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Paleoceanographic Investigation from the Calcareous Skeletons of the Pleistocene Seoguipo Formation, Cheju Island, Korea

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제주도 플라이스토세 서귀포층에서 산출되는 석회질 화석을 이용한 고해양학적 연구

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Stable isotopic and elemental compositions were analyzed for well-preserved calcareous skeletons (gastropods, pectenids, brachiopods, a scaphopod, and other bivalves) of the Pleistocene Seoguipo Formation from Cheju Island, Korea. Mineralogically and texturally, aragonitic and calcitic fossils still retain their original mineralogy and microstructure. High $\delta^{18}O$ and $\delta^{13}C$ contents indicate that the shells have not been altered by the post-burial diagenesis. Also, this is supported by high Na and Sr contents as well as low Mn and Fe compositions of the shells. Oxygen isotopic compositions of the well preserved fossils show that the organisms had lived under the lower paleotemperature or within the isotopically enriched paleo-seawater during the deposition of the Seoguipo Formation. This result strongly implies that the Seoguipo Formation was deposited during a glacial period. The paleotemperature variation throughout the sequence during the deposition of the Sewguipo Formation was negligible.

제주도에 분포하는 플라이스토세 서귀포층에서 산출되는 탄산염 광물로 이루어진 화석 중에서 속성변질을 받지않은 복족류, 가리비조개를 포함하는 이매패류, 완족류 및 뿔조개류에 대한 안정동위원소와 미량원소 성분을 분석하였다. 화석들의 각질부분은 고유의 광물성분인 아라고나이트와 방해석으로 보존되어 있으며 미세구조도 속성변질을 받지 않고 보존되어 있다. 각질내의 높은 산소 및 탄소동위원소 성분과 높은 Na와 Sr 성분, 그리고 낮은 Mn과 Fe 성분들은 일부 각질들이 퇴적된 후 속성작용에 의해 변질받지 않았음을 지시한다. 산소동위원소 성분 분석결과에 의하면 서귀포층 퇴적당시 화석으로 보존된 동물들은 현재보다 약간 낮은 수온이나 산소동위원소 성분이 약간 부화 (enriched)되었던 해수로부터 각질을 형성하였던 것으로 생각된다. 이러한 결과는 서귀포층의 퇴적동안에 한반도가 빙하기에 속하였던 것을 암시한다. 서귀포층의 하부로부터 상부에 이르기까지 수직적 온도 변화는 별로 크지 않았다.

INTRODUCTION

Global environmental change of the earth has been one of the interesting issues to scientists past tens of years. It is well understood that the surface condition of the earth, especially atmospheric conditions, can be easily manipulated by oceanographic changes. Recently, burning fossil fuels has increased in atmospheric pCO_2, which has caused a global warming. Even though many scientists warn that a global warming will threaten the fate of humans, we simply do not understand thoroughly about the paleoclimatic and paleoceanographic coniditions of the Earth, thus, it is quite hard to predict the environmental conditions of the Earth in the future. Throughout the geologic history, anormalously higher atmospheric pCO_2 content has been reported (e.g., Arthur et al., 1985). Therefore, it is significantly important to understand paleoceanographic as well as paleoclimatic conditions of the past to predict the global change of the Earth environment in the future.

Numerous studies have been reported based on the oxygen isotopic compositions from microfossils (e.g., Douglas and Savin, 1975; Savin, 1975; etc.) as well as macrofossils (e.g., Brand, 1986; Popp et al., 1986, Woo et al., 1992) to infer the paleoceanographic conditions of the Earth past twenty years. A vast amounts of data have been collected and reported worldwide, however, relatively few data on paleoceanographic information have been reported in Korea. Woo (1989) analyzed the stable isotopic compositions of cultured pearls, and stated that the oxygen isotopic composition of the pearl layer reflect the growth temperature during summer. Paik et al. (1992) analyzed the oxygen isotopic contents of the mollusks from the Miocene Songjeon Formation (Eoil Basin), and reported the anomalously high temperature range (26~32°C) for shallow seawater. Recently, paleoceanographic results based on the oxygen isotopic compositions of the ostracodes and mollusk fossils from the Miocene Chunbuk Formation in Pohang Basin have been reported (Woo et al., 1994; Woo et al., in press). Park et al. (1994) reported the stable isotopic compositions of the ostracodes of the Seoguipo Formation, and suggested that the formation was deposited during a glacial period.

The main purpose of this study is to understand the paleoceanographic conditions under which the Seoguipo Formation was deposited, based on the coordinated textural, chemical and stable isotopic compositions of the well preserved fossils such as bivalve, gastropod, brachiopod, and scaphopod. The analysis of these macrofossils is advantageous for paleoceanographic investigation, because these organisms secreted their shells in isotopic equilibrium

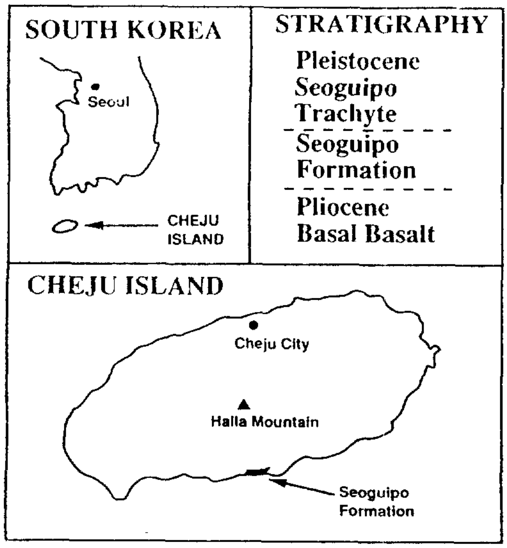

Fig. 1. Geographic location of the study area.

with ambient seawater (Anderson and Arthur, 1983), and possible diagenetic influence on the textural and chemical alteration of the fossils can be relatively well evaluated.

GEOLOGIC SETTING

The Seoguipo Formation is located in the southern part of the Cheju Island, which is in the Korean Strait to the south of the Korean peninsula (Fig. 1). The Cheju Island consists of voluminous basalt and minor hawaiite and trachyte, forming a continuous series of alkali basalt-trachyte association, with some sedimentary rocks of late Neogene to Pleistocene (Won, 1976). The geologic history of the Cheju Island has been widely investigated by many geologists (Kim, 1969, 1972; Yoon, 1970; Won, 1975; Lee, 1982, Paik and Lee, 1984, 1986; Sohn and Chough, 1989; Yoon and Chough, 1990; Lee et al., 1994; Lee et al., 1994). The southern part of the Cheju Island is mostly composed of alkaline volcanic rock series of lava, basalt, andesite, trachyte, and trachytic andesite. The ages of these volcanic rocks range 0.9 Ma to 0.03 Ma by K-Ar radiometric datings (Lee et al., 1994). The island was initially emerged by successive central eruptions during the late Pliocene to early Pleistocene, and the final er-

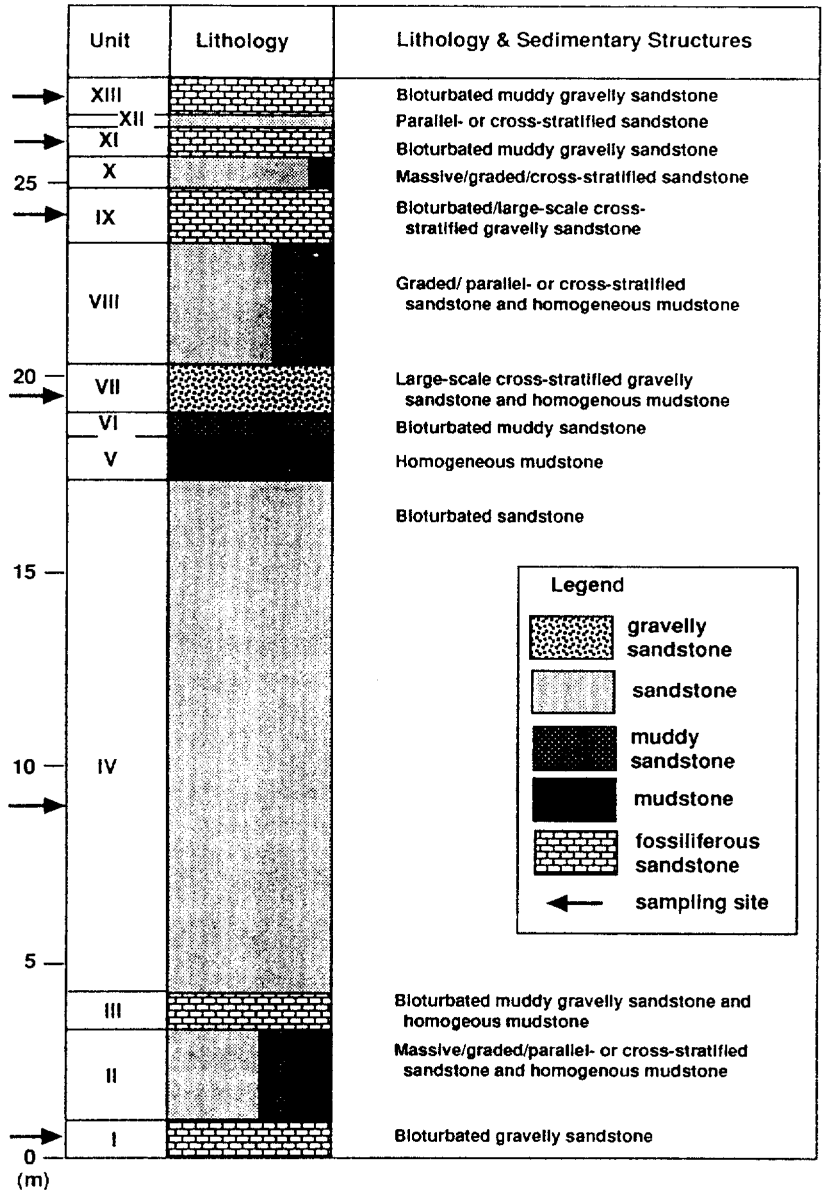

Fig. 2. Simplified columnar section and sedimentary features of the Seoguipo Formation showing 13 units (modified from Lee et al., 1994), and sampling sites for stable isotope and trace element analyses are indicated by arrows.

uptions were recorded in 1002 and 1007 A.D. (Won, 1976; Lee, 1982).

The Seoguipo Formation is composed of about 60 m-thick siliciclastic, bioclastic, and volcaniclastic sequence which is underlain by Pliocene basal basalt and overlain by Pleistocene trachyte (Fig. 1). The formation consists of shell-rich, light-gray, fine to coarse sandstones, pebbly sandstones, sandy mudstones, and agglomerates, showing a fining-upward trend. Various sedimentary structures such as wavy, flaser, and lenticular beddings, planar cross-beddings, ripple marks, and thin laminations, can be observed. Main components of coarse clasts in sandstones are basalt fragments and shell debris, and oth-

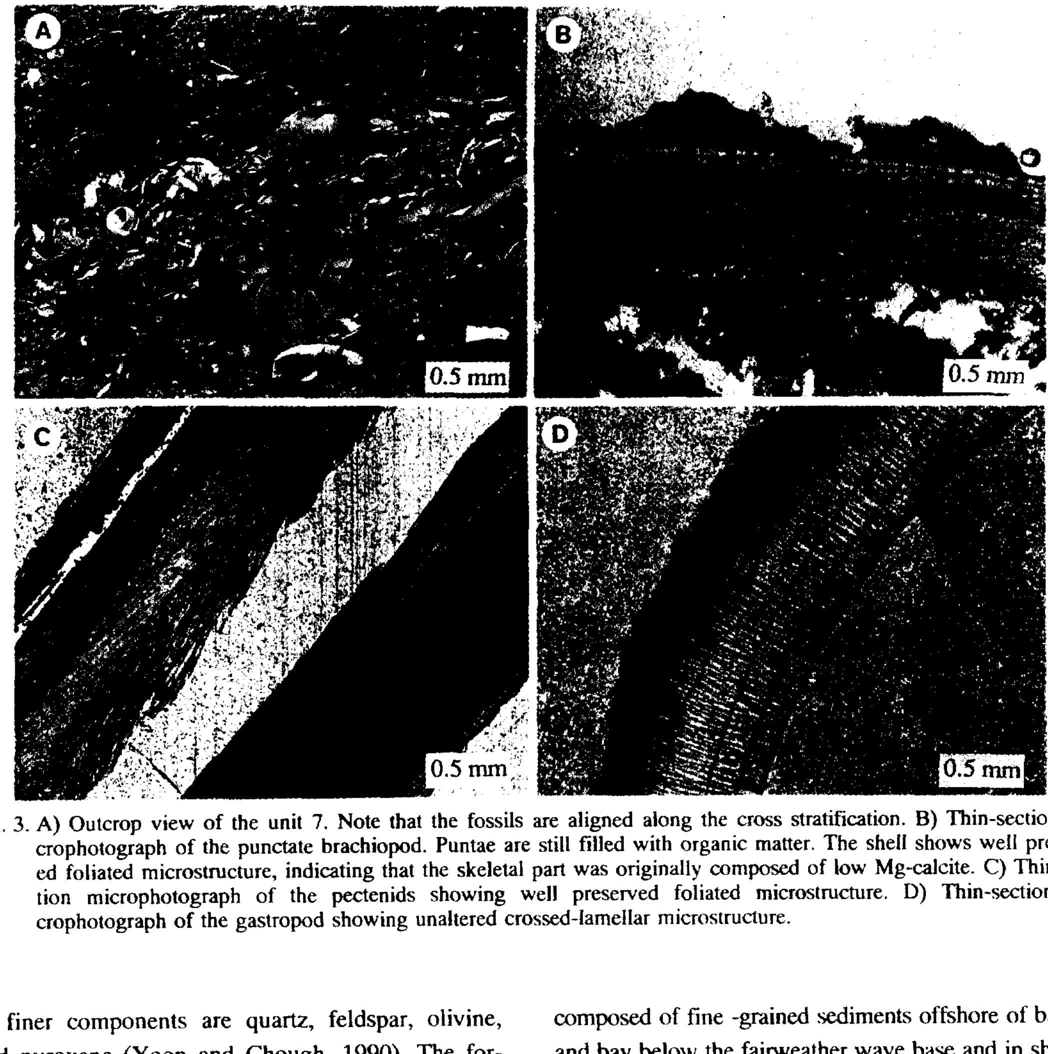

Fig. 3. A) Outcrop view of the unit 7. Note that the fossils are aligned along the cross stratification. B) Thin-section microphotograph of the punctate brachiopod. Puntae are still filled with organic matter. The shell shows well preserved foliated microstructure, indicating that the skeletal part was originally composed of low Mg-calcite. C) Thin-section microphotograph of the pectenids showing well preserved foliated microstructure. D) Thin-section microphotograph of the gastropod showing unaltered crossed-lamellar microstructure.

er finer components are quartz, feldspar, olivine, and pyroxene (Yoon and Chough, 1990). The formation is composed of two parts: 1) the lower part of the formation consists of alternated fossiliferous strata and non-fossiliferous siliciclastic strata, which are subdivided into eight fossilifeous units and five non-fossiliferous units (Fig. 2) (Lee et al., 1994); and 2) the upper part of the formation comprises volcanic ash and agglomerate beds. The lower I, II, III units in the lower part represent storm deposits accumulated on nearshore banks or spits and subsequently reworked by tidal currents and waves above the fair weather wave base. The unit IV of thick bioturbated sandstone is a relict sediment winnowed by strong waves and currents on nearshore sand bank, foreshore, and shoreface. The middle V, VI units are composed of fine -grained sediments offshore of bank and bay below the fairweather wave base and in shelf. The upper VII, VIII, IX, X, XI, XII, XIII units are interpreted to be nearshore storm surge deposits, and shoreface tidal sand and mud deposits above the fair weather wave base (Lee et al., 1994). The overall sedimentary facies show a deepening-upward trend up to the unit V and a consequent shallowing-upward trend in upper units. Yoon (1995) interpreted that two trends are associated with a relative sea-level rise and a successive sea-level fall, respectively. The lower unit includes six fossiliferous strata (Fig. 2 & Fig. 3A), which contain various bivalves including pectenids, gastropods, scaphopods, brachiopods, echinoids, barnacles, corals, bryozoans, fish teeth, and numerous other microfossils such as foraminifers, ostracodes,

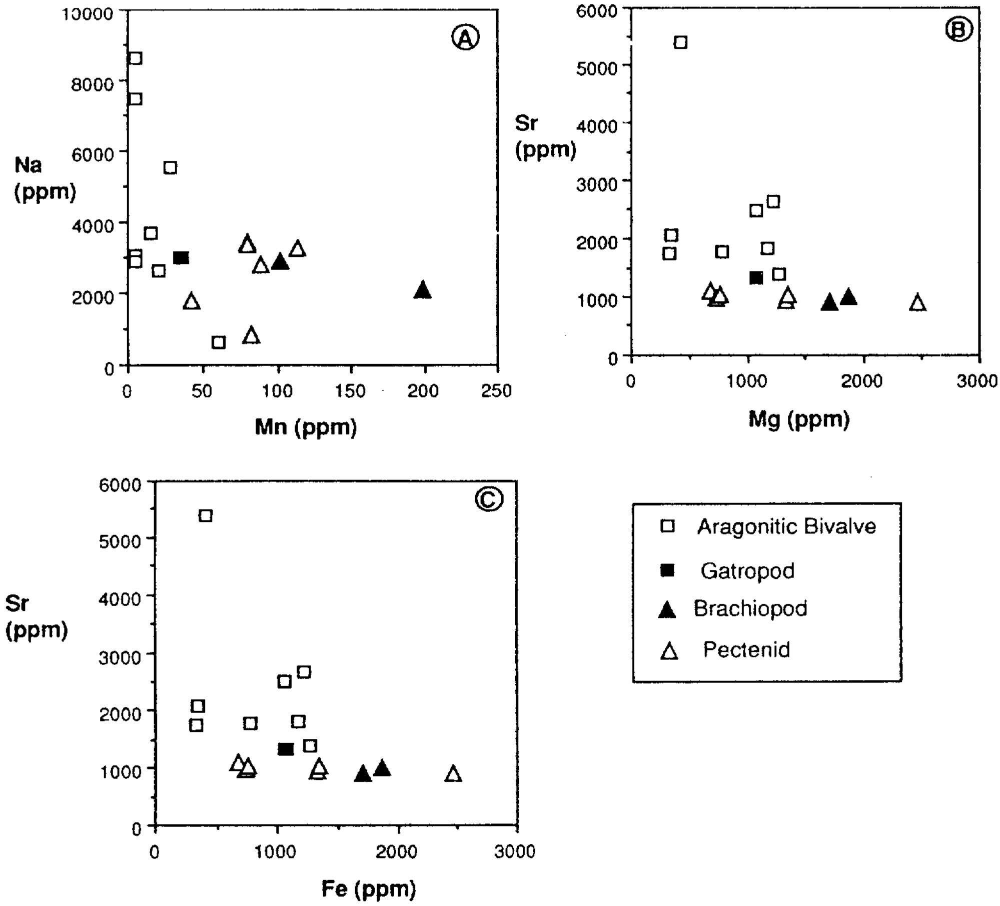

Fig. 4. Elemental compositions of aragonitic gastropod, aragonitic bivalve, calcitic brachiopod, and calcitic pectenid in the Seoguipo Formation. A) Scatter plot of Na vs. Mn contents. B) Scatter plot of Sr vs. Mg contents. C) Scatter plot of Sr vs. Fe contents.

nannofossils, etc..

The geologic age of the formation is still controversial, and has been suggested to be late Pliocene based on mollusk fauna (Yoon, 1988), Pliocene based on planktonic and benthic foraminifers (Kim, 1972), Pleistocene based on ostracodes (Lee, 1990), and Plio-Pleistocene based on nannofossils (You et al., 1986). From the paleomagnetic data, the Gauss normal epoch (late Pliocene) was suggested by Min et al. (1986), and the Brunhes normal epoch (middle Pleistocene) was suggested by Lee et al. (1987). Recently, Lee et al. (1994) suggested that the Seoguipo Formation was deposited during the late Pleistocene transgressive period of 0.73 Ma to 0.41 Ma.

METHODS

All the fossils were carefully collected from the six fossiliferous strata of the outcrop (Fig. 2). The samples were impregnated, thin-sectioned and routinely examined by petrographic microscope to determine the state of textural preservation. For geochemical analysis, sample powders were drilled out using a micromill. For stable isotopic result, about 5 mg of the sample powders were reacted with 100% phosphoric acid at 90°C for 5 minutes, and CO_2 gas is automatically injected and analyzed by mass spectrometer (VG Prism II). Analytical error of carbon and oxygen isotopes is ±0.2‰ All the stable isotopic values reported in this paper are relative to

Table 1. $\delta^{18}O$ values (PDB) with their corresponding paleotemperatures at which fossils grew as well as elemental compositions of some mollusk samples of the Seoguipo Formation Paleotemperature was calculated using the equation by Epstein et al. (1953) for calcitic molusks [$T(^{\circ}C)=16.0-4.14\ (\delta^{18}O_{calcite}-\delta^{18}O_{water})+0.13\ (\delta^{18}O_{calcite}-\delta^{18}O_{water})^2$] and the equation by Grossman and Ku (1986) for aragonitic mollusks [$T(^{\circ}C)=21.8-4.69\ (\delta^{18}O_{aragonite}-\delta^{18}O_{water})$]. T and T* are calculated from the assumption that $\delta^{18}O_{water}$ is 0‰ and +1.2‰ (SMOW), respectively.

Sample No.	Unit	Taxon	Min.	$\delta^{13}C$	$\delta^{18}O$	T(°C)	T(°C)*	Na	Mg	Fe	Sr	Mn
SG-U1-1	1	bivalve	A	-0.45	0.11	21.3	26.9	3314	335	256	1935	24
SG-U1-2	1	bivalve	C	-0.58	0.78	13.7	18.7	802	1271	387	880	692
SG-U1-3	1	pectenid	C	1.76	2.19	8.5	12.9	3593	651	70	1067	122
SG-U1-4	1	pectenid	C	1.79	1.42	11.3	16.0	3242	673	69	1103	113
SG-U1-5	1	bivalve	A	1.69	0.32	20.3	25.9	3068	418	24	5392	5
SG-U3-1	4	pectenid	C	1.12	2.7	6.7	11.0	2477	535	121	970	46
SG-U3-2	4	pectenid	C	1.12	2.04	9.0	13.5	839	737	90	968	82
SG-U3-3	4	pectenid	C	1.29	2.06	8.9	13.4	1809	755	82	1032	43
SG-5A-12	7	pectenid	C	-0.19	-0.1	17.3	22.5	2565	1654	685	999	76
SG-5A-13	7	bivalve	A	1.58	0.68	18.6	24.2	606	1171	1341	1827	61
SG-5A-14	7	gastropod	A	0.72	1.3	15.7	21.3	2994	1065	1432	1317	35
SG-5A-15	7	bivalve	A	0.69	0.11	21.3	26.9	2906	328	382	1757	5
SG-5A-16	7	gastropod	A	2.41	1.68	13.9	19.5	1331	1329	1134	1317	65
SG-5A-17	7	bivalve	A	1.62	0.6	19.0	24.6	3165	577	360	1961	5
SG-5B-13	9	brachiopod	C	1.36	0.53	14.7	19.7	3271	1948	1108	843	56
SG-5B-14	9	bivalve	A	1.18	1.14	16.5	22.1	7448	1065	119	2486	5
SG-5B-15	9	bivalve	A	0.89	1.04	16.9	22.6	8646	1213	270	2646	5
SG-5B-16	9	brachiopod	C	0.44	-0.09	17.3	22.5	3282	3007	1752	833	107
SG-5B-17	9	pectenid	C	1.87	1.45	11.2	15.9	4419	778	241	1156	85
SG-5B-18	9	pectenid	C	0.49	0.88	13.4	18.2	3433	2457	2043	914	80
SG-5C-13	11	bivalve	A	0.12	0.7	18.5	24.1	5166	1204	604	2046	5
SG-5C-14	11	bivalve	A	-0.36	0.91	17.5	23.2	4121	2090	1622	2701	14
SG-5C-15	11	bivalve	A	0.9	1.49	14.8	20.4	9846	1823	663	2790	18
SG-5C-16	11	brachiopod	C	0.16	0.35	15.5	20.5	2652	2035	662	901	105
SG-5C-17	11	brachiopod	C	1.27	0.55	14.7	19.6	2894	1864	759	992	102
SG-5C-18	11	pectenid	C	1.1	1.02	12.8	17.6	3359	1341	328	1029	80
SG-5C-19	11	pectenid	C	1.64	1.64	10.5	15.1	2804	1334	908	945	89
SG-5D-6	13	brachiopod	C	0.98	0.57	14.6	19.6	2551	924	159	1011	127
SG-5D-16	13	brachiopod	C	-2.88	-1.38	22.9	28.4	5491	6420	5254	604	458
SG-5D-18	13	bivalve	A	0.66	0.69	18.6	24.2	5552	776	922	1790	28
SG-5D-19	13	pectenid	C	1.25	1.08	12.6	17.4	3631	1692	1099	1103	163
SG-5D-20	13	bivalve	A	2.17	1.04	16.9	22.6	3680	340	394	2078	16
SG-5D-21	13	scaphopod	A	-0.4	-1.12	27.1	32.7	6662	2227	1553	4401	27
SG-5D-22	13	brachiopod	C	0.8	0.1	16.5	21.6	2119	1698	727	917	198

PDB. For elemental data, about 0.05 to 0.5 g of samples were reacted with 5% HCl, and insoluble residue was removed, and the rest of the solution was measured using ICP-AES (Shimazu 1000III). All the geochemical analyses were carried out at the Korea Basic Science Research Center.

STATE OF PRESERVATION

Brachiopods, gastropods, pectenids, and other aragonitic bivalves were examined petrographically to determine the state of preservation. All the skeletons have retained their original mineralogy and mi-

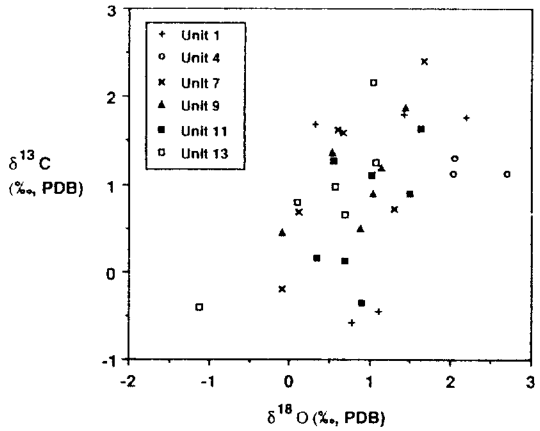

Fig. 5. Scatter diagram of $\delta^{18}O$ vs. $\delta^{13}C$ for well preserved calcitic and aragonitic fossils according to the sampling units of the Seoguipo Formation in the study area.

crostructure. Brachiopods show calcitic, foliated microstructure with punctae which cross the whole shell, and even the organic matter within the punctae is still preserved (Fig. 2B). A gastropod (e.g., *Cryptonatica* sp.) is still composed of aragonite, and has retained crossed-lamellar microstructure. Calcitic pectenids show foliated microstructure (Fig. 2C). Aragonitic bivalves (e.g. *Glycymeris* sp.) have retained the original mineralogy and microstructure (i.e., crossed-lamellar microstructure, Fig. 2D).

TRACE AND MINOR ELEMENTS

Na contents of the aragonitic skeletons are quite high and range from ca 2900 to 8650 ppm except for one sample (*Glycymeris* sp.) of 600 ppm (Table 1, Fig. 4A). The Na content of the same species is 2906 ppm. Calcitic shells show relatively lower Na contents of 1809-3433 ppm than aragontic shells. One pectenid shows relatively lower Na content (839 ppm). Even though a few shells show low Na contents, the overall Na compositions of both aragonitic and calcitic shells are within the normal range of the Recent shallow marine carbonates (Milliman, 1973; Masuda and Hirano, 1980). Except for one sample (SG-5D-22; brachiopod) of ca 200 ppm in Mn, the Mn contents of all the fossils are less than ca 120 ppm (Fig. 4A). This low Mn

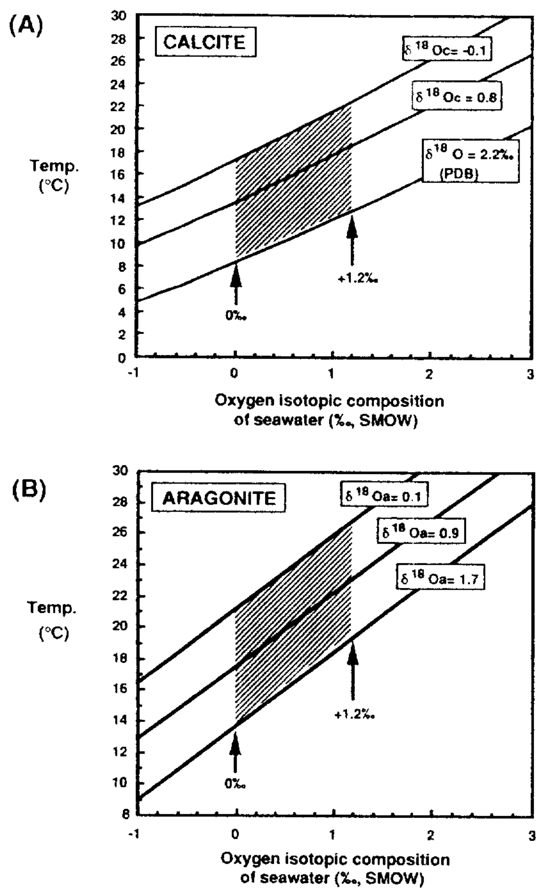

Fig. 6. A) Relationship between $\delta^{18}O$ of calcite ($\delta^{18}O_c$), $\delta^{18}O$ of water ($\delta^{18}O_w$), and temperature assuming T (°C)=16.9-4.2($\delta^{18}O_c$-$\delta^{18}O_w$)+0.13($\delta^{18}O_c$-$\delta^{18}O_w$)^2 where the values of $\delta^{18}O_c$ and $\delta^{18}O_w$ are relative to PDB and SMOW standards (Epstein et al., 1985). Three lines are drawn from the maximum ($\delta^{18}O$=2.2‰), minimum ($\delta^{18}O$=-0.1‰), and average ($\delta^{18}O$=0.8‰) oxygen isotopic compositions of well preserved calcitic fossils analyzed. $\delta^{18}O_w$ of +1.2‰ denotes the presumed oxygen isotopic composition of seawater during maximum glacial period (Dansgaard and Tauber, 1969), and $\delta^{18}O_w$ of 0‰ represents the oxygen isotopic composition of present-day interglacial seawater. The dashed area shows the possible range of paleotemperature and isotopic composition of paleo-ocean during the deposition of the Seoguipo Formation. (B) Relationship between $\delta^{18}O$ of aragonite ($\delta^{18}O_a$), $\delta^{18}O$ of water ($\delta^{18}O_w$), and temperature assuming T(°C)=21.8-4.69($\delta^{18}O_a$-$\delta^{18}O_w$), where the values of d$\delta^{18}O_a$ and $\delta^{18}O_w$ are relative to PDB and SMOW standards (Grossman and Ku, 1986). Three lines are drawn from the maximum ($\delta^{18}O$=1.7‰), minimum ($\delta^{18}O$=0.1‰), and average ($\delta^{18}O_c$=0.9‰) oxygen isotopic compositions of well preserved aragonitic fossils analyzed.

compositions can be expected because of the oxidizing setting of shallow marine environment, in which the formation was deposited. Sr contents of aragonitic shells show higher and wider range than those of calcitic shells (Fig. 4B). Aragonitic shells show a Sr range of ca 1320 to 5390 ppm, whereas calcitic shells of ca 910 to 1110 ppm. The Sr contents of both aragonitic and calcitic shells are within the reasonable range of marine carbonates reported previously (Milliman, 1973; Masuda and Hirano, 1980). Mg contents of calcitic shells (ca 670 to 2460 ppm) are higher than those of aragonitic shells (420 to 1220 ppm). High Na and Sr contens and low Mn contents strongly suggest that the fossils in this study are not chemically altered by post-burial diagenesis.

STABLE ISOTOPES AND PAEOCEANOGRAPHIC IMPLICATION

The temperature of the growth for modern calcareous shells can be directly measured from $\delta^{18}O$ of ambient seawater or can be inferred from salinity data of seawater. In fossils, however, the isotopic composition of the water is unknown and cannot be easily assumed especially for the Pleistocene fossils, because it is widely known that glacial and interglacial periods have been alternated during this period on the Earth's surface, and thus, the isotopic composition of paleo-seawater may have been changed due to the change in glacier volume. Commonly, increase in the $^{18}O/^{16}O$ ratio of calcareous skeletons (e.g., foraminiferal test; Emiliani, 1966) during glacial period could be caused by the decrease in paleotemperature as well as the increase in the $\delta^{18}O$ of the oecan water. Emiliani (1955, 1966) has shown that isotopic variations in foraminiferal tests undergo quasi-periodic changes corresponding to glacial and interglacial periods, and that the changes were due entirely to temperature changes. He estimated that ca 70% of the maximum isotopic change in $\delta^{18}O$ of calcite was due to changes in temperature (i.e., 5-6°C), the other 30% resulting from changes in the isotopic composition of ocean water (to +0.5‰ during maximum glaciations). However,

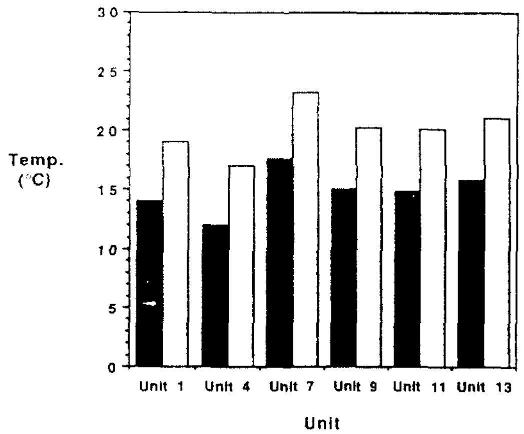

Fig. 7. Averaged paleotemperatures calculated from oxygen isotopic compositions of the well preserved mollusk fossils according to the sampling units of the Seoguipo Formation in the study area. Open bars represent the paleotemperatures when $\delta^{18}O_{seawater}$ is 0‰ (SMOW), and filled bars represent the paleotemperatures when $\delta^{18}O_{seawater}$ is +1.2‰(SMOW)

Dansgaard and Tauber (1969) argued that the present isotopic composition of precipitation in the world, and the measured isotopic composition of glacial-age precipitation in ice cores, point to much lower ^{18}O concentrations in continental and polar ice sheets. Thus, they estimated that the isotopic composition of seawater during maximum glaciation was +1.2‰ accounting for ca 70% of the observed isotopic change in foraminiferal carbonate at that time.

Carbon isotopic compositions of aragonitic bivalves, a gastropod, brachiopods, and pectenids of the Seoguipo Formation range from +0.5 to +2.2‰ (Fig. 5), which reflects marine carbonate carbon values (Anderson and Arthur, 1983). Oxygen isotopic contents are from +0.6 to +2.1‰ (Fig. 5). This is a reasonable range for shallow water carbonates deposited in shallow temperate region (Anderson and Arthur, 1983). There is no significant discrepancy of the $\delta^{18}O$ values between aragonitic and calcitic shells (Table 1). All the units show similar oxygen isotopic ranges except for the pectenids in Unit 4 which show relatively higher values (Fig. 5). These higher values of Unit 4 may indicate the deeper water conditions (thus, lower temperature) where the pectenids lived. This result coincides well with the depositional interpretation by Yoon (1995). Possible diagenetic alteration by meteoric water can be easily excluded by the state of texutural preservation, high Na and Sr contents, and relatively low Mn and Fe compositions as well as heavy oxygen isotopic contents of the shells examined in this study.

Fig. 6 shows the possible range of the paleotemperature calculated from the oxygen isotopic compositions at which the fossils of the Seoguio Formation may have lived. Dashed areas are shown by the assumption that the oxygen isotopic composition of the contemporaneous seawater could vary from maximum glacial condition (+1.2‰ SMOW) to present-day interglacial condition (0‰ SMOW). If we assume that the Seoguipo Formation was deposited during Pleisotcene epoch (Lee et al., 1994) when glaciers were present around polar regions, the actual oxygen isotopic compostion of seawater during the deposition of the Seoguipo Formation should have been between 0 to +1.2‰ (SMOW). If the $\delta^{18}O$ value of ambient sewater was +1.2‰ the paleotemperature of the calcitic shells ranges from 12.9 to 21.6°C with an average of 18.6 and that of the aragonitic shells ranges from 19.5 to 26.5°C with an average of 23.2°C (Table 2). Also, if the $\delta^{18}O$ value of ambient sewater was the same as that of the present-day seawater (i.e., 0‰, the paleotemperature of the calcitic shells ranges from 8.5 to 16.5°C with an average of 13.7°C and that of the aragonitic shells ranges from 13.9 to 21.3°C with an average of 17.6°C. The present-day temperature of shallow seawater near Cheju Island ranges from 20~27°C during summer (Fisheries Research and Development Agency, 1986), and it is well known that most of the shell growth occur during the warm period of the year. Therefore, this result clearly indicate that, during the deposition of the Seoguipo Formation, the paleotemperature of the shallow seawater was lower than that of the present seawater, or $\delta^{18}O$ of composition of paleoseawater was heavier due to the increase in ice volume. This means that the Seoguipo Formation was deposited probably during the glacial period.

From the Unit 1 to Unit 13, the overall temperature trend does not vary much (Fig. 7). Assuming that the oxygen isotopic composition of paleoseawater is 0‰ (+1.2‰) (SMOW), fossils of the Unit 1, Unit 9, Unit 11, and Unit 13 shows the paleotemperature range of 14~17°C (19~21°C). Unit 4 shows a little lower paleotemperature of ca 13°C (18°C), and Unit 7 shows higher paleotemperature of ca 18°C (24°C). As mentioned above, the lower temperature of Unit 4 probably reflects the different paleoecologic conditions of large pectenids (Table 1). Thus, the paleotemperature change during the deposition of the Sewguipo Formation may have been more or less uniform except the Unit 7.

SUMMARY

Mineralogically, texturally, and chemically well-preserved calcareous skeletal components such as aragonitic bivalves (including pectenids), gastropods, scaphpods, and brachiopods show lower paleotemperature or isotopically enriched paleoseawater during the deposition of the Seoguipo Formation. This result indicates that the Seoguipo Formation was deposited during glacial period. The paleotemperature variation throughout the sequence during the deposition of the Sewguipo Formation was negligible.

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