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Conodont fauna of the Machari Formation (Middle and Upper Cambrian), Yeongweol area, Gangweon Province, Korea

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Abstract. A diverse conodont fauna from the Machari Formation in the Yeongweol area of Gangweon (formerly Kangweon) Province, Korea, includes protoconodonts, paraconodonts, and euconodonts. Protoconodonts (assigned to Phylum Chaetognatha Leuckart and to Order Protoconodontida Landing) include *Gapparodus* Abaimova, *Gumella* Müller and Hinz, *Hertzina* Müller, and *Phakelodus* Miller. Paraconodonts (assigned to Phylum Chordata Bateson, to Superclass Conodonta Pander, and to Class Paraconodontida Müller) include species of *Furnishina* Müller, *Muellerodus* Miller, *Proacodus* Müller, *Proacontiodus* An, *Prooneotodus* Müller and Nogami, *Prosagittodontus* Müller and Nogami, and *Westergaardodina* Müller. Euconodonts (assigned to Phylum Chordata, to Superclass Conodonta Pander, and to Class Conodonti Branson) include species of *Cambrooistodus* Miller, *Coelocerodontus* Ethington, *Granatodontus* Chen and Gong, *Proconodontus* Miller, and *Teridontus* Miller. Upper Middle Cambrian occurrences of *Coelocerodontus* and *Granatodontus* are some of the oldest occurrences of euconodonts. Seventeen species referable to eight genera are reported for the first time from the Middle to Upper Cambrian of Korea. These include the protoconodonts *Gapparodus* n. sp. A and *Gumella cuneata* Müller and Hinz and the paraconodonts *Furnishina bicarinata* Müller, *F. curvata* Müller and Hinz, *F. gossmannae* Müller and Hinz, *F. ovata* Müller and Hinz, *F. pernica* An, *F. polonica* Szaniawski, *F. tortilis* (Müller), *F. vasmerae* Müller and Hinz, *Muellerodus*? *erectus* (Xiang in An *et al.*), *Prosagittodontus minimus* Müller and Hinz, *Westergaardodina nogamii* Müller and Hinz, and *W. quadrata* An. Euconodonts recovered for the first time from the Machari Formation include *Coelocerodontus bicostatus* van Wamel, *Granatodontus ani* (Wang), and *G. hwajeolensis* (Lee and Lee). These taxa are illustrated and correlated herein with the equivalent local and global trilobite and conodont zonal schemes.

Resumen. Fauna de Conodontes de la Formación Macharí (Cámbrico Medio y Superior), área de Yeongweol, provincia de Gangeweon, Corea. La formación Machari en el área Yeongweol de la provincia de Gangweon, Corea, contiene una fauna diversa de protoconodontes, paraconodontes y euconodontes. Los protoconodontes (correspondientes al filo Chaetognatha Leuckart y al orden Protoconodontida Landing) incluyen *Gapparodus* Abaimova, *Gumella* Müller y Hinz, *Hertzina* Müller y *Phakelodus* Miller. Paraconodontes (correspondientes al filo Chordata Bateson, a la superclase Conodonta Pander, y a la clase Paraconodontida Müller) incluyen las especies *Furnishina* Müller, *Muellerodus* Miller, *Proacodus* Müller, *Proacontiodus* An, *Prooneotodus* Müller y Nogami, *Prosagittodontus* Müller y Nogami, y *Westergaardodina* Müller. Euconodontes (correspondientes al filo Chordata, la superclase Conodonta Pander, y a la clase Conodonti Branson) incluyen las especies *Cambrooistodus* Miller, *Coelocerodontus* Ethington, *Granatodontus* Chen y Gong, *Proconodontus* Miller, y *Teridontus* Miller. La presencia de *Coelocerodontus* y *Granatodontus* en el Cámbrico Medio corresponde a una de las mas antiguas occurrencias de euconodontes. Diecisiete especies pertenecientes a ocho géneros se reportan aquí por primera vez para el Cámbrico Medio y Cámbrico Superior de Corea. Estos incluyen los protoconodontes *Gapparodus* n. sp. A y *Gumella cuneata* Müller y Hinz, y los paraconodontes *Furnishina bicarinata* Müller, *F. curvata* Müller y Hinz, *F. gossmannae* Müller y Hinz, *F. ovata* Müller y Hinz, *F. pernica* An, *F. polonica* Szaniawski, *F. tortilis* (Müller), *F. vasmerae* Müller y Hinz, *Muellerodus*? *erectus* (Xiang en An *et al.*), *Prosagittodontus minimus* Müller y Hinz, *Westergaardodina nogamii* Müller y Hinz, y *W. quadrata* An. Euconodontes encontrados por vez primera en la Formación Machari incluyen *Coelocerodontus bicostatus* van Wamel, *Granatodontus ani* (Wang), and *G. hwajeolensis* (Lee and Lee). Se anexa su ilustración y su correlación con los esquemas zonales de trilobites y conodontes a escala local y global.

Key words. Conodonts, Taxonomy, Biostratigraphy, Middle Cambrian, Upper Cambrian, Machari Formation, Korea.

Palabras clave. Conodontes, Taxonomía, Bioestratigrafía, Cámbrico Medio, Cámbrico Superior, Formación Machari, Corea.

Introduction

The Machari Formation in Korea contains a diverse fauna of Middle to Upper Cambrian conodonts. The informal names of four fossil groups include the suffix "-conodonts," namely, euconodonts (Bengtson, 1976), paraconodonts (Müller, 1962), protoconodonts (Bengtson, 1976), and pseudoconodonts (Landing, 1995). Euconodont taxa were described first by Pander (1856), and the Machari Formation has yielded the euconodonts *Cambrooistodus* Miller, 1980, *Coelocerodontus* Ethington, 1959, *Granatodontus* Chen and Gong, 1986, *Proconodontus* Miller, 1969, and *Teridontus* Miller, 1980. Paraconodont taxa were described first by Müller (1959), and the Machari Formation has yielded the paraconodont genera *Furnishina* Müller,

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1959, *Muellerodus* Miller, 1980, *Proacodus* Müller, 1959, *Proacontiodus* An, 1982, *Prooneotodus* Müller and Nogami, 1971, *Prosagittodontus* Müller and Nogami, 1971, and *Westergaardodina* Müller, 1959. Paraconodonts and euconodonts are considered to be primitive representatives of the Phylum Chordata Bateson, 1886, and they are probably vertebrates (Sweet and Donoghue, 2001). Protoconodonts are considered to be unrelated to paraconodonts and euconodonts, and Szaniawski (1982, 2002) and Sweet and Donoghue (2001) assign protoconodonts to the Phylum Chaetognatha Leuckart, 1854, commonly called arrow worms. The Machari Formation has yielded the protoconodont taxa *Gapparodus* Abaimova, 1978, *Gumella* Müller and Hinz, 1991, *Hertzina* Müller, 1959, and *Phakelodus* Miller, 1980.

Pseudoconodonts are latest Proterozoic to Early Cambrian phosphatic problematica that include *Rhombocorniculum cancellatum* Cobbold, 1921 and *Protohertzina anabarica* Missarzhevsky, 1977 (Landing, 1995); these taxa are unrelated to the other three groups of "-conodonts" and do not occur in the Machari Formation.

Bengtson's (1983) study of early conodonts and Landing's (1984) study of the histology and taxonomy of lapworthellids showed that these groups are not related to each other despite a grossly similar size and shape. Landing (1977, 1984) and Müller and Hinz (1991, 1998) revised the taxonomy and studied the internal structures of protoconodont and paraconodont elements. Their reports represent major advances in the taxonomy of Cambrian conodonts, but the details of the histological relationships among pseudoconodonts, protoconodonts, paraconodonts, and primitive euconodonts are incompletely known. Paraconodont and protoconodont faunas described prior to the report of Landing (1984) and Müller and Hinz (1991) may require reevaluation following the taxonomic revisions of those authors.

Conodonts are used extensively in Paleozoic and Triassic strata as biostratigraphic tools, and uppermost Cambrian to Triassic conodont zonal frameworks are based on euconodonts. The oldest conodont zones that have been recognized widely are based primarily on a succession of species of the primitive euconodont genus *Proconodontus*, namely *Proconodontus tenuiserratus* Miller, 1980, *P. posterocostatus* Miller, 1980, and *P. muelleri* Miller, 1969. Zones based on these species are recognizable in many parts of North America (Fåhraeus and Nowlan, 1978; Miller, 1980, 1988, 1992; Landing *et al*., 1980; Miller *et al*., 1982; Taylor *et al*., 1991; Runkel *et al*., 1999, 2007; Myrow *et al*., 2003) and in China (Chen *et al*., 1988; Dong *et al*., 2004). These species are also known in Kazakhstan (Dubinina, 1998, 2001) and Sweden (Szaniawski and Bengtson, 1998), and in Australia (Shergold and Nicoll, 1992), where part of the Upper Cambrian conodont zonation is based on species of the primitive euconodont *Hispidodontus* Nicoll and Shergold, 1991, which has not been found in other areas.

Cambrian paraconodonts and protoconodonts may have less biostratigraphic utility than euconodonts. Some Middle Cambrian and lower Upper Cambrian conodont zones are based on paraconodont and protoconodont elements (An, 1982; Chen and Gong, 1986; Lee *et al*., 1991; Mei, 1993; Dong, 1999; Dong *et al*., 1999; Dong and Bergström, 2001; Dubinina, 2001; Dong *et al*., 2004; Qi *et al*., 2006; Bagnoli *et al*., 2008). These studies are mostly based on faunas from various parts of Asia. It cannot be determined if the regional zones proposed in those reports will have global utility until cosmopolitan faunas are found and until there is reevaluation of older reports of primitive conodonts. Some protoconodont and paraconodont taxa are known to have long stratigraphic ranges, and some may prove to be endemic; both situations pose potential limitations for their use in biostratigraphy. More occurrences of these taxa from other paleogeographic areas are needed. Eventually, evaluation of the stratigraphic and geographic distribution of protoconodont and paraconodont taxa may reveal consistencies that can be incorporated into a broadly applicable zonation for the part of the Cambrian that is below the interval containing the euconodont index genus *Proconodontus*.

In order to improve knowledge of the taxonomic diversity and the stratigraphic and paleogeographic distribution of Middle to Upper Cambrian conodont faunas, we document herein a diverse fauna of protoconodont, paraconodont, and euconodont taxa recovered from the Machari Formation in the Yeongweol area of Korea. Most taxa are paraconodonts, and *Furnishina* is the most common and diverse genus. Müller and Hinz (1991) named many of the taxa reported herein. The Machari Formation includes conodonts from two general stratigraphic intervals. The lower interval is characterized by many protoconodont and paraconodont elements as well as the primitive euconodont genera *Coelocerodontus*, *Granatodontus*, and *Teridontus*. The higher interval of strata contains many protoconodont and paraconodont elements as well as the primitive euconodont genera *Cambrooistodus*, *Coelocerodontus*, *Proconodontus*, and *Teridontus*.

We correlate these Korean conodont faunas with coeval trilobite and conodont biostratigraphic zones in other parts of the world. Conodont elements were recovered previously from the Upper Cambrian of Korea (Lee, 1975; Lee, 1988; Lee and Lee, 1988; Lee, 1989a, 1989b, 1990).

Stratigraphy of the Machari Formation

The Joseon (formerly Choseon) Supergroup in the Yeongweol area (figure 1) comprises five lithostratigraphic units, namely the Sambangsan, Machari, Wagok (formerly Wagog), Mungok (formerly Mungog), and Yeongheung formations, in ascending order (figure 2). The lower three are Cambrian and the higher two are Ordovician. The Machari Formation conformably overlies the Sambangsan Formation and is conformably overlain by the Wagok Formation. The base of the Machari Formation is recognized by the lowest occurrence of thick-bedded bioclastic grainstones to packstones above light brown sandstones of the Sambangsan Formation. The top of the Machari Formation is defined by the base of the Wagok Formation and corresponds with the change to massive dolostone above the uppermost occurrence of thin-bedded dolostone with shale interlayers. The Machari Formation is approximately 300 m thick in the study area.

The Machari Formation (Yosimura, 1940) crops out as a broad belt across the south slope of Mt. Sambang (Sambangsan on figure 1) and extends farther south as north-south-trending narrow belts. This formation consists mainly of bioclastic grainstone to packstone, dark gray to black laminated shale, and dolomitic limestone and ribbon limestone; these strata display a distinctive banded structure (figure 3). Reedman and Um (1975) and Lee (1995) concluded that the Machari Formation was deposited in a deepwater environment ranging from deep shelf to pelagic basin, whereas Chung and Lee (1992) suggested that the formation was deposited on the slope of a carbonate platform, and sediments were introduced episodically by tubidity currents and debris flows.

Some carbonate lithologies in the Machari Formation are slope deposits, such as limestone breccia, shell beds, and slump features. However, these lithofacies are very minor in volume, and the abundance of dark-colored lime mudstone and laminated black shale with thin, uniform stratification is interpreted to represent a hemipelagic sedimentation in a deepwater setting by suspension settling (Lee, 1995). Most of the Upper Cambrian trilobite specimens studied by Lee (1995), Choi and Lee (1995) and Choi *et al.* (2004, 2008) are disarticulated. Occasionally, some specimens preserved in the laminated black shale and shale-parted carbonate lithofacies are articulated. The presence of articulated exoskeletons, lack of obvious size sorting or fragmentation of disarticulated sclerites, and association with dark gray lime mudstone and black shale is interpreted to indicate that the trilobite faunas represent in situ basinal assemblages that lived at or near where their remains were buried. Lithologic features and the abundance of agnostoid trilobites suggest that the Machari Formation was deposited in a deep-water environment ranging from deep shelf to pelagic basin (Lee, 1995; Choi and Lee, 1995; Choi *et al.*, 2004, 2008).

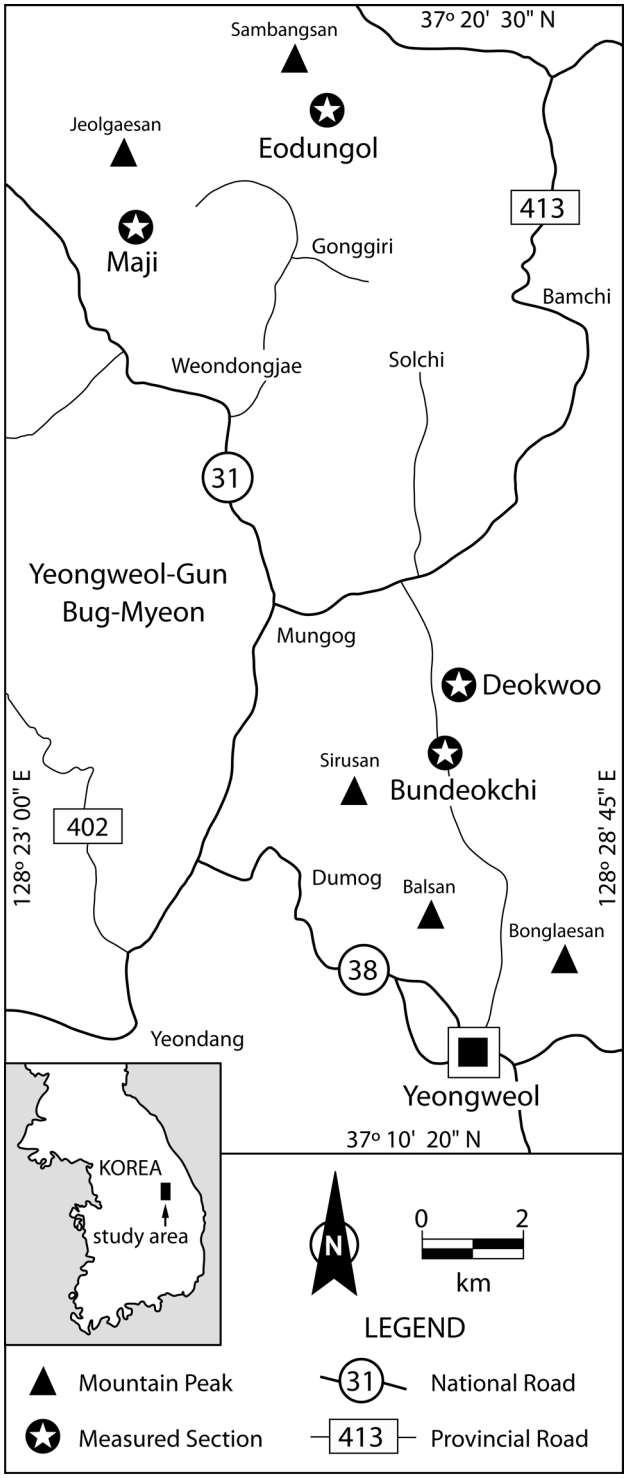


Figure 1. Map showing the location of measured sections of the Machari Formation in the Yeongweol area, Korea / *mapa mostrando la localización de las secciones estudiadas en el área de Yeongweol, Corea.*

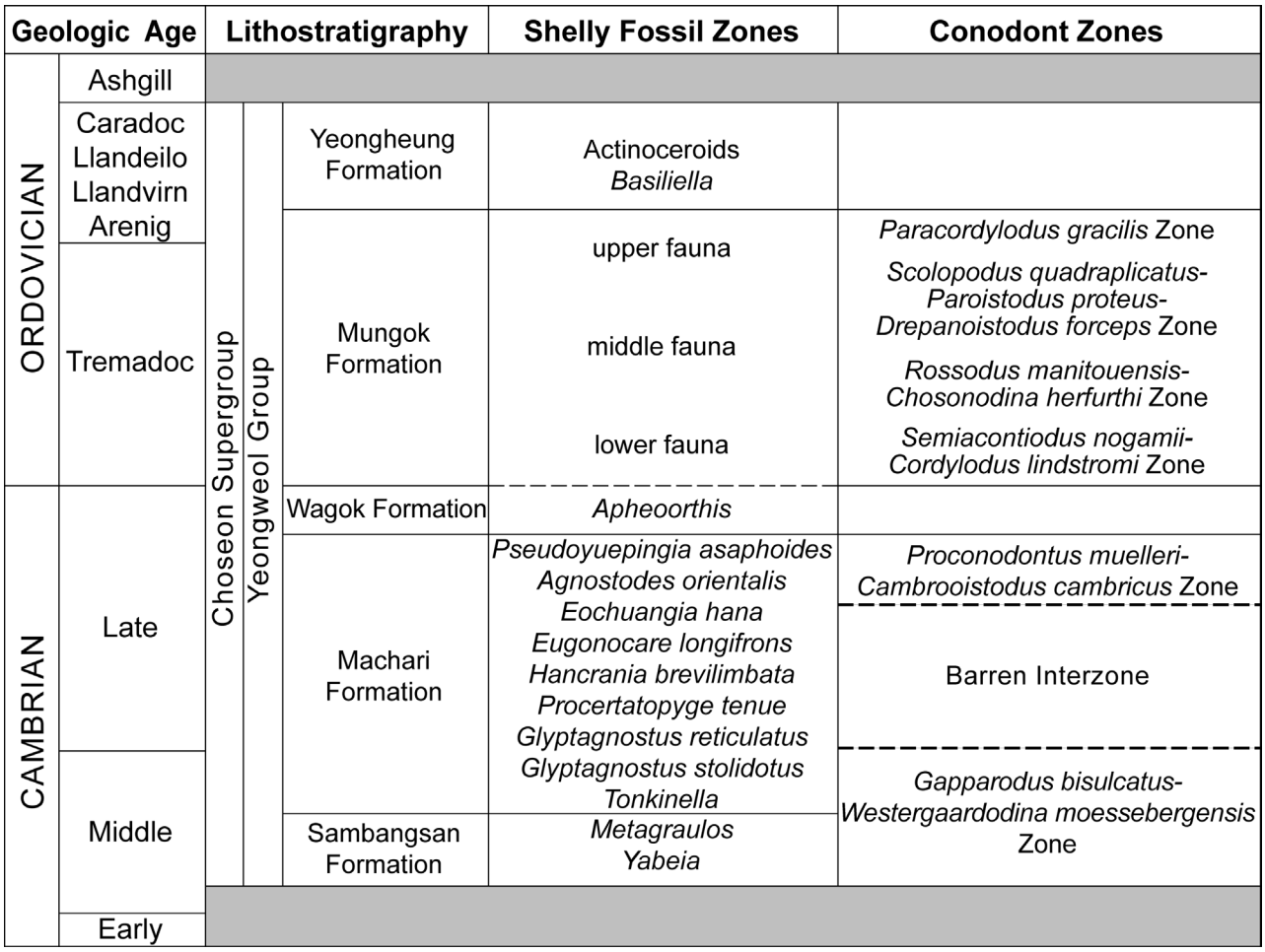


Figure 2. Summary of Cambrian–Ordovician stratigraphy of the Yeongweol area, Korea (Kobayashi, 1961, 1962, 1966; Lee et al., 1991; Lee, *et al*., 1997; Lee and Lee, 1999). Traditional British Ordovician series names are used for general reference, but only Cambrian strata are discussed in this report / *resumen de la estratigrafía del Cámbrico-Ordovícico del área de Yeongweol, Corea (Kobayashi, 1961, 1962, 1966; Lee et al., 1991; Lee, et al., 1997; Lee and Lee, 1999). Los nombres británicos tradicionales del Ordovícico son usados como referencia general pero sólo es discutida en este trabajo la estratigrafía del Cámbrico.*

The boundary between the Middle and Upper Cambrian is now placed at the base of the *Glyptagnostus reticulatus* Trilobite Zone (Peng *et al*., 2004). The Machari Formation has been dated as late Middle to middle Late Cambrian, based primarily on trilobite assemblages reported by Kobayashi (1961, 1962, 1966), who established five zones: *Olenoides*, *Tonkinella*, *Eochuangia*, *Komaspis–Koptura–Iwayaspis*, and *Olenus–Glypagnostus*. This zonation was refined by Lee (1995) and Lee *et al*. (1997), who erected nine trilobite zones: *Tonkinella*, *Glypagnostus stolidotus*, *Glypagnostus reticulatus*, *Proceratopyge tenue*, *Hancrania brevilimbata*, *Eugonocare longifrons*, *Eochuangia hana*, *Agnostodes orientalis*, and *Pseudoyuepingia asaphoides*, in ascending order (figures 2, 4). Some of these trilobite zones are recognized in South China (Lu and Lin, 1989). Hong *et al*. (2000) also discussed trilobites from the Machari Formation.

Lee (1975) described some paraconodont elements from two exposures of the Machari Formation in the Yeongweol area, and he correlated these faunas with the Upper Cambrian of other areas. Later, Lee *et al.* (1991) studied the conodont fauna systematically and erected two zones, namely the lower *Gapparodus bisulcatus–Westergaardodina matsushitai–W. moessebergensis* Assemblage Zone and the upper *Proconodontus muelleri–Cambrooistodus cambricus* Assemblage Zone.

Measured sections and sample collection

Rock samples for conodont elements were collected from four sections of the Machari Formation in the northwestern Yeongweol area of Gangweon Province (figures 1, 3). The Eodungol section (~ 97 m thick) is about 1.5 km southeast of the summit of Mt. Sambang and exposes the top of the Sambangsan Formation. The base of the Machari Formation is noncalcareous laminated black shale overlain by

thick dolomitic, bioclastic grainstone to packstone beds. Overlying strata are mainly dark gray laminated shale with intercalated thin-bedded limestone. Of sixteen samples, one yielded a variety of protoconodont, paraconodont, and euconodont elements. The Maji section (44 m thick) is at Maji village in the Pyeongchang area. The lower part of the section is covered, and exposure begins ~ 20 m above the base of the Machari Formation. Most strata are limestone with thin shale partings, but the lithology changes to massive limestone near the top. Only one of four samples yielded abundant protoconodont, paraconodont, and euconodont elements.

The other two sections are located farther south (figure 1). The Deokwoo section (~ 180 m thick) is about 2 km south of Machari village and has two covered intervals (figure 3). The lower part of this section is mostly black shales with some thin limestones with thin shale partings; the upper part is massive shale-parted or banded limestone. Of ten samples, four yielded abundant conodont elements. The Bundeokchi section (43 m thick) is about 1 km south of the Deokwoo section and includes the highest strata of the four sections. Limestones with shale partings in the lower part of the section grade upward into thin-bedded limestone and dolostone. Of thirteen samples, two yielded abundant conodont elements.

Lithologies from which conodonts were extracted for this study are thin-bedded dolomitic limestone (with or without shale layers), shale-parted limestone, and light gray massive limestone. These lithologies were not deposited by turbidity currents and debris flows, thus negating the possibility of redeposition of conodonts from shallow depositional settings.

Processing methods and conodont faunas

Each of the 43 conodont samples from the Machari Formation had a mass of 1 to 3 kg and was dissaggregated in acetic acid. Eight of the 43 samples yielded a total of 1,305 conodont elements. The preservation is relatively good, but some specimens are corroded. The conodont elements are referred to 51 species referable to 16 genera (table 1). The two most productive samples are Bd8 (234 elements) and Bd9 (211 elements), and the dominant species are the paraconodonts *Furnishina furnishi* Müller, 1959 and *Prooneotodus gallatini* (Müller, 1959) and the protoconodonts *Phakelodus tenuis* (Müller, 1959) and *P. elongatus* (Zhang in An *et al*., 1983). These two samples yielded more than 34 percent of the total conodont elements.

These numbers of productive samples and recovered elements are comparable to data from other reports of conodonts of similar age. Bagnoli *et al.* (2008) studied upper Middle Cambrian conodonts from the type section for the base of the Gushanian Stage in Hunan, South China. They collected 86 samples having a mass of 430 kg; 13 productive samples produced 236 conodont elements. Qi *et al*. (2006) studied upper Middle and lower Upper Cambrian conodonts from the type section for the base of the Furongian Series and the Paibian Stage in Hunan, South China. They collected 220 samples having a mass of 1000 kg; 26 productive samples produced 561 conodont elements.

Twenty-three species of ten genera were recovered for the first time from the Machari Formation, although some other species are known from other strata in Korea (Lee and Lee, 1999). These include the protoconodonts *Gapparodus* n. sp. A, *Gumella cuneata* Müller and Hinz, 1991, *Hertzina americana* Müller, 1959, and *Hertzina triquetra* Chen and Gong, 1986, and the paraconodonts *Furnishina bicarinata* Müller, 1959, *F. curvata* Müller and Hinz, 1991, *F. gossmannae* Müller and Hinz, 1991, *F. longibasis* Bednarczyk, 1979, *F. ovata* Müller and Hinz, 1991, *F. pernica* An, 1982, *F. polonica* Szaniawski, 1971, *F. primitiva* Müller, 1959, *F. tortilis* (Müller, 1959), *F. vasmerae* Müller and Hinz, 1991, *Muellerodus pomeranensis* (Szaniawski, 1971), *Prooneotodus terashimai* (Nogami, 1967), *Prosagittodontus dahlmani* (Müller, 1959), *P. dunderbergiae* (Müller, 1959), *P. minimus* Müller and Hinz, 1991, *Westergaardodina nogamii* Müller and Hinz, 1991, and *W. quadrata* An, 1982 (see figures 4, 5). Euconodonts recovered for the first time from the Machari Formation are *Coelocerodontus bicostatus* van Wamel, 1974, *Granatodontus ani* (Wang, 1985), and *Granatodontus hwajeolensis* (Lee and Lee, 1988).

Distribution and age of Machari conodont taxa

Intra- and interspecific variation in morphology, occurrence, and stratigraphic range of Middle Cambrian to lower Upper Cambrian paraconodonts are not fully understood at this time, although major paraconodont lineages are relatively well defined for the upper half of the Upper Cambrian (Dong, 1997). For these reasons, some stratigraphic intervals are correlated primarily on trilobite biostratigraphy (table 1, figures 3 and 4). Figure 3 shows in the Eodungol section the stratigraphic position of two trilobite collections that contain *Kootenia* Walcott, 1889, *Olenoides* Meek, 1877, *Peronopsis* Hawle and Corda, 1847, *Tonkinella* Mansuy, 1916, and other trilobites; these collections are assigned to the upper Middle Cambrian *Tonkinella* Zone. One higher collection contains the trilobite *Glyptagnostus reticulatus*

Table 1. Numerical distribution of conodont taxa from the Machari Formation, Yeongweol area, Korea . One asterisk * indicates euconodonts, two asterisks ** indicate protoconodonts. Ohters are paraconodonts / *distribución numérica de taxones de conodontes de la Formación Macharí, área de Yeongweol, Corea. Un asterisco * indica euconodontes, dos asteriscos ** indican protoconodontes. Otros son paraconodontes.*

Taxon Sample	Ed14	Mj7	Dw13	Dw9	Dw7	Dw4	Bd8	Bd9	Total
*Cambrooistodus cambricus**					8			1	9
*Coelocerodontus bicostatus**	2	1							3
*Coelocerodontus kosangolensis**		1		2	6		2		11
Furnishina asymmetrica		17					6	6	29
Furnishina bicarinata								6	6
Furnishina curvata								3	3
Furnishina furnishi		23	14	12	27	10	12	29	127
Furnishina gossmanae		2					3	2	6
Furnishina longibasis	1	1					1	2	5
Furnishina ovata		1	3					2	6
Furnishina pernica		1	27	2	3	10	10	17	70
Furnishina polonica		2							2
Furnishina primitiva		14	2	11	2		4	9	42
Furnishina tortilis								2	2
Furnishina triangulata			1			2	3	1	7
Furnishina vasmerae								1	1
Furnishina sp.		1	22	8	13	14	10	1	69
*Gapparodus bisulcatus***	92								92
Gapparodus n. sp. *A***	3								3
Granatodontus primitivus	1	2							3
*Granatodontus hwajeolensis***		1							1
*Gumella cuneata***	4								4
*Hertzina americana***		3		2	4		4		13
*Hertzina triquetra***	1	1	9	12	9		4	1	37
Muellerodus cambricus		1					1		2
Muellerodus? erectus		2						1	3
Muellerodus? oelandicus		4				2	5	3	14
Muellerodus pomeranensis								1	1
Muellerodus sp.		1						1	2
*Phakelodus elongatus***	3	26		26	9	11	41	6	122
*Phakelodus tenuis***	2	24	2	21	7	13	56	4	129
Proacodus cf. *pulcherus*		1							1
*Proconodontus muelleri**				2			4	3	9
*Proconodontus posterocostatus**				1			2	1	4
Proconodontus aff. *posterocostatus**							1		1
Prodistacodus palmeri	3	4	19	14	12	7	4	23	86
Prooneotodus gallatini		27	14	17	3	19	47	38	165
Prooneotodus rotundatus		22	1	3	2	6	6	21	61
Prooneotodus terashimai		7		1		1	1	3	13
Prosagittodontus dahlmani		2		1				1	4
Prosagittodontus cf. *dahlmani*								1	1
Prosagittodontus dunderbergiae		1		11		1		4	17
Prosagittodontus eureka			1	8		7	2	2	20
Prosagittodontus minimus		2							2
Prosagittodontus sp.		1		5		3	1	1	11
*Teridontus nakamurai**			14	6			2	13	35
Unassigned Coniform Element**				1			1		2
Westergaardodina bicuspidata	17	1			1				19
Westergaardodina moessebergensis	2								2
Westergaardodina nogamii								1	1
Westergaardodina quadrata	10								10
Westergaardodina sp.	12		1		2		1		16
Total	153	197	130	166	108	106	234	211	1305

Angelin, 1851 and is assigned to the basal Upper Cambrian *G. reticulatus* Zone. These collections demonstrate that the lower part of the Machari Formation is Middle Cambrian and the middle and upper parts are Upper Cambrian. Conodonts from samples Ed14 and Mj7 (figure 3) are from the Middle Cambrian part of the Machari Formation, and conodonts from other collections are from the Upper Cambrian part.

Protoconodonts

Only four genera of protoconodonts (chaetognaths) occur in the Machari Formation. *Gapparodus bisulcatus* (Müller, 1959) (figures 6.1,11,15,22) was recovered only from sample Ed14, 22.55 m above the base of the formation. This sample is part of the *Tonkinella* Trilobite Zone (upper Middle Cambrian; figures 2, 3). Müller and Hinz (1991) recovered *Gumella cuneata* Müller and Hinz, 1991 from strata roughly equivalent to this horizon in Baltica. *Phakelodus tenuis* (Müller, 1959) (figures 6.12,14) and *P. elongatus* Zhang in An *et al*., 1983 (figures 6.9,10) are cosmopolitan Middle Cambrian to Early Ordovician protoconodonts that occur through the Machari Formation, the Sesong Slate (Lee, 1990), and the Hwajeol Formation (Lee and Lee, 1988). *Gapparodus bisulcatus*, *Gumella cuneata*, and *Phakelodus tenuis* occur in the upper Middle Cambrian and lowermost Upper Cambrian parts of the Huaqiao Formation in Hunan Province, South China (Qi *et al*., 2006; Bagnoli *et al*., 2008).

Hertzina americana (figure 7.20) is also known as a cosmopolitan Middle to Upper Cambrian protoconodont. It occurs in the *Irvingella major* Trilobite Zone in Nevada (Müller, 1959), the Gushan Formation in Shantung Province (An, 1982; An *et al*., 1983), the *Chuangia* or *Changshania* Trilobite Zone of the Changshan Formation in Shantung Province (An, 1982; An *et al*., 1983), and in the *Eoconodontus notchpeakensis* Conodont Zone in the Hwajeol Formation (Lee and Lee, 1988). *Hertzina triquetra* (figure 8.6) occurs in the upper Upper Cambrian *Cordylodus proavus* Conodont Zone in Jilin Province, North China (Chen and Gong, 1986).

Paraconodonts

Paraconodonts comprise most of the taxa found in the Machari Formation. *Furnishina* is the most abundant and diverse genus, and most of the *Furnishina* elements were recovered from sample Mj7. Of fourteen species of *Furnishina* recovered, eight were found for the first time in Korea. In terms of global occurrence, *Furnishina bicarinata* (figure 6.5) ranges throughout the Upper Cambrian. *Furnishina longibasis* (figure 6.3), *F. pernica* (figure 8.4), and *F. vasmerae* (figure 6.6) are confined to the lower Upper Cambrian. *Furnishina tortilis* (figures 8.1,13) occurs at the top of the Middle Cambrian and ranges into the lower Upper Cambrian in South China (Qi *et al*., 2006); elsewhere it ranges throughout the Upper Cambrian. *Furnishina longibasis* was reported from the Upper Cambrian of Poland (Bednarczyk, 1979), the *Olenus* Trilobite Zone of Sweden (Müller and Hinz, 1991), the Gushan Formation of North China (An *et al*., 1983), and the lower part of the Upper Cambrian in Hunan Province, South China (Qi *et al*., 2006). *Furnishina longibasis* is recorded in samples Ed14, Mj7, Bd8, and Bd9.

Furnishina curvata Müller and Hinz, 1991 (figure 7.11), *F. furnishi* (figures 6.17, 7.16, 8.10), *F. asymmetrica* Müller, 1959 (figures 8.5, 9.4) and *F. gossmannae* (figures 6.16, 7.17, 8.9) are common and occur worldwide in the middle to upper Upper Cambrian, *e.g*., in the *Olenus* Trilobite Zone of Sweden (Müller and Hinz, 1991). *Furnishina furnishi* occurs throughout the *Proconodontus* Conodont Zone of the Hwajeol Formation of Korea (Lee and Lee, 1988), whereas the species occurs from the uppermost part of the Changxia Formation (Middle Cambrian) to the Fengshan Formation (upper Upper Cambrian) of North China (An *et al*., 1983). *Furnishina ovata* (figures 6.23, 8.14) was known previously only from the *Protopeltura praecursor* Trilobite Zone to the *Peltura scarabaeoides* Trilobite Zone of Sweden (Müller and Hinz, 1991). The stratigraphic occurrence of this species in Sweden is similar to that of Korea.

Furnishina polonica (Fig. 8.12) was recorded originally from the upper Middle Cambrian *Agnostus pisiformis* Trilobite Zone of Poland (Szaniawski, 1971). Later, this species was reported from strata of similar or slightly younger age in California (Miller and Paden, 1976), North China (An, 1982), South China (Qi *et al*., 2006), Sweden (Müller and Hinz, 1991), and Canada (Hein and Nowlan, 1998). *Furnishina pernica* and *F. triangulata* Xiang and Zhang in An *et al*., 1983 (figure 9.15) were recovered originally from the middle Upper Cambrian *Blackwelderia paronai* Trilobite Zone of China (An, 1982; An *et al*., 1983). *Furnishina triangulata* was recovered from somewhat younger beds (samples Dw13, Dw4, Bd8 and Bd9) in the Machari Formation. *Furnishina primitiva* (figures 6.2,4,7) has a long range through the Machari Formation (samples Mj7, Dw13, Dw9, Dw7, Bd8, Bd9), and it was known previously from Sweden (Müller, 1959; Müller and Hinz, 1991), Poland (Abaimova and Ergaliev, 1976), China (Wang, 1985; Chen and Gong, 1986; An, 1987), and Korea (Lee and Lee, 1988).

Muellerodus cambricus (Müller, 1959) (figure 9.3) occurs in the lower (sample Mj7) and upper (sample Bd8) parts of the Machari Formation. *Muellerodus*? *oelandicus* (Müller, 1959) (figure 7.10) occurs in the lower (sample Mj7) to upper beds (sample Dw4) (table 1, figure 5). *Muellerodus pomeranensis* (figure 8.3) was recovered in the upper part (sample Bd9) of the Machari Formation. These species were reported from the uppermost Middle Cambrian to the lower to middle Upper Cambrian of Sweden (Müller, 1959; Müller and Hinz, 1991), North and South China (Nogami, 1966; An, 1982; An *et al*., 1983; Dong, 1993, 1999; Qi *et al*., 2006), and north Poland (Szaniawski, 1971; Bednarczyk, 1979). In Korea, *Muellerodus cambricus*, *M*.? *oelandicus*, and *M. pomeranensis* were recovered previously from the lower to middle part of the Hwajeol Formation (Lee *et al*., 1991; Lee and Lee, 1988). *Muellerodus*? *erectus* (Xiang in An *et al*., 1983) (figures 6.8, 7.4, 9.12) is an endemic species of the middle Upper Cambrian Chengshan Formation of North China (An, 1982; An *et al*., 1983; Mei, 1993). In this study, *M*.? *erectus* was recovered from the lower (sample Mj7) to middle beds (sample Bd9) of the Machari Formation.

Proacontiodus palmeri (Müller, 1959) (Figs. 9.8,13) was recovered from the *Elvinia* Trilobite Zone in the USA (Müller, 1959), from the *Quadraticephalus* Trilobite Zone of the Changshan and Fengshan formations of North China (An, 1982; An *et al*., 1983), from the lower part of the upper member of the Machari Formation (Lee *et al*., 1991), and from the *Proconodontus* to *Eoconodontus notchpeakensis* conodont zones (Lee and Lee, 1988) of Korea.

Prooneotodus gallatini (figures 7.12,15, 8.16, 9.2) and *P. rotundatus* (Druce and Jones, 1971) (figure 9.1) are long-ranging species, but *Prooneotodus terashimai* (figure 9.11) is restricted to the lower half of the Upper Cambrian (Nogami, 1966; An, 1982; An *et al*., 1983; Lee and Lee, 1988). In this study, *Prooneotodus terashimai* is known in the lower to upper parts of the Machari Formation (figure 5).

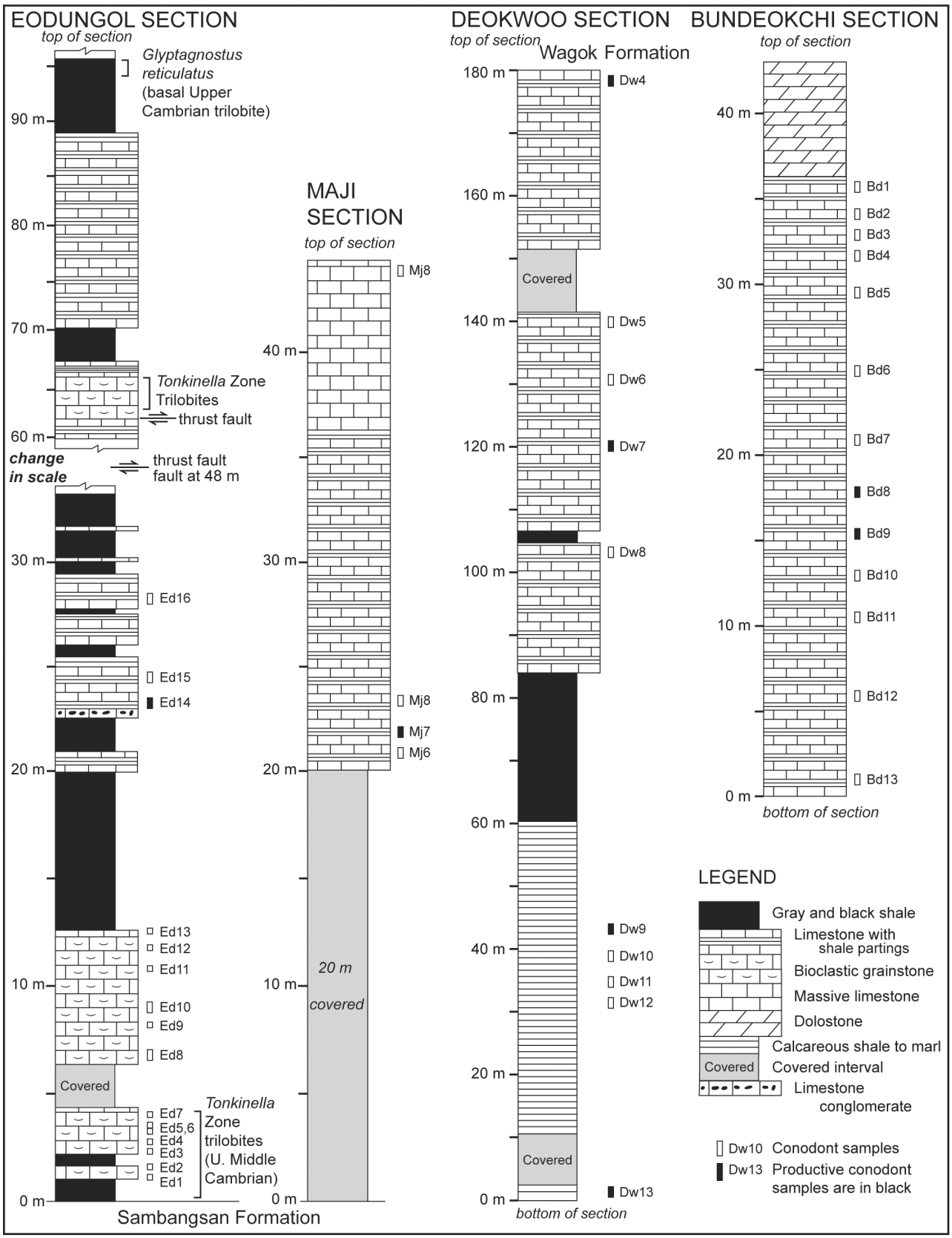
Prosagittodontus dunderbergiae (figure 8.8) occurs in slightly lower beds than *P. eureka* (Müller, 1959) (figure 8.11) (Nogami, 1966; Müller, 1973; An *et al*., 1983; An, 1987; Lee and Lee, 1988; Lee *et al*., 1991; this paper). Also, these two species occur in the *Elvinia* Trilobite Zone in the USA (Müller, 1959), in the *Changshania* Trilobite Zone of North China (An, 1982; An *et al*., 1983; Mei, 1993), and in the *Proconodontus* to *Cambrooistodus minutus* conodont zones of the Hwajeol Formation of Korea (Lee and Lee, 1988). The lowest occurrence of *P. dunderbergiae* herein is from sample Mj7.

Prosagittodontus dahlmani (figure 9.6) and *P. minimus* (figures 7.21, 8.7) are common in sample Mj7. The former is a long-ranging species in the Upper Cambrian, but the latter is restricted to the middle to upper Upper Cambrian (Müller and Hinz, 1991; An and Mei, 1994).

Five species of *Westergaardodina* were recovered from the Machari Formation. *Westergaardodina bicuspidata* Müller, 1959 (figure 7.1) was recovered from the lower to upper Upper Cambrian of Sweden (Müller and Hinz, 1991), north Poland (Bednarczyk, 1979), Estonia (Mens *et al*., 1993), western Newfoundland (Fortey *et al*., 1982), New York (Landing, 1977), Argentina (Heredia, 1999), China (Chen and Gong, 1986; Jiang *et al*., 1986; Dong, 1999; Qi *et al*., 2006), and Korea (Lee and Lee, 1988; Lee *et al*., 1991). This species occurs in the lower to middle parts of the Machari Formation.

Westergaardodina moessebergensis Müller, 1959 (figures 8.17, 9.14), *W. nogamii* (figure 8.18), and *W. quadrata* (figures 8.19, 9.16) are good index fossils for the upper Middle Cambrian to lower Upper Cambrian. *Westergaardodina moessebergensis* is known from the *Agnostus pisiformis* Trilobite Zone and the *Olenus* Trilobite Zone of Sweden (Szaniawski, 1971; Müller and Hinz, 1991). *Westergaardodina moessebergensis* was reported also from correlative beds of the upper Middle to lower Upper Cambrian, namely the Chatsworth Limestone of Australia (Jones, 1971), Gushan Formation of North China (Nogami, 1966; An *et al*., 1983; Mei, 1993), the lower part of the Machari Formation in the Eodungol section (Lee *et al*., 1991) and the Sesong Slate (Lee, 1990) of Korea. *Westergaardodina moessebergensis* and *W. nogamii* occur commonly in upper Middle Cambrian strata in China. However, *W. moessebergensis* ranges from the *Agnostus pisiformis* Trilobite Zone to the lowermost part of the *Parabolina spinulosa* Trilobite Zone in

Figure 3. Lithology, sample horizons, and some trilobite zones for measured sections. Solid bars to left of sample numbers indicate samples that produced conodonts; open bars indicate unproductive samples. Most strata shown are assigned to the Machari Formation; contact with underlying Sambangsan Formation is at base of Eodungol section, and contact with overlying Wagok Formation is at top of Deokwoo section. Only lower part of Eodungol section was sampled for conodonts, but the complete section is ~ 98 m thick. Middle Cambrian trilobites (*Kootenia*, *Olenoides*, *Peronopsis*, *Tonkinella*) occur in intervals 0–5 m and 62–65 m. Basal Upper Cambrian trilobite *Glyptagnostus reticulatus* occurs in interval 95–97 m. See figure 2 for succession of trilobite zones. Thrust faults occur at 49 m and 62 m / *litología, horizontes muestreados y algunas zonas de trilobites de las secciones estudiadas. Barras sólidas a la izquierda de los números de muestra indican las muestras que proveyeron conodontes; barras abiertas indican las muestras no productivas. La mayoría de los estratos mostrados son asignados a la Formación Machari; el contacto con la subyacente Sambangsan Formation está en la base de la sección Eodungol y el contacto con la supra-*



yacente Formación Wagok está al tope de la sección Deokwoo. Solamente la parte inferior de la sección Eodungol fue muestreada para conodontes, pero la sección completa posee aproximadamente 98 m de espesor. Trilobites del Cámbrico Medio (Kootenia, Olenoides, Peronopsis, Tonkinella) *aparecen en los intervalos 0-5 m y 62-65 m. El trilobite del Cámbrico Superior basal* Glyptagnostus reticulatus *se encuentra en el intervalo 95-95 m. Ver figura 2 para la sucesión de zonas de trilobites. Un corrimiento ocurre a los 49 m y otro a los 62 m.*

Figure 4. Correlation chart of Upper Cambrian conodont and trilobite zones in Korea with those of Europe, western USA, and North and South China / *cuadro de correlación de las zonas de conodontes y trilobites cámbricos de Corea con aquellas de Europa, Estados Unidos occidental y norte y sur de China.*

Estonia (Mens *et al*., 1993). *Westergaardodina nogamii* occurs in sample Bd9 with *Proconodontus posterocostatus* and *P. muelleri*..

Westergaardodina quadrata was found first in the *Blackwelderia paronai* Trilobite Zone of the Gushan Formation (upper Middle Cambrian) of North China (An, 1982; Dong, 1993). Later the species was recovered from the *Agnostus pisiformis* Trilobite Zone and

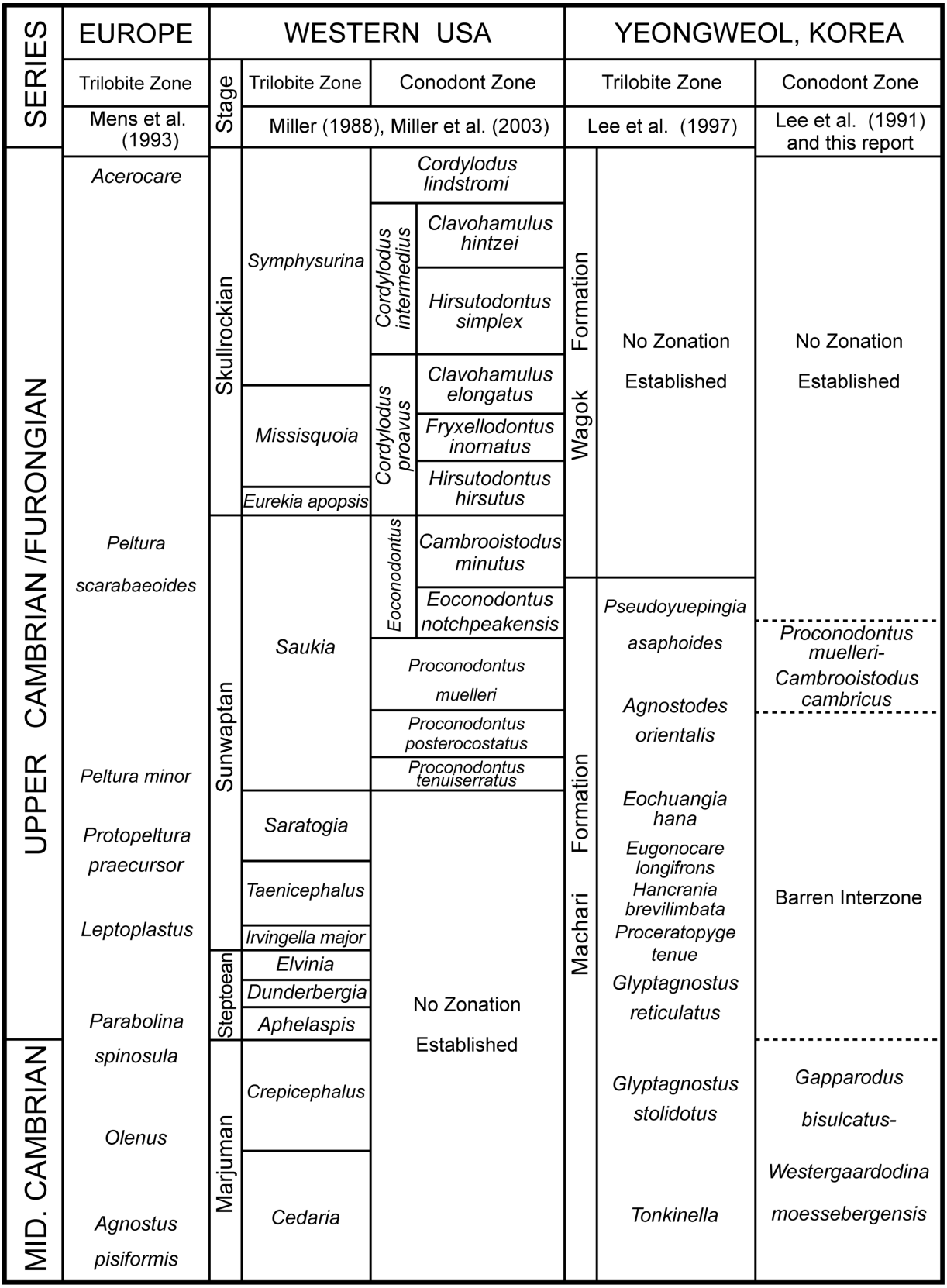


Figure 4. Continuación / *continuation*.

the *Olenus* Trilobite Zone of Sweden (Müller and Hinz, 1991), from the Chefu Formation and the Huaqiao Formation (lower Upper Cambrian) of South China (Dong, 1999; Qi *et al*., 2006), and from the lower part of the Machari Formation in this study.

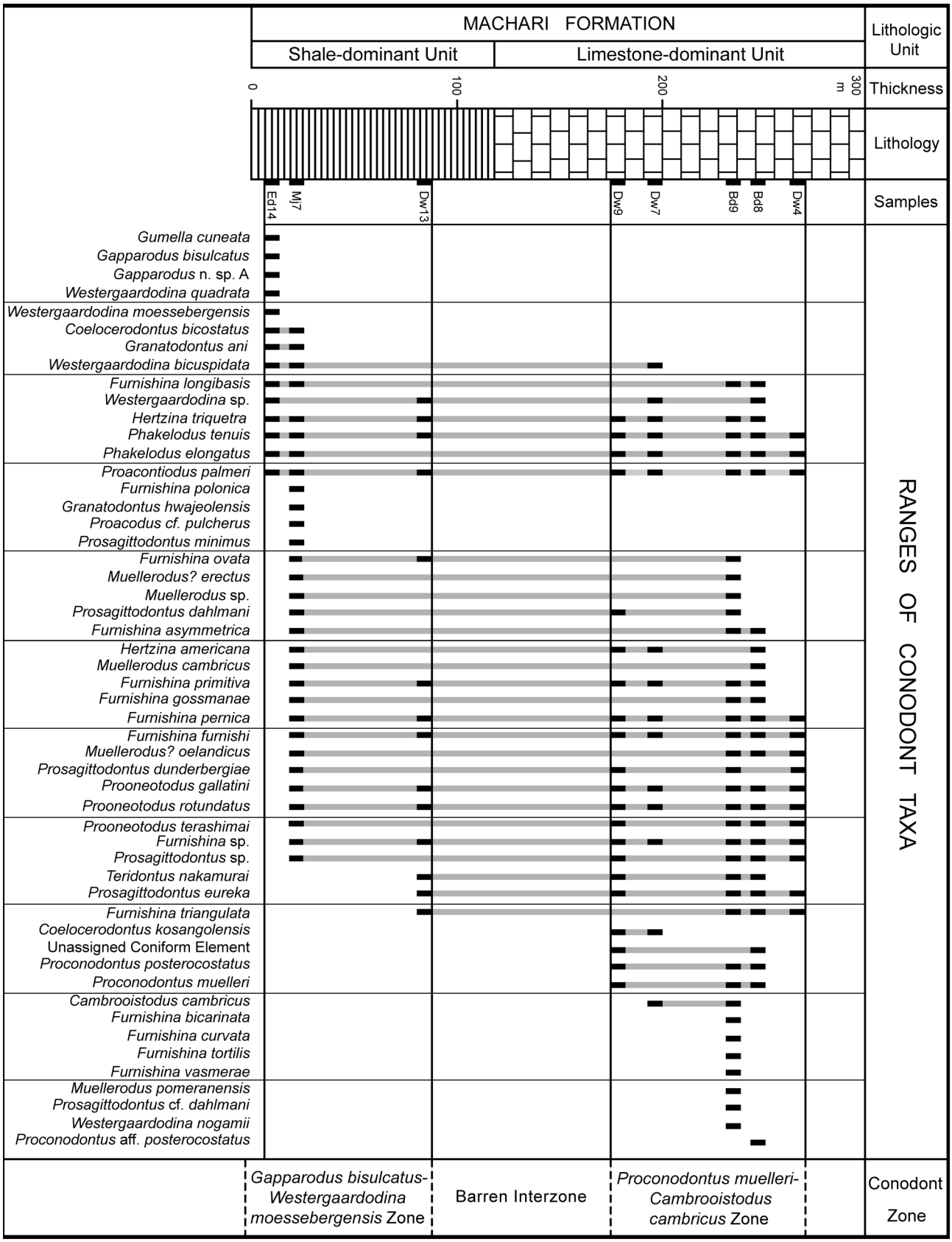


Figure 5. Ranges and biozonal assignment of conodont taxa recovered from the Machari Formation, Yeongweol area, Korea / *rangos y asignación bioestratigráfica de los taxones de conodontes recuperados de la Formación Macharí, área de Yeongweol, Corea.*

Euconodonts

Only five euconodont genera occur in the Machari Formation. *Coelocerodontus bicostatus* (figures 7.18) previously was reported from the upper Middle Cambrian to Ordovician (van Wamel, 1974; Apollonov *et al*., 1984; Landing, 1984; An, 1987; Dong, 1999; Lee and Lee, 1988; Dong *et al*., 2004; Qi *et al*., 2006), and it occurs in the upper Middle Cambrian part of the Machari Formation. *Coelocerodontus kosangolensis* Lee, Choi, and Lee, 1991 (figures 7.13,14) was recovered from the middle part of the Machari Formation (Lee *et al*., 1991), and the occurrence of this species herein is roughly equivalent to that of Lee *et al*. (1991). Both of these species were recovered from the lower Upper Cambrian part of the Machari Formation.

Granatodontus ani (Wang, 1985) (Figs. 7.19, 8.2) previously was known from China, Korea, southern Kazakhstan, and western Canada (see discussion in systematics). This species occurs in the Middle Cambrian part of the Machari Formation (samples Ed14 and Mj7; figure 3). *Granatodontus hwajeolensis* Lee and Lee, 1988 (figure 9.10) is an endemic species. Both species of *Granatodontus* occur in sample Mj7, and in general the genus ranges from the upper Middle Cambrian to the middle Upper Cambrian.

Species of *Proconodontus* and *Cambrooistodus cambricus* (Miller, 1969) are key elements of Upper Cambrian conodont zones in many parts of the world. *Proconodontus posterocostatus* (figures 7.7,9; also see figure 7.3) and *P. muelleri* (figure 7.8) co-occur in two of the youngest samples, namely Bd8 (57.5 m below the top of the formation) and Bd9 (2.5 m below Bd8), and *Cambrooistodus cambricus* (figure 7.5) occurs in sample Bd9 (figure 3). These two sample horizons belong to the *Pseudoyuepingia asaphoides* Trilobite Zone of Lee (1995) (figure 2). *Teridontus nakamurai* (Nogami, 1967) (figure 7.2) is known from China, Korea, Iran, southern Kazakhstan, Siberia, Australia, USA, and Canada (western Newfoundland). *Teridontus nakamurai* is a long-ranging species in the Upper Cambrian and lowermost Ordovician. In this study, *T. nakamurai* was recovered from the middle (sample Dw13) to upper beds (sample Bd8) of the Machari Formation.

Biostratigraphic summary

Lee *et al*. (1991, figure 4) divided the conodont faunal assemblages of the Machari Formation into two conodont zones, namely the lower *Gapparodus bisulcatus–Westergaardodina matsushitai–Westergaardodina moessebergensis* Zone and the upper *Proconodontus muelleri–Cambrooistodus cambricus* Zone. For brevity, we herein shorten the name of the former zone to the *Gapparodus bisulcatus–Westergaardodina moessebergensis* Zone. The present conodont assemblages fit well into this zonation, although the examined samples are not closely spaced enough to delineate the precise boundary between the two zones (see Lee *et al*., 1991 for detail). Accordingly, we recognize a Barren Interzone between strata assigned to the two conodont zones (figure 5). This generalized biozonation is appropriate for this report because the number of samples and the recovered faunas reported herein are relatively small.

The lower assemblage includes *Coelocerodontus bicostatus*, *Gapparodus bisulcatus*, *Gumella cuneata*, *Granatodontus ani*, *Granatodontus hwajeolensis*, *Teridontus nakamurai*, *Westergaardodina moessebergensis*, and *W. quadrata* and is roughly equivalent to the lower zone of Lee *et al.* (1991). We assign three of the eight fossiliferous samples to this lower conodont zone, namely samples Ed14, Mj7, and Dw13 (figure 5). The *Gapparodus bisulcatus–W. moessebergensis* Zone correlates well with the *Westergaardodina matsushitai–W. moessebergensis* Zone of the Sesong Slate, Korea (Lee, 1990), the early Late Cambrian fauna of northern Europe and North America (Müller, 1959; Müller and Hinz; 1991), the fauna of the Gushan Formation (Nogami, 1966), and the *W. matsushitai* Zone or *W. matsushitai–W. grandidens* Zone of North and South China (An *et al*., 1983; Mei, 1993; Dong, 1999; Dong *et al*., 2004; see figure 4 herein). No conodont biozonation has been established for coeval strata in North America (figure 4).

Occurrences of *Coelocerodontus bicostatus*, *C. kosangolensis*, *Granatodontus ani*, and *G. hwajeolensis* in the *Gapparodus bisulcatus–W. moessebergensis* Zone are some of the oldest occurrences of euconodonts known anywhere in the world. Qi *et al*. (2006) reported one element of *Coelocerodontus bicostatus* from the upper Middle part of the Huaqiao Formation in Hunan Province, South China. Occurrences of this species in the Machari Formation are of approximately the same age. These Middle Cambrian occurrences in the Machari Formation are only slightly older than previously reported occurrences of euconodonts in Hunan Province, South China by Dong *et al.* (2004, Fig. 2). They reported *C. bicostatus* from as low as the lowest Upper Cambrian *Westergaardodina lui–W.* ani Zone, and they reported *Granatodontus ani* from as low as the overlying *Westergaardodina* cf. *calix–Prooneotodus rotundatus* Zone (figure 4). Both species have relatively long ranges and occur in younger zones in Hunan.

The Barren Interzone between samples Dw13 and Dw9 (figures 3–5) may correlate with the *Wester-*

gaardodina lui–W. ani Zone, *W.* cf. *calix–Prooneotodus rotundatus* Zone, and the *Proconodontus tenuiserratus* Zone in Hunan, South China (Dong *et al*., 2004).

The upper conodont assemblage of the Machari Formation includes *Proconodontus posterocostatus*, *P. muelleri*, and *Cambrooistodus cambricus* and is roughly equivalent to the *Proconodontus muelleri–Cambrooistodus cambricus* Zone of Lee *et al.* (1991). Many taxa recovered from the Machari Formation occur in both of the zones recognized herein (figure 5). The *Proconodontus muelleri–Cambrooistodus cambricus* Zone is recognized through the upper part of the Machari Formation, and we assign five of the fossiliferous samples to this upper conodont zone, namely samples Dw7, Dw9, Bd8, Bd9, and Dw4 (figures 3, 5). The above taxa are characteristic elements of the *Proconodontus* Conodont Zone of the Hwajeol Formation in the Duwibong area of Korea (Lee and Lee, 1988). Therefore, the zone is closely correlated with zones of the middle Upper Cambrian, including the *P. muelleri* Conodont Zone and lower part of the *Eoconodontus* Conodont Zone of western United States (Miller, 1988; Ross *et al*., 1997; Miller *et al*., 2003), the *P. muelleri muelleri* Subzone of the *Proconodontus* Conodont Zone of the Canadian Arctic Islands and western Canada (Nowlan, 1985, Hein and Nowlan, 1998), and the upper part of the *Proconodontus* Zone and the lower part of the *Cambrooistodus* Zone of North China (An *et al*., 1983; Chen and Gong, 1986; Chen *et al*., 1988).

Systematic paleontology

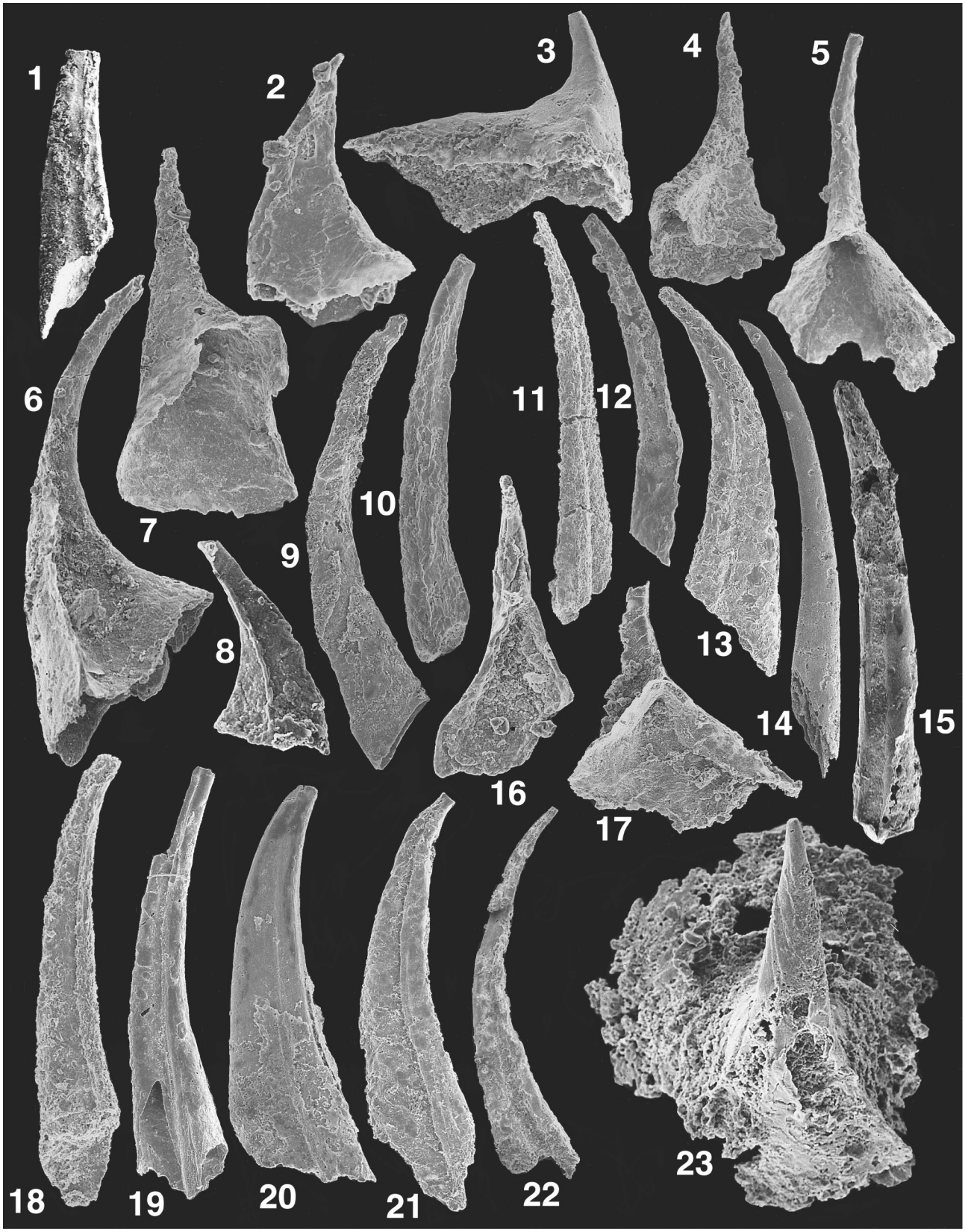
This report illustrates new faunas from the Middle to Upper Cambrian Machari Formation, Korea (figures 6–9). Taxa discussed include those described for the first time in Korea, taxa named since the report of Lee *et al*. (1991) (especially those named by Müller and Hinz, 1991), and some taxa in open nomenclature. All figured specimens are deposited in the collections of the School of Earth and Environmental Sciences, Seoul National University, Seoul, and have collection numbers SNUG 0001–0094.

Conodont taxonomists often have not dealt with suprageneric classification of conodont faunas, but that procedure is impossible for this report, which deals with taxa as different as protoconodonts (classified in one phylum) and paraconodonts and euconodonts (classified in another phylum). Herein we assign to Phylum Chaetognatha and Order Protoconodontida those conodonts with protoconodont histology. Sweet (1988) assigned euconodonts to Phylum Conodonta, which is based on the informal name *Conodonten* of Pander (1856). We follow the classification of Sweet and Donoghue (2001) and recognize their Superclass Conodonta, and we assign to it those genera with paraconodont or euconodont histology. Superclass Conodonta is assigned to Phylum Chordata Bateson, 1886. We transfer the Order Paraconodonta of Müller (1962) to the level of Class Paraconodonta Müller, 1962 and assign to it those genera with paraconodont histology. Sweet (1988) and Sweet and Donoghue (2001) assigned euconodonts to Subclass Conodonti Branson, 1938, although they raised it to the level of Class. We follow this classification and assign conodonts with euconodont histology to Class Conodonti Branson, 1938.

There has been uncertainty about whether some Cambrian conodont genera have paraconodont versus euconodont histology. Dong *et al*. (2005) studied the histology of some Cambrian conodont genera and clarified some of that uncertainty. Based on their research, we assign to the euconodonts the genera *Coelocerodontus* Ethington, 1959 and *Granatodontus* Chen and Gong, 1986, which we recovered from the Machari Formation. Some genera recovered from the Machari Formation have always been considered to be euconodonts, including *Cambrooistodus* Miller, 1969, *Proconodontus* Miller, 1969, and *Teridontus* Miller, 1980.

Several short, general taxonomic comments are presented here: 1) This study follows Müller and Hinz (1991, 1998), which was based on large collections, in taxonomic assignment based on internal structure and the outer morphologic features; 2) *Furnishina lingulata* Xiang in An et al., 1983 is regarded herein as a junior subjective synonym of *F. longibasis* Bednarczyk, 1979; 3) *Proacontiodus palmeri* (Müller,

Figure 6. Scanning electron micrographs of conodonts from the Machari Formation, Yeongweol area, Korea. All images are lateral views except as noted below. See figure 3 for sample numbers / *Microfotografías de barrido electrónico de conodontes de la Formación Macharí, área de Yeongweol, Corea. Todas las imágenes son vistas laterales excepto las indicadas debajo. Véase figura 3 para números de muestra.* **1, 11, 15, 22, *Gapparodus bisulcatus*** (SNUG 0005–0008), all from / *todas de* Ed14, 1 is a phosphatic internal mold / *es un molde fosfático interno*, X112, X58, X112, X58, respectively / *respectivamente*; **2, 4, 7, *Furnishina primitiva*, 2,** (SNUG 0019), Bd8, X179, **4, 7** are posterolateral views / *vistas posterolaterales* (SNUG 0017, 0018), Mj7, Bd8, X83, X126, respectively / *respectivamente*; **3, *Furnishi*na *longibasis*** (SNUG 0020), Ed14, X146; **5, *Furnishina bicarinata*** (SNUG 0021), posterior view / *vista posterior*, Bd9, X83; **6, *Furnishina vasmerae*** (SNUG 0016), Bd9, X146; **8, *Muellerodus? erectus*** (SNUG 0039), Dw7, X194; **9, 10, *Phakelodus elongatus*** (SNUG 0003, 0004), both from / *ambos de* Ed14, X58, X73, respectively / *respectivamente*; **12, 14, *Phakelodus tenuis*, 12,** (SNUG 0001), Mj7, X97, **14,** (SNUG 0002), Ed14, X38; **13, 18, *Gapparodus*** n.



sp. A, both from / *ambos de* Ed14, **13,** oblique posterolateral view/ *vista posterior oblicua* (SNUG 0009), X58, **18,** (SNUG 0010), X58; **16, *Furnishina gossmannae*** (SNUG 0022), posterior view / *vista posterior*, Bd8, X136; **17, *Furnishina furnishi*** (SNUG 0023), posterior view /*vista posterior*, Bd9, X97; **19–21, *Gumella cuneata*** (SNUG 0011–0013), all are "morphotype beta" of / *todos son "morfotipos beta"* de Müller and Hinz (1991), all from / *todos de* Ed14, X53, X53, X58, respectively / *respectivamente*; **23, *Furnishina ovata*** (SNUG 0024), upper view /*vista superior*, Mj7, X146.

1959) has symmetrical to subsymmetrical tri- and tetracostate elements with a broad basal cavity; 4) *Coelocerodontus kosangolensis* Lee, Choi, and Lee, 1991 has symmetrical to asymmetrical tri- and tetracostate elements with a small lateral expansion of the cusp; and 5) *Coelocerodontus bicostatus* van Wamel, 1974 has a different costae and cusp morphology compared with *C. kosangolensis* Lee, Choi, and Lee, 1991. *Coelocerocontus bicostatus* is relatively large, bilaterally expanded, and has a lateral costa(e), but *C. kosangolensis* is relatively small, slightly expanded, and has two posterior or/and anterior costae.

Protoconodonts

Phylum CHAETOGNATHA Leuckart, 1854
Order PROTOCONODONTIDA Landing, 1995

Genus ***Gapparodus*** Abaimova, 1978

Type species. *Hertzina*? *bisulcata* Müller, 1959.

Gapparodus new species A
Figures 6.13, 6.18

Occurrence. Sample Ed14; *Gapparodus bisulcatus–W. moessebergensis* Zone.

Diagnosis. Long, slightly expanded coniform protoconodont with a very deep internal cavity. Anterior side rounded, posterior side flat to obliquely concave, producing two posterolateral costae.

Description. Very long, slender, evenly recurved coniform elements with deep internal cavities extending to near the apical end. Anterior side broadly rounded, and posterior side flat or slightly concave, no lateral furrows.

Material examined. Illustrated specimens SNUG 0009, 0010, and one additional element.

Remarks. These specimens closely resemble other species of the genus, but this species lacks any lateral furrows.

Paraconodonts

Phylum CHORDATA Bateson, 1886
Superclass CONODONTA Pander, 1856
[*nomen translatum* (*pro* phylum Conodonta Sweet, 1988, p. 170); *ex* Conodonten Pander, 1856]
Class PARACONODONTIDA Müller, 1962
[*nomen translatum* (*pro* Order Paraconodontida Müller, 1962), *emended* Landing, 1995]

Genus ***Furnishina*** Müller, 1959

Type species. *Furnishina furnishi* Müller, 1959.

Furnishina polonica Szaniawski, 1971
Figure 8.12

See synonymy in Müller and Hinz (1991).

Occurrence. Sample Mj7; *Gapparodus bisulcatus–W. moessebergensis* Zone.

Material examined. Illustrated specimen SNUG 0034, plus one other element.

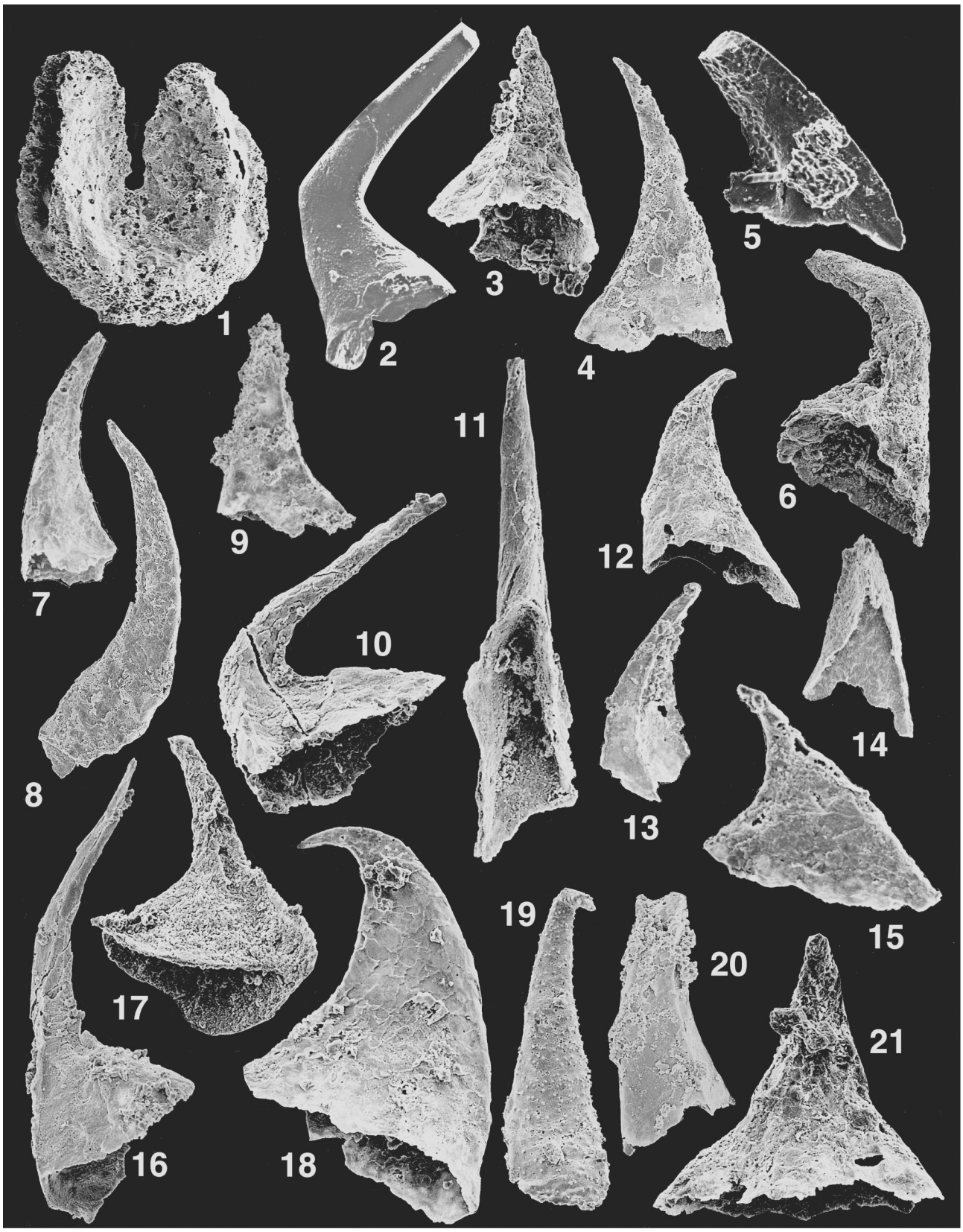
Remarks. Our elements are proclined and consist of a circular cusp set off from the flared base, a convex anterior face with two anterolateral keels, and an extremely large base without a distinct posterior costa. The present specimens coincide with the type material in overall morphologic characters, although the anterior face is broadly convex and not flat as are the figured types of Szaniawski (1971).

Furnishina sp.
Figures 9.5, 9.9

Occurrence. Samples Mj7, Dw13, Dw9, Dw7, Dw4, Bd8, Bd9; *Gapparodus bisulcatus–W. moessebergensis* Zone and *Proconodontus muelleri–Cambrooistodus cambricus* Zone.

Material examined. Illustrated specimens SNUG 0026, 0027, plus 67 other elements.

Figure 7. Scanning electron micrographs of conodonts from the Machari Formation, Yeongweol area, Korea. All images are lateral views except as noted below. See figure 3 for sample numbers / *microfotografías de barrido electrónico de conodontes de la Formación Machari, área de Yeongweol, Corea. Todas las imágenes son vistas laterales excepto las indicadas debajo. Véase figura 3 para números de muestra.* **1,** ***Westergaardodina bicuspidata*** (SNUG 0070), posterior view / *vista posterior*, Ed14, X117; **2,** ***Teridontus nakamurai*** (SNUG 0088), Bd8, X73; **3,** ***Proconodontus*** sp. aff. ***posterocostatus*** (SNUG 0076), posterior view / *vista posterior*, Bd8, X194; **4,** ***Muellerodus*? *erectus*** (SNUG 0043), posterolateral view / *vista posterolateral*, Mj7, X107; **5,** ***Cambrooistodus cambricus*** (SNUG 0089), Bd9, X117; **6,** Unassigned Coniform Element / *elemento coniforme no asignado* (SNUG 0075), form with a costa on one lateral face / *forma con una costa en una cara lateral*, Dw9, X97; **7, 9,** ***Proconodontus posterocostatus***, **7,** (SNUG 0090), Dw7, X107; **9,** (SNUG 0091), posterolateral view / *vista posterolateral,* Bd8, X112; **8,** ***Proconodontus muelleri*** (SNUG 0080), Bd8, X74; **10,** ***Muellerodus*? *oelandicus*** (SNUG 0044), Mj7, X194; **11,** ***Furnishina curvata*** (SNUG 0036), posterior view / *vista posterior*, Bd9, X194; **12, 15,** ***Prooneotodus gallatini*****, 12,** (SNUG 0049), Dw7, X146; **15,** (SNUG 0092), Bd9, X97; **13, 14,** ***Coelocerodontus kosangolensis*****, 13,** small, flattened tetracostate element / *perqueño elemento tretacostulado aplastado* (SNUG 0093), Dw7, X156; **14,** small, flattened tricostate element / *elemento pequeño, tricostulado aplastado* (SNUG 0094),



Dw7, X146; **16,** ***Furnishina furnishi*** (SNUG 0038), Dd 9, X146; **17,** ***Furnishina gossmannae*** (SNUG 0045), posterior view / *vista posterior*, Bd9, X194; **18,** ***Coelocerodontus bicostatus*** (SNUG 0083), 'Morphotype alpha' of Müller and Hinz (1991), Mj7, X194; **19,** ***Granatodontus ani*** (SNUG 0062), posterolateral view, Mj7, X146; **20,** ***Hertzina americana*** (SNUG 0073), posterolateral view / *vista posterolateral*, Mj7, X117; **21,** ***Prosagittodontus minimus*** (SNUG 0054), posterior view / *vista posterior*, Mj7, X194.

Remarks. These are preserved commonly as elements (figure 9.5) that were distorted due to post-sedimentation deformation, or they are elements with broken bases (figure 9.9). As a result, they do not allow a specific identification.

Genus ***Proacodus*** Müller, 1959

Type species. *Proacodus obliquus* Müller, 1959.

Proacodus cf. ***pulcherus*** (An, 1982)
Figure 9.7

1982. *Muellerodus pulcherus* n. sp. An, p. 139, pl. 9, figs. 13, 15; pl. 10, figs. 12, 14.
1991. *Muellerodus pulcherus* An. Müller and Hinz, p. 34, 35, pl. 22.3–5, 7–11; fig. 13A, B.

Occurrence. Sample Mj7; *Gapparodus bisulcatus–W. moessebergensis* Zone.

Material examined. One element, illustrated specimen SNUG 0055.

Remarks. Our specimen differs from *Proacodus pulcherus* (An, 1982) in having a cusp that is undifferentiated from the base, but the remaining characteristics conform to those of the holotype of this species.

Genus ***Westergaardodina*** Müller, 1959

Type species. *Westergaardodina bicuspidata* Müller, 1959.

Westergaardodina sp.
Figure 9.17

Occurrence. Sample Ed14; *Gapparodus bisulcatus–W. moessebergensis* Zone.

Material examined. Illustrated specimen SNUG 0065, plus 15 other elements.

Remarks. Two of our elements have a strong similarity to those of *Westergaardodina matsushitai* in their shape and size, but the basal part has a strong similarity to that of *W. bicuspidata*. Accordingly, we leave them in open nomenclature.

Euconodonts

Class CONODONTI Branson, 1938
[*nomen translatum* (*pro* Subclass Conodonti Branson, 1938)]

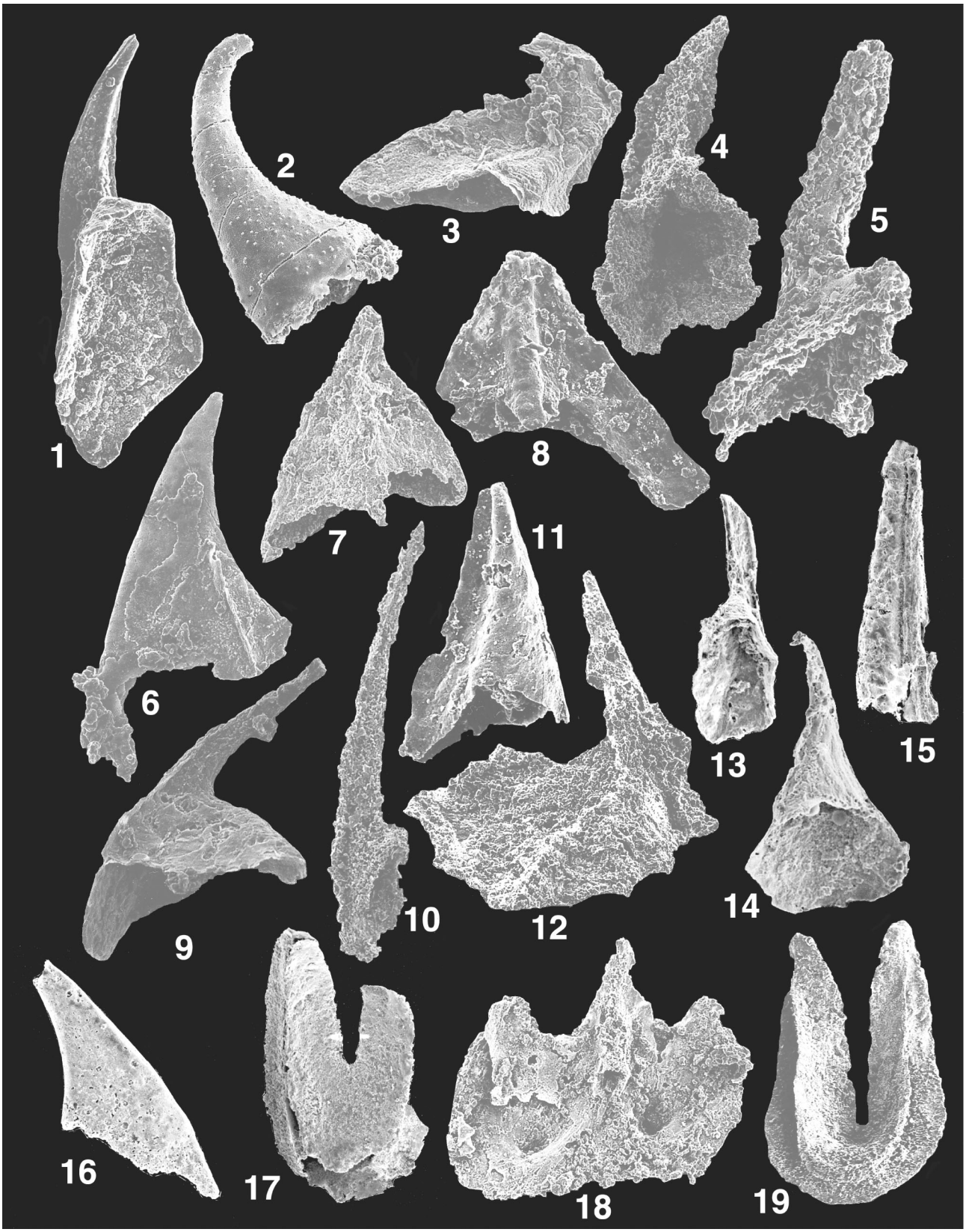
Genus ***Granatodontus*** Chen and Gong, 1986

Type species. *Hirsutodontus*? *ani* Wang, 1985.

Remarks. Chen and Gong (1986, p. 148, 149) assigned *Hirsutodontus*? *ani* Wang, 1985 to the genus *Granatodontus* Chen and Gong, 1986 because elements have no white matter, and they considered this species and *Granatodontus* to be paraconodonts. However, we assign this genus to the euconodonts because Chen and Gong's (1986) elements appear to have euconodont histology, as does the genus *Hirsutodontus* (Dong *et al*., 2005). The species name *Granatodontus ani* (Wang, 1985) is appropriate rather than *Hirsutodontus primitivus* An *et al*., 1985, because the latter species was designated without any relevant description as a new species, so it is a *nomen nudum* (see Chen and Gong, 1986, p. 149).

Granatodontus, with fine granulose ornament, is a distinctive genus that is closely related to the euconodont genera *Rotundoconus* An and Zhang in An *et al*., 1983, *Hirsutodontus* Miller, 1969, *Dasytodus* Chen and Gong, 1986, and *Teridontus* Miller, 1980. *Rotundoconus* and *Granatodontus* are euconodonts (Dong *et al*., 2005) with fine granulose ornament. Both are primitive in that they are not differentiated into a distinct base and a cusp, which the other genera possess. *Granatodontus* has a pointed tip, whereas the tip of *Rotundoconus* has a rounded to bulbous tip. Both genera had been considered as endemic to Korea and China, but Pyle and Barnes (2002) reported *Granatodontus* cf. *ani* in western Canada; their material is Tremadocian in age. Miller *et al.* (2003) reported *Rotundoconus* sp. from the *Proconodontus posterocostatus* Zone in the Ibex area, Utah; they reported a different species (*Rotundoconus*? sp.) from top of the *Cambrooistodus minutus* Subzone of the *Eoconodontus* Zone in the Ibex area, Utah and in central Texas, USA. The latter species was illustrated by Miller *et al*. (2006, Figs. 9G, 10G) as *Rotundoconus* sp.

Figure 8. Scanning electron micrographs of conodonts from the Machari Formation, Yeongweol area, Korea. All images are lateral views except as noted below. See figure 3 for sample numbers / *microfotografías de barrido electrónico de conodontes de la Formación Machari, área de Yeongweol, Corea. Todas las imágenes son vistas laterales excepto las indicadas debajo. Véase figura 3 para números de muestra.* **1, 13, *Furnishina tortilis*, 1,** (SNUG 0029), posterior view / *vista posterior*, Bd9, X146; **13,** (SNUG 0084), posterior view / *vista posterior*, Bd9, X87; **2, *Granatodontus ani*** (SNUG 0061), Mj7, X146; **3, *Muellerodus pomeranensis*** (SNUG 0042), Bd9, X146; **4, *Furnishina pernica*** (SNUG 0030), posterior view, Dw13, X97; **5, *Furnishina asymmetrica*** (SNUG 0031), oblique posterolateral view, Bd9, X194; **6, *Hertzina triquetra*** (SNUG 0071), inner lateral view / *vista interna lateral*, Bd9, X194; **7, *Prosagittodontus minimus*** (SNUG 0051), posterior view, Bd9, X146; **8, *Prosagittodontus dunderbergiae*** (SNUG 0052), posterior view / *vista posterior*, Dw9, X194; **9, *Furnishina gossmannae*** (SNUG 0032),



Bd9, X194; **10,** ***Furnishina furnishi*** (SNUG 0033), Dw13, X97; **11,** ***Prosagittodontus eureka*** (SNUG 0053), oblique posterolateral view / *vista oblicua posterolateral*, Dw9, X194; **12,** ***Furnishina polonica*** (SNUG 0034), Mj7, X97; **14,** ***Furnishina ovata*** (SNUG 0035), posterior view / *vista posterior*, Bd9, X126; **15,** ***Gumella cuneata*** (SNUG 0085), Ed14, X42; **16,** ***Prooneotodus gallatini*** (SNUG 0086), Bd9, X97; **17,** ***Westergaardodina moessebergensis*** (SNUG 0087), posterior view / *vista posterior*, Ed14, X78; **18,** ***Westergaardodina nogamii*** (SNUG 0068), posterior view / *vista posterior*, Bd9, X97; **19,** ***Westergaardodina quadrata*** (SNUG 0069), posterior view / *vista posterior*, Ed14, X117.

Dubinina (2001) considered *Granatodontus* to be a junior synonym of *Hirsutodontus*. We disagree and consider both to be valid genera that are closely related. *Granatodontus* has fine granulose ornament and is primitive in not being differentiated into a distinct base and cusp. *Hirsutodontus* has nodose or spiny ornament and is advanced in having a distinct base and cusp, and the cusp often contains white matter.

Granatodontus hwajeolensis (Lee and Lee, 1988)
Figure 9.10

1988. *Hirsutodontus* n. sp. A, Lee, p. 88, 89, pl. 5, figs. 7–12, text-figs. 5.G–12.
1988. *Hirsutodontus hwajeolensis* Lee and Lee, p. 366, 367, pl. 2, figs. 1, 2.

Occurrence. Sample Mj7; *Gapparodus bisulcatus–W. moessebergensis* Zone.

Material examined. One element, illustrated specimen SNUG 0060.

Description. Nearly erect, posteriorly expanded, undifferentiated coniform euconodont with deep basal cavity extending nearly to tip of cusp. Anterior side flat to broadly rounded, posterior side carinated, showing a triangular cross section in posterior view. Surface sculptured with numerous tiny spines and nodes, especially on the posterior face.

Remarks. *Granatodontus hwajeolensis* is easily distinguished from *Granatodontus ani* by its subtriangular cross section. *Granatodontus ani* has a rounded to oval cross section.

Genus ***Proconodontus*** Miller, 1969

Type species. *Proconodontus muelleri* Miller, 1969.

Proconodontus sp. aff. ***posterocostatus*** Miller, 1980
Figure 7.3

Occurrence. Sample Bd8; *Proconodontus muelleri–Cambrooistodus cambricus* Zone.

Material examined. One element, illustrated specimen SNUG 0076.

Remarks. Very small, nearly erect coniform conodont with deep basal cavity. This single specimen resembles *Proconodontus posterocostatus* in having a costa on the entire length of the posterior edge, but it is greatly expanded in all directions, producing a circular cross section throughout the cone (compare figure 7.3 with figures 7.7,9).

Unassigned Coniform Element
Figure 7.6

Occurrence. Samples Dw9, Bd8; *Proconodontus muelleri–Cambrooistodus cambricus* Zone.

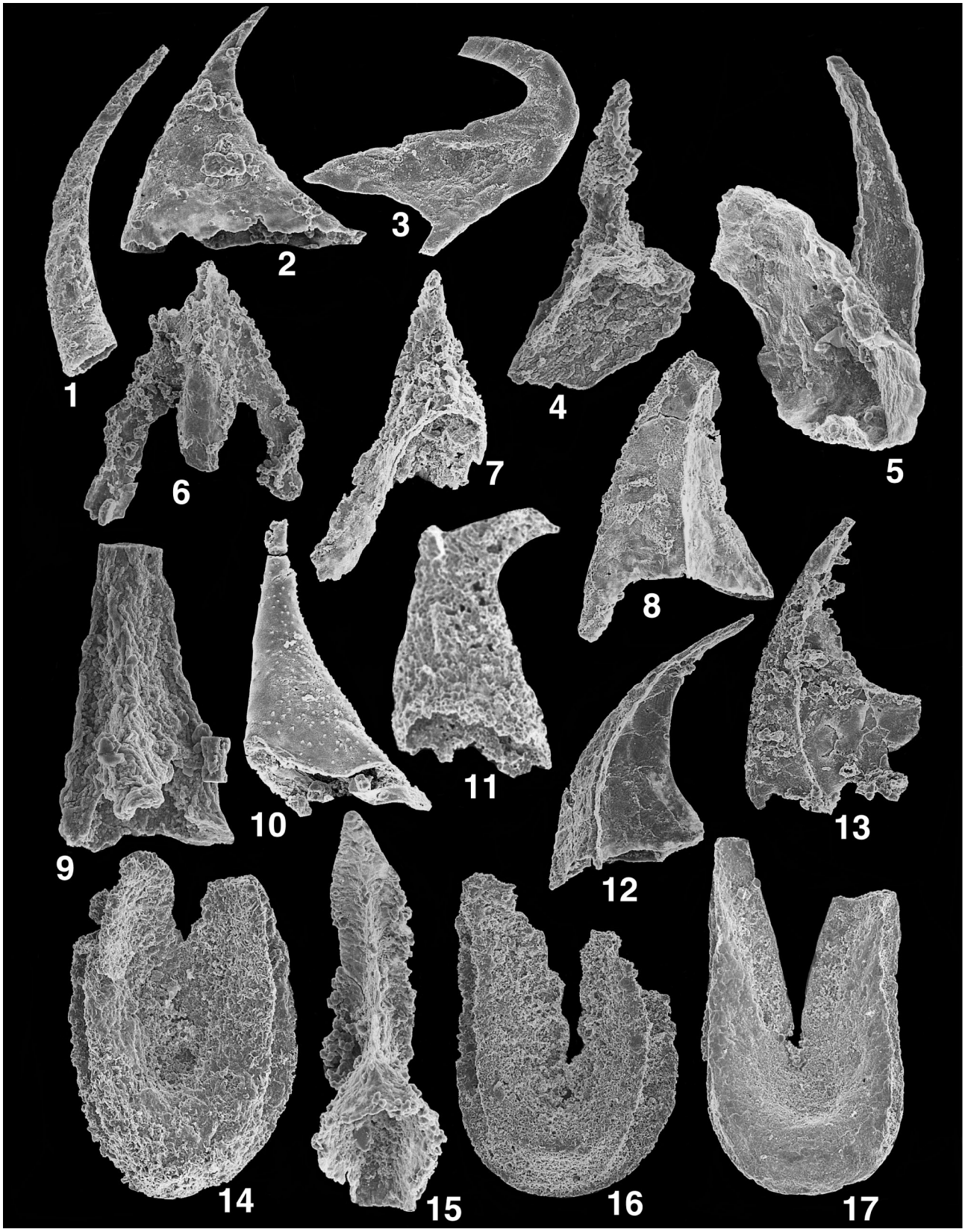
Material examined. Illustrated specimen SNUG 0075, plus one other element.

Remarks. Two elements recovered herein have a postero-lateral costa and a furrow. All other sides are smooth, rounded, and lack any surface structures. The illustrated specimen is badly corroded. Similar elements that lack the costa and furrow are assigned to *Teridontus nakamurai* (figure 7.2), but the two elements considered here are left in open nomenclature.

Conclusions

The Machari Formation (upper Middle Cambrian to middle Upper Cambrian) is ~ 300 m thick in the Yeongweol area, Gangweon Province, Korea. Forty-three conodont samples were collected from four measured sections of the Machari Formation; eight samples produced 1,305 conodont elements. Elements are assigned to four genera and seven species of protoconodonts (Phylum Chaetognatha, Order Protoconodontida), seven genera and thirty-five species of paraconodonts (Phylum Chordata, Superclass Conodonta, Class Paraconodontida), and five genera and nine species of euconodonts (Phylum Chordata, Superclass Conodonta, Class Conodonti). Twenty-three species of ten genera were recovered for the first time from the Machari Formation, but other species are known from many parts of the world. Upper Middle Cambrian occurrences of *Coelocerodontus* and *Granatodontus* are among the old-

Figure 9. Scanning electron micrographs of conodonts from the Machari Formation, Yeongweol area, Korea. All images are lateral views except as noted below. See figure 3 for sample numbers / *microfotografías de barrido electrónico de conodontes de la Formación Machari, área de Yeongweol, Corea. Todas las imágenes son vistas laterales excepto las indicadas debajo. Véase figura 3 para números de muestra.* **1, *Prooneotodus rotundatus*** (SNUG 0046), Mj7, X92; **2, *Prooneotodus gallatini*** (SNUG 0047), Bd8, X146; **3, *Muellerodus cambricus*** (SNUG 0041), Mj7, X126; **4, *Furnishina asymmetrica*** (SNUG 0025), posterior view / *vista posterior,*, Mj7, X136; **5, 9, *Furnishina*** sp., posterolateral view / *vista posterolateral*, (SNUG 0026), Bd9, X185, **9,** posterior view / *vista posterior,* (SNUG 0027), Bd8, X224; **6, *Prosagittodontus dahlmani*** (SNUG 0050), posterior view, Bd9, X117; **7, *Proacodus*** cf. ***pulcherus*** (SNUG 0055), posterior view / *vista posterior*, Mj7, X126; **8, 13, *Proacontiodus palmeri*,** large, inflated distacodiform elements / *elementos distacodiformes grandes, inflados*, **8,** (SNUG 0056), Bd9, X97; **13,** (SNUG 0057),



Ed14, X126; **10, *Granatodontus hwajeolensis*** (SNUG 0060), posterolateral view / *vista posterolateral*, Mj7, X156; **11, *Prooneotodus terashimai*,** (SNUG 0048), Mj7, X107; **12, *Muellerodus? erectus*** (SNUG 0040), Bd9, X126; **14, *Westergaardodina moessebergensis*** (SNUG 0062), posterior view / *vista posterior*, Ed14, X78; **15, *Furnishina triangulata*** (SNUG 0028), posterior view / *vista posterior*, Bd9, X165; **16, *Westergaardodina quadrata*** (SNUG 0064), posterior view / *vista posterior*, Ed14, X63; **17, *Westergaardodina*** sp. (SNUG 0065), posterior view / *vista posterior*, Ed14, X73.

est occurrences of euconodonts known anywhere. The lower three productive samples are assigned to the upper Middle Cambrian *Gapparodus bisulcatus–Westergaardodina moessebergensis* Zone. The upper five productive samples are assigned to the middle Upper Cambrian *Proconodontus muelleri–Cambrooistodus cambricus* Zone. Strata from the lower part of the Upper Cambrian are represented by a Barren Interzone. These faunas allow correlation with regional conodont biozonal frameworks in various parts of the world.

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