $\delta^{18}\text{O}$ values on this locality, the precise maximum and minimum temperatures are not able to be estimated. This calculated seasonal temperature range seems to be less than the natural variation of seawater temperature in this coastal environment. The main reason that the $\delta^{18}\text{O}$ profile of specimen YS-1 records the incomplete seasonal range of seawater temperature is attributed to the cessation of shell growth over the some range of seawater temperature (Krantz *et al.*, 1987; Tanabe and Oba, 1988; Weidman *et al.*, 1994). In addition, because the resolution of sampling (1 mm interval) is not high enough to cover the complete shell growth, the much wider range of seasonal variation would not be obtained.

In comparison, specimen ES-1 has a similar and clear annual cycle in the $\delta^{18}\text{O}$ profile (Fig. 3b). A total range of the $\delta^{18}\text{O}$ profile is approximately 2.7‰ from the most positive $\delta^{18}\text{O}$ value in the record of 1.71‰ to the most negative value of -0.98‰ (Table 1) and the average $\delta^{18}\text{O}$ value of the profile is 0.56 (s.d., ± 0.66) ‰ , which is heavier by about 2.0‰ than that of specimen YS-1. The oxygen isotope profile of this specimen also records the seasonal variation of seawater temperature and different summer $\delta^{18}\text{O}$ values seems to be due to the interannual variability. Seasonal temperature range estimated from the amplitude of $\delta^{18}\text{O}$ profile is about 12°C with assumption that the oxygen isotopic fractionation depends solely on the temperature, not the $\delta^{18}\text{O}$ value of seawater (Epstein *et al.*, 1953; Grossman and Ku, 1986). In this

locality, annual fluctuation of salinity is minimal at least for the habitat of *S. sachalinensis* (NFRDA, 1996). This suggests the cyclic pattern in the $\delta^{18}\text{O}$ profiles of this specimen mostly reflect the annual fluctuation of seawater temperature during the shell growth.

In the $\delta^{18}\text{O}$ profile of specimen ES-1, one of the distinguishing features is the occurrence of heavy ^{18}O values during the late spring (at around 83 mm shell height) before the culmination of summer season (Fig. 3b). The more positive $\delta^{18}\text{O}$ values over the warm temperature season can be attributed to the cold water appearance. In the adjacent area at collection site of specimen ES-1, the upwelling events have not usually been observed (pers. cumm. with Dr. Kim, K.). In contrast, the wind-induced upwelling events are well recorded in the southern part of eastern coast (Byun, 1989). Thus, the inversed pattern of isotope profile may result from the intermittent and seasonal appearance of the cold water that is intensified to flow southward (Kim and Kim, 1983; Kim *et al.*, 1991). However, an insufficient interpretation is the duration of cold water event, which has to be consistent with the occurrence of heavier $\delta^{18}\text{O}$ values in the isotope profile. Therefore, in this situation it is necessary to substantiate this character of isotope profile with better specimens in a control of physical oceanographic aspects. If this can be verified, the living mollusk shell along with stable isotope profile are one of the most potential agent to record the cold water appearance in the East Sea coastal setting.

Carbon isotope profiles

The causes of variation in carbon isotopes of biogenic carbonates are less well understood than those of oxygen isotopes because of the interaction with both physical-chemical and biological processes. The potential influences on shell $\delta^{13}\text{C}$ include the environmental conditions such as the ambient temperature of seawater, regional primary productivity, and the concentration of dissolved inorganic carbon (Rubinson and Clayton, 1969; Emrich *et al.*, 1970; Grossman and Ku, 1986; Romanek *et al.*, 1992). The $\delta^{13}\text{C}$ of the seawater DIC reservoir is also influenced by the input of terrestrial organic matter with relatively lighter $\delta^{13}\text{C}$ values and dissolved carbonate species (Mook and Vogel, 1968). Additionally, physiological effects and food source may affect mollusk shell $\delta^{13}\text{C}$

values (Krantz *et al.*, 1987). Other biological effects include the incorporation of metabolically produced CO_2 into the shell, growth rate, and ontogeny (Tanaka *et al.*, 1986). However, the main source of carbon for the shell carbonate is known as the DIC of seawater (Kroopnick, 1980).

The carbon isotope profile of specimen YS-1 displays cyclic variations similar to the oxygen isotope profile, but is indistinct in seasonality (Fig. 3a). Prominent negative peaks in the $\delta^{13}\text{C}$ profile occur before the summer peaks identified by the $\delta^{18}\text{O}$ profile. Overall annual range of the $\delta^{13}\text{C}$ variation is about 1.0‰ and the mean $\delta^{13}\text{C}$ value for the profile is calculated as -1.31 (s.d., ± 0.27)‰. Seasonal trends are discernible in the $\delta^{13}\text{C}$ profile of specimen YS-1, with more positive $\delta^{13}\text{C}$ values in the winter and more negative values in the late spring or early summer. In this study, the $\delta^{13}\text{C}$ profiles of the shells would be interpreted as primarily recording changes in the $\delta^{13}\text{C}$ of seawater DIC, which in turn is controlled largely by seasonal phytoplankton productivity (Killingley and Berger, 1979; Arthur *et al.*, 1983; Krantz *et al.*, 1987).

Earlier studies on the carbon isotope profiles (Killingley and Berger, 1979; Arthur *et al.*, 1983; Krantz *et al.*, 1987) proposed hypothetical models which emphasized the role of phytoplankton productivity and water-mass movement on the $\delta^{13}\text{C}$ of mollusk shell carbonate. Phytoplankton fractionates CO_2 during photosynthesis producing organic matter which is isotopically very light (approximately -20‰). In this condition, $\delta^{13}\text{C}$ of seawater becomes heavier and more heavy carbon can be easily incorporated into the formation of shell carbonate. On the other hand, isotopically light CO_2 is released from these organic matters during decomposition at depth causing $\delta^{13}\text{C}$ depletion in the bottom-water ΣCO_2 (Kroopnick, 1980). It results in the lighter trend of $\delta^{13}\text{C}$ values in the profile. Therefore, seasonal changes in the $\delta^{13}\text{C}$ of seawater DIC of coastal areas may be controlled by hydrographic processes and the resulting patterns of phytoplankton productivity.

The shell $\delta^{13}\text{C}$ profile of specimen ES-1 is also shown in Fig. 3b. In contrast to the profile of specimen YS-1, the $\delta^{13}\text{C}$ values of specimen ES-1 are almost consistent during the year which was identified from the $\delta^{18}\text{O}$ values. The total range of the profile is 1.27‰ which is similar to that of YS-1, but this wider range is caused by the lighter value of first two samples. Over the shell height between 70

mm and 83 mm, a little variation was observed as much as just 0.4‰. The mean $\delta^{13}\text{C}$ for the profile is 0.17 (s.d., ± 0.37)‰, which is more positive by approximately 1.5‰ than that of specimen YS-1. Compared with the pattern of $\delta^{13}\text{C}$ variation in specimen YS-1, the carbon isotope profile of specimen ES-1 shows that the variation is not significant, which may reflect little change in the $\delta^{13}\text{C}$ value of seawater DIC controlled largely by phytoplankton activity. However, in the comparison between two profiles, the difference between habitat depth of two specimens is necessary under consideration. Specimen YS-1, *C. sinensis* lived in the inter- to subtidal environment whereas the specimen ES-1, *S. sachalinensis* generally lived in the inner shelf area of water depth up to 20 to 30 m. This different condition in water depth may cause the inconsistent behavior and transport of carbon in the coastal waters.

Coastal water properties compared between isotope profiles of two specimens

The comparison in the oxygen and carbon isotope profiles between two bivalve specimens is represented in Fig. 4. At the first glance, the overall values between two profiles are distinctly differentiated; the isotope values of specimen YS-1 are much lighter than those of specimen ES-1. Since the oxygen isotope profiles show a seasonal periodicity, the strongest signal in the oxygen isotope profile can be interpreted as recording primarily seasonal temperature cycles. Thermodynamically and theoretically, the deviation between the baselines (overall heaviest values) of each oxygen isotope profiles can be explained as the temperature difference. In other words, the baselines of each profiles representing the heaviest $\delta^{18}\text{O}$ values are equivalent to the lowest temperature of cold winter season. Thus, in consideration of the thermodynamic behavior (Grossman and Ku, 1986), the offset (about 2.0‰) between two baselines can be calculated as the difference of about 9°C in seasonal winter temperature (Fig. 4a). However, this temperature gap would not be totally acceptable.

The oxygen isotopic composition of marine carbonate is also controlled by the oxygen isotopic composition of the seawater itself from which the carbonate precipitated (Epstein *et al.*, 1953). In this case, the large part of difference of $\delta^{18}\text{O}$ value (as much as 2.0‰) between two isotope profiles may

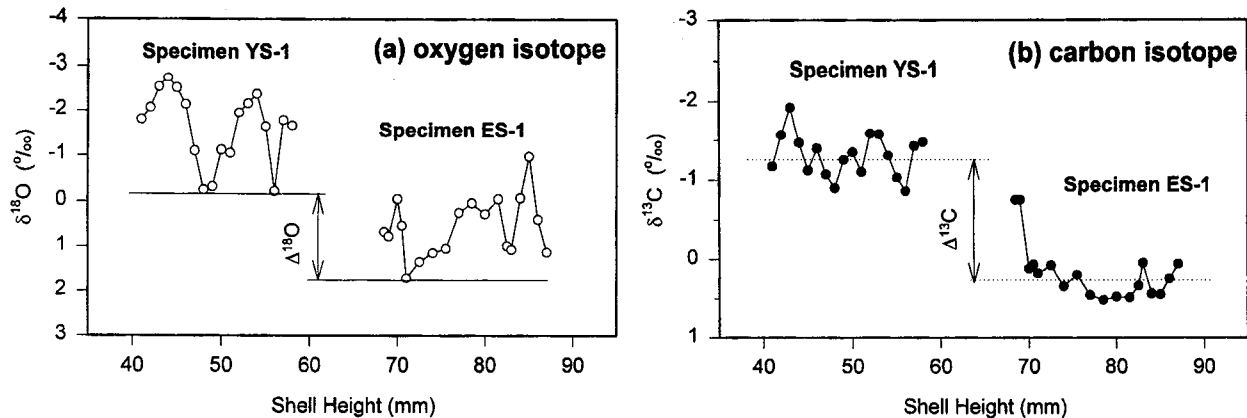


Fig. 4. (a) The comparison of oxygen isotope profiles between specimen YS-1 and specimen ES-1. The offset of the baseline (difference of maximum $\delta^{18}\text{O}$ values, i.e., $\Delta^{18}\text{O}$) between two specimens is largely attributed to differences in seawater $\delta^{18}\text{O}$ values and temperatures between two localities. (b) The comparison of carbon isotope profiles between specimen YS-1 and specimen ES-1. The difference ($\Delta^{13}\text{C}$) of mean $\delta^{13}\text{C}$ values between two specimens may reflect the different $\delta^{13}\text{C}$ value of the dissolved inorganic carbon between the coastal waters at the collection sites.

be interpreted as the different $\delta^{18}\text{O}$ values of ambient seawater in each coastal setting. There are not enough oxygen isotope data of the seawater around the Korean Peninsula. However, genetically, the entire setting of the Yellow Sea is markedly distinguishable from that of the East Sea. It is the main point that the Yellow Sea has a tremendous riverine discharge from the surrounded continents (Milliman and Meade, 1983). Generally, the oxygen isotope value of riverine freshwater is much lighter than that of the marine water (Fairbanks, 1982; Khim and Krantz, 1996). In addition, the habitat of specimen YS-1 (*C. sinensis*) is easily affected by the nearby stream water of lighter $\delta^{18}\text{O}$ values, even from the Han River. In spite of lack of seawater oxygen isotope data, the $\delta^{18}\text{O}$ value of Yellow Sea seawater (-2.0 to 0‰) is lighter than that of the East Sea proper (0 to 1.0‰) (Oba *et al.*, 1980; Wu, 1991; Kang *et al.*, 1994).

In another aspect of interpretation on the difference of $\delta^{18}\text{O}$ value between two profiles, it may more preferably rely on the combined effects, both temperature and seawater $\delta^{18}\text{O}$, which are more plausible and acceptable to play an interactive role on the isotope fractionation. This is more consistent with the background of thermodynamic behavior of oxygen isotope at the time of carbonate formation. However, in this situation, the ratio between temperature and isotopic composition of seawater cannot be clearly estimated due to no information on controlled physical oceanographic data. Finally, in extreme case, vital effect should not be excluded on the explanation. This variability might reflect

isotopic disequilibrium precipitation of calcium carbonate on either side of different species, but such a possibility has not been adequately tested. Although the interspecies effect is minimal on the oxygen isotope fractionation, verification is necessary for two different bivalve specimens under controlled condition of physical oceanographic base. However, it seems to be fairly difficult to use the same species to compare the marine settings between eastern and western coasts of Korea (Je, 1993).

The comparison between the $\delta^{13}\text{C}$ profiles of two specimens is also illustrated in Fig. 4b. In this case, due to the fact that there was insufficient information on the carbonate system of seawater in our study area, the overall mean values are compared. The deviation in mean values between two profiles is as much as 1.5‰, in which the specimen ES-1 has more positive values than specimen YS-1. As mentioned previously, the habitat difference of each organism should be considered with regards to the transport and behavior of carbon in coastal waters. However, it is generally known that most marine bivalves reflect the $\delta^{13}\text{C}$ of total dissolved inorganic carbon of the ambient seawater in which they form (Mook and Vogel, 1968). As in the case of oxygen isotope, the temperature difference between two sites may affect the carbon isotope fractionation, but it seems to be minimal (Grossman and Ku, 1986; Romanek *et al.*, 1992). In addition, the different $\delta^{13}\text{C}$ values can be maintained by the hydrographic condition such as mixing of water mass or upwelling.

Freshwater runoff brings isotopically lighter

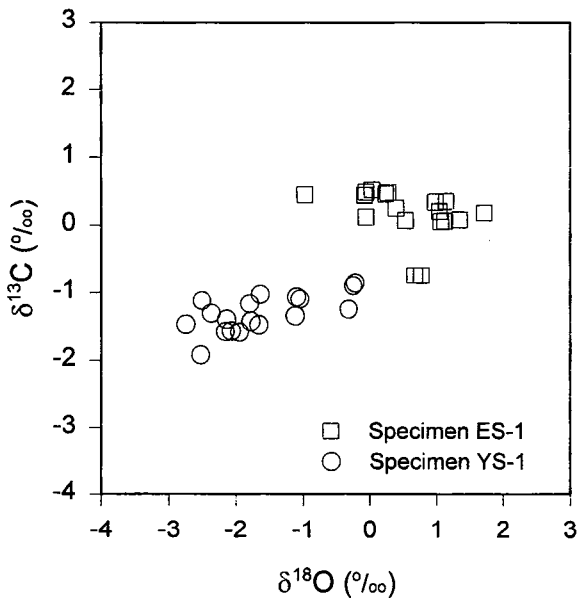


Fig. 5. The $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ pair diagram of the shell isotope data representing the relationships between the shell isotopic composition and the coastal water properties. This crossplot denotes two distinct categories that mark the isotopic properties of coastal seawater where the mollusk shells grow.

carbon into the marine system (Mook, 1971). The $\delta^{13}\text{C}$ value of this carbon may vary widely, depending on soil, bedrock, and vegetation conditions in the runoff drainage basin. Similar to the oxygen isotope, the Yellow Sea into which the large rivers discharge the lighter $\delta^{13}\text{C}$ may be characterized by the lighter $\delta^{13}\text{C}$ value of seawater DIC than the East Sea in which the prolific branch of Tsushima Current dominates (Kim and Legeckis, 1986). However, it is somewhat speculative to interpret this $\delta^{13}\text{C}$ gap between two localities because there has not been measured on $\delta^{13}\text{C}$ of seawater DIC and the different metabolism of two specimens can presumably play an additional effect on the carbon isotope transport.

Finally as a summary, pair diagram of oxygen and carbon isotope data obtained from two bivalve specimens is displayed in Fig. 5, although this plot highlights a number of assumptions and difficulties. Similar to temperature-salinity diagram and salinity- $\delta^{18}\text{O}$ of seawater diagram, which are used to identify the water masses, this diagram clearly denotes two distinct categories that mark the different properties of coastal seawater where the mollusk shells grow. The specimen ES-1 lies in the range of more positive $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values whereas the specimen YS-1 is placed in the more negative $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values. Each category can reflect the isotopically

characteristic properties of coastal water, which presents the physical, biological and chemical properties of coastal seawater. Thus, mollusk shells have the potential of revealing much information about the paleoenvironmental changes, particularly in the shallow coastal and inner continental shelf setting where the knowledge of paleoceanographic history is very limited (Khim, 1996). Similarly, the usefulness of pair diagram between $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values including the fossil and live shells will enhance our understanding of paleoceanographic and paleoenvironmental reconstruction.

CONCLUSIONS

The stable oxygen and carbon isotope data of the two bivalve shells obtained from the western (subtidal flat of Namyang Bay) and eastern (beach of Namdaechun, Yang Yang) coastal setting of Korea were documented. The oxygen and carbon isotope profiles of shell mollusks are constructed using the sequential sampling along the axis of maximum growth to provide high-resolution records of seawater properties. From the preliminary results of the present study, the following information can be obtained.

(1) Cycles in the $\delta^{18}\text{O}$ profiles are interpreted as annual along with the growth bands; maximum $\delta^{18}\text{O}$ values correspond with the coldest water temperature whereas minimum $\delta^{18}\text{O}$ values mark the warmest temperature. The primary control on the amplitude of the $\delta^{18}\text{O}$ profiles is seasonal variation of seawater temperature. The offset of the baseline between $\delta^{18}\text{O}$ values of the specimens is largely attributed to differences in seawater $\delta^{18}\text{O}$ values and temperature between two localities.

(2) The $\delta^{13}\text{C}$ profiles show the much clear seasonality of phytoplankton productivity in the western specimen (*C. sinensis*) than in the eastern specimen (*S. sachalinensis*). The offset in the $\delta^{13}\text{C}$ profiles between two specimens is likely to be due to the different $\delta^{13}\text{C}$ value of the dissolved inorganic carbon between coastal waters.

(3) Relationships between the shell isotopic composition and the coastal water of shell growth are readily interpreted from the $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ pair diagram of the shell isotope data. In spite of preliminary isotope results, mollusk shell geochemistry may be useful to monitor the paleoseawater properties when compared with fossil mollusks in pair diagrams.

(4) Application of the present method should considerably facilitate the paleoceanographic study and further enhance the values as ubiquitous monitoring of the paleoenvironment, even in ancient time, provided the fossil specimens are well preserved. However, clearly, an extensive isotopic survey of recent shells is necessary before positive statements can be made with regards to paleoceanographic interpretation.

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