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Conodonts from the Hwajeol Formation (Upper Cambrian) in the Seokgaejae area, southeast margin of the Taebaeksan Basin

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ABSTRACT: The Cambrian-Ordovician succession crops out well in the Seokgaejae area of the southeastern margin of the Taebaeksan Basin. The Upper Cambrian Hwajeol Formation of the Seokgaejae section was studied to refine the conodont zones previously proposed and to correlate them with other areas. Based on euconodont species, four zones are recognized: a new and unnamed informal lowermost and the *Proconodontus, Eoconodontus notchpeakensis* and *Cambrooistodus minutus* zones in ascending order. This zonal framework is basically equivalent to that of southern (Lee and Lee, 1988; Lee, 2001, 2002) and northern (Lee, 1989, 1990, 2004) limbs of Paekunsan syncline. The four zones of Seokgaejae section are correlated with those of other parts of the world, including North China, North America and Australia. The study was unable to refine conodont zonation of the basal and uppermost parts of the formation. This may be related to either sealevel change or structural control on sediment deposition in the section.

Key words: Upper Cambrian, Hwajeol Formation, conodont biostratigraphy, Seokgaejae section.

1. INTRODUCTION

This study is principally intended to re-examine the conodont biostratigraphic zones of the Hwajeol Formation in the Seokgaejae section, located in the southeastern margin of the Taebaeksan Basin, and also to correlate the zones proposed herein with those established in other parts of the world. In particular, the conodont succession of the intervals near base and top of the formation is the target to supplement for solid zonation of the Upper Cambrian of Korea.

Kobayashi (1935) first recognized five megafossil zones in the Upper Cambrian Hwajeol Formation, namely *Prochuangia, Chuangia, Kaolishania, Dictyites* and *Eoorthis* zones in stratigraphic order. Recently Choi et al. (2004) and Sohn and Choi (2007) recognized *Asioptychaspis*, *Quadraticephalus* and *Mictosaukia* zones from the Hwajeol Formation.

Previous conodont studies of the Hwajeol Formation in Taebaeksan Basin have been restricted to the area west of Dongjeom. Lee and Lee (1971) provided a preliminary report on Cambrian-Ordovician conodonts from Dongjeom area, and described a few conodonts from the Upper Cambrian. Subsequently, Lee, H. Y. (1975) and Lee, B. S. (1983) also described Upper Cambrian conodonts from the Hwajeol Formation in the south and north side of the Paekunsan syncline, respectively.

A conodont zonal scheme for the Hwajeol Formation was first established by Lee and Lee (1988) and subsequently modified and further refined by Lee, B. S. (1989, 1990, 1992) and Lee and Lee (1993). The following conodont zones have been recognized: *Proconodontus, Eoconodontus notchpeakensis, Cambrooistodus minutus, Cordylodus proavus* and *Monocostodus sevierensis-Semiacontiodus nogamii-Fryxellodontus inornatus* zones in ascending order.

2. STRATIGRAPHIC SUMMARY

The Cambrian-Ordovician Choseon Supergroup is well exposed in the Taebaeksan Basin, Kangweon Province. The Duwibong-type sequence of the supergroup is best known along the southern limb of the Paekunsan syncline.

Many stratigraphical and paleontological contributions of the supergroup have been made in this area. Kobayashi (1935) originally defined dark reddish slate and limestone beds overlying the Daegi Limestone near the Dongjeom area as two separate formations, namely the lower Sesong Slate and the upper Hwajeol Formation. The Geological Investigation Corps of the Taebaeksan Region (GICTR) (1962) and Cheong (1969) incorporated the Sesong Slate into the Hwajeol Formation. Particularly, Cheong (1969) divided the Hwajeol Formation into four members: basal member (dark reddish slate interval, Sesong Slate of Kobayashi, 1935), lower member (banded limestone interval), middle member (sandstone and limestone conglomerate-intercalated interval) and upper member (banded limestone with limestone conglomerate interval).

The Hwajeol Formation in the Seokgaejae section is composed mainly of a mixture of carbonate and shale with repeated intercalations of limestone conglomerates (Fig. 2). The shale-dominant facies includes calcareous shale, nodule-bearing shale and laminated fine-grained sandstone, whereas the carbonate-dominant facies consists of flaser wackestone to packstone, massive grainstone, limestone-shale couplets and limestone pebble conglomerate (Choi et

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al., 2004).

Choi et al. (2004) divided the Hwajeol Formation in the Seokgaejae section into three parts, consisting of lower (34 m thick), middle (14 m thick) and upper (ca. 5 m thick) parts. The lower part consists of nodule-bearing shale, limestone-shale couplets and limestone pebble conglomerate. The middle part consists of cyclic alternations of nodule-bearing shale or calcareous shale and flaser wackestone to packstone. The upper part consists of nodule-bearing shale, laminated fine-grained sandstone and calcareous shale with limestone pebble conglomerate.

Kobayashi (1935) correlated the Hwajeol Formation with the Chaumitian Series (upper part of the Furongian) of China based on his megafossil collection, and Choi et al. (2004) and Sohn and Choi (2007) correlated their *Asioptychaspis*, *Quadraticephalus* and *Mictosaukia* faunas with the uppermost Cambrian faunas of North China and Australia.

Conodont correlation data of the Hwajeol Formation (Lee, B. S. and Lee, H. Y., 1988; Lee, 1989, 1990, 1992; Lee, B. S. and Lee, J. D., 1993) are also similar to those of trilobite, representing time span from Franconian to Trempealeauan age (post-Paibian of the Furongian) of North America (Miller, 1988) and from Changshanian to Fengshanian age (also post-Paibian of the Furongian) of North China (An et al., 1983; Chen, 1986), respectively.

3. SECTION AND CONODONT OCCURRENCE

The Seokgaejae section including full sequence of the Hwajeol Formation is located along a sinuous mountain trail ca. 25 km southeast of Taebaek City (Fig. 1). The outcrops of the section are well exposed along south side of mountain slope at the elevation of about 900 m near a border between Kangweon and Kyeongbuk provinces.

Twenty three limestone samples were collected from two segments of the Seokgaejae section. Sample horizons and their lithologies are shown on Figure 2. Each of samples, having the weight of 1 or 2 kg, was dissolved by acetic acid.

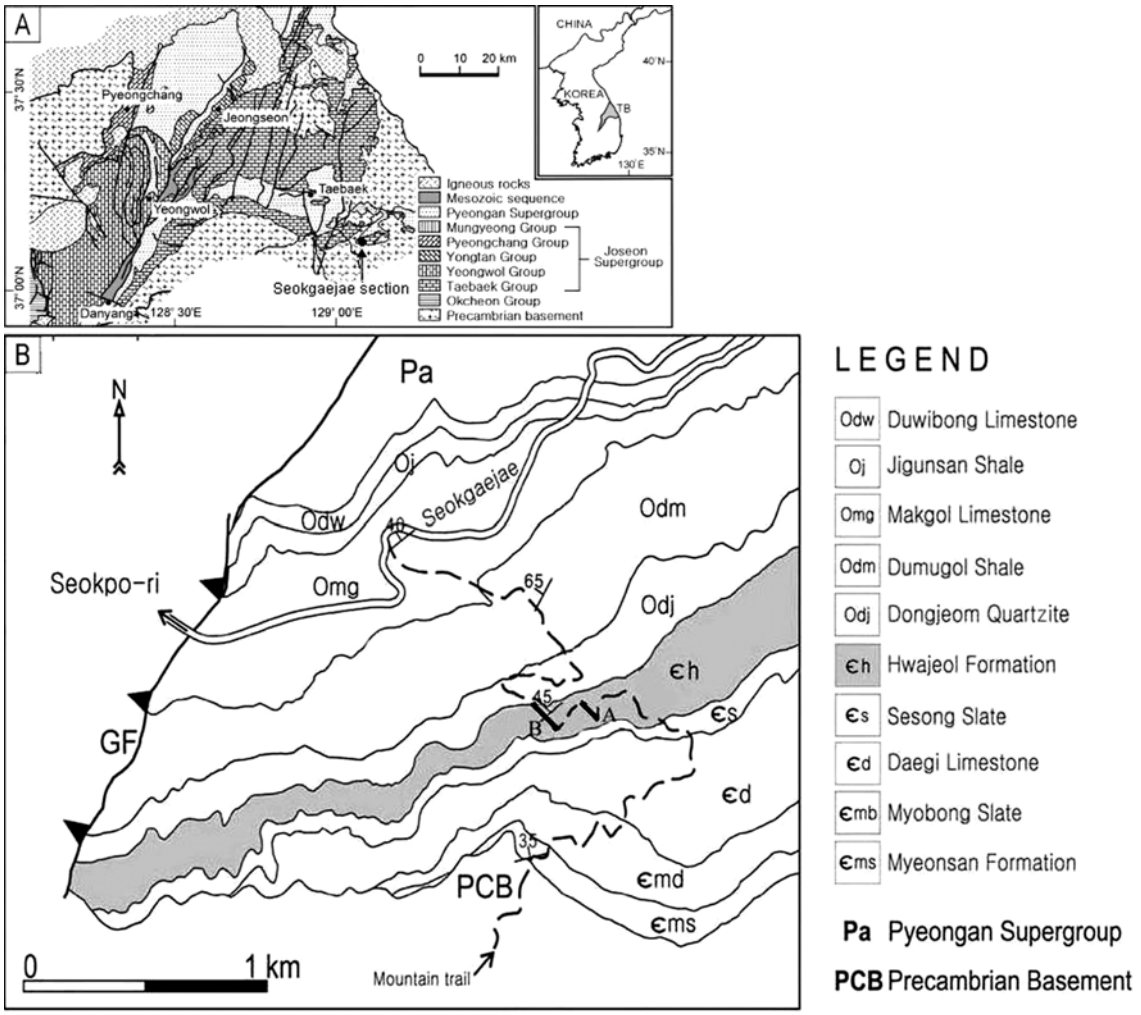

Fig. 1. (A) Simplified geologic map of the Choseon Supergroup in the Taebaeksan Basin and the location of study area. (B) Detailed geologic map of the Seokgaejae area, showing section locations (A, B), southeast Taebaeksan Basin (modified from Choi et al., 2004; Kwon and Chough, 2005).

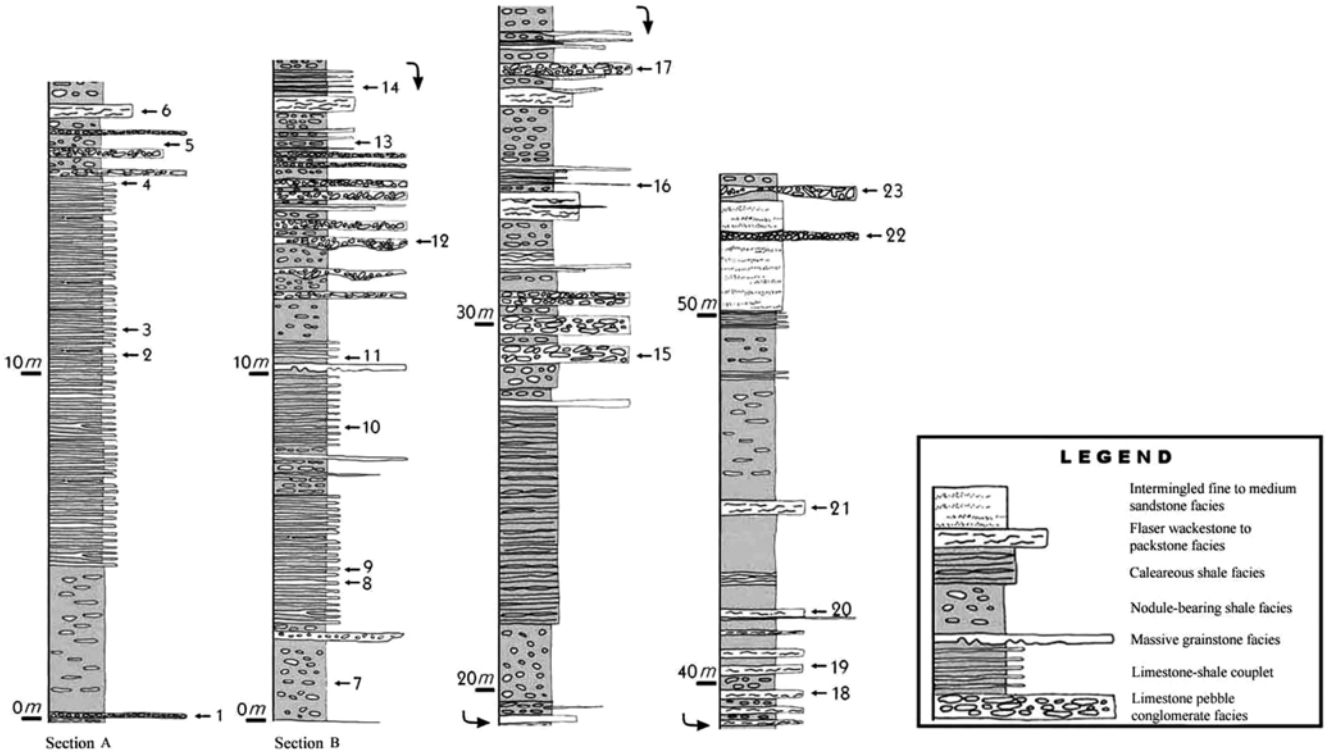

Fig. 2. Columnar sections of the Hwajeol Formation, with sample horizons and numbers (KH 1~23).

Table 1. Stratigraphic nomenclature of the Choseon Supergroup in the Taebaeksan Basin (Lee, 2001).

Duwibong area			
Age	Supergr.	Group	Formation
Ordovician	Choseon	Great Limestone	Duwibong Limestone
			Jigunsan Shale
			Maggol Limestone
			Dumugol Shale
			Dongjeom Quartzite
Cambrian			Hwajeol Formation
			Sesong Slate
			Daegi Limestone
		Yangdeok	Myobong Slate
			Jangsan Quartzite

Of the twenty three, twenty one samples yielded 575 identifiable conodont elements and nineteen specimens of *Phosphannulus universalis* (Table 2). Conodont abundance from the upper part of the section is relatively greater than that from the lower of the section. Only two samples (KH 14, 18) contained more than 100 elements, and the average recovery was 27.38 elements. This recovery value is very similar to those of any other parts of Duwibong area (Lee and Lee, 1988).

Euconodont elements exceed protoconodont and paraconodont elements in number. Particularly, elements of *Furnishina*, *Rotundoconus* and *Westergaardodina* were scarce in comparison of other areas in Taebaeksan Basin (Lee and Lee, 1988). The two most dominant euconodont species are *Eoconodontus notchpeakensis* (128 specimens) and *Proconodontus muelleri* (106 specimens).

Average element size of the Seokgaejae section was relatively small as compared to those of any parts of Duwibong area. However, Seokgaejae conodonts have similar state of preservation and surface color (CAI 5.5) like other Duwibong conodonts have.

Recovered conodont elements are referred to thirty three species belong to sixteen genera. Ranges of conodonts in the short (Section A) and long (Section B) segments with biostratigraphic units recognized in full Seokgaejae section are shown on Figure 3. Note the overlap of conodont ranges between two segments, particularly in the lower interval of the Hwajeol Formation.

4. CONODONT BIOSTRATIGRAPHY

The conodont fauna of the Hwajeol Formation in the Seokgaejae section is useful for zonation and worldwide correlation, except in both the lowermost and uppermost parts of the formation. Protoconodonts and paraconodonts have long ranges, and the zonation is based on many worldwide index euconodonts, particularly those of the *Procon-*

Table 2. Numerical distribution of conodont taxa in the samples from the Hwajeol Formation, Seokgaejae section.

Species / Sample (KH)	1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	17	18	19	20	21	22
Cambrooistodus cambricus															1	1	12			1	
Cambrooistodus minutus																	10	3		3	
Dasytodus nodus	1			1		1					1		6	1			4	1	2		
Dasytodus transmutatus				2							3		3								
Eoconodontus notchpeakensis																					
rounded el.														1			23	22	1	11	1
compressed el.														1			39	13	1	15	
Fryxellodontus fengshanensis																		1			
Furnishina dayangchaensis																	1				
Granatodontus ani				9								1	2		1		7	1	1		
Granatodontus asymmetrica				8				5		1		3	13				3		1		
Granatodontus hwajeolensis				6				1					4				1				
Granatodontus multicorrugata				3	1			1			3				1						
Hertzina triquetra				1																	
Muellerodus cambricus	1																				
Muellerodus? *oelandicus*	1																				
Muellerodus hunjiangensis					2				1					1							
Phakelodus elongatus	15	2		3			1			2	1		8		1		2				
Phakelodus tenuis	2			1			1				3		2				1				
Proconodontus serratus																			1		
Proconodontus tenuiserratus				2	4																
Proconodontus muelleri				2	1	1					11	2	52	2	3	4	15	5	7	1	
Prooneotodus gallatini		1	1	1	2				1		1								1		
Prooneotodus rotundatus		3		9	1				1			1									
Prosagittodontus eureka					1							1	1	1	1						
Prosagittodontus cf. *minimus*													1								
Prosagittodontus sp.					1			1					1								
Proscandodus dissimilaris				1				1	1												
Rotundoconus bulbousus																					
noncarinate el.													3			1					
tricarinate el.														1							
tetracarinate el.											1	3	1								
Rotundoconus jingxiensis																					
tricarinate el.								1					2								
tetracarinate el.													2	1							
Semiacontiodus cf. *lavadamensis*																			2		
Semiacontiodus nogamii				1									1	2			1				
Semiacontiodus cf. *nogamii*																			1		
Teridontus nakamurai	1			5	6		1	1	1		6	7	10	12		1	29	2		2	
Westergaardodina bicuspidata																1					
Westergaardodina sp.					1																
Phosphannulus universalis									1				1	1	2	10	1	1	1	1	
Total	21	6	1	55	20	2	3	11	6	3	30	18	113	24	10	19	149	49	19	34	1

odontus lineage. Four conodont zones are established for the Hwajeol Formation in the Seokgaejae Sections A and B: Unnamed, *Proconodontus, Eoconodontus notchpeakensis* and *Cambrooistodus minutus* zones in ascending order (Figs. 3 and 4). The base of each conodont zones are drawn at the successive first appearance of nominated taxa. The four zones are essentially equivalent to the conodont zones of southern (Lee and Lee, 1988) and northern (Lee, 1989, 1990, 2004) limbs of the Paekunsan syncline, Korea.

Unfortunately, no named zonally indicative conodont species are recovered from the lower interval below KH 4 of Section A and KH 12 of Section B, so the interval is termed 'unnamed'. Likewise, no zonally indicative conodonts are recovered from the interval above KH 21 of Section B,

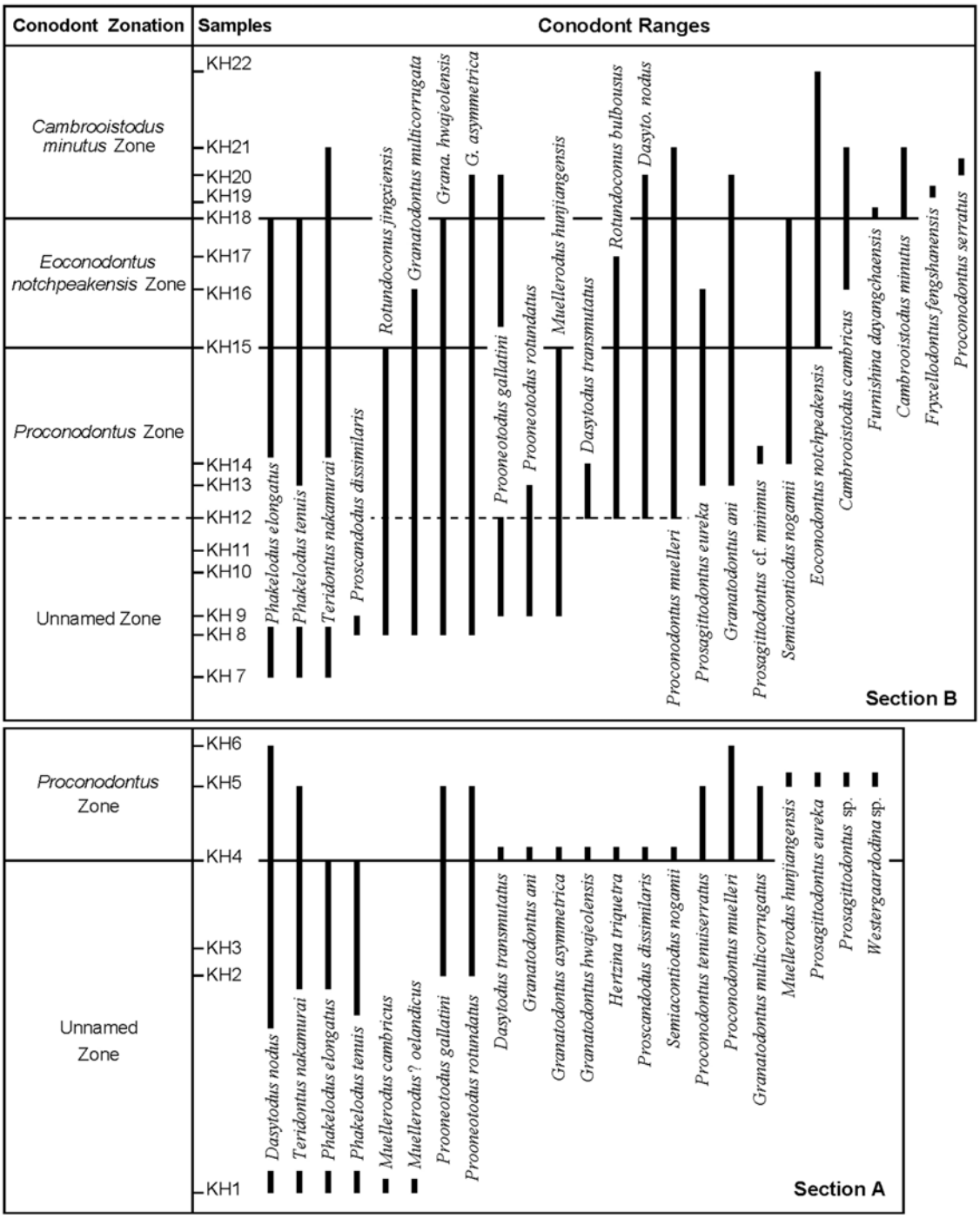

Fig. 3. Stratigraphic ranges of conodonts and their zones of the Hwajeol Formation in the Sections A and B, southeast Taebaeksan Basin.

representing KH 22 and KH 23, so the uppermost conodont zones in other areas, namely *Cordylodus proavus* and *Monocostodus sevierensis-Semiacontiodus nogamii-Fryellodontus inornatus* zones, are not recognized in this study.

The lowest 'Unnamed' Zone is designated for the sample KH 1-3 of Section A and KH 7-11 of Section B (Table 2; Fig. 3). This zone contains several long-ranging species of protoconodonts (*Pakelodus*), paraconodonts (*Prooneotodus* and *Muellerodus*), and euconodonts (*Dasytodus* and *Teridontus*) (Table 2; Fig. 3) before the first proconodontiids appeared in KH 4 and KH 12. These two horizons (KH 4 and KH 12) of Sections A and B are provisionally correlated based on the common occurrence of *Proconodontus muelleri*. Some interval near the lower boundary of the Hwajeol Formation appeared to be structurally controlled together with deformation caused by intrusion. This zone is

the lowest, new one of the Hwajeol Formation, and equivalents to *Distacodus*? *palmeri-Prooneotodus rotundatus* Zone of Changshanian, North China (An et al., 1983) and pre-*Proconodontus muelleri* Zone, North America (Miller et al., 2003).

The *Proconodontus* Zone starts with the first appearance of *Proconodontus tenuiserratus* and *Proconodontus muelleri* (KH 4, 12) (Table 2; Fig. 3) and the upper boundary is drawn at the lowest appearance of *Eoconodontus notchpeakensis* (KH 15). In view of the range of *Proconodontus muelleri*, the base of the *Proconodontus* Zone in the Section B appeared to be drawn at the lower horizon than KH 12. This zone contains several protoconodonts and paraconodonts, together with euconodonts listed above and *Dasytodus* spp. and *Teridontus nakamurai*. One more exceptional recovery from KH 4 of Section A is *Semiacontiodus nogamii* which commonly occurs from the *Cordylodus proavus* Zone. This single specimen appears to be a morphologic variant of the *Teridontus* lineage. Unfortunately, the subdivision of the *Proconodontus* Zone like Miller (1988) is unsuccessful in this study due to lack or overlapping in range of *Proconodontus posterocostatus* and *Proconodontus muelleri*. This zone is correlated with the *Proconodontus-Rotundoconus* Zone of North China (An et al., 1983), *Proconodontus tenuiserratus-Proconodontus muelleri* zones (Miller, 1988) and *Proconodontus muelleri* Zone (Miller et al., 2003) (Fig. 4).

Eoconodontus notchpeakensis first occurs from sample KH 15 of Section B and persists into the top productive sample (KH 22) in the overlying *Cambrooistodus minutus* Zone. Sample KH 15 marks the base of the *Eoconodontus notchpeakensis* Zone. *Eoconodontus notchpeakensis* occurs in association with many euconodont species including *Dasytodus nodus, Proconodontus muelleri, Cambrooisto-*

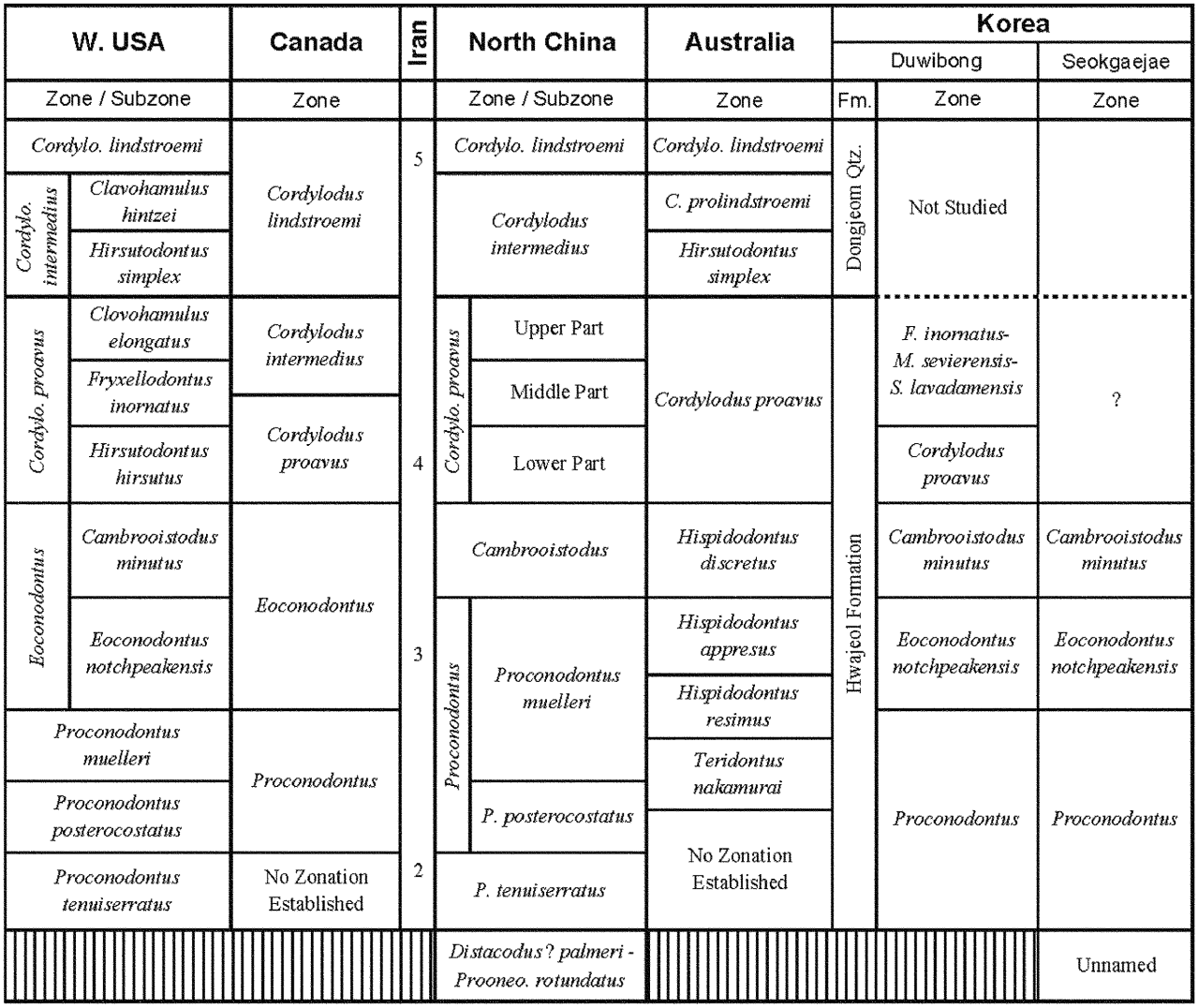

Fig. 4. International correlation of the Upper Cambrian conodont zones in Western USA (Miller, 1988; Miller et al., 2003), Canada (Cooper et al., 2001), Iran (Müller, 1973), North China (An et al., 1983; Chen and Gong, 1986), Korea (Lee, 2004) and Australia (Nicoll and Shergold, 1991).

dus cambricus, Semiacontiodus nogamii and *Teridontus nakamurai*, along with some protoconodonts and paraconodonts. The *Eoconodontus notchpeakensis* Zone of the Seokgaejae section is correlated with the lower part of the same-named zones of North America (Miller, 1988; Miller et al., 2003; Cooper et al., 2001), the upper part of the *Proconodontus* Zone of North China (Chen and Gong, 1986) and the *Hispidodontus appresus* Zone of Australia (Nicoll and Shergold, 1991) (Fig. 4).

The interval from sample KH 18 to 22 of Section B represents the *Cambrooistodus minutus* Zone. These samples yielded *Cambrooistodus minutus* along with species of *Cambrooistodus cambricus, Eoconodontus notchpeakensis, Granatodontus ani, Proconodontus tenuiserratus, Proconodontus muelleri, Semiacontiodus nogamii, Semiacontiodus* cf. *nogamii, Semiacontiodus* cf. *lavadamensis, Teridontus nakamurai*, and some paraconodonts. The upper limit of this zone is unclear due to the lack of any more zonal conodonts. This zone corresponds to the same-named subzone of the *Eoconodontus* Zone of Miller (1988), the upper part of the *Eoconodontus notchpeakensis* Zone of Cooper et al. (2001), the *Cambrooistodus* Zone of Chen et al. (1988) and the *Hispidodontus discretus* Zone of Nicoll and Shergold (1991).

5. CONCLUSIONS

1. This conodont biostratigraphic study was designed to re-evaluate the biozones of the Hwajeol Formation that have been established at other areas in the Taebaeksan Basin, through the detail examination of the Seokgaejae section, located in the southeastern margin of the basin.

2. Of 23 limestone samples collected from two segments of a section of the Hwajeol Formation in Seokgaejae area, 21 samples yielded 594 identifiable conodont elements and *Phosphannulus universalis* (incertae sedis).

3. The recovered conodont elements are assigned to thirty three species belong to sixteen genera.

4. Four conodont zones are recognized in the Hwajeol Formation in Seokgaejae section: Unnamed, *Proconodontus*, *Eoconodontus notchpeakensis* and *Cambrooistodus minutus* zones in ascending order.

5. The conodont zones recognized herein are basically similar to those of other parts of the Taebaeksan Basin. However, the basal "Unnamed" Zone is older than the lowermost conodont zone recognized in other sections of the Hwajeol Formation. Conversely, the two uppermost zones of the formation that have been established in other areas viz. *Cordylodus proavus* and *Monocostodus sevierensis-Semiacontiodus nogamii-Fryellodontus inornatus* zones have not been recognized in this study.

6. A portion of the section near the lower boundary and another near the uppermost parts of the Hwajeol Formation in the Seokgaejae section appeared to have been structurally controlled together with deformation caused by intrusion. A possible cause for the inability to recognize the upper two zones of the Hwajeol Formation found in other areas may be a sea-level change that has been recognized in this interval near the worldwide Cambrian-Ordovician boundary.

7. Four conodont zones proposed herein of the Hwajeol Formation are correlated with the equivalent zones of the Upper Cambrian in North China, North America, and Australia.

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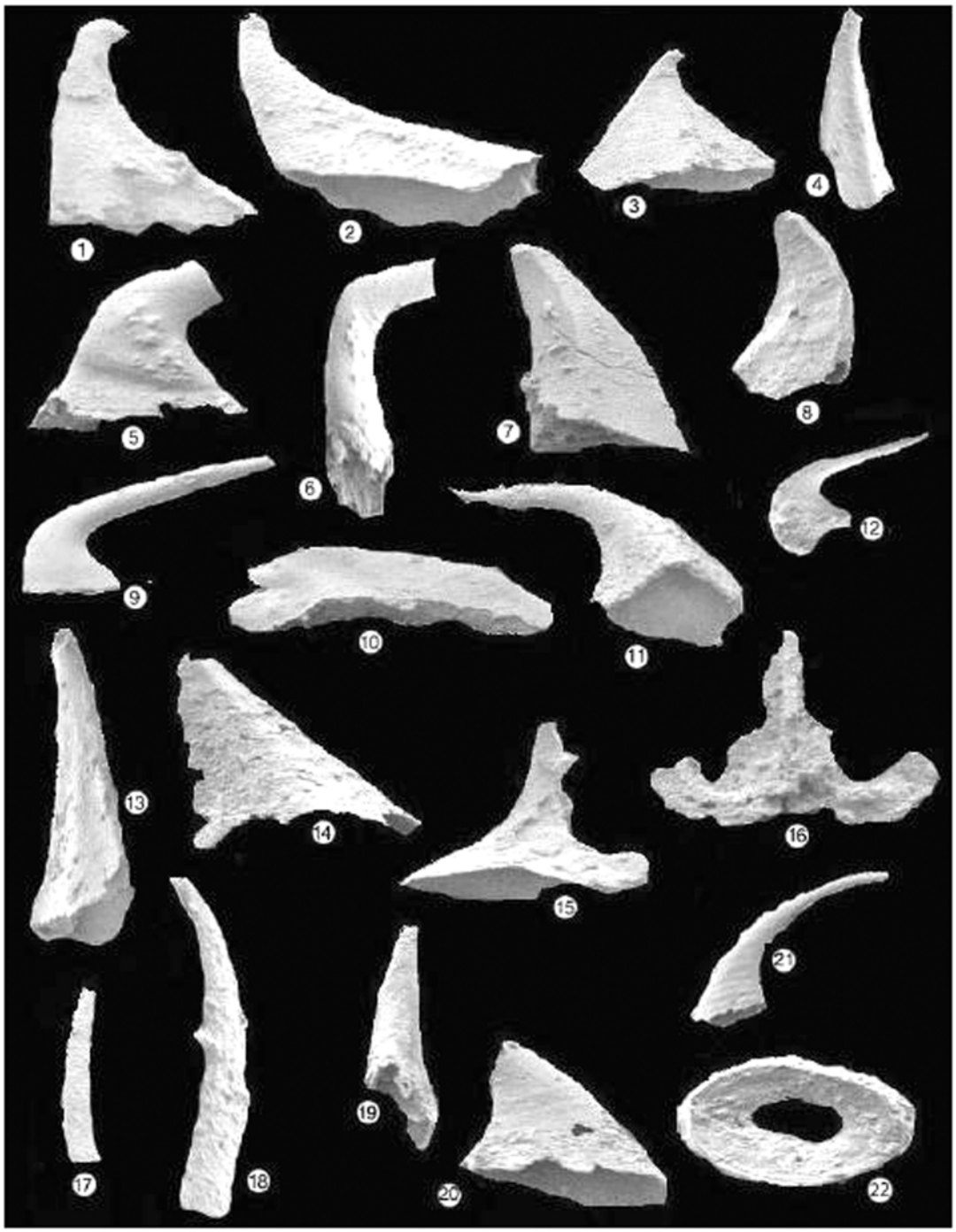

Plate 1. SEM micrographs of selected conodonts from the Hwajeol Formation in the Seokgaejae section, southeast Taebaeksan Basin. (1-2) lateral views of *Rotundoconus bulbousus* Lee, 2002, tricarinate (KH 15, x100) and tetracarinate (KH 14, x100) elements. (3-4) lateral views of *Rotundoconus jingxiensis* (An and Zhang, 1983), tricarinate (KH 14, x50) and tetracarinate (KH 14, x50) elements. (5) lateral view of *Dasytodus nodus* (Zhang and Xiang, 1983), KH 12 (x50). (6) lateral view of *Dasytodus transmutatus* (Xu and Xiang, 1983), KH 12 (x50). (7) lateral view of *Hertzina triqueta* Chen and Gong, 1986, KH 4 (x75). (8) lateral view of *Proscandodus dissimilaris* Lee, 2002, KH 8 (x50). (9) lateral view of *Teridontus nakamurai* (Nogami, 1967), KH 7 (x75). (10) lateral view of *Fryxellodontus fengshanensis* Lee, 2002, KH 19 (x50). (11) lateral view of *Muellerodus cambricus* (Müller, 1959), KH 1 (x50). (12) lateral view of *Muellerodus*? *oelandicus* (Müller, 1959), KH 1 (x100). (13) posterolateral view of *Muellerodus hunjiangensis* Chen and Gong, 1986, KH 5 (x100). (14) posterior view of *Prosagittodontus eureka* (Müller, 1959), KH 5 (x75). (15) posterior view of *Prosagittodontus* sp., KH 14 (x100). (16) posterior view of *Westergaardodina* sp., KH 5 (x75). (17) lateral view of *Phakelodus elongatus* (An, 1983), KH 14 (x50). (18) lateral view of *Phakelodus tenuis* (Müller, 1959), KH 18 (x100). (19) lateral view of *Furnishina dayangchaensis* Chen and Gong, 1986, KH 18 (x100). (20) lateral view of *Prooneotodus gallatini* (Müller, 1959), KH 4 (x75). (21) lateral view of *Prooneotodus rotundatus* (Druce and Jones, 1971), KH 5 (x35). (22) upper view of *Phosphannulus universalis* (Müller, 1959), KH 14 (x75).

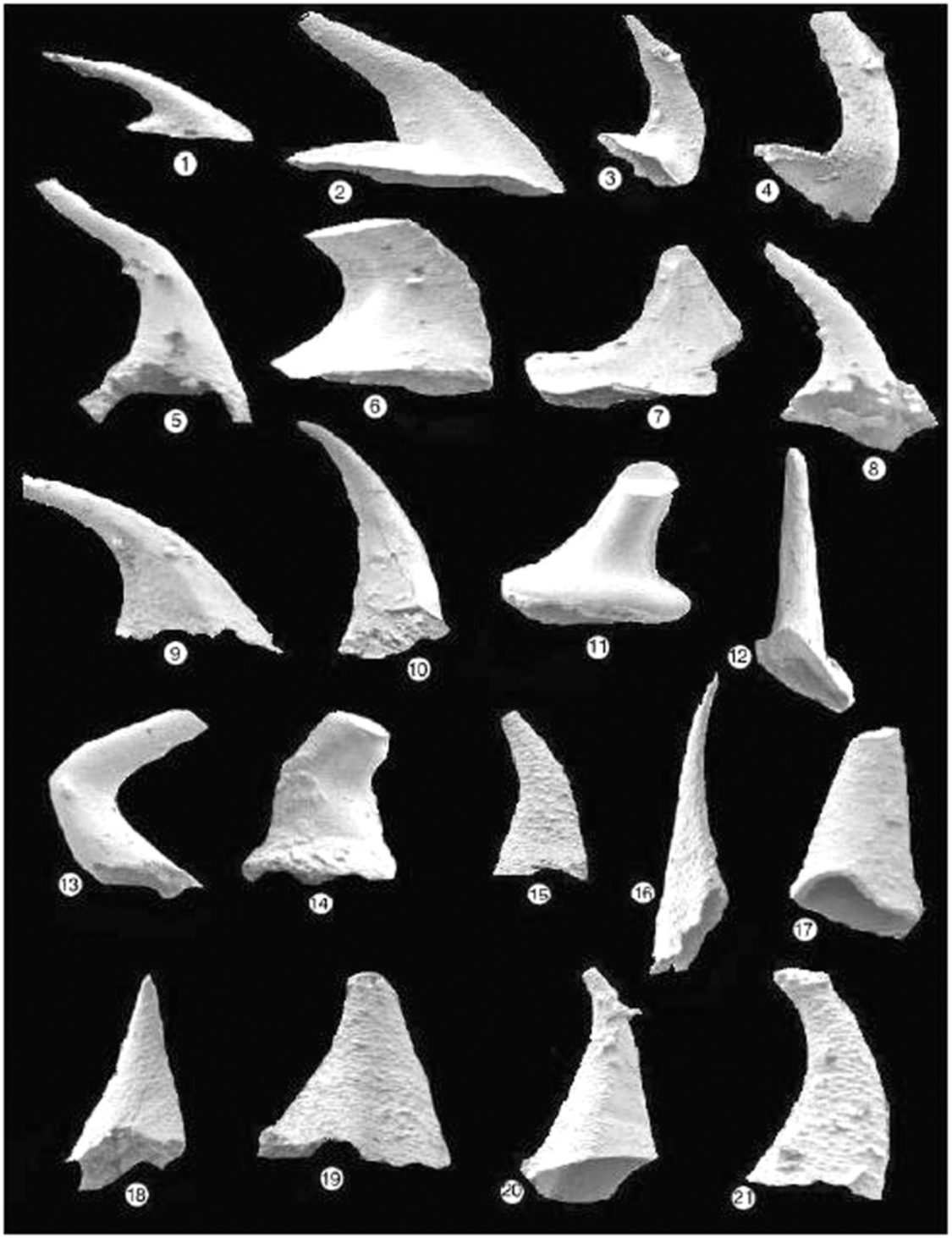

Plate 2. (1-2) lateral views of *Cambrooistodus cambricus* Miller, 1969, KH 15 (x50), KH 18 (x100). (3-4) lateral views of *Cambrooistodus minutus* (Miller, 1969), KH 15 (x50), KH 16 (x75). (5-6) lateral views of *Eoconodontus notchpeakensis* (Miller, 1969), rounded (KH 15, x75) and compressed (KH 18, x100) elements. (7) lateral view of *Proconodontus serratus* Miller, 1969, KH 20 (x50). (8) lateral view of *Proconodontus tenuiserratus* Miller, 1980, KH 5 (x75). (9-10) lateral views of *Proconodontus muelleri* Miller, 1969, KH 13 (x75), KH 17 (x50). (11-12) posterior views of *Semiacontiodus* cf. *lavadamensis* Miller, 1980, KH 18 (x100), KH 20 (x35). (13) lateral view of *Semiacontiodus nogamii* Miller, 1980, KH 15 (x50). (14) lateral view of *Semiacontiodus* cf. *nogamii* Miller, 1980, KH 15 (x50). (15) lateral view of *Granatodontus ani* (Wang, 1985), KH 13 (x50). (16-17) lateral and posterolateral views of *Granatodontus asymmetrica* sp. nov. (Lee, 2008), KH 4 (x50), KH 14 (x100). (18) posterior view of *Granatodontus hwajeolensis* (Lee, 2002), KH 4 (x50). (19-20) posterolateral and lateral views of *Granatodontus multicorrugata* sp. nov. (Lee, 2008), KH 4 (x50), KH 5 (x75). (21) lateral view of *Rotundoconus bulbousus* Lee, 2002, noncarinate element (KH 14, x100).