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Geological age of the Jeongseon Formation, Joseon Supergroup (lower Paleozoic): a perspective from carbon isotope stratigraphy

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ABSTRACT: Due to the lack of index fossils and extensive alteration, the geological age of the Jeongseon Formation, Jeongseon Unit of the Joseon Supergroup (lower Paleozoic) is yet clearly defined by any chronostratigraphic mean. In this study, we present a high-resolution carbon isotopic curve for the upper part of the Jeongseon Formation. The carbon isotopic values of the Jeongseon Formation fluctuate between -3‰ and +1‰, which are within the range of those of Middle Ordovician carbonate. Also, the $\delta^{13}C$ curve of the upper part of the Jeongseon Formation is well correlated with that of the uppermost Middle-lowermost Upper Ordovician Copenhagen Formation in the Great Basin, U.S.A. (Saltzman and Young, 2005). Considering general biostratigraphy and carbon isotope stratigraphy together, the age of the upper part of the Jeongseon Formation can be assigned to late Middle to early Late Ordovician.

Key words: Lower Paleozoic, Jeongseon Formation, Carbon isotope

1. INTRODUCTION

The Joseon Supergroup is a lower Paleozoic sequence distributed in eastern central Korea and conventionally subdivided into five units based on lithology and geographic distribution: namely, the Duwibong, Yeongweol, Pyeongchang, Jeongseon and Mungyeong units (Kobayashi et al., 1942) (Fig. 1A). The Jeongseon Formation of the Jeongeson Unit is composed of carbonate rock and is distributed in the vicinity of Jeongseon Eup, Gangweon-do Province (Fig. 1B). Because this formation was much deformed by post depositional tectonic processes, it has been rarely studied except for few paleontological approaches (Hisakoshi, 1943; GICTR, 1962; Kim et al., 1973; Lee, 1976). Compared with the well-studied stratigraphic succession of the adjacent Duwibong Unit, the chronostratigraphic position of the Jeongseon Formation in the Joseon Supergroup has not been established well yet due to the deficiency of fossils and the lithological difference between the Jeongseon and Duwibong units. The geologic age of the Jeongseon Formation suggested so far ranges from Middle to Late Ordovician (Hisakoshi, 1943; GICTR, 1962; Kim et al., 1973; Lee, 1976, Cheong et al., 1979). Due to the lack of index fossils in the Jeongseon Formation, alternative stratigraphic approaches are needed to constrain its age and for correlation with other stratigraphic units of the Joseon Supergroup.

Carbon isotopic variations are widely used for chemostratigraphic correlation. Sharp shifts in $\delta^{13}C$ values of marine carbonates are known to indicate world-wide biotic events and stratigraphic boundaries in geological history (Veizer et al., 1999). Also, the carbon isotope pattern of one section tends to be similar to those of other sections of the same age if carbon isotopic values were not influenced by local paleoceanographic and diagenetic conditions. Accordingly, the evolution of carbon isotopic ratios has been widely used as a tool for intracratonic and global stratigraphic subdivision and correlation for stratigraphic intervals that lack age-diagnostic fossil markers (Ripperdan and Miller, 1995; Hayes et al., 1999; Veizer et al., 1999; Montaòez et al., 2000; Buggisch et al., 2003).

The nearly complete sequence of the upper part of the Jeongseon Formation is well exposed at the quarry of Taeyoung Lime Mine Company, Jeongseon Gun (Fig. 1B). The purpose of this study is to provide the carbon isotopic curve of the upper part of the Jeongseon Formation at this section and to infer the geological age of the Jeongseon Formation from a perspective of carbon isotopic stratigraphy by comparing our result with available carbon isotopic curve (Saltzman and Young, 2005) and values of the Ordovician (Marshall and Middleton 1990; Wadleigh and Veizer, 1992; Qing and Veizer, 1994; Carden, 1995; Gao et al., 1996; Ludvigson et al., 1996; Tobin and Walker, 1996; Shields et al., 2003).

2. GEOLOGICAL SETTING

The stratigraphic classifications for the Jeongseon Unit suggested so far are shown in Figure 2. The stratigraphic position of the Jeongseon Formation has been variously suggested. Hisakoshi (1943) first defined thick Ordovician limestone distributed in the central and eastern Jeongseon areas as the Jeongseon Formation. Also, he defined the strata below the Jeongseon Formation as the Jaun Formation in the central area, and the Jukryeom, Dongjeom and Dumugol formations in the eastern area. The Jaun Formation is correlated with the Jukryeom, Dongjeom and Dumugol

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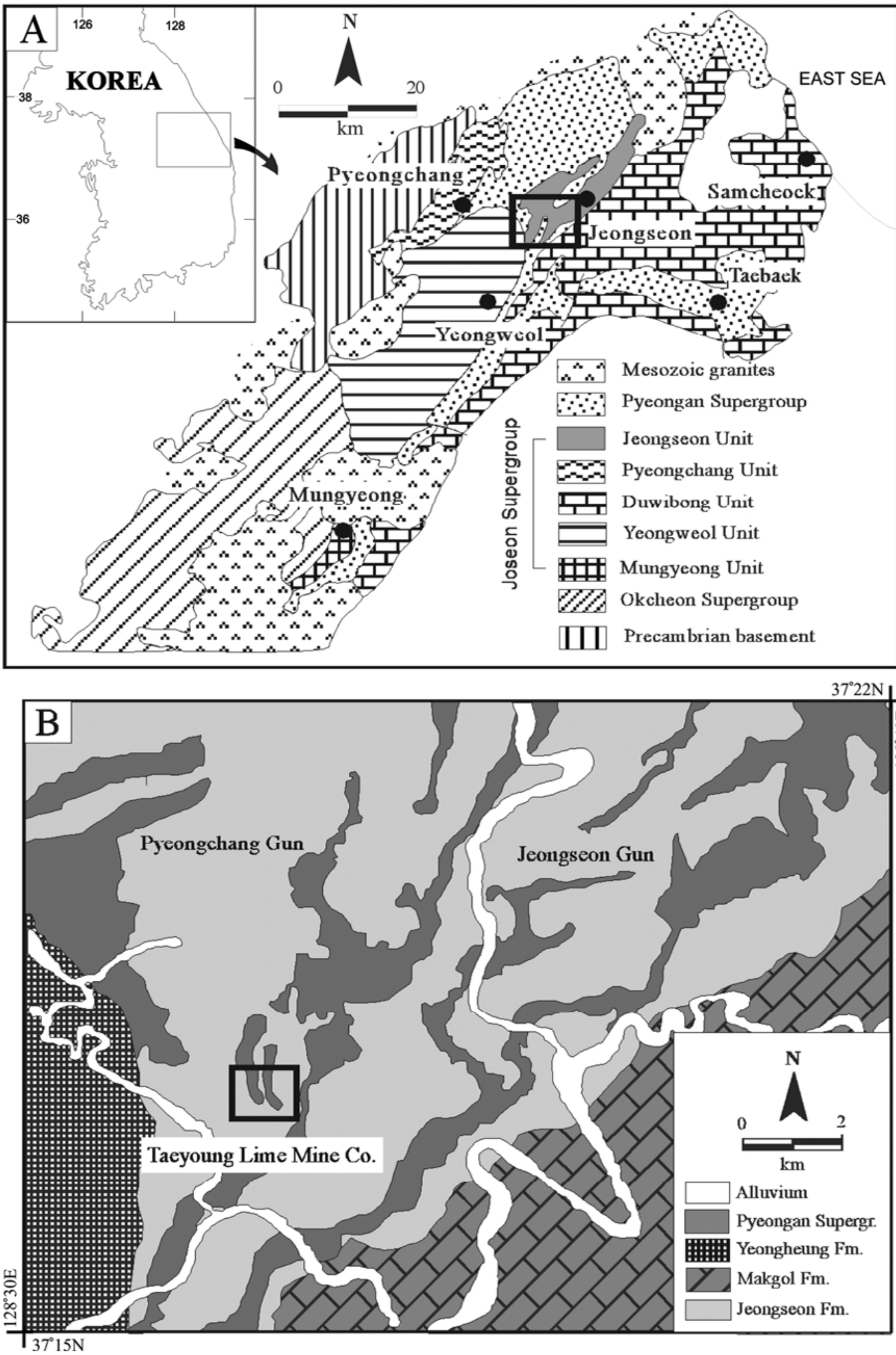

Fig. 1. (A) Index map showing simplified geology and distribution of the lower Paleozoic Joseon Supergroup (modified after GICTR, 1962). (B) Geological map of the Jeongseon area (modified after GICTR, 1962).

formations, which are correlated with the Hawjeol, Dongjeom and Dumugol formations of the Duwibong Unit, respectively. The Jeongseon Formation of Hisakoshi's (1943) classification corresponds to the composite sequence of the Ordovician Makgol, Jigunsan and Duwibong formations of the Duwibong Unit. However, in the western area Hisakoshi (1943) subdivided the Jeongseon Unit into the three lithostratigraphic units: the Lower Limestone, the Haengmae Formation and the Upper Limestone, of which the last may correlate with the Jeongseon Formation in the central and eastern areas. Kobayashi (1953) suggested that the Jeongseon Unit comprises the Lower Limestone, the Gyomai Formation and the Upper Limestone in ascending order. He correlated the Upper Limestone with the Jeongseon Formation of Hisakoshi (1943). GICTR (1962) applied the Duwibong Unit classification for the Jeongseon Unit, except for the uppermost formation, which was named the Jeongseon Formation. Kim et al. (1973) considered that the Jeongseon Unit is not a different sequence from the Duwibong Unit, but is a sequence complicately composed of the Hwajeol, Dumugol and Makgol formations of the Duwibong Unit due to structural repetition. Son and Cheong (1976) redefined yellowish brown limestone overlying the Jeongseon Formation as the Haengmae Formation. Cheong et al. (1979) defined the Silurian conodont-yielding limestone bed that overlies unconformably the Haengmae Formation as the Hoedongri Formation. They suggested that the Jeongseon Unit comprises the Jeongseon, Haengmae and Hoedongri formations in ascending order. The Hoedongri Formation consists mainly of light gray, massive, microcrystalline limestone. Although the geological age and stratigraphic position of the Jeongseon, Haengmae and Hoedongri formations have not been established clearly due to the lack of index fossils, Cheong et al. (1979) considered that the Jeongseon Formation is overlain conformably by the Haengmae Formation which is in turn overlain unconformably by the Silurian Hoedongri Formation. The stratigraphic classification proposed by Cheong et al. (1979) is followed in this study (Fig. 2).

Lee (1976) and Cheong et al. (1979) discovered the Middle Ordovician conodonts from the Jeongseon Formation. Although Cheong et al. (1979) proposed that the geological age of the Jeongseon Formation is Middle Ordovician based on the occurrence of lower Middle Ordovician conodonts in the middle part of the Jeongseon Formation, it would be roughly assigned as the Middle to Late Ordovician due to the lack of the index fossil in the overlying Haengmae Formation. Thickness of the Jeongseon Formation is estimated over 300 m (Lee, 1987).

Age		Hisakoshi (1943) Western side	Hisakoshi (1943) Central & eastern side		Kobayashi (1953)	GICTR (1962)	Kim et al. (1973)	Cheong et al. (1979)
Silurian								Hoedongri Fm.
Ordovician	Ashgillian					Jeongseon Fm.		
	Caradocian	Upper Limestone	Jeongseon Fm.		Upper Limestone	Makgol Fm.		Haengmae Fm.
	Llandellian							Jeongseon Fm.
	Lanvirnian						Makgol Fm.	
	Arenigian		Jaun Fm.	Dumugol Fm.	Gyomai Fm.	Dumugol Fm.	Dumugol Fm.	
	Tremadocian	Haengmae Fm.		Dongjeom Fm.		Dongjeom Fm.	Dongjeom Fm.	
Cambrian	Late	Lower Limestone		Jukryeom Fm.	Lower Limestone	Hwajeol Fm.	Hwajeol Fm.	
	Middle		Daegi Fm.			Daegi Fm.	Daegi Fm.	
	Early		Myobong Fm. Jangsan Fm.			Myobong Fm. Jangsan Fm.	Myobong Fm. Jangsan Fm.	

Fig. 2. Stratigraphic subdivisions of the Jeongseon Unit of the Joseon Supergroup.

3. STUDY SITE AND METHODS

Although the Jeongseon Formation is distributed in wide area, good outcrop exposures are rather poor. Also, in places where outcrop exposure of the Jeongseon Formation is extensive, it is difficult to identify the stratigraphic position of the strata within the formation due to much alteration and fault-related stratal repetition. The studied section at Taeyoung Lime Mine Company quarry comprises a nearly complete, about 100 m thick succession representing the upper part of the Jeongseon Formation (Fig. 3), which is located near the administrative boundary between Jeongseon Gun and Pyeongchang Gun (128°33′E, 37°19′N-128°34′E, 37°18′N) (Fig. 1B). At this section, the Jeongseon Formation at this section is unconformably overlain by the Carboniferous Manhang Formation of the Pyeongan Supergroup (Fig. 3). Bong and Chung (2000) classified the Jeongseon Formation into eight lithofacies. However, there exists some discrepancy between Bong and Chung (2000) and this study, due to different studied sections. This study follows classification of Hong (2006) who subdivided the Jeongseon Formation at this section into seven lithofacies, such as peloidal dolomite, massive limestone, massive dolostone, bioturbated limestone, laminated limestone and microbial lime/dolostone. Arrangement of these lithofacies generally shows a shallowing-upward cycle with some noncyclic intervals. The lithofacies characteristics and arrangement of lithofaceis suggest that the upper part of the Jeongseon Formation was deposited in peritidal environment.

For a stable isotope study, samples were collected at about 1 m interval. The carbon isotopic values were analyzed by using micritic components drilled from polished slabs. Isotopic analysis was conducted using a Micromass OPTIMA mass spectrometer at the Korea Basic Science Institute. Isotopic ratios are reported in per mil relative to the PDB. Accuracy and precision for both carbon and oxygen isotope values is better than 0.1‰.

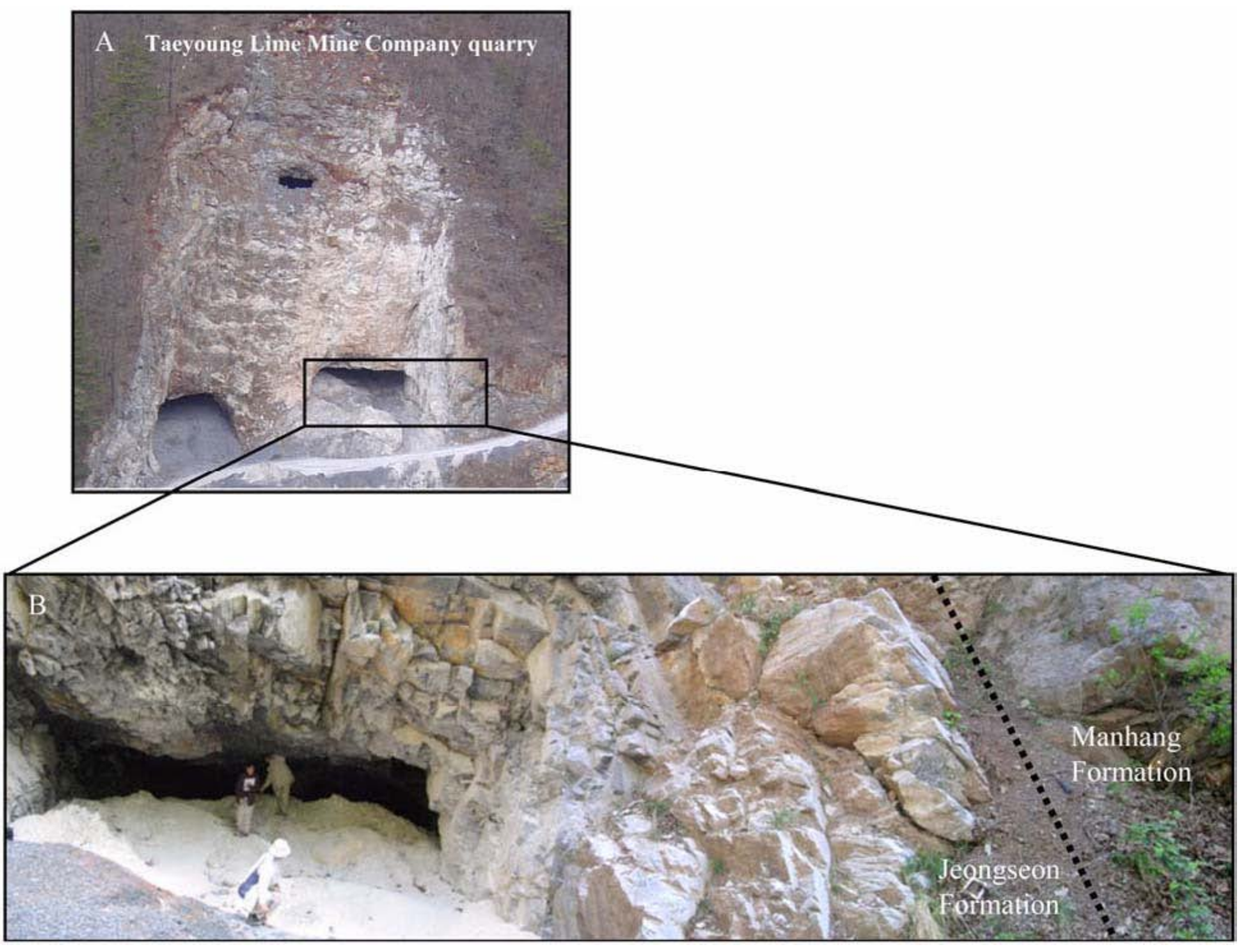

Fig. 3. Photographs showing (A) part of the outcrop of the upper part of the Jeongseon Formation (about 100 m thick) and (B) the boundary between of the Jeongseon and Manhang formations at Taeyoung Lime Mine Company quarry.

Table 1. Stable isotopic data of the upper part of the Jeongseon Formation.

Meter*	Composition	$\delta^{13}C$	$\delta^{18}O$	Meter*	Composition	$\delta^{13}C$	$\delta^{18}O$
1	calcite	-2.04	-13.26	49	calcite	-1.71	-8.97
2	dolomite	-0.36	-4.93	50	calcite	-1.51	-12.51
3	calcite	-0.82	-4.59	51	calcite	-0.66	-12.35
4	calcite	-2.65	-16.57	52	calcite	-0.87	-13.06
5	calcite	-2.53	-8.61	54	calcite	-1.74	-13.48
6	calcite	-2.08	-9.05	55	calcite	-1.60	-8.78
7	calcite	-1.82	-10.10	58	calcite	-2.56	-13.91
8	calcite	-2.02	-13.54	59	dolomite	-0.16	-3.35
9	calcite	-1.03	-10.33	60	dolomite	-0.18	-3.83
11	dolomite	-0.67	-9.38	62	calcite	-0.47	-14.59
12	calcite	-1.24	-15.78	63	calcite	-0.71	-9.84
13	calcite	-1.52	-11.08	64	calcite	-0.44	-14.88
14	calcite	-1.22	-16.04	65	dolomite	1.10	-4.95
15	calcite	-1.34	-9.56	66	calcite	-0.20	-11.10
16	calcite	-0.95	-9.24	67	calcite	-1.01	-9.91
17	calcite	-1.31	-11.00	68	calcite	-0.14	-8.89
19	calcite	-1.34	-10.85	69	calcite	-0.17	-9.62
20	calcite	-1.23	-10.16	70	calcite	-0.54	-10.31
21	calcite	-1.15	-15.27	73	calcite	-1.24	-10.60
22	calcite	-3.15	-15.07	74	calcite	0.05	-9.60
23	dolomite	-0.32	-6.04	77	dolomite	-0.72	-5.64
24	calcite	-3.21	-16.03	78	calcite	-3.02	-11.20
25	calcite	-0.70	-8.00	79	calcite	-2.40	-11.85
26	calcite	-0.84	-13.45	80	calcite	-0.77	-10.53
27	calcite	-1.86	-7.35	81	calcite	-0.46	-10.36
28	calcite	-2.37	-12.26	82	dolomite	-0.10	-4.21
29	calcite	-2.58	-6.95	83	dolomite	0.53	-5.23
30	calcite	-2.69	-9.69	84	calcite	-1.76	-10.96
31	calcite	-0.98	-7.33	85	dolomite	0.92	-3.59
32	calcite	-1.39	-16.70	86	calcite	0.40	-13.30
33	calcite	-1.39	-17.00	87	dolomite	0.98	-4.05
34	calcite	-1.03	-15.15	88	dolomite	0.08	-5.97
35	calcite	-1.76	-9.57	89	dolomite	0.37	-4.68
36	calcite	-1.01	-11.60	91	calcite	0.88	-12.76
37	calcite	-1.76	-12.71	92	dolomite	1.12	-5.27
38	calcite	-0.94	-6.84	93	calcite	-0.04	-14.32
39	calcite	-0.94	-14.42	94	calcite	0.35	-11.30
41	calcite	-1.74	-13.88	95	calcite	-1.43	-11.06
42	calcite	-2.14	-9.57	96	calcite	-2.00	-9.81
43	calcite	-1.11	-7.55	97	calcite	-2.03	-9.98
44	calcite	-1.52	-11.53	98	calcite	-1.62	-8.65
45	dolomite	-0.10	-4.96	99	calcite	-1.78	-10.37
46	calcite	-1.32	-16.01	100	calcite	-2.39	-12.38
47	calcite	-0.29	-10.08	101	calcite	-2.40	-13.17
48	calcite	-1.51	-13.36	102	calcite	-1.59	-13.59

Meter* represents distance from the base of the measured section.

4. RESULTS

High-resolution $\delta^{13}C$ curve was constructed from 75 calcite samples and 15 dolomite samples (Table 1). The $\delta^{13}C$ value of calcite varies between −3.21‰ and +0.88‰, and that of dolomite between from −0.72‰ and +1.12‰ (Fig. 4). As shown in Figure 4, the carbon isotopic values show high frequency fluctuations between −3‰ and 1‰. In general, a slightly increasing $\delta^{13}C$ trend is observed in the lower two thirds of the section and the pronounced positive shift of the carbon isotopic ratio is noted beginning about 75 m above the base of the measured section and continues upward over the next 15 m interval. After such a positive excursion, the carbon isotopic value decreases down to about −3‰ in a short interval.

5. DISCUSSION AND SUMMARY

Although the upper part of the Jeongseon Formation consists of various lithofacies, the carbon isotopic values show only slight deviations from the mean (−1.2‰), independent of the lithofacies (Fig. 4). Furthermore, the cross-plot of carbon isotopic vs. oxygen isotopic values shows a poor correlation (r^2=0.23) (Fig. 5). Therefore, the carbon isotopic values are interpreted to reflect changes in the carbon reservoir during the deposition of the upper part of the Jeongseon Formation, rather than alteration during diagenesis.

Because the secular trend in the carbon isotopic compositions of marine carbonate tends to represent global carbon cycle, the carbon isotopic trend provides a useful tool for stratigraphic correlation. Carbon isotopic changes during the Ordovician were investigated by many researchers. The results of these studies reveal that Lower and Middle Ordovician carbonates show slight negative carbon isotopic values (Wadleigh and Veizer, 1992; Johnson and Goldstein, 1993; Qing and Veizer, 1994; Shields et al., 2003), whereas Upper Ordovician carbonates are characterized by positive carbon isotopic values (Marshall and Middleton 1990; Wadleigh and Veizer, 1992; Qing and Veizer, 1994; Carden, 1995; Gao et al., 1996; Ludvigson et al., 1996, Tobin and Walker, 1996; Shields et al., 2003). Several researchers suggested that the positive carbon isotope values of the Upper Ordovician carbonates coincide with either global faunal extinction, major eustatic sea-level change, or glaciation (Brenchley et al., 1994; Kump et al., 1999; Kaljo et al., 2004; Saltzman and Young, 2005). Although the carbon cycling mechanism is not completely understood, it is generally considered that effects of the glaciation and sea-level fall might have been related to changing partitions between marine organic carbon and carbonate carbon during this time interval.

Shields et al. (2003) summarized all these carbon isotopic studies as the followings: (1) Lower Ordovician carbonate yields negative $\delta^{13}C$ between −1.2‰ and 0‰, with an average of −0.9‰; (2) Middle Ordovician carbonate shows a wide range of $\delta^{13}C$ between −3.0‰ and +1.8‰, averaging −1.2‰; and (3) $\delta^{13}C$ of Upper Ordovician carbonate reveals a considerable range between +0.2‰ and +5.8‰. Accordingly, the carbon isotopic values change from moderately negative values in the Early and Middle Ordovician to moderately positive values in the Late Ordovician. Generally, it is difficult to define the stratigraphic age only by correlating carbon isotopic values because the magnitude of the carbon isotopic values can be changed by local factors. Kroopnick (1985) presented the distribution of the $\delta^{13}C$ in the world ocean. According to his results, the carbon isotopic value of the global surface ocean ranges between 1.0‰ and 1.5‰. Furthermore, the modern tropical and subtropical oceans differ in $\delta^{13}C$ by 0.5‰ (Gruber et al., 1999) and the modern South China Sea also differs from the Pacific Ocean by up to 0.5‰ (Lin et al., 1999). In the case for the Ordovician, the difference in carbon isotopic values between the Middle and Late Ordovician (minimum: 1.6‰; maximum: 8.8‰) exceeds the regional variation of modern oceans (≤ 0.5‰), and thus carbon isotopic values can be used as additional evidence for Ordovician stratigraphic subdivision. Our $\delta^{13}C$ values generally range between −3.2‰ and +1.1‰, averaging −1.2‰ and shows only slight deviation from the mean. Comparison with the summary data of Shields et al. (2003) suggests that the carbon isotopic values of the studied upper part of the Jeongseon Formation are similar to those of the Middle Ordovician.

For the Late Ordovician, many studies reported major positive carbon isotopic excursion events such as the Mohawkian excursion (≥ 3‰) and Hirnantian excursion (≥ 7‰) (Kump et al., 1999; Shields et al., 2003; Kaljo et al., 2004; Saltzman and Young, 2005; Young et al., 2005). The carbon isotopic values of the upper part of the Jeongseon Formation do not show such a distinctive positive shift like the Mohawkian and Hirnantian excursions, thus excluding the possibility of Late Ordovician in age for the studied section of the Jeongseon Formation.

For the Middle to Late Ordovician, Saltzman and Young (2005) presented the first time for the high resolution carbon isotopic curve from the Great Basin, U.S.A. (Fig. 6). The carbon isotopic curve of the upper part of the Jeongseon Formation matches well with that of the upper Middle Ordovician to the lowest Upper Ordovician part of the Saltzman and Young (2005)'s curve (Fig. 6). Although global significance of Saltzman and Young (2005)'s curve is yet certain, the Saltzman and Young (2005)'s curve offers an unique possibility to define the stratigraphy of the upper part of the Jeongseon Formation. Combining with conodont biostratigraphic study (Lee, 1976), the present carbon isotopic study suggests that the age of the upper part of the Jeongseon Formation can be assigned to latest Middle Ordovician to earliest Late Ordovician. Although it is difficult to define the precise age of the upper part of the

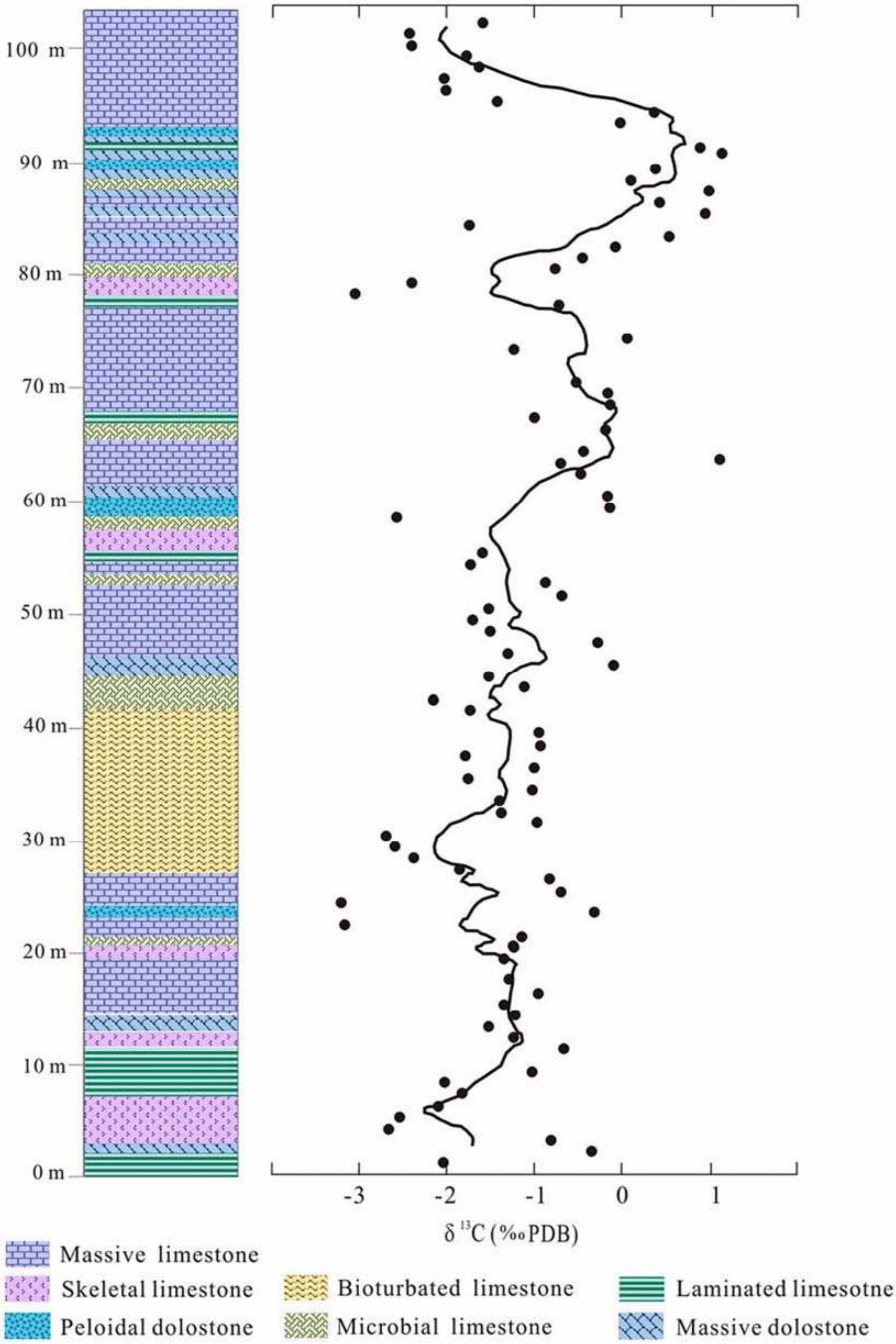

Fig. 4. Lithostratigraphy and carbon isotopic stratigraphy of the upper part of the Jeongseon Formation at the Taeyoung Lime Mine Company quarry. Due to the high frequency fluctuations of $\delta^{13}C$ values, five-point running average is plotted as curved line. Lithostratigraphy zones are based on Hong (2006) who interpreted that the upper part of the Jeongseon Formation at this section was deposited in peritidal environment under semi-arid climates. The depositional environment of each lithofacies is interpreted as follows: peloidal dolomite-intertidal; massive limestone subtidal; massive dolostone-supratidal; bioturbated limestone-subtidal; laminated limestone-intertidal and microbial lime/dolostone-intertidal.

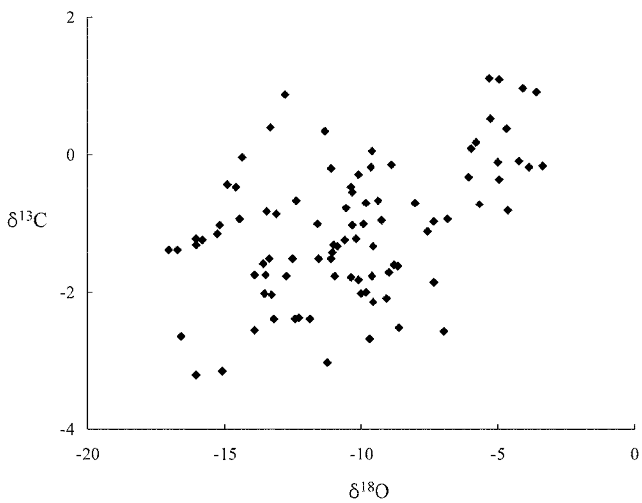

Fig. 5. $\delta^{13}C$ vs. $\delta^{18}O$ for samples from the upper part of the Jeongseon Formation showing poor correlation of these two stable isotopes (r^2=0.23).

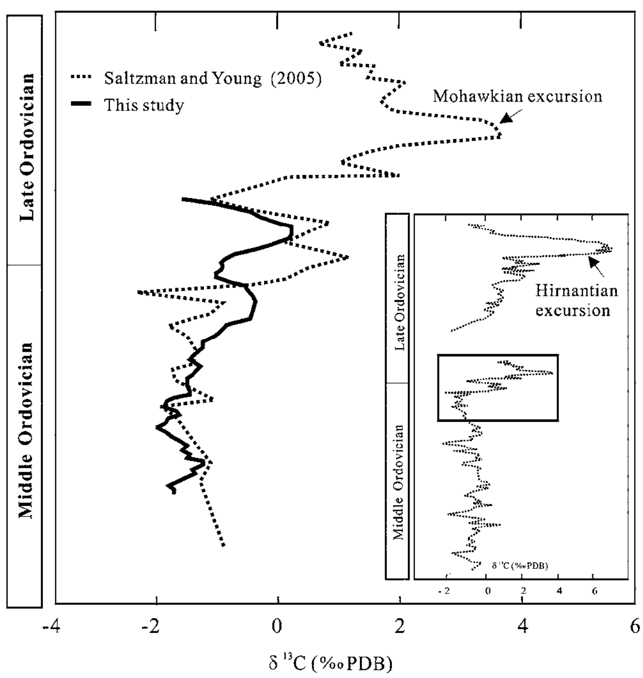

Fig. 6. Correlation of the carbon isotopic curve of the upper part of the Jeongseon Formation in Korea with that of the Great Basin in Nevada, U.S.A. (Saltzman and Young, 2005).

Jeongseon Formation by using carbon isotopic data only because of the lack of information on the global high-resolution carbon isotopic curve of the Middle Ordovician at present, our study provides a first approximation of the geological age for the upper part of the Jeongseon Formation.

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