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Upper Ordovician (Sandbian) conodonts from the Hoedongri Formation of western Jeongseon, Korea

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ABSTRACT: Five sections in western Jeongseon–eastern Pyeongchang provide a relatively complete composite section of carbonate platform facies through the upper part of the Hoedongri Formation. A total of 29 samples (125 kg) yielded 669 relatively well-preserved conodont specimens, which are classified into 16 species representing 10 genera. The fauna is dominated by *Panderodus gracilis* (Branson and Mehl) (55%), which generally is believed to have been pelagic and eurytopic, and comprises characteristic elements of North China faunal affinities. Other taxa include *Aphelognathus solidum* Pei, *Belodina* sp., *Eoligonodina prima* (Branson and Mehl), *Erismodus asymmetricus* (Branson and Mehl), *E. quadridactylus* (Stauffer), *Plectodina aculeata* (Stauffer), *P. alatheta* An, *Tasmanognathus careyi* Burrett, and *T. sishuiensis* Zhang. This assemblage was assigned to the *Tasmanognathus sishuiensis-Erismodus asymmetricus* Zone herein. The interval of the zone is between the first and last occurrences of the eponymous species. The lower limit of the zone is unclear due to the absence of conodont data from underlying dolomitic limestone beds. The *T. sishuiensis-E. asymmetricus* Zone is the youngest conodont zone in the Taebaeksan Basin, Korea and was correlated to the 'upper fauna' of the Yeongheung Formation in Yeongwol, Korea, to the *Belodina compressa-Microcoelodus symmetricus* Zone in Shandong, to the *T. sishuiensis-Erismodus typus* Zone in Gansu, and to the *T. sishuiensis* Zone in the Ordos Basin, North China, representing the interior platform and slope facies of Sandbian age. Based on the recent recognition of the *Aurilobodus serratus* Zone and *T. sishuiensis-E. asymmetricus* Zone, the Hoedongri Formation was assigned to the Middle Ordovician to early Late Ordovician (Darriwilian, D3 to Sandbian, Sa2).

Key words: Upper Ordovician, conodonts, Hoedongri Formation, Jeongseon area, Korea

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1. INTRODUCTION

The present contribution is the second publication arising from an ongoing research project "Conodont Biostratigraphy of the early Paleozoic Sequence in the Jeongseon–Pyeongchang Area, Korea." Lee (2018) erected the *Aurilobodus serratus* Zone for the lower part of the Hoedongri Formation (Cheong et al., 1979) in the Jeongseon–Pyeongchang area and correlated the zone to the Darriwilian zones in North China (An et al., 1983; An and Zheng, 1990). This paper deals with the remaining ~150 m of the upper Hoedongri Formation. The objective of this study aims to measure in detail sections of the upper part of the Hoedongri Formation, to sample for conodonts, and to provide a more precise biostratigraphic correlation, both regionally and internationally.

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2. GEOLOGICAL SETTING

The lower Paleozoic stratigraphy in the western Jeongseon and eastern Pyeongchang areas was summarized by Lee (2018), and this report focuses only on the stratigraphy of the Hoedongri Formation in the area. The name "Upper Limestone" was informally proposed by Hisakoshi (1943) for the Ordovician succession of about 200 m of limestone and dolomitic limestone that succeed the "Haengmak Bed" in western Jeongseon area. The term Hoedongri Formation was raised to the formal status by Cheong et al. (1979), who modified the age of the formation to the Early Silurian based on their conodont data.

The Hoedongri Formation is best exposed in Seongmaryeong section, which is located along a forest road, west of Seongmaryeong (950 m above sea level), near the boundary between Pyeongchang-gun and Jeongseon-gun (Fig. 1). The formation at the section is exposed except the uppermost covered interval (6.7 m) probably

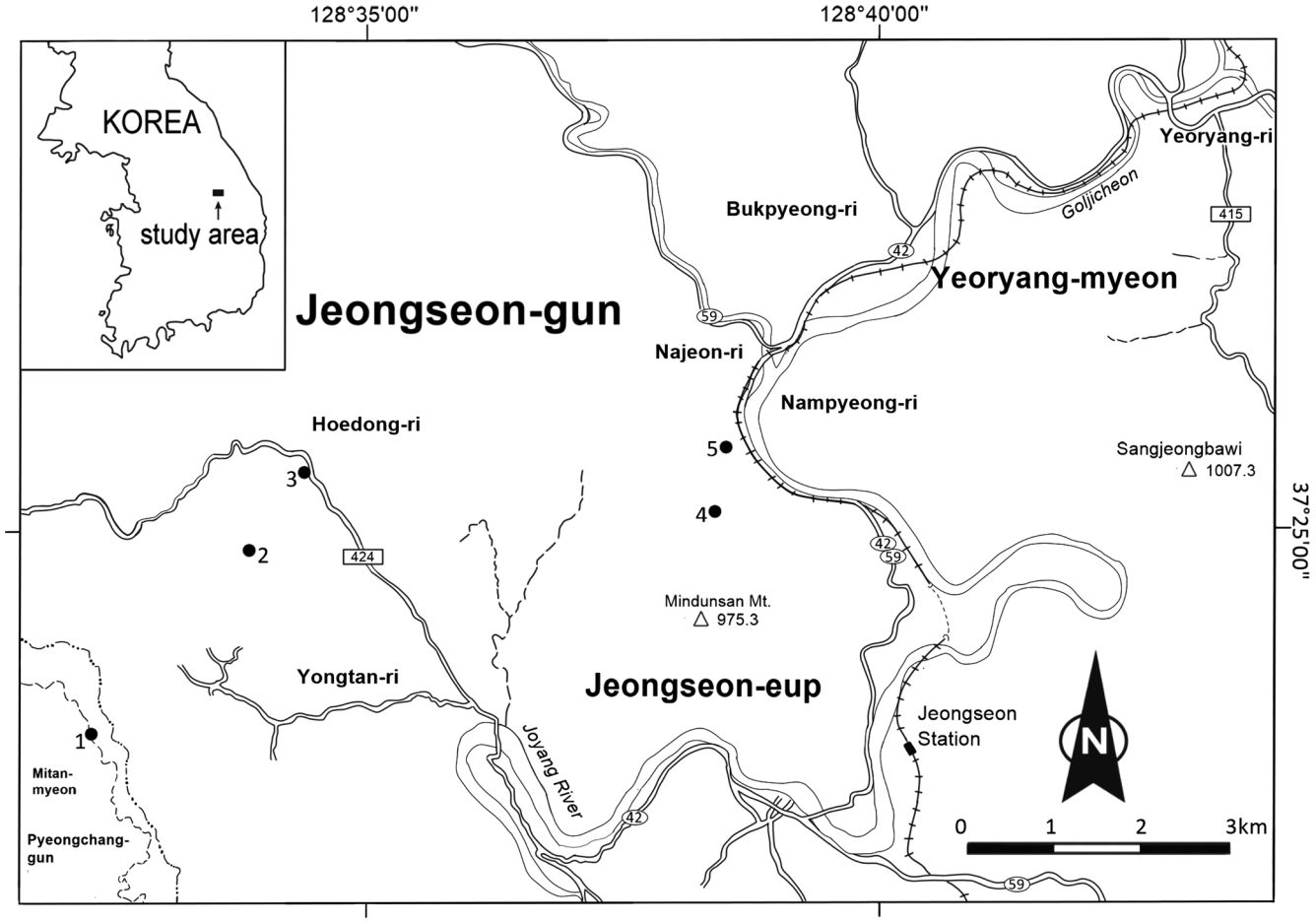

Fig. 1. Simplified map of western Jeongseon–eastern Pyeongchang showing section locations (1–5).

Fm.	Member	Lithology	(m)	Lithologic character	Scope
Hoedongri	Alternation		17.7	limestone, dolomitic, milky white to light gray; wackestone, gray; white calcite veins in lower part	study interval
	Upper Limestone		12.5	wacke- to packstone, partially laminated, gray to dark gray; mudstone, thick bedded; dark gray; bioturbated in the lower part	
	Dolomitic Limestone		117	limestone, dolomitic, milky white to light gray; limestone, calcareous; laminated, light gray to gray	
	Lower Limestone		43	interbedded limestone, massive to laminated, dark gray to mottled shale, argillaceous, light gray	

Fig. 2. Generalized columnar section of the Hoedongri Formation at section 1, forest roadcut east of Hanchidong village, Pyeongan-ri, Mitan-myeon, Pyeongchang-gun. Refer to Figure 3 for lithologic "key".

owing to unconformity with the Upper Carboniferous Hongjeom (Manhang) Formation.

The Hoedongri Formation at the Seongmaryeong section is subdivided into four informal members (Fig. 2). Unit 1 (lower limestone, ±43 m) consists of dark gray to mottled, massive to laminated limestone with interbedded shale; these strata weathered light gray. Unit 2 (dolomitic limestone, ±117 m) is a series of milky white to gray dolomitic limestone and intermittently interbedded, light gray to gray, laminated limestone. This unit accounts for more than half of the Hoedongri Formation in the total thickness. Unit 3 (upper limestone, ±12.5 m) consists of gray to dark gray wackestone to packstone, partially laminated, and dark gray thick-bedded lime mudstone, bioturbated in the lower part. Unit 4 (±17.7 m) consists of alternating milky white

to light gray dolomitic limestone and gray wackestone; white calcite veins are present in the lower part of the unit.

3. SECTIONS

A total of 29 samples were collected from five measured sections, including the Seongmaryeong, Hoedong, Ice Cave, Yami, and Halmigol sections and more than 125 kg of limestone was processed in formic acid using standard methods of conodont extraction. Details about the location of section, lithology, thickness and sample number of the former three sections are shown in Figures 1 to 3.

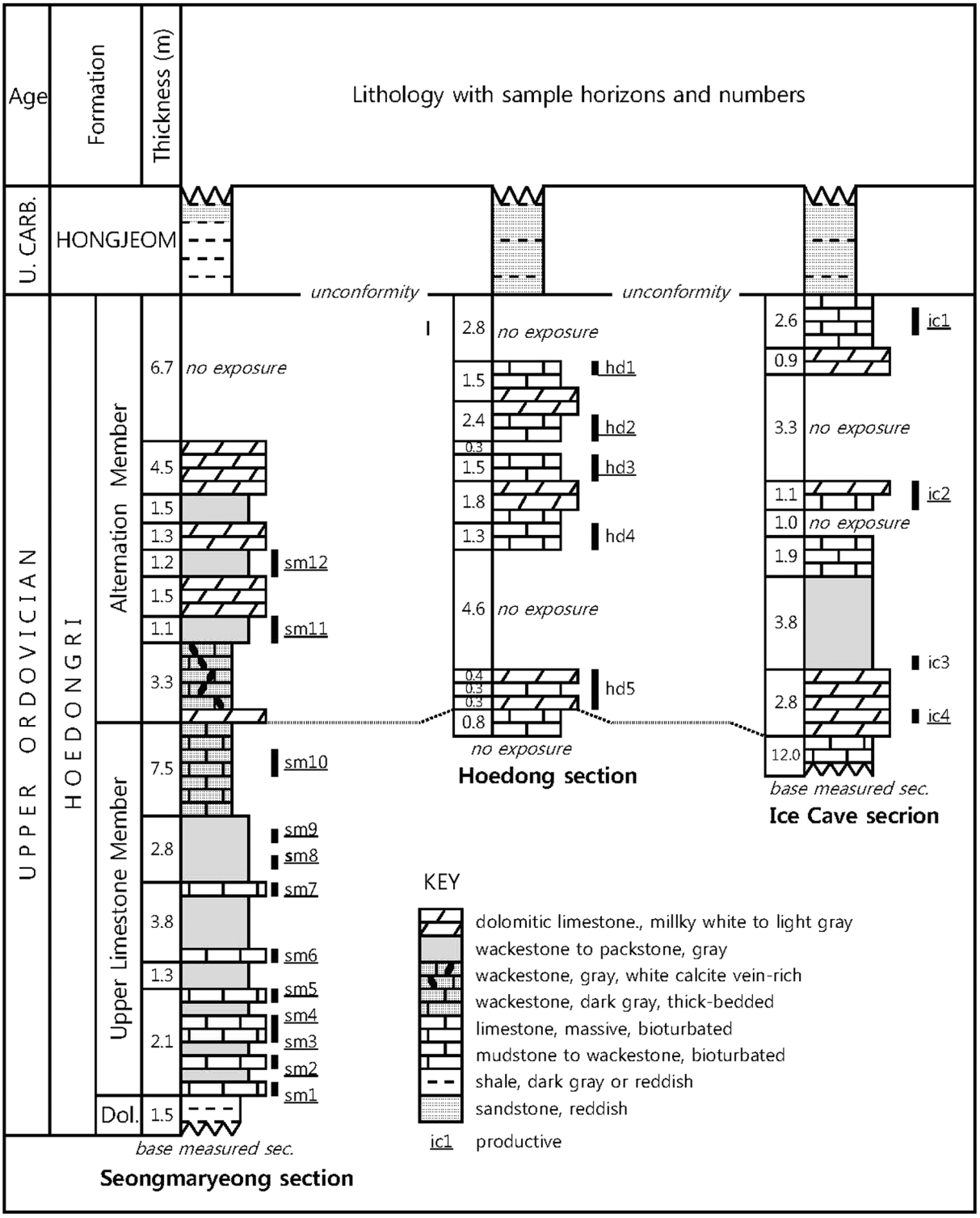

Fig. 3. Vertical lithology of the Seongmaryeong (1), Hoedong (2) and Ice cave (3) sections.

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3.1. Seongmaryeong Section

The Seongmaryeong section includes parts of Unit 3 and 4 (Figs. 2 and 3) and is 38.6 m thick. Unit 3 consists of gray to dark gray, partially laminated wackestone to packstone, with intercalations of thick-bedded mudstone with bioturbated parts. Ten samples were collected for conodonts within this unit. Unit 4 consists of milky white to light gray, dolomitic limestone and gray wackestone, with white calcite veins in lower part. Only two samples were collected for conodonts within this unit.

3.2. Hoedong Section

The Hoedong section is located on a mountain slope about 1.5 km west of Hoedong village, Jeongseon-eup, Jeongseon-gun and is 15.2 m thick. The top 2.8 m of the Hoedongri Formation is covered. This unit consists of milky white to light gray, dolomitic limestone and dark gray wackestone. Five samples were collected for conodonts within Unit 4.

3.3. Ice Cave Section

Outcrops of the Ice Cave section constitute a steep cliff between Gariwangsan mountain ice valley and a campground north of Hoedong village. This section is 29.4 m thick and includes the topmost bed of the formation. Lithology is similar to that of the Hoedong section. Five samples were collected for conodonts within only Unit 4.

3.4. Yami and Halmigol Sections

The Yami (28.5 m thick) and Halmigol sections (37.0 m thick) are located near the Joyang River, about 5.0 km north of Jeongseon-eup, Jeongseon-gun (Fig. 1). Six samples were collected within Unit 4 of the Yami and Halmigol sections.

4. CONODONT FAUNA

A total of 669 conodont specimens were collected from 21 samples from the upper part, that is Unit 3 and 4, of the Hoedongri Formation at five measured sections in the eastern Pyeongchang–eastern Jeongseon area (Fig. 3 and Table 1). Conodonts are classified into 16 species representing 10 genera.

Sample 'ic1' contains an unusually abundant (217 specimens) and diverse (11 species representing 8 genera) conodonts among all samples from the upper part of the Hoedongri Formation. The most dominant species of the fauna is *Panderodus gracilis* (Branson and Mehl, 1933) (55 percent), which is a pandemic species with a relatively long biostratigraphic range, so the species was found in most samples of the studied sections. The numerical distribution of conodonts in each sample is shown in Table 1.

The conodont specimens are relatively well-preserved, although many are fragmentary, particularly the coniform elements. Conodonts have Color Alteration Index (CAI, Epstein et al., 1977) of 5, indicating burial temperatures of less than 300 °C.

5. ZONATION AND CORRELATION

5.1. Zonation

The presence of *Aphelognathus solidum* Pei, *Belodina* sp., *Eoligonodina prima* (Branson and Mehl), *Erismodus asymmetricus* (Branson and Mehl), *E. quadridactylus* (Stauffer), *Plectodina aculeata* (Stauffer), *P. alatheta* An, *Tasmanognathus careyi* Burrett, and *T. sishuiensis* Zhang in the fauna of the upper part of the Hoedongri Formation indicates a Sandbian age. Long-ranging species are *Panderodus gracilis* (Branson and Mehl), *Panderodus nogamii* (Lee), *Drepanoistodus* sp., *Oulodus* sp., and *Phragmodus* sp.

The species of the genus *Tasmanognathus* Burrett were recovered from the Hoedongri Formation: *T. alatheta* An, *T. careyi* Burrett, and *T.* sp. These species are less common than the average in the samples, but occur from the lowest sample ('sm1') of the Seongmaryeong section and from the uppermost bed ('ic1') of the Ice Cave section. From this appearance these species seem to be ranging throughout the studied interval (Fig. 4).

Tasmanognathus sishuiensis, Eoligonodina prima and *Erismodus asymmetricus* occur in sample 'sm2' near the base of the Seongmaryeong section (Figs. 3 and 4), together with Ordovician *Belodina* Ethington, 1959. The three species range up into the top bed (sample 'ic1') of the Hoedongri Formation, that is, they occur in the 16.4 m interval (samples 'sm2' to 'sm10') at the Seongmaryeong section, in the 5.7 m interval (samples 'hd3' to 'hd1') at the Hoedong section, and in the 7.9 m interval (samples 'ic2' to 'ic1') at the Ice Cave section (Figs. 3 and 4).

Eoligonodina prima is also known from the Fengfeng Formation in Henan Province, North China (Pei and Cai, 1987). *T. sishuiensis* and *E. asymmetricus* are distinctive zonal species of Sandbian age in North China (An et al., 1983; Pei and Cai, 1987; An and Zheng, 1990; Leslie, 2000; Kuhn and Barnes, 2005; Wang et al., 2013).

Erismodus quadridactylus was found at the Yami section in sample 'ya2', approximately 19.0 m below the top of the Hoedongri Formation. This species has been reported from the *Erismodus quadridactylus* Zone to the *Belodina compressa* Zone of the Pingliang Formation in North China. The two biozones are generally regarded as Sandbian in age.

Table 1. Conodont species of the Hoedongri Formation (upper part), Pyeongchang-Jeongseon area

Section	Seongmaryeong												Hoedong			Ice cave			Yami		Hm	Total
Species / Sample number	1	2	3	4	5	6	7	8	9	10	11	12	3	2	1	4	2	1	2	1	2	
Aphelognathus solidum																						
Sa el.																		2				2
Sc el.																		2				2
Belodina sp.																						
compressiform el.		1	1																			2
Drepanoistodus sp.																						
drepanodiform (Sc) el.			1																			
Eoligonodina prima		3	1															3				7
Erismodus asymmetricus																						
asymmetrical (Sc) el.		1	1				6			6					2		1	7				24
symmetrical (Sa) el.			1			2	4	1		5			1				4	15				33
Erismodus quadridactylus																						
Sc el.																			1			1
Oulodus sp.																						
Sb el.																		3				
Panderodus gracilis																						
graciliform el.	10	29	16	10	5	1	1	2	1						2		1	15			1	94
transitional el.	17	30	25	10	2		1											19				104
compressiform el.	20	40	25	11	4	4	1	1			1			1	3		2	50			1	164
Panderodus nogamii																						
symmetrical(Pa) el.	2	6									1							8				17
asymmetrical(Sb) el.	4	5	4	1		1				1	1							7				24
Panderodus sp.																						
asymmetrical(Sb) el.		1																				1
Phragmodus sp.																						
Sc el.		1																				
Plectodina aculeata																						
Sb el.			1							3	1			1	1	1	2	7				17
Plectodina alatheta																						
cyrtoniodontiform(M) el.		2															1					3
dichognathiform(Pb) el.	2	1	1																1			5
proniodiniform(Pa) el.	17	14	23	1				1	1	1	2				4			46		1		114
subcordylodontiform(M) el.	2											2			1			2				7
trichonodelliform(Sa) el.		1																4				5
zygognathiform(S) el.																		3				3
Tasmanognathus careyi																						?
Pa el.	1																	3				4
Sa el.	1																	12				13
Tasmanognathus sishuiensis																						
cordylodontiform(M) el.		1																8				9
trichonodelliform(Sa) el.				1																		1
ozakodiniform(Pa) el.		1																				1
zygognathiform(S) el.		1	1	1				1	1													5
Tasmanognathus sp.																						
Pb el.																		1				1
Trucherognathus? sp.		1																				1
Total	76	139	101	35	11	8	13	6	3	16	6	2	2	2	13	1	11	217	2	1	2	669

'el.' = 'element'.

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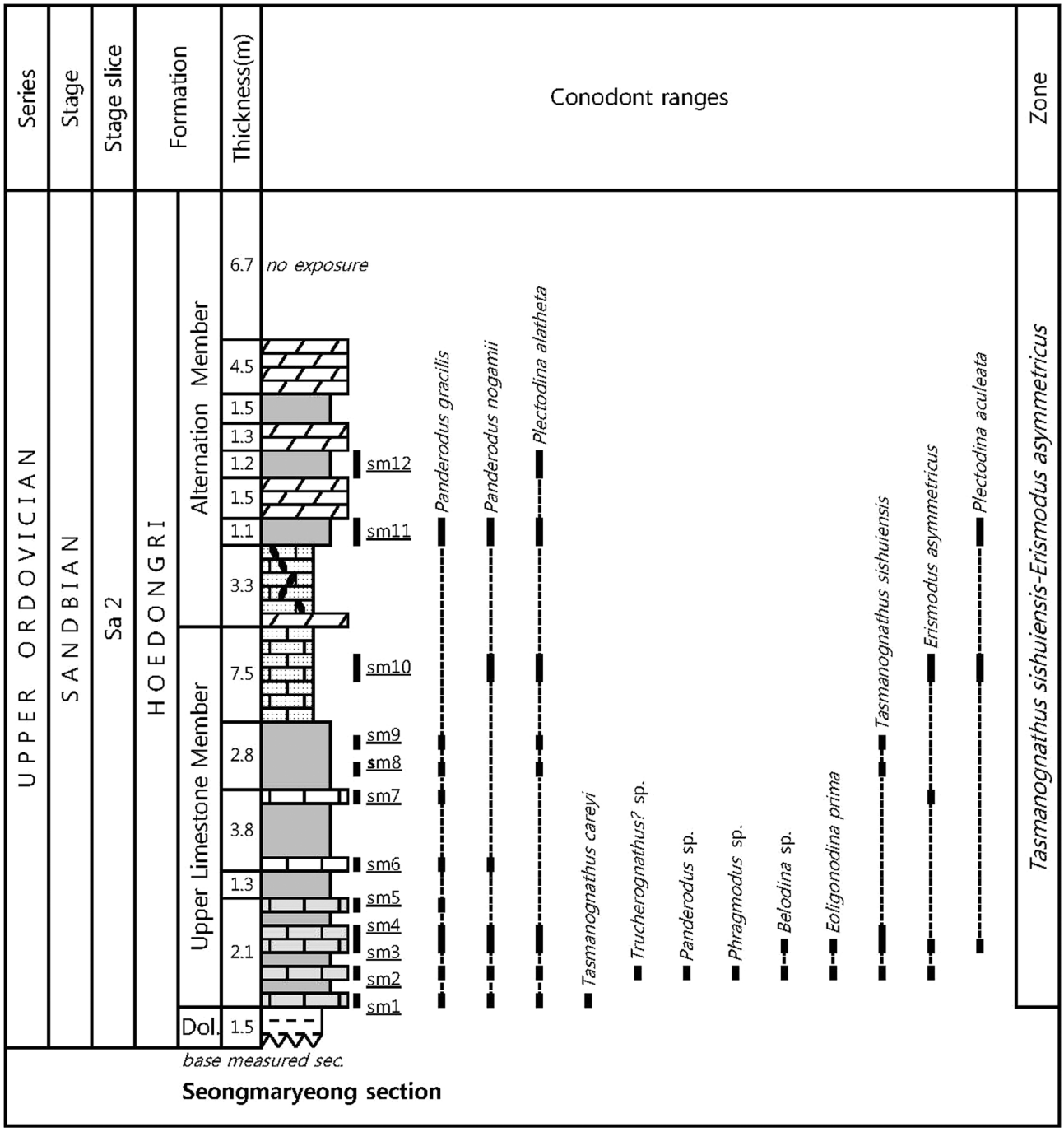

Fig. 4. Conodont distribution in the upper part of the Hoedongri Formation at Seongmaryeong section (Section 1), forest roadcut east of Hanchidong village, Pyeongan-ri, Mitan-myeon, Pyeongchang-gun.

In conclusion, the *Tasmanognathus sishuiensis-Erismodus asymmetricus* Zone was assigned herein, based on the common occurrence of both index species within the 38.6 m interval of Unit 3 and 4 (Upper Limestone and Alternation members in Figs. 2 and 3) of the upper Hoedongri Formation. This zone is particularly easily recognized in the Seongmaryeong and Hoedong sections (Fig. 4). This is the youngest conodont zone in the Taebaeksan Basin, Korea.

5.2. Correlation

Tasmanognathus sishuiensis has been recovered from the *Belodina compressa-E. asymmetricus* Zone of the upper part of the Fengfeng Formation in Shandong Province, North China in association with *B. compressa, E. asymmetricus,* and *Panderodus gracilis* (An et al., 1983).

Tasmanognathus. alatheta was known from the *Yaoxianognathus*

yaoxianensis Zone of the Upper Ordovician Baiyanhuashan Formation, and *Tasmanognathus gracilis-T. multidentatus* Zone of the Middle Ordovician Wulanhudong Formation in Inner Mongolia, China (An, 1993).

Tasmanognathus careyi was well known from the Shiyanhe Formation in Henan Province, China, together with *Aphelognathus solidum* Pei (Pei and Cai. 1987). *T. careyi* was also recovered from the upper part of the Youngheung Formation in Yeongwol, Korea (Lee, 1990) in association with *Eoligonodina prima* (Branson and Mehl) and *Panderodus gracilis* (Branson and Mehl). The common occurrence of *Tasmanognathus* species both in North China and Korea indicates a close relationship between two areas in view of the Sandbian provincialism (Lee, 2018).

Erismodus asymmetricus (Branson and Mehl, 1933) has been reported from the *Belodina compressa-Microcoelodus symmetricus* Zone of the Fengfeng Formation in Shandong Province, North China (An et al., 1983) (*E. asymmetricus* is a multielement species of form species *Microcoelodus asymmetricus* Branson and Mehl, 1933 and *Microcoelodus symmetricus* Branson and Mehl, 1933) and from the *M. symmetricus* Zone in Henan Province, North China (Pei and Cai, 1987). They are associated with *Tasmanognathus careyi*, *Oulodus* sp., *T. sishuiensis*, *Panderodus gracilis*, and *Eoligonodina prima*. In Korea, *Erismodus asymmetricus* was previously known from the upper part of the Yeongheung Formation in the Yeongwol area (Lee, 1990). The stratigraphic range of *E. asymmetricus* is expected to be extended to the younger age, at least Sandbian, judging from the common occurrence of the species with *E. quadridactylus* (Stauffer) in Korea (Table 1) and North China. The *E. quadridactylus* Zone is established between the two Sandbian zones, i.e., *Plectodina aculeata* Zone and *Belodina compressa* Zone in North America (Sweet, 1984) and in North China (Wang et al., 2013; Jing et al., 2017).

Plectodina aculeata (Stauffer) was recovered from sample 'sm10' (10.2 m above the base) to sample 'sm11' at the Seongmaryeong section and from the uppermost samples at Hoedong (sample 'hd1') and Ice Cave (sample 'ic1') sections, along with *Aphelognathus solidum* Pei. Therefore, *P. aculeata* appears to be a useful index species for the upper 28.6 m of the Hoedongri Formation. Wang et al. (2013) reported that *P. aculeata* ranges from the *P. aculeata* Zone to the *Belodina compressa* Zone of the Sandbian Pingliang Formation, Gansu Province, North China. Regional correlation of the Hoedongri zones are summarized in Figure 5.

The *T. sishuiensis-E. asymmetricus* Zone of the Hoedongri Formation was correlated to the early Late Ordovician *Belodina compressa-Microcoelodus symmetricus* Zone in Shandong Province, North China (An et al., 1983), to the *Tasmanognathus sishuiensis-Erismodus typus* Zone in Ordos Basin, North China (An and Zheng, 1990), and partly to the *Erismodus quadridactylus* zones

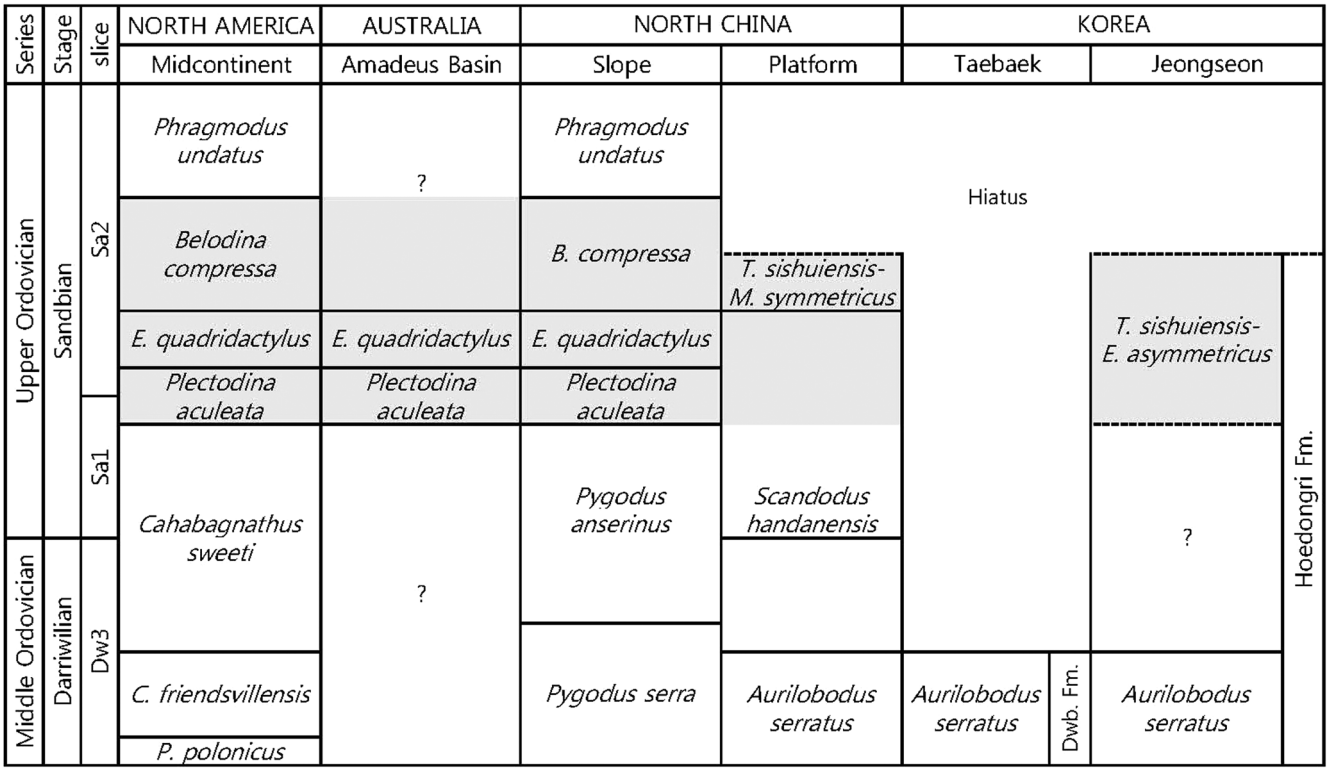

Fig. 5. Correlation of the *Tasmanognathus sishuiensis–Microcoelodus symmetricus* Zone of the Hoedongri Formation with North American Midcontinent (Sweet, 1984), Amadeus Basin of Australia (Zhang et al., 2003), North China (An and Zheng, 1990; Wang et al., 2016) and other areas of Taebaeksan Basin, Korea (Lee and Lee, 1986; Lee and Lee, 1990; Seo, 1997, 2000). 'Dwb. Fm.' = 'Duwibong Formation'.

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in North American Midcontinent (Sweet, 1984) and in Amadeus Basin, Australia (Zhang et al., 2003) (Fig. 5). This zone is believed to be found in the interior platform facies of the Sandbian Stage.

Cheong et al. (1979) first studied conodonts from the Hoedongri Formation in the northwestern Jeongseon area, based on 81 samples. They correlated their conodont fauna to the Early Silurian of the Carnic Alps. However, Lee (2018) erected the *Aurilobodus serratus* Zone for the lower part of the formation and assigned it to the Darriwilian Stage in North China (An et al., 1983; An and Zheng, 1990). In view of the recognition of this zone and of the present *T. sishuiensis-E. asymmetricus* Zone in the lower and upper parts of the Hoedongri Formation, the formation is correlated to the late Middle Ordovician to early Late Ordovician (Darriwilian, D3 to Sandbian, Sa2). Unfortunately, most of the present conodonts including Ordovician index species were not included in the collection of Cheong et al. (1979).

The Hoedongri fauna is closely related to the North American Midcontinent fauna and includes species of *Belodina*, *Erismodus*, and *Plectodina*. The Hoedongri fauna also includes *Tasmanognathus* Burrett, 1979, described from central Tasmania, Australia (Zhen et al., 2010). This genus has been reported from several localities on the North China Platform (An et al., 1983; An and Ding, 1985; Pei and Cai, 1987; An and Zheng, 1990; Lin and Qiu, 1990).

6. CONCLUSIONS

A total of 29 conodont samples was collected for conodonts from the upper part of the Hoedongri Formation at five measured sections in Jeongseon–Pyeongchang area. Twenty-one productive samples yielded 669 conodont specimens, and 16 species representing 10 genera were identified. The dominant two species of the fauna, *Panderodus gracilis* and *Plectodina alatheta,* have relatively long biostratigraphic ranges, and they are found in most samples from the upper part of the Hoedongri Formation.

Biostratigraphically important taxa include *Aphelognathus solidum* Pei, *Belodina* sp., *Eoligonodina prima* (Branson and Mehl), *Erismodus asymmetricus* (Branson and Mehl), *E. quadridactylus* (Stauffer), *Plectodina aculeata* (Stauffer), *P. alatheta* An, *Tasmanognathus careyi* Burrett, and *T. sishuiensis* Zhang.

This conodont assemblage was assigned to the *Tasmanognathus sishuiensis-Erismodus asymmetricus* Zone, which corresponds to the 38.6 m interval of the upper Hoedongri Formation. The zone is the youngest conodont zone in the Taebaeksan Basin, Korea.

The *T. sishuiensis-E. asymmetricus* Zone was correlated to the early Late Ordovician (Sandbian) 'upper fauna' of the Yeongheung Formation in Yeongwol, based on the common occurrence of *Aphelognathus solidum*, *Eoligonodina prima*, *Plectodina aculeata*, *Microcoelodus symmetricus,* and *Tasmanognathus careyi*. This zone was also correlated to the Sandbian Chinese zones, i.e., the *Belodina compressa-Microcoelodus symmetricus* Zone in Shandong Province and the *T. sishuiensis-Erismodus typus* Zone in Ordos Basin, North China, and partly to North America Midcontinent and Australian *Erismodus quadridactylus* zones.

7. PALEONTOLOGICAL NOTES

Most of the species are well known and need no formal taxonomic treatment, but some species with open nomenclature are here illustrated briefly, owing to insufficient elements at this time.

The specimen numbers prefixed by "JBNU" are illustrated specimens (JBNU-1701~JBNU-1867) that are reposited in the Department of Earth Sciences, Chonbuk National University, Jeonju, Korea.

Genus *Belodina* Ethington, 1959

Type species – *Belodina grandis* Ethington, 1959

Belodina sp.

Figures 6.16 and 6.17

Remarks – Two specimens recovered from this study appear externally to be juvenile forms of the genus *Belodina*. They are not well preserved and are referred tentatively to the genus.

Material studied – Two specimens.

Occurrence – Lower beds (samples 'sm2' and 'sm3') of the Seongmaryeong section.

Genus *Panderodus* Ethington, 1959

Type species – *Paltodus unicostatus* Branson and Mehl, 1933

Panderodus sp.

Figure 6.18

Remarks – This specimen has weak furrows on the lateral and posterior faces, arranged asymmetrically. It is impossible to determine that the feature is consistent in a particular species of the genus because only one specimen was recovered.

Material studied – One specimen.

Occurrence – Lower bed (sample 'sm2') of the Seongmaryeong section.

Genus *Tasmanognathus* Burret, 1983

Type species – *Tasmanognathus careyi* Burrett, 1979

Tasmanognathus sp.

Figure 6.35

Remarks – This single specimen is very similar to a Pb element of *Tasmanognathus* cf. *carey* Burret from the Fengfeng Formation, North China (Plate 9, fig. 19, Pei and Cai, 1987). However, the skeletal apparatus of this specimen is unclear.

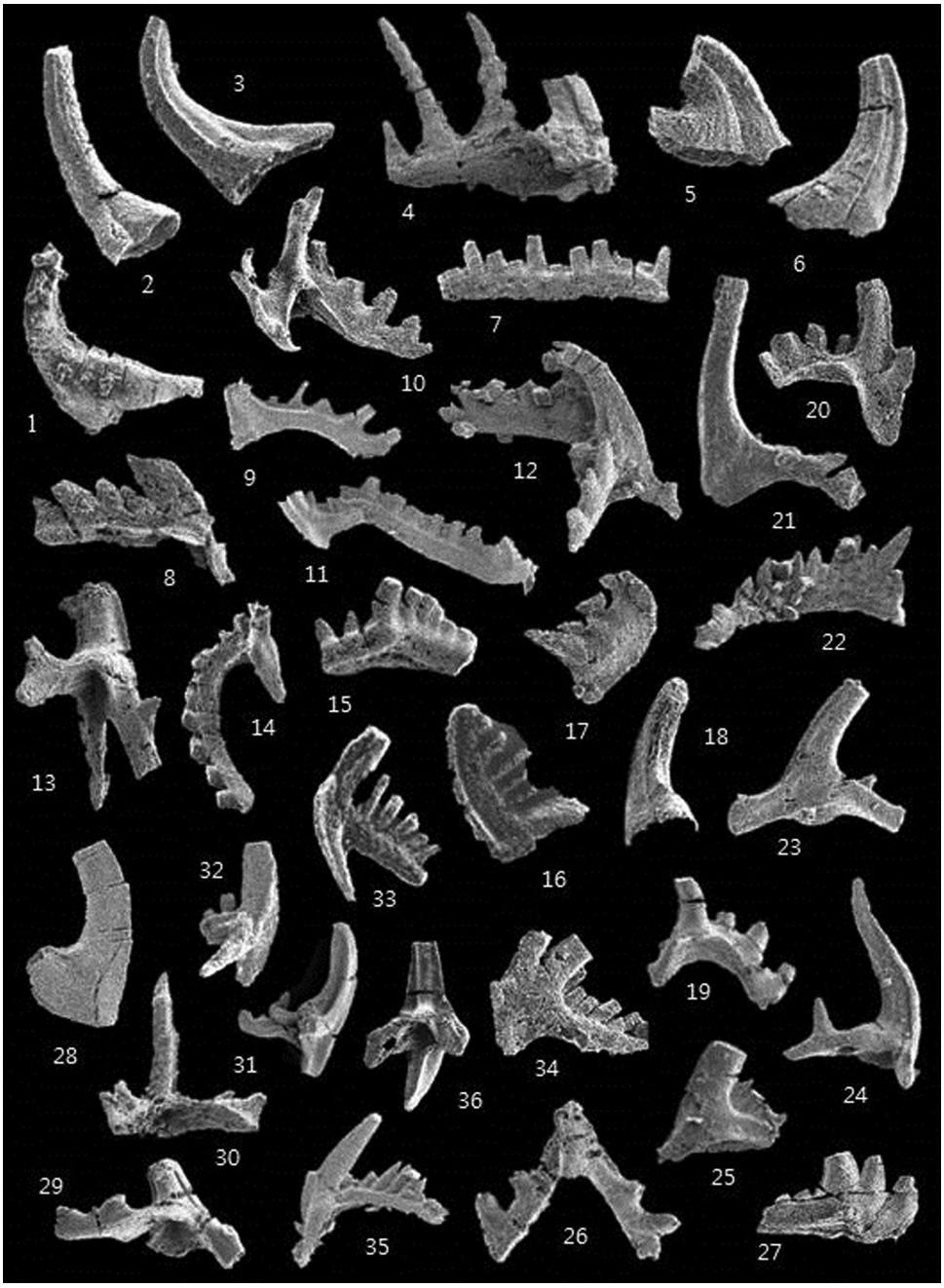

Fig. 6. (1–3) *Panderodus gracilis* (Branson and Mehl, 1933), compressed, rounded and transitional elements, lateral views, samples sm2, sm3, sm3, JBNU-1701, JBNU-1833, JBNU-1842, ×55, ×70, ×70. (4) *Erismodus quadridactylus* (Stauffer, 1935), Sc element, upper view, lateral view, sample ya2, JBNU-1805, ×50. (5 and 6) *Panderodus nogamii* (Lee, 1975), symmetrical (Pa) and asymmetrical (Sb) elements, lateral views, samples sm2, sm1, JBNU-1806, JBNU-1813, ×85, ×110. (7) *Trucherognathus*? sp., lateral view, sample sm2, JBNU-1802, ×75. (8, 10, and 12–15) *Plectodina alatheta* An, 1993, cordylodontiform, cordylodontiform, trichonodelliform, dichognathiform, dichognathiform, zygognathiform, and spathognathodiform elements, lateral (8, 9, and 12–15) and posterior (10) views, samples sm2, ic1, ic1, sm1, sm2, ic1, sm3, JBNU-1823, JBNU-1866, JBNU-1858, JBNU-1809, JBNU-1840, JBNU-1823, JBNU-1702, ×100, ×60, ×60, ×65, ×60, ×80, ×75. (11) *Phragmodus* sp., cordylodontiform element, lateral view, sm2, JBNU-1818, ×90. (16 and 17) *Belodina* sp., juvenile forms, lateral views, samples sm3, sm2, JBNU-1733, JBNU-1803, ×130, ×110. (18) *Panderodus* sp., asymmetrical element, posterolateral view, sample sm2, JBNU-1704, ×40. (19) *Oulodus* sp., Sb element, posterior view, sample ic1, JBNU-1851, ×80. (20–24) *Tasmanognathus sishuiensis* Zhang, 1983, trichonodelliform, cordylodontiform, ozarkodiniform, prioniodiniform and zygognathiform elements, lateral views, samples sm2, sm2, sm2, ic1, sm3, JBNU-1824, JBNU-1815, JBNU-1828, JBNU-1865, JBNU-1838, ×110, ×130, ×55, ×78, ×45. (25 and 26) *Aphelognathus solidum* Pei, 1987, Sc and Sa elements, lateral and posterior views, samples ic1, ic1, JBNU-1846, JBNU-1852, ×100, ×80. (27) *Tasmanognathus* sp., Pb element., lateral view, sample ic1, JBNU-1857, ×60. (28) *Paroistodus proteus* (Lindström, 1955), drepanodontiform element, lateral view, sample sm3, JBNU-1836, ×70. (29 and 30) *Erismodus asymmetricus* (Branson and Mehl, 1933), posterior views, asymmetrical and symmetrical elements, samples ic2, ic1, JBNU-1867, JBNU-1844, ×65, ×60. (31 and 32) *Plectodina aculeata* (Stauffer, 1930), Sb elements, lateral views, samples ic1, sm3, JBNU-1847, JBNU-1835, ×35, ×40. (33 and 34) *Eoligonodina prima* (Branson and Mehl, 1933), inner-lateral views, samples ic1, sm3, JBNU-1737, JBNU-1806, ×70, ×80. (35 and 36) *Tasmanognathus careyi* Burrett, 1979, Pa and Sa elements, lateral and posterior views, samples sm1, ic1, JBNU-1807, JBNU-1863, ×100, ×40.

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Material studied – One specimen.

Occurrence – The uppermost bed (sample 'ic1') of the Ice cave section.

Genus *Trucherognathus* Branson and Mehl, 1933

Type species – *Trucherognathus distorta* Branson and Mehl, 1933

Trucherognathus? sp.

Figure 6.7

Remarks – One fragmentary specimen, recovered from a lower bed of the Seongmaryeong section, is similar to the species that Pei and Cai (1987) reported from the Shiyanhe Formation, Henan Province, China.

Material studied – One specimen.

Occurrence – Lower bed (sample 'sm2') of the Seongmaryeong section.

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REFERENCES

An, T., 1993, Conodonts and conodont biostratigraphy of the Middle and Upper Ordovician in North China. Unpublished Ph. D. Thesis, Tsukuba University, Tsukuba, 171 p.

An, T. and Ding, L., 1985, Ordovician conodont biostratigraphy in Hexian, Anhui Province. Geological Review, 31, 1–12.

An, T. and Zheng, Z., 1990, The conodonts of the marginal areas around the Ordos Basin, North China. Science Press, Beijing, 199 p. (in Chinese with English abstract)

An, T., Zhang, F., Xiang, W., Zhang, Y., Xu, W., Zhang, H., Jiang, D., Yang, C., Lin, L., Cui, Z., and Yang, X., 1983, The conodonts of North China and the adjacent regions. Beijing, Science Press of China, 233 p. (in Chinese with English abstract)

Branson, E.B. and Mehl, M.G., 1933, Conodont studies, numbers 1 and 2. University of Missouri Studies, 8, 167 p.

Burrett, C.F., 1979, *Tasmanognathus*: a new Ordovician conodontophorid genus from Tasmania. Geologica et Palaeontologica, 13, 31–38.

Chen, M.J. and Zhang, J.H., 1984, Middle Ordovician conodonts from Tangshan, Nanjing. Acta Micropalaeontologica Sinica, 1, 120–137. (in Chinese with English abstract)

Cheong, C.H., Lee, H.Y., Ko, I.S., and Lee, J.D., 1979, A study on stratigraphy and sedimentological environments of the lower Paleozoic sequences in South Korea (chiefly in Jeongseon area). Journal of National Academy of Sciences, Republic of Korea, Natural Science Series, 18, 123–169.

Epstein, A.G., Epstein, J.B., and Harris, L., 1977, Conodont color alteration – an index to organic metamorphism. U.S. Geological Survey Professional Paper, Washington D.C., 995, 27 p.

Ethington, R.L., 1959, Conodonts of the Ordovician Galena Formation. Journal of Paleontology, 33, 257–292.

Hisakoshi, S., 1943, Geology of Seizen (Jeongseon) district, Kogendo, Tyosen. Journal of the Geological Society of Japan, 50, 269–277. (in Japanese)

Kuhn, T. and Barnes, C., 2005, Ordovician conodonts from the Mithaka Formation (Georgina Basin, Australia). Regional and paleobiogeographical implications. Geology Acta, 3, 317–337. https://doi.org/10.1344/105.000001382

Lee, H.Y., 1975, Conodonten aus der unteren und mittleren Ordovizium von Nord-Korea. Paleontolographica, 150, 161–186.

Lee, S.J., 1990, Conodont biostratigraphy and paleoecology of the Yeongheung Formation in the Yeongwol area. Unpublished MS. Thesis, Yonsei University, Seoul, 150 p.

Lee, B.S., 2018, Recognition and significance of the *Aurilobodus serratus* Conodont Zone (Darriwilian) in lower Paleozoic sequence of the Jeongseon–Pyeongchang area, Korea. Geosciences Journal, 22, 683–696.

Lee, Y.N. and Lee, H.Y., 1986, Conodont biostratigraphy of the Jigunsan Shale and Duwibong Limestone in the Nokjeon–Sangdong area, Yeongweol-Gun, Kangwon-Do, Korea. Journal of the Paleontological Society of Korea, 2, 114–136.

Lee, K.W. and Lee, H.Y., 1990, Conodont biostratigraphy of the upper Choseon Supergroup in Jangseong–Dongjeom area, Gangwondo. Journal of the Paleontological Society of Korea, 6, 188–210.

Leslie, S.A., 2000, Mohakian (Upper Ordovician) conodonts of Eastern North America and Baltoscandia. Journal of Paleontology, 74, 1122–1147.

Lin, B. and Qiu, H., 1990, Geological and geographical distribution of the Ordovician conodont genus *Tasmanognathus* Burrett in North China. Courier Forschungsinstitut Senckenberg (CFS), 117, 55–59.

Lindström, M., 1955, Conodonts from the lowermost Ordovician strata of south–central Sweden. Geologiska Föreningen i Stockholm Förhandlingar, 76, 517–604.

Pei, F. and Cai, S., 1987, Ordovician conodonts of Henan Province, China. Geology Publishing House of Wuhan College, Wuhan, 142 p. (in Chinese with English abstract)

Seo, K.S., 1997, Conodont fauna from the Goseong Limestone in the Danyang area, Chungcheongbuk-do and its biostratigraphy. Journal of the Geological Society of Korea, 33, 220–233. (in Korean with English abstract)

Seo, K.S., 2000, Conodonts from the lower Paleozoic strata in Sindong-eup, Jeongseon-gun, Gangweon-do and their biostratigraphy. Journal of the Geological Society of Korea, 36, 499–516. (in Korean with English abstract)

Stauffer, C.R., 1930, Conodonts from the Decorah Shale. Journal of Paleontology, 4, 121–128.

Stauffer, C.R., 1935, The conodont fauna of the Decorah Shale (Ordovician). Journal of Paleontology, 9, 596–620.

Sweet, W.C., 1982, Conodonts from the Winnipeg Formation (Middle Ordovician) of the Northern Black Hills, South Dakota. Journal of Paleontology, 56, 1029–1049.

Sweet, W.C., 1984, Graphic correlation of upper Middle and Upper Ordovician rocks, North American Midcontinent Province, U.S.A. In: Bruton, D.L. (ed.), Aspects of the Ordovician System. Palaeontological Contributions from the University of Oslo, 295, p. 23–25.

Wang, Z., Bergström, S.M., Zhen, Y., and Zhang, Y., 2013a, New discovery of conodonts from the Upper Ordovician Pingliang Formation of Pingliang, Gansu, China and its significance. Acta Micropalaeontologica Sinica, 30, 123–131. (in Chinese with English abstract)

Wang, Z., Bergström, S.M., Zhen, Y., Chen, X., and Zhang, Y., 2013b, On the integration of Ordovician conodont and graptolite biostratigraphy: new examples from Gansu and Inner Mongolia in China. Alcheringa, 37, 510–528.

Wang, Z.H., Zhen, Y.Y., Zhang, Y.D., and Wu, R.C., 2016, Review of Ordovician conodont biostratigraphy in the different facies of North China. Journal of Stratigraphy, 40, 1–16. (in Chinese with English abstract)

Zhang, J., Barnes, C.R., and Cooper, B.J., 2003, Early Late Ordovician conodonts from the Stokes Siltstone, Amadeus Basin, central Australia. Courier Forschungsinstitut Senckenberg, 245, 1–38.

Zhen, Y., Zhang, Y., and Percival, I.G., 2009, Early Sandbian (Late Ordovician) conodonts from the Yenwashan Formation, western Zhejiang, South China. Alcheringa, 33, 133–161.

Zhen, Y., Burrett, C.F., Percival, I.G., and Lin, B.Y., 2010, A Late Ordovician conodont fauna from the Lower Limestone Member of the Benjamin Limestone of central Tasmania, and revision of *Tasmanognathus careyi* Burrett, 1979. Proceedings of Linnean Society of New South Wales, 131, 43–72.

https://doi.org/10.1007/s12303-019-0009-8