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THE CAMBRIAN－ORDOVICIAN BOUNDARY IN THE TAEBAEGSAN REGION, KOREA : A REVIEW

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ABSTRACT

The Cambrian-Ordovician boundaries in Korea have been traditionally placed between the Hwajeol and Dongjeom formations in the Duwibong-type sequence of the Joseon Supergroup and between the Wagog and Mungog formations in the Yeongweol-type sequence of the Joseon Supergroup. Primarily stimulated by the efforts of the International Working Group on the Cambrian-Ordovician Boundary initiated in the early 70's, this study attempts to review the faunal features, mainly focused on the trilobites and conodonts, across the potential Cambrian-Ordovician boundary intervals in Korea. Although the currently available biostratigraphic data do not permit the resolution of the global stratotype that can provide a guide for the definition of the Cambrian-Ordovician boundary, two biostratigraphic intervals in Korea show faunal features close to the Cambrian-Ordovician boundary point. One is the *Fryxellodontus inornatus-Monocostatus sevierensis-Semiacontiodus lavadamensis* Zone in the uppermost part of the Hwajeol Formation and the other is the lower fauna of the Mungog Formation. The lower fauna of the Mungog Formation is characterized by the occurrence of *Yosimuraspis, Jujuyaspis,* and *Pseudokainella* and is presumed to be equivalent to the *Cordylodus intermedius-Utahconus beimadaoensis* conodont zone. These faunal features suggest that the Cambrian-Ordovician boundary of the Duwibong sequence may lie within the uppermost part of the Hwajeol Formation, while that of the Yeongweol sequence below the base of the Mungog Formation.

INTRODUCTION

In Korea, the Cambrian-Ordovician boundary lies within the Joseon Supergroup, a thick (1500－2000 m) sequence of late Early Cambrian to Middle Ordovician age. The Cambrian-Ordovician boundary has been traditionally placed between the Hwajeol and Dongjeom formations in the Duwibong-type sequence of Joseon Supergroup and between the Wagog and Mungog formations in the Yeongweol-type sequence of Joseon Supergroup (Kobayshi, 1966; Lee, 1987). These Cambrian-Ordovician boundary interval strata have seldom been critically examined, until recently Lee and Lee (1988), based on a conodont study, suggested a possibility that the boundary may lie within the uppermost part of the Hwajeol Formation in Duwibong area. Similarly, Choi (1992) doubted that the Cambrian-Ordovician boundary in Yeongweol area may be placed within the uppermost part of the Wagog Formation on the basis of a preliminary study of trilobite occurrences in the Mungog Formation.

During the past two decades, the Cambrian-Ordovician boundary sequences around the world have been examined in detail by the International Working Group on the Cambrian-Ordovician Boundary (Bassett and Dean, 1982;Norford, 1988). The main objectives of the working group are (Norford, 1988, p.324) :

1) to stimulate intensive study of the boundary interval and its faunas and floras, 2) to document the best stratigraphic sections spanning the boundary in the various part of the world that have the sequences through the boundary interval, 3) to consider recommendations for the biostratigraphic or other event to serve as the boundary and to decide on the most appropriate horizon, and 4) to decide on an accessible type section within a suitable type region to serve as the permanent reference (global stratotype) for the Cambrian-Ordovician Boundary.

It is however frustrating that in spite of intense efforts of the working group international agreement for the definition of the Cambrian-Ordovician boundary on a worldwide basis has not been made yet. Thus, it may be premature to place precisely the Cambrian-Ordovician boundary in Korea. Nonetheless, it would be worthwhile to examine the sequences spanning the boundary intervals, to document their faunal successions, and to compile up-to-date informations on the putative Cambrian-Ordovician boundary intervals in Korea. The specific objective of this review is to synthesize the biotic successions of the Cambrian-Ordovician boundary intervals in Korea, mainly focused on conodonts and trilobites, so as to provide a basis for better understanding of the Cambrian-Ordovician boundary in Korea.

STRATIGRAPHY OF THE CAMBRIAN-ORDOVICIAN BOUNDARY INTERVALS IN KOREA

The Cambro-Ordovician sedimentary rocks in southern Korea, which collectively make up the Joseon Supergroup, are mainly exposed in the Taebaegsan region. Five types of sequences were recognized in the Joseon Supergroup, each with distinct lithologic succession and geographic distribution ; i.e., Duwibong, Yeongweol, Jeongseon, Pyeongchang, and Mungyeong sequences (Kobayashi et al., 1942). Of these, the Duwibong and Yeongweol sequences are by far the most intensively studied owing to their prolific occurrences of trilobites and conodonts. Figure 1 summarizes the stratigraphic nomenclature of the Duwibong and Yeongweol sequences discussed in the following.

Duwibong Sequence

The Duwibong-type Joseon Supergroup comprises ten formations : the lower five formations (Jangsan, Myobong, Daegi, Sesong, and Hwajeol formations) were attributed to the Cambrian in age, while the upper five (Dongjeom, Dumugol, Maggol, Jigunsan, and Duwibong formations) to the Ordovician (Kobayashi, 1966). The Sesong and Hwajeol formations were originally identified as separate stratigraphic units by Kobayashi (1935, 1966), whereas

Cheong (1969) incorporated the Sesong and Hwajeol formations into the Hwajeol Formation (sensu lato). treating the Sesong Slate as a member of the Hwajeol Formation (sensu lato). Kobayashi (1935, 1966) recognized two trilobite zones (*Stephanocare* and *Drepanura* zones) from the Sesong Slate and five trilobite zones (*Prochuangia, Chuangia, Kaolishania, Dictyites,* and *Eoorthis* zones) from the Hwajeol Formation. These trilobite assemblages have generally been known to represent Late Cambrian in age. Recently, Lee and Lee (1988) proposed four conodont zones in the Hwajeol Formation, namely *Proconodontus, Eoconodontus* (*E.*) *notchpeakensis, Cambrooistodus minutus,* and *Cordylodus proavus* zones in ascending order and correlated these zones with the Late Cambrian ones of China, Iran and North America. They suggested that the Cambrian-Ordovician boundary may lie within the uppermost part of the Hwajeol Formation.

The Dongjeom Formation underlain by the Hwajeol Formation is composed of light to dark gray sandstone with occasional intercalations of shale and limestone lenses. *Pseudokainella iwayai* is so far the only known trilobite species from the Dongjeom Formation, which led Kobayashi (1966) to draw the Cambrian-Ordovician bounary in the Duwibong sequence between the *Eoorthis* Zone of the Hwajeol Formation and the *Pseudokainella iwayai* Zone of the Dongjeom Formation. The overlying Dumugol Formation is an alternating sequence of limestone and shale layers and measures 150−200 m in thickness. Kobayashi (1934) established two trilobite zones in the Dumugol Formation, whereas Kim et al. (1991) recognized three trilobite zones within the formation in the Gumunso section. The lower two zones. *Asaphellus* and *Protopliomerops* zones, were assigned to the late Tremadoc, while the upper *Kayseraspis* Zone to the Arenig. The conodont assembalges (Seo et al., 1994) also indicate that the Dumugol Formation ranges from the late Tremadoc to Arenig in age, but placed the Tremadoc-Arenig boundary to the stratigraphically lower horizon than suggested by Kim et al. (1991).

Yeongweol Sequence

The Joseon Supergroup in Yeongweol area was divided into five formations ; namely, Sambangsan, Machari, Wagog, Mungog, and Yeongheung formations in ascending order (Yosimura, 1940). Although somewhat different views on the stratigraphy and geologic age of the Yeongweol-type Joseon Supergroup were suggested (GICTR, 1962;Son et al., 1969;Kim et al., 1973), recent investigations of Yeongweol area generally follow the lithostratigraphic scheme proposed by Yosimura (Lee, 1975, 1980;Kim et al., 1985;Lee et al., 1986;Lee et al., 1991;Park et al., 1994).

The Middle to Late Cambrian Machari Formation, the most fossiliferous formation in the Cambro-Ordovician sequences in Korea, attains a thickness of up to 400m. The lower part comprises dark gray dolomitic limestone, shale, and lime breccia and yields abundant and diverse Middle Cambrian trilobites (Kobayashi, 1935, 1962). The middle part consists dominantly of dark gray to black laminated calcareous shale with occasional intercalations of thin dolomitic limestone beds. Trilobite fossils are particularly abundant in this interval. The upper part of the formation is characterized by alternations of thin-bedded gray dolomitic limestone and finely laminated black shale beds, showing a distinctive banded appearance, but has been known to be poorly fossiliferous. The overlying Wagog Formation is composed exclusively of light gray to gray massive dolostone. Kobayashi (1960, 1966), based on the occurrence of some trilobites and brachiopods, considered the age of the Wagog Formation as latest Cambrian.

The Mungog Formation is characterized by alternations of diverse lithotypes (Paik et al., 1991;Choi et al., 1993;Park et al., 1994) and measures up to 200 m in thickness. Park et al., (1994) recognized four informal members within the Mungog Formation, based on the association of dominant lithofacies such as ribbon rock, grainstone to packstone, flat-pebble conglomerate, and marlstone to shale facies. The basal member, ca. 45 m thick, consists mainly of ribbon rock and grainstone to packstone with intercalations of thin flat-pebble conglomerate beds. The lower member is recognized by the occurrence of a thick (30−35 m in thickness) sequence of massive dolostone. The middle member, 35−60 m thick, is characterized by alternations of ribbon rock and flat-pebble conglomerate lithofacies with occasional intercalations of grainstone to packstone beds. The upper member, 50−60 m thick, comprises ribbon rock, grainstone to packstone, flat-pebble conglomerate, and marlstone to shale facies. The Mungog Formation has been known to produce fairly diverse invertebrate faunas which indicate an Early Ordovician in age (Kobayashi, 1960;Park et al., 1994; Kim and Choi, 1995). The conodont fauna of the Mungog Formation also suggests an age of Tremadoc to early Arenig (Won and Lee, 1977;Choi, 1993).

TRILOBITE BIOSTRATIGRAPHY

Historical Review

Kobayashi (1933) developed the first biozonation for the Late Cambrian strata in Korea. In 1934, Kobayashi introduced three Ordovician zones for the Dumugol and Maggol formations ; namely, *Asaphellus*, *Protopliomerops*, and *Clarkella* zones in ascending order. In a monographic study for the Cambrian faunas of South Korea, Kobayshi (1935) proposed 13 biostratigraphic zones for the Cambrian strata of the Duwibong sequence.

In the Yeongweol sequence, the *Yosimuraspis* Zone was established at the basal part of the Mungog Formation, while the invertebrate faunal assemblage above the *Yosimuraspis* Zone was collectively correlated with the *Asaphellus*, *Protopliomerops*, and *Clarkella* zones of the Dumugol fauna (Kobayashi, 1960, 1966). The trilobite fauna of the Machari Formation was described comprehensively by Kobayashi (1962) who proposed five biozones for the Machari Formation. The contrasting faunal contents between the Duwibong and Yeongweol sequences resulted in two separate biostratigraphic frameworks for the Cambro-Ordovician sequences of South Korea (Kobayashi, 1966). Over twenty biozones or fossiliferous beds were recognized in the Duwibong sequence, whereas eleven zones were established in the Yeongweol sequence (Fig. 1).

Recently Kim et al. (1991) confirmed three trilobite zones in the Dumugol Formation and Park et al. (1994) recognized two trilobite assemblages from the Mungog Formation. Lee and Choi (1994) and Choi and Lee (1995) established two early Late Cambrian zones in the Machari Formation. Lee and Choi (1995) recognized three additional trilobite zones from the Machari Formation which occupy the interval above the *Glyptagnostus reticulatus* Zone ;

namely, *Proceratopyge tenue, Hancrania brevilimbata* and *Eugonocare longifrons* zones in ascending order.

Late Cambrian Biostratigraphy

The Late Cambrian trilobite biostratigraphy of the Duwibong and Yeongweol sequences will be discussed separately, as their faunal contents are quite distinct from each other. Unfortunately, we had no opportunity to study the Late Cambrian trilobites from the Sesong and Hwajeol formations of the Duwibong sequence. Thus the biotratigraphic information of the Duwibong sequence is summarized following the work of Kobayashi(1966). On the

Duwibong Sequence		
Formation	Macrofossil zone	Conodont zone
Duwibong	Actinoceroids	*Aurilobodus serratus* *Plectodina onychodonta*
Jigunsan	Orthoceroids	*Eoplacognathus suecicus - E. jigunsanensis*
Maggol	*Sigmorthoceras* *Polydesmia* *Manchuroceras* *Clarkella*	*Aurilobidus leptosomatus*
Dumugol	*Protopliomerops* *Asaphellus*	*Triangulodus dumugolensis* *Paracordylodus gracilis* *Glyptoconus quadraplicatus* *Chosonodina herfurthi - Rossodus manitouensis*
Dongjeom	*Pseudokainella*	
Hwajeol	*Eoorthis* *Dictyites* *Kaolishania* *Chuangia* *Prochuangia*	*Cordylodus proavus* *Cambrooistodus minutus* *Eoconodontus (E.) notchpeakensis* *Proconodontus*
Sesong	*Drepanura* *Stephanocare*	
Daegi	*Olenoides* *Solenoparia* *Megagraulos*	
Myobong	*Bailiella* *Mapania* *Elrathia* *Redlichia*	
Jangsan		

Yeongweol Sequence		
Formation	Macrofossil zone	Conodont zone
Yeongheung	Actinoceroids *Basiliella*	
Mungog	*Yosimuraspis*	*Triangulodus dumugolensis* unnamed *Glyptoconus quadraplicatus* *Chosonodina herfurthi - Rossodus manitouensis* *Cordylodus intermedius - Utahconus beimadaoensis*
Wagog	*Aphaeoorthis*	
Machari	*Hancrania* *Olenus* *Iwayaspis* *Eochuangia* *Tonkinella*	*Proconodontus muelleri - Cambrooistodus cambricus* *Gapparodus bisulcatus - Westergaardodina matsushitai - W. moessebergensis*
Sambangsan	*Metagraulos* *Yabeia*	

Fig. 1. Lithostratigraphic and biostratigraphic nomenclature of the Duwibong and Yeongweol-type sequences of the Joseon Supergroup in Korea (compiled from Kobayashi, 1966 ; Lee and Lee, 1986 ; Lee and Lee1988 ; Lee et al., 1991 ; Choi, 1993 ; Seo et al., 1994).

other hand, the Machari Formation of Yeongweol sequence produces abundant and diverse trilobites of Late Cambrian age. Some of the preliminary results will be described in the following.

Duwibong Sequence. The Late Cambrian trilobites were known from the Sesong and Hwajeol formations in the Duwibong sequence. Kobayashi (1935, 1960, 1966) established two zones (*Stephanocare* and *Drepanura* zones) from the Sesong Slate and five zones (*Prochuangia, Chuangia, Kaolishania, Dictyites,* and *Eoorthis* zones) from the Hwajeol Formation (Fig. 1).

The *Stephanocare* Zone stands for the lowest Upper Cambrian zone in the Duwibong sequence and comprises three species such as *Stephanocare richthofeni, Pseudagnostus douvillei,* and *Eodiscus* (?) sp. Similar faunal assemblage has been known from the *Blackwelderia* Zone of Noth China (Chang, 1988). The overlying *Drepanura* Zone produces a fairly diverse trilobite fauna including *Pseudagnostus douvillei, Stephanocare bergeroni,* S. (?) *quinquispina, Damesella paronai, D.* cf. *brevicaudata, Blackwelderia monkei, B. sinensis, B. paronai, Parablackwelderia spectabilis, Drepanura ketteleri, D. premesnili, Lorenzella quadrata,* and *Liostracina krausei.*

The *Prochuangia* Zone occupies the lowest zone of the Hwajeol Formation and contains *Pseudoliostracina monkei, Prochuangia mansuyi,* and *P. posterospina.* The suceeding *Chuangia* Zone yields *Homagnostus hoiformis, Pseudagnostus chinensis, Kabutocrania fossula, Prochuangia angusta, Chuangia nitida, C. taihakuensis, C.* aff. *batia, Lioparia vulgaris, L. coniculus,* and *Maladioides coreanicus.* Althlough Kobayashi (1966) placed the *Prochuangia* Zone below the *Chuangia* Zone, Shergold (1980) doubted that the latter may precede the former in reference to the faunal successions in Australia. The *Kaolishania* Zone comprises *Pseudagnostus cyclopygeformis, Kaolishania granulata, K. obsoleta, K.* (?) *latiura, K.* (?) *orientalis, K.* sp., *Kaolishaniella transita, Tingocephalus magnus, Lioparia obsoleta, Koptura typa, Calvinella* (?) sp., *Shirakiella elongata, S. laticonvexa,* and *Megamansuyia glabra.* The *Dictyites* Zone yields a very diverse triloite fauna including *Geragnostus obsoletus, G. cambria, Pagodia shumardoides, P. coreanica, Prolloydia orientalis, Kaolishania* (?) sp., *Mimana eurycephala, M* (?) sp., *Haniwa quadrata, H. oblongata, H. convexa, H. conica, Iddingsia orientalis, Plethometopus longispinus, Megamansuyia glabra, Mansuyia trigonalis, Kingstonia parallela, Tsinania canens, T. ceres, Dictyites dictys, D. trigonalis, D. depressa, D. longicauda, Coreanocephalus kogenensis, C.* (?) *cylindricus, Saukia* sp., *Saukiella* sp., *Prosaukia* (?) sp., *Calvinella walcotti, C.* sp., *Tellerina coreanica, Platysaukia euryrachis, Asioptychaspis subglobosa, Changia chosensis, Quadraticephalus teres, Q. coreanicus, Q. quadratus, Q. elongatus, Mareda mukazegata,* and *Lichengia eurychephala.* The uppermost *Eoorthis* Zone comprises mostly fossils of Cambrian affinity, such as *Pseudagnostus cyclopygeformis, Chuangiella elongata, Haniwa* (?) sp., "*Pseudokainella*" *maladiformis, Coreanocephalus* (?) *tenuisulcata, Tellerina coreanica,* and *T.* (?) *obsoleta.*

Yeongweol Sequence. Late Cambrian trilobites of the Yeongweol sequence are known from the Machari Formation. Kobayashi (1962) proposed biostratigraphic zones for the Machari Formation : i.e., *Olenoides* (including *Tonkinella* and *Eochuangia* faunas), *Komaspis-Iwayaspis,* and *Olenus-Glyptagnostus* zones in ascending order, and the *Hancrania* shale was considered to be correlative of *olenus-Glyptagnostus* Zone. The inappropriateness of this biostratigraphic zonation has been discussed elsewhere (Choi, 1992;Lee and Choi, 1994;Choi and Lee, 1995). The Late Cambrian trilobite stratigraphy of the Machari Formation has recently been modified by Lee (1995), which is summarized in the following.

The oldest Late Cambrian biozone of the Machari Formation was recognized by the occurrence of *Olenus asiaticus* and *Glyptagnostus reticulatus* (Kobayashi, 1944, 1962). Apart from the occurrence of *Olenus asiaticus* and *Glyptagnostus reticulatus*, five more species were found associated with them : they are *Glyptagnostus stolidotus, Pseudagnostus leei, Aspidagnostus stictus, Innitagnostus innitens*, and *Peratagnostus obsoletus* (Lee and Choi, 1994). Based on the stratigraphic occurrences of these trilobites, two trilobite zones, i, e., *Glyptagnostus stolidotus* and *Glyptagnostus reticulatus* zones, are proposed. The *Glyptagnostus reticulatus* Zone is equivalent to the previous *Olenus-Glyptagnostus* Zone, while *Glyptagnostus stolidotus* Zone occupies the interval just below the *Glyptagnostus reticulatus* Zone (Choi and Lee, 1995).

The overlying *Proceratpyge tenue* Zone represents rather sparsely fossiliferous interval of the Machari Formation. Trilobites include *Proceratopyge tenue, Erixanium* sp., *Pseudagnostus idalis*, and *Peratagnostus obsoletus*. The *Hancrania brevilimbata* Zone is dominated by the nominal species and also contains *Proceratopyge elongata, Stigmatoa coreanica, Innitagnostus inexpectans, Peratagnostus obsoletus, Phalagnostus minor* and *Pseudagnostus idalis*. The *Hancrania brevilimbata* Zone can be equated with the *Hancrania* shale (s.s. Kobayashi, 1962). The succeeding *Eugonocare longifrons* Zone comprises *Eugonocare longifrons, Proceratopyge praelonga, Irvingella prisca, Erixanium similis, Kormagnostella* sp., *Peratagnostus obsoletus, Pseudagnostus idalis*, and *Innitagnostus* sp. The *Proceratpyge tenue, Hancrania brevilimbata* and *Eugonocare longifrons* zones are collectively comparable to the lower to middle Changshanian of China, middle to upper Idamean of Australia, and middle to upper Dresbachian of North America (Lee and Choi, 1995).

Above the *Eugonocare longifrons* Zone, three biozones are recognized : i.e., *Oncagnostus machariensis, Irvingella antigena*, and *Pseudoyuepingia asaphoides* Zones in ascending order. The *Oncagnostus machariensis* zone is easily identified by the occurrence of some diagnostic taxa such as *Irvingella, Jegorovaia, Haniwoides, Eochuangia, Oncagnostus, Ivshinagnostus* among others. This zone should include the previous *Eochuangia* Zone (Kobayashi, 1966), as *Eochuangia* is found exclusively in this interval. The *Irvingella antigena* Zone is extremely diverse and comprises *Haniwoides, Eugonocare, Irvingella, Proceratopyge, Chuangia, Agnostotes, Innitagnostus, Kormagnostella, Neoagnostus, Oncagnostus, Pseudagnostus*, and *Ivshinagnostus*. Of these, the occurrence of *Agnostotes* is significant, as this genus has a restricted geographic distribution and narrow stratigraphic range. The succeeding *Pseudoyuepingia asaphoides* Zone is distinct form the lower zones in having relatively long-ranging trilobite taxa. The genus *Pseudoyuepingia* has a priority over *Iwayaspis*, and thus this zone should comprise the previous *Komaspis-Iwayaspis* Zone. The *Pseudoyuepingia asaphoides* Zone is the youngest zone recognized in the Machari Formation and can be correlated with the middle Changshanian of China, lower Iverian of Australia, and middle Franconian of North America.

The upper part of the Machari Formation is poorly fossiliferous and an attempt to find fossils from the Wagog Formation was also unsuccessful. Therefore no paleontological information for the uppermost Cambrian sequences in Yeongweol area is available for the moment.

Early Ordovician Biostratigraphy

Duwibong Sequence. As stated in the preceding, it cannot be ruled out that the Cambrian-Ordovician boundary may be placed within the *Eoorthis* Zone of the Hwajeol Formation. Undoubtedly more paleontological data should be gathered for defining the Cambrian-Ordovician boundary within the interval. The *Pseudokainella* Zone of the Dongjeom Formation was established based on the sole occurrence of *Pseudokainella iwayai* (Kobayashi, 1953). However, the holotype, the only known specimen of the species, is poorly preserved and its assignment to *Pseudokainella* seems doubtful. Therefore, the currently available data show that the earliest Ordovician trilobites are poorly represented in the Duwibong sequence.

The Lower Ordovician trilobite faunas of the Duwibong sequence have been known to be relatively diverse (Kobayashi, 1934) and were differentiated into three biozones : i. e., *Asaphellus, Protopliomerops,* and *Clarkella* Zones in ascending order. The *Asaphellus* and *Protopliomerops* zones of the Dumugol Formation were assigned to the Tremadoc, while the *Clarkella* Zone of the Maggol Formation to the Arenig (Kobayashi, 1966). Recently Kim et al. (1991), however, recognized three biozones within the Dumugol Formation, namely *Asaphellus, Protopliomerops,* and *Kayseraspis* zones in ascending order, which modifies slightly the biozonation proposed by Kobayashi (1966);i. e., the *Kayseraspis* Zone replacing the previous *Clarkella* Zone has been extended down to the upper part of the Dumugol Formtion. Kobayashi (1934) reported a fairly diverse trilobite fauna comprising 13 species from the *Asaphellus* Zone, while Kim et al. (1991) listed only three species. This zone is roughly comparable to *Chosonodina herfurthi-Rossodus manitouensis* and *Glyptoconus quadraplicatus* conodont zones (Seo et al., 1994) and was considered to be late Tremadoc in age (Fig. 1). The *Protopliomerops* Zone has also been known to contain fairly rich trilobite fauna (Kobayashi, 1934). Kim et al. (1991) identified *Apatokephalus* (?) sp. from the *Protopliomerops* Zone and considered its age as late Tremadoc. This interval may correspond to the *Paracordylodus gracilis* conodont zone (Seo et al., 1994). which was however assigned to the early Arenig. The *Kayseraspis* Zone was originally recognized from the Maggol Formation and comprises a distinct trilobite assemblage (Kobayashi, 1934). It is of note that *Asaphopsis nakamurai* is associated with *Kayseraspsis nakamurai as a member of Asaphellus* Zone. The known geologic age of *Asaphopsis* elsewhere and the co-occurrence of *Asaphopsis* and *Kayseraspis* in the Dumugol Formation strongly suggests that *Asaphopsis nakamurai* must have been included in the *Clarkella* Zone. The *Triangulodus dumugolensis* conodont Zone approximately corresponds to this zone, which was assigned to the Arenig (Seo et al., 1994).

Yeongweol Sequence. Trilobite occurrences in the Mungog Formation are confined to the three widely separated intervals, which are herein refered to the lower, middle and upper faunas, respectively. The lower and upper faunas were procured from the lowermost part of the basal member and the lower half of the upper member, which were formerly designated as assemblages A and B, respectively (Park et al., 1994). The middle fauna was recently documented from the middle member (Kim and Choi, 1995).

The lower fauna, equivalent to the *Yosimuraspis* Zone of Kobayashi (1960) and Assemblage A of Park et al. (1994), is characterized by the dominance of kainellid trilobites. The fauna consists dominantly of *Yosimuraspis* and subordinately of Jujuyaspis and *Pseudokainella.* Brachiopods occur commonly at some horizons and include *Lingulella, Eoorthis,* and *Aphaeorthis.* The occurrence of the lower fauna is confined to the lowermost several-meter-thick interval above the boundary between the Wagog and Mungog formations, where planar-to nodular-bedded ribbon rock facies is dominant. Although Kobayashi (1960, 1966) reported *Asaphellus tomkolensis* from the *Yosimuraspis* Zone, no specimens of Asaphellus are so far found in the lower fauna. Instead, it is noteworthy that *Jujuyaspis* and *Pseudokainella* are associated with *Yosimuraspis,* as these genera are representative trilobites of early Tremadoc age. This fauna may be comparable to either part of the *Eoorthis* Zone of the Hwajeol Formation or *Pseudokainella* Zone of the Dongjeom Formation of the Duwibong-type Joseon Supergroup, as the latter two zones have been known to yield *Pseudokainella* (Kobayashi, 1966). Similar faunal assemblages to the lower fauna are however better represented in North China. The genus *Yosimuraspis* has been employed as a zonal taxon for the lower Tremadoc sequences of North China (Zhou and Zhang, 1984;Chen et al., 1985;Chen et al., 1988). The association of *Jujuyaspis* and *Pseudokainella* with *Yosimuraspis* has also been documented in Hebei Province, North China (Chen et al., 1983;Zhou and Zhang, 1984;Duan et al., 1986; Chen et al., 1988). Thus, the lower fauna of the Mungog Formation is well correlated with the *Yosimuraspis* Assemblage Zone of North China.

The genus *Jujuyaspis* has been known to be one of the most diagnostic trilobites in recognizing the Cambrian-Ordovician boundary, as having a short time range and a wide geographic distribution (Stitt and Miller, 1987;Acenolaza and Acenolaza, 1992). In Scandinavia, *Jujuyaspis keideli norvegica* occurs within the *Boeckaspis* Zone at a slightly higher horizon than *Dictyonema flabelliforme* and the putative Cambrian-Ordovician boundary has been drawn at the base of the *Boeckaspis* Zone, about three meters below the *Jujuyaspis*-bearing horizon (Bruton et al., 1982, 1988). The conodont species associated with *Jujuyaspis* Norway (Bruton et al., 1988) are *Cordylodus proavus, C. lindstromi, Eoconodontus notchpeakensis, Phakelodus tenuis,* and *Iapetognathus preaengensis.* In South America, the occurrence of *Jujuyaspis keideli* associated with *Dictyonema flabelliforme* has been reported in the '*Parabolina argentina*' Zone (Harrington and Leanza, 1957;Acenolaza nad Acenolaza, 1992). *Jujuyaspis sinensis* was reported from the middle upper part of the *Yosimuraspis* Assemblage Zone in North China (Zhou et al., 1984;Zhou and Zhang, 1984). The associated conodont species include *Cordylodus intermedius, C. prion, C. proavus, "Acodus" oneotensis, Utachconus utahensis, Prooneotodus gallatini* and *Teridontus nakamurai.* The *Dictyonema flabelliforme-Staurograptus dichotomus* Zone has been correlated with the upper part of *Yosimuraspis* Zone and the lower part of *Wangliangtingia* Zone. In the western United States, the genus *Jujuyaspis* has been known to occur in the basal Ordovician (Winston and Nicholls, 1967;Norford, 1969;Dean, 1989;Stitt and Miller, 1987;Loch et al., 1993).

The middle fauna is represented by the sole occurrence of *Kainella* sp. cf. *K. euryrachis,* Kobayashi, 1953 from the basal part of the middle member (Kim and Choi, 1995). The genus *Kainella* has been reported from North America, South America, and Asia. In Korea, *Kainella euryrachis* has previously been known to occur in an argillaceous limestone bed, Sangdong area (Kobayashi, 1953). The precise stratigraphic position of *Kainella euryrachis* is however uncertain, albeit Kobayashi (1966) listed the species as a member of the *Asaphellus* Zone of the Dumugol Formation. In North America, *Kainella* has been exclusively reported from Zone D and E which are approximately correlated with the middle Tremadoc (Ross, 1982). Three species of *Kainella* have been documented from the lower Tremadoc of South America (Kobayashi, 1935;Harrington and Kay, 1951;Harrington and Leanza, 1957). The interval producing *Kainella* sp. cf. *K. euryrachis* can be correlated with Zone D of North America and *Kainella meridionalis* Zone of Argentina. This conclusion is consistent with the occurrence of an early Tremadoc trilobite *Jujuyaspis* in the lower fauna of the Mungog Formation (Park et al., 1994), Zone A of North America (Dean, 1989) and *Parabolina argentina* Zone of Argentina (Harrington and Leanza, 1957).

The upper fauna, equivalent to the Assemblage B of Park et al. (1994), includes *Micragnostus coreanicus* Kobayashi, 1934, *Shumardia pellizzarii* Kobayashi, 1934, *Apatokephalus hyotan* Kobayashi, 1953, *Hystricurus megalops* Kobayashi, 1934, *Dikelokephalina asiatica* Kobayashi, 1934, *Asaphellus* sp., and *Koraipsis spinus* Kobayashi, 1934. Apart from trilobites, observed are inarticulate brachiopods, ostracods, crinoids, *Sphenothallus, Plumulites,* and *Anatifopsis.* The upper fauna of the Mungog Formation as a whole shows a close resemblance to the Dumugol fauna (Kobayashi, 1934;Kim et al., 1991). However, it should be noted that the biostratigraphic zones of the Dumugol Formation are not directly applicable to the upper fauna:in other words, the upper fauna collectively comprises elements of the *Asaphellus* Zone, *Protopliomerops* Zone and *Kayseraspis* Zone. Comparable faunas to the upper fauna are also found in the upper Tremadoc sequences of North China, South China and Australia. In North China, Chen et al. (1983) and Zhou and Fortey (1986) reported the occurrence of *Asaphellus, Hystricurus, Koraipsis,* and *Dikelokephalina* along with other endemic genera from the late Tremadoc *Asaphellus trinodus* Zone (or horizon 1 in Zhou and Fortey, 1986) of the Yehli Formation. The co-occurence of the trilobite genera mentioned above suggests that the upper fauna is correlative with the *Asaphellus trinodus* Zone of the Yehli Formation. The fairly abundant and diverse late Tremadoc trilobite faunas were also recorded from the South China (Peng, 1990b). Although their faunal contents are quite different from the upper fauna, the occurrence of some cosmopolitan genera such as *Asaphellus, Shumardia,* and *Apatokephalus* makes it possible to correlate the upper fauna with part of the *Apatokephalus latilimbatus-Taoyuania affinis* and *Shumardia acutifrons-Asaphopsoides* assemblage zones of the Jiangnan Slope Belt.

CONODONT BIOSTRATIGRAPHY

Historical Review

Müller (1964) was the first to report the occurrence of conodont fossils from Korea. Since then, the conodont was the most intensively studied fossil group in the Cambro-Ordovician Joseon Supergroup of Korea.

Lee (1970, 1975) described a fairly diverse conodont fauna from the Dumugol Formation and concluded that the conodont assemblage indicates an Arenig age. Lee and Lee (1971) made a reconnaissance study for conodont assemblages of the Duwibong sequence, which provided a basis for subsequent conodont stuies. However, it was in recent years that the Late Cambrian and Early Ordovician conodont faunas of Korea have been intensively investigated. Subsequently it has been claimed that the uppermost part of the Hwajeol Formation contains the earliest Ordovician conodonts (Lee and Lee, 1988;Lee, 1989a, 1989b, 1990;Lee and Lee 1993). Seo et al. (1994) recognized four conodont biozones in the Dumugol Formation, ranging from late Tremadoc to early Arenig age. Lee and Lee (1986) established a conodont zone, *Eoplacognathus suecicus-E. jigunsanensis* Zone, in the upper part of the Jigunsan Formation and two conodont zones, the *Plectodina onychodonta* and *Aurilobodus serratus* Zones, in the Duwibong Formation. Lee and Lee (1990) supplemented the previous works to recognize the *Aurilobodus leptosomatus* Zone in the Maggol Formation.

Won and Lee (1977) reported the first conodont faunal assemblage from the Mungog Formation of the Yeongweol sequence. Lee (1989) described conodont assemblages from the Yeongheung Formation, which were interpreted ranging from Arenig to Caradoc. Lee et al. (1991) found some Late Cambrian conodont assemblages from the Machari Formation. Choi (1993) reported a fairly diverse conodont fauna from the Mungog Formation, indicating of an age of Tremadoc to Arenig.

Duwibong Sequence

The conodont zones for the Late Cambrian Hwajeol Formation were first proposed by Lee and Lee (1988) and include *Proconodontus, Eoconodontus (E) notchpeakensis, Cambrooistodus minutus,* and *Cordylodus proavus* zones in ascending order. These zones were correlated with *Distacodus ? palmeri-Prooneotodus rotundatus, Proconodontus-Rotundoconus,* and *Cordylodus proavus* zones of North China and with *Proconodontus* and lowermost *Cordylodus proavus* zones of the western United States. They suggested a possiblity that the Cambrian-Ordovician boundary may lie within the uppermost part of the Hwajeol Formation. Similar biozones were subsequently confirmed and/or modified by Lee (1989a, 1989b, 1990, 1992). Lee (1992) added a new conodont zone, *Fryxellodontus inornatus-Monocostodus sivierensis-Semicacontiodus lavadamensis* Zone, above the *Cordylodus proavus* Zone, and suggested the Cambrian-Ordovician bounary at the base of the *Fryxellodontus inornatus-Monocostodus sivierensis-Semiacontiodus lavadamensis* Zone. Recently Lee and Lee (1993) presented a considerably revised conodont biostratigraphy of the Hwajeol Formation and also stated that the Cambrian-Ordovician boundary lies within the uppermost part of the Hwajeol Formation : the *Proconodontus, Eoconodontus notchpeakensis,* and *Cambroositodus minitus* zones put collectively together into the *Proconodontus* Zone ; the *Cordylodus proavus* Zone maintains to represent the uppermost Cambrian ; and the *Semiacontiodus nogamii* Zone occupies the basal Tremadoc. This implies that the Cambrian-Ordovician boundary can be drawn between the *Cordylodus proavus* Zone and *Semiacontiodus nogamii* Zone in the Duwibong sequence. The overlying Dongjeom Formation is composed of light-to dark-gray sandstone and has been so far known to yield no conodont fossils.

The succeeding Dumugol Formation comprises a diverse conodont fauna. Seo et al. (1994) recognized four biostratigraphic zones in the Dumugol Formation:i.e., *Chosonodina herfurthi-Rossodus manitouensis, Glyptoconus quadraplicatus, Paracordylodus gracilis,* and *Triangulodus dumugolensis* Zones in ascending order. These biozones are correlated with the *Cordylodus rotundatus-Acodus oneotensis, Scolopodus quadriplicatus-S. opimus,* and *Scalpelloldus tersus* Zones of North China, with the *Cordylodus angulatus, Drepanoistodus deltifer, Parositodus proteus, Prioniodus elegans,* and *Oepikodus evae* Zones of the North Atlantic Province, with the Fauna C through *Oepikodus communis* Zone of North America, and with *Chosonodina herfurthi-Acodus* and *Drepanodus(?) gracilis-Scolopodus sexplicatus* Zones of Australia. Seo et al. (1994) referred the lower two zones to the Tremadoc and the upper two to early Arenig in age.

Yeongweol Sequence

Lee et al. (1991) established two conodont assemblages in the Machari Formation. The lower *Gapparodus bisulcatus-Westergaardodina matsusitai-W. moessebergensis* Assemblage has been compared with early Late Cambrian faunas of the Duwibong sequence, China, and northern Europe. The upper *Proconodontus muelleri-Cambrooistodus cambricus* Assemblage is correlated with the middle Late Cambrian *Proconodontus* Zone of the Hwajeol Formation, North China, and North America. No conodont fossils have been reported to occur in the Wagog Formation.

Choi (1993) recognized five conodont zones from the Mungog Formation:i.e. *Cordylodus intermedius-Utahconus beimadaoensis, Chosonodina herfurthi-Rossodus manitouensis, Glyptoconus quadraplicatus,* unnamed, and *Triangulodus dumugolensis* zones in asecending order (Fig. 2). The biozones above the *Cordylodus intermedius-Utahconus beimadanoensis* Zone basically follow those of the Dumugol Formation (Seo et al., 1994), which implies that conodont faunal assemblages of the Yeongweol and Duwibong sequences are closely comparable to each other.

The *Cordylodus intermedius-Utahconus beimadaoensis* zone occupies the lower part of the

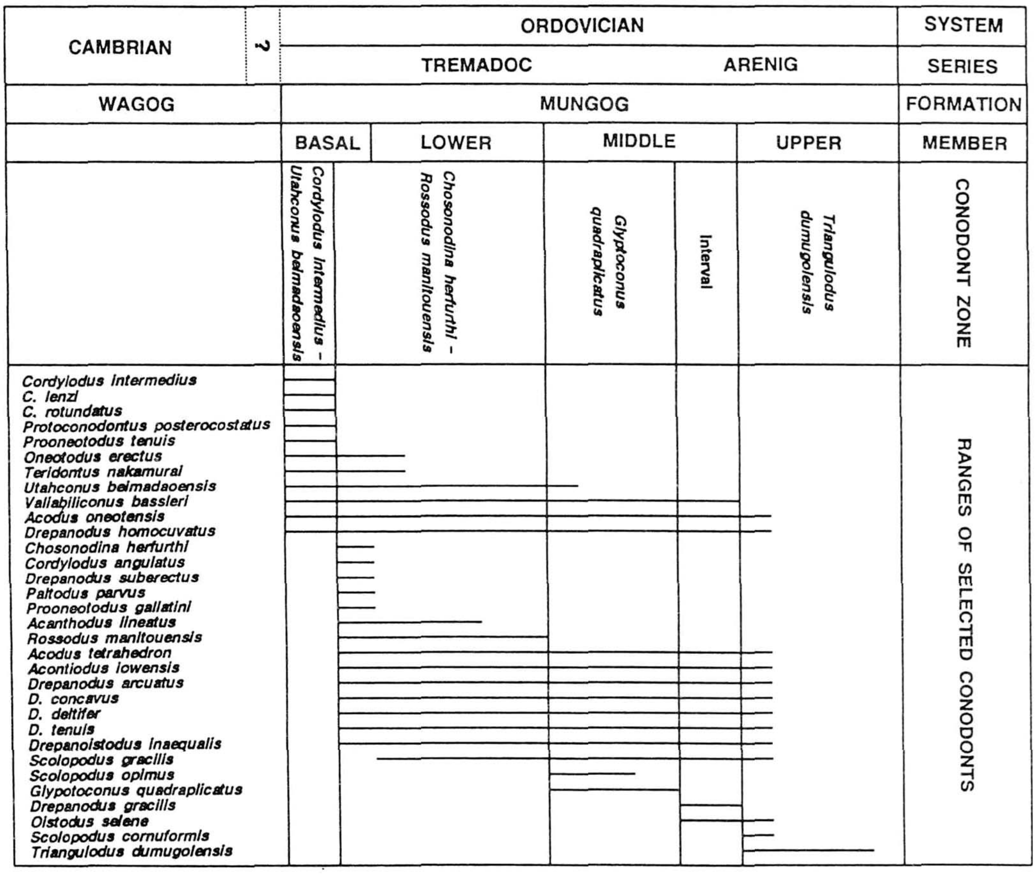

Fig. 2. Stratigraphic ranges of selected conodont species from the Mungog Formation (compiled from Choi, 1993).

basal member and the top of the zone is defined at the base of *Chosonodina herfurthi-Rossodus manitouensis* Zone. Among the taxa found in this interval are *Cordylodus intermedius, C. lenzi, C. rotundatus, Acodus oneotensis, Drepanodus homocuvatus, Oneotodus erectus. Protoconodontus posterocostatus, Prooneotodus tenuis, Teridontus nakamurai, Utahconus beimadaoensis, Valiabiliconus bassleri,* and *Scolopodus* sp. (Choi, 1993, fig. 5). Of these, *Cordylodus intermedius, C. lenzi, C. rotundatus, Protoconodontus posterocostatus,* and *Prooneotodus tenuis* are confined to this zone. It is noteworthy that *Cordyeodus intermedius* and *C. rotundatus* occur in the *Cordylodus intermedius-Utahconus beimadaoensis* Zone, as these species have been employed as key taxa to recognize the Cambrian-Ordovician boundary interval in North America (Miller, 1988).

The *Chosonodina herfurthi-Rossodus manitouensis* zone collectively covers the upper part of the basal member and presumably the lower member. The base of the zone is at the lowest occurrence of *Chosonodina herfurthi* and *Rossodus manitouensis,* while its top is at the base of the overlying *Glyptoconus quadraplicatus* Zone. Conodont species include *Chosonodina herfurthi, Rossodus manitouensis, Acanthodus lineatus, Cordylodus angulatus, Acodus tetrahedron, Acontiodus iowensis, Drepandodus arcuatus, D. concavus, D. deltifer, D. parallelus, D. tenuis, D. toomeyi, Drepanoistodus inaequalis, Paltodus parvus, Prooneotodus gallatini,* and *Furnishina* (?) sp. Of these, *Chosonodina herfurthi, Rossodus manitouensis, Acanthodus lineatus, Cordylodus angulatus, Drepanodus tenuis, Paltodus parvus, Prooneotodus gallatini,* and *Furnishina* (?) sp. occur exclusively in this zone.

The *Glyptoconus quadraplicatus* zone is a range zone of the nominal species and roughly occupies the middle member. This zone comprises many conodont species which range from the *Cordylodus intermedius-Utahconus benimadaoensis* Zone to the *Triangulodus dumugolensis* Zone. The conodont taxa restricted within the zone are *Glyptoconus quadraplictus, Distacodus stola, Protopanderodus* sp., *Scolpopodus warendensis, Utahphospha* sp. and *Acontiodus shuiyuensis.*

The unnamed zone is stratigraphically rather narrow and occupies the interval between the last occurrence of *Glpytoconus quadraplicatus* and the first occurrence of *Triangulodus dumugolensis.* It may be comparable to the *Paracordylodus gracilis* Zone of the Dumugol Formation, as the two faunas share such conodont species as *Acodus dumugolensis* and *Scolopodus triplicatus. Drepanodus gracilis* and *Oistodus selene* appear to be restricted within the zone.

The *Triangulodus dumugolensis* zone represents the youngest conodont zone of the Mungog Formation and is recognized within the upper member. Most of the species in the zone have a relatively long range, whereas *Triangulodus dumugolensis* and *Scolopodus cornuformis* are restricted within the zone.

Choi (1993) considered that the lower three zones, i. e., *Cordylodus intermedius-Utachconus beimadaoensis, Chosonodina herfurthi-Rossodus manitouensis,* and *Glyptoconus quadraplicatus* zone, are assignable to the Tremadoc, while the upper two zones to the Arenig. Although Choi (1993) did not mention the Cambrian-Ordovician boundary in the Yeongweol sequence, the biostratigraphic scheme presented above suggests that the Cambrian-Ordovician boundary should be placed within the Wagog Formation.

INTERCONTINENTAL CORRELATION

Precise correlation of the Cambrian-Ordovician boundary sequences of Korea with those of other parts of the world may not be easy due to the sporadic fossil occurrences in the putative Cambrian-Ordovician boundary intervals in Korea. Nevertheless, trilobites and conodonts from the basal member of the Mungog Formation apparently represent one of the earliest Ordovician faunal assemblages in Korea, which provides a good starting point for discussion on the Cambrian-Ordovcian boundary intervals of Korea. Even though trilobite data from the Hwajeol Formation of the Duwibong sequence has not been substantiated during this study, recent investigations on the conodont assemblages from the Hwajeol Formation (Lee and Lee, 1988;Lee, 1989a, 1989b, 1990;Lee and Lee, 1993) and Dumugol Formation (Seo et al., 1994) assist the discussion on the faunal features across the Cambrian-Ordovician boundary intervals in Korea.

North China

Trilobite assemblages of the Mungog Formation are closely comparable to those from No-

AGE		1 YEONGWEOL	2 DUWIBONG	3 NORTH CHINA	4 SOUTH CHINA	5 AUSTRALIA	6 NORTH AMERICA
ORDOVICIAN	ARENIG		*Kayseraspis*			Assemblage 3	*Protopliomerops contracta* (G2)
ORDOVICIAN	TREMADOC	upper fauna	*Protopliomerops*	*Asaphellus trinodosus*	*S. acutifrons - Asaphopsoides*	Assemblage 2	*Protopliomerops celsaora* (G1)
ORDOVICIAN	TREMADOC		*Asaphellus*	*Euleiostegium - Aristokainella*	*A. latilimbatus - T. affinis*		*Protopliomerops superciliosa* (F) *Tesselacauda* (E)
ORDOVICIAN	TREMADOC	middle fauna		*Wanliangtingia*			*Leiostegium - Kainella* (D)
ORDOVICIAN	TREMADOC		*Pseudokainella*				*Paraplethopeltis* (C)
ORDOVICIAN	TREMADOC	lower fauna		*Yosimuraspis*	*Onychopyge - Hysterolenus*		*Bellefontia -Xenostegium* *Symphysurina woosteri* *Symphysurina bulbosa* *Symphysurina brevispicata*
ORDOVICIAN	TREMADOC			*Missisquoia perpetis*			*Missisquoia typicalis* *Missisquoia depressa*
CAMBRIAN	LATE CAMBRIAN		*Eoorthis* *Dictyites* *Kaolishania*	*Mictosaukia orientalis* *Changia* *Tsinania - Ptychaspis* *Kaolishania*	*Lotagnostus hedini* *Acaroceras - Antacaroceras* *Lotagnostus punctatus*	*Mictosaukia perplexa* *N. quasibilobus - T. nomas* *Sinosaukia impages* *R. clarki maximus - R. papilio* *R. bifax - N.(N.) denticulatus* *R. clarki prolatus - C. sectatrix* *R. clarki patulus - C. squamosa* *Hapsidocara lilyensis* *P. tertia - P. quarta* *P. secunda - P. glabella*	*Eurekia apopsis* *Saukiella serotina* *Saukiella junia* *Saukiella pyrene* *Drumaspis* *Idahoia*
CAMBRIAN	LATE CAMBRIAN	*Pseudoyuepingia asaphoides*	*Chuangia*	*Maladioella*		*W. iota - R. apsis*	*Teanicephalus*

Fig. 3. Correlation of the Late Cambrian-Early Ordovician trilobite biostratigraphy of Korea with coeval ones of North China, South China, Australia, and North America : 1. Park et al. (1994), Lee (1995), Kim and Choi (1995) ; 2. Kobayashi (1966), Kim et al. (1991) ; 3. Zhou and Zhang (1984), Chang (1988), Chen et al. (1988) ; 4. Lu and Lin (1989), Peng (1990a, b), Peng (1992) ; 5. Shergold (1975, 1980, 1991) ; 6. Palmer (1965), Stitt (1971, 1977, 1983), Ross et al. (1982), Dean (1989), Loch et al. (1993).

rth China (Fig. 3, colunm 3). The genus *Yosimuraspis* appears to be very abundant and has been employed as a zonal taxon for the lower Tremadoc sequences of North China (Zhou and Zhang, 1984;Chen et al., 1985;Chen et al., 1988). The association of *Jujuyaspis* and *Pseudokainella* with *Yosimuraspis* has also been documented in Hebei Province, North China (Chen et al., 1983;Zhou and Zhang, 1984;Chen et al., 1988). Thus, the lower fauna of the Mungog Formation is well correlated with the *Yosimuraspis* Assemblage Zone of North China.

Kainella chinensis Duan and An in Duan et al., 1986, has been reported from the *Wanliangtingia* Assemblage Zone of North China and its stratigraphic occurrence appears to fall within the range of the Tremadoc. However, the Chinese species does not appear to be typical *Kainella* as its preocular sutures are less divergent and its glabella is distinct from that of the genotype, *Kainella billingsi* (Wallcott, 1913). Therfore comparable faunal assemblages to the middle fauna of the Mungog Formation cannot be recognized in North China with certainty.

Chen et al. (1983) and Zhou and Fortey (1986) reported the occurrence of *Asaphellus, Hystricurus, Koraipsis,* and *Dikelokephalina* along with other endemic genera from the late Tremadoc *Asaphellus trinodus* Zone (or horizon 1 in Zhou and Fortey, 1986) of the Yehli Formation. The cooccurence of the trilobite genera mentioned above suggests that part of the Dumugol fauna (*Asaphellus* and *Protopliomerops* zones) and the upper fauna of the Mungog Formation are correlative of the *Asaphellus trinodus* Zone of the Yehli Formation. In summary, overall similarity of the Tremadoc trilobite faunas of Korea to those of North China is evident. Nonetheless, the supposedly lowest Tremadoc zone recognized in North China (i. e., *Missisquoia perpetis* Assemblage Zone of Zhou and Zhang, 1984;*Leiostegium* Assembalge Zone of Chen et al., 1988) has not yet been found in Korea.

The conodont zones established at the Dayangcha section of North China are *Proconodontus tenuiserratus, Proconodontus* (with *P. posterocostantus* and *P. muelleri* subzones), *Cambrooistodus, Cordylodus proavus* (divided into three parts), *C. intermedius, C. lindstomi* and *C. angulatus-Chosonodina herfurthi* zones in ascending order (Chen et al., 1985;Chen et al., 1988) which are partly comparable to those of Korea (Fig 4, column 3).

The *Proconodontus* Zone, the oldest conodont zone in the Duwbong sequence(Lee and Lee, 1988), and *Eoconodontus* (*E.*) *notchpeakensis* of the Hwajeol Formation may be collectively comparable to *Proconodontus tenuiserratus* and *Proconodontus* zones of North China, as they share many conodont species in common with each other. The overlying *Cambrooistiodus minutus* Zone is also recognized in the Dayangcha section of North China as *Cambrooistodus* Zone. The succeeding *Cordylodus proavus* Zone of the Hwajeol Formation comprises a rather small conodont fauna, but can be broadly compared with the *Cordylodus proavus* Zone of North China. Lee (1992) added a new conodont zone, *Fryxellodontus inornatus-Monocostodus sivierensis-Semiacontiodus lavadamensis* Zone, in the uppermost part of the Hwajeol Formation and suggests that the Cambrian-Ordovician boundary can be drawn at the base of *Fryxellodontus inornatus-Monocostodus sivierensis-Semiacontiodus lavadamensis* Zone. All of these name-bearing species have been documented in the *Cordylodus intermedius* and *C. lindstromi* zoens of the Dayangcha section. Chen et al. (1988) favord to place the Cambrian-Orodvician boundary within the *Cordylodus intermedius* Zone, more specifically at the level of first appearance of *Hirsutodontus simplex, Cordylodus drucei,* and *Albiconus postcostatus,* thus equating with Lee's

(1992) suggestion.

The *Cordylodus lindstromi* Zone in the Dayangcha section appears to be comparable to *Utahconus beimadaoensis-Monocostodus sevierensis* Zone established in the northeastern China (An et al., 1983). The trilobite *Yosimuraspis* occurs exclusively in the *Cordylodus lindstromi* Zone in North China (Chen et al., 1988), and thus the *Cordylodus lindstromi* and *Yosimuraspis* zones of North China are well traced at the basal part of the Mungog Formation in Korea as *Cordylodus intermedius-Utahconus beimadaoensis* Zone and lower fauna, respectively. The *Cordylodus angulatus-Chosonodina herfurthi* Zone underlain by the *Cordylodus lindstromi* Zone (Chen et al., 1988) is also comparable to *Cordylodus rotundatus-"Acodus" oneotensis* (=*Rossodus manitouensis*) Zone (An et al., 1983), and in turn to the *Chosonodina herfurthi-Rossodus*

AGE		1 YEONGWEOL	2 DUWIBONG	3 NORTH CHINA	4 SOUTH CHINA	5 AUSTRALIA	6 NORTH AMERICA
ORDOVICIAN	TREMADOC	*Chosonodina herfurthi - Rossodus manitouensis*	*Chosonodina herfurthi - Rossodus manitouensis*	*Cordylodus angulatus - Chosonodina herfurthi*	*Acanthodus costatus - Acodus oneotensis*	*Chosonodina herfurthi - Cordylodus angulatus*	*Loxodus bransoni* / *Cordylodus angulatus*
ORDOVICIAN	TREMADOC	*Cordylodus intermedius - Utahconus beimadaoensis*	*F. inornatus - M. sivierensis - S. lavadamensis*	*C. lindstromi*	*Monocostodus sivierensis*	*Cordylodus lindstromi*	*Cordylodus lindstromi*
CAMBRIAN	LATE CAMBRIAN			*C. intermedius*		*Cordylodus prolindstromi*	*Clavohamulus hintzei*
CAMBRIAN	LATE CAMBRIAN					*Hirsutodontus simplex*	*Hirsutodontus simplex*
CAMBRIAN	LATE CAMBRIAN		*Cordylodus proavus*	*Cordylodus proavus*		*Cordylodus proavus*	*Cordylodus proavus*: *Clavohamulus elongatus* / *Fryxellodontus inornatus* / *Hirsutodontus hirsutus*
CAMBRIAN	LATE CAMBRIAN		*Cambrooistodus minutus*	*Cambrooistodus*		*Hispidodontus discretus*	*Eoconodontus*: *Cambrooistodus minutus*
CAMBRIAN	LATE CAMBRIAN		*Eoconodontus notchpeakensis*			*Hispidodontus appressus*	*Eoconodontus*: *Eoconodontus notchpeakensis*
CAMBRIAN	LATE CAMBRIAN	*Proconodontus muelleri - Cambrooistodus cambricus*	*Proconodontus*	*Proconodontus*		*Hispidodontus resimus*	*Proconodontus muelleri*
CAMBRIAN	LATE CAMBRIAN					*Teridontus nakamurai*	*Proconodontus posterocostatus*
CAMBRIAN	LATE CAMBRIAN			*Proconodontus tenuiserratus*			*Proconodontus tenuiserratus*

Fig. 4. Correlation of conodont biostratigraphy at the Cambrian-Ordovician boundary intervals based on the information derived from the following : 1. Lee et al. (1991), Choi (1993) ; 2. Lee and Lee (1988), Lee (1992), Seo et al. (1994) ; 3. An et al. (1983), Chen et al. (1985) ; 4. An et al. (1985) ; 5. Shergold and Nicoll (1992) ; 6. Miller (1988).

manitouensis zones of Korea (Choi, 1993;Seo et al., 1994). This implies that the Cambrian-Ordovician boundary in the Yeongweol sequence should be very close to or slightly below the boundary between the Wagog and Mungog Formations.

South China

The fairly abundant and diverse Tremadoc trilobite faunas were recorded from South China (Peng, 1990a, b). Although their faunal contents are quite different from those of the Mungog Formation, a somewhat generalized correlation can be made (Fig. 3, column 4). The oldest trilobite zone, *Onychopyge-Hysterolenus* Zone, in the Jiangnan Slope Belt has been correlated with *Yosimuraspis* Assemblage Zone of North China (Peng, 1990b), which is comparable to the lower fauna of the Mungog Formation. The co-occurrence of some cosmopolitan genera such as *Asaphellus, Shumardia,* and *Apatokephalus* makes it possible to correlate the upper fauna of the Mungog Formation with part of the *Apatokephalus latilimbatus-Taoyuania affinis* and *Shumardia acutifrons-Asaphopsoides* assemblage zones of the Jiangnan Slope Belt.

Two Tremadoc trilobite zones have been established in the Nantsinkwan Formation of the Yangtze Platform : i, e., the lower *Apatokephalops yanheensis-Songtaoia cylindrica* Assemblage Zone and the upper *Dactylocephalus latus-Asaphellus inflatus* Assemblage Zone (Peng, 1990a). The genus *Yosimuraspis* has been known to be scarce, while *Apatokephalops* and *Songtaoia* are abundant there. Although most of the trilobite elements in the Yangtze Platform are endemic, the occurrence of *Yosimuraspis, Asaphellus, Shumardia,* and *Geragnostus* indicates that the lower fauna may be roughly comparable to part of the *Apatokephalops yanheensis-Songtaoia cylindrica* and *Dactylocephalus latus-Asaphellus inflatus* Assemblage zones of the Yangtze Platform.

An et al. (1985) established five conodont zones in the Nantsinkwan Formation : *Monocostodus sevierensis, Acanthodus costatus-"Acodus" oneotensis* (=*Rossodus manitouensis*), *Scolopodus pseudoplanus, Scolopodus quadriplicatus,* and *Scolopodus paucicostatus* zones in ascending order (Fig. 4, column 4). The *Monocostodus sevierensis* Zone is comparable to *Utahconus beimadaoensis-Monocostodus sevierensis* Zone (An et al., 1983) and *Cordylodus lindstomi* Zone (Chen et al., 1988) of North china, and in turn to *cordylodus intermedius-Utahconus beimadaensis* Zone of the Mungog Formation (Choi, 1993) and presumably part of *Fryxellodontus inomatus-Monocostodus sivierensis-Semiacontiodus lavadamensis* Zone of the Hwajeol Formation (Lee, 1992). The *Acanthodus costatus-"Acodus" oneotensis* Zone is equivalent to *Cordylodus rotundatus-"Acodus" oneotensis* Zone of North China (An et al., 1983) and should be comparable to *Chosonodina herfurthi-Rossodus manitouensis* zones of Korea (Choi, 1993;Seo et al., 1994).

Australia

The trilobite fauna across the Cambrian-Ordovician boundary in Australia is poorly represented. The *Mictosaukia perplexa* Assemblage Zone recognized by Shergold (1975) is the youngest Cambrian trilobite Zone in Australia and is certainly younger than the *Cordylodus proavus* conodont Zone (Shergold, 1988). A late Tremadoc trilobite fauna along with some late Cambrian and Arenig assemblages has been reported from the Pacoota Sandstone, Northern Territory (Shergold, 1991) (Fig. 3, column 5). The late Tremadoc trilobite assemblage, designated as Assemblage 2 by Shergold (1991), shows a close similarity to the upper fauna of the Mungog Formation, in sharing several genera such as *Asaphellus, Shumardia, Apatokephalus, Hystricurus,* and *Koraipsis.*

Meanwhile, conodont faunas across the Cambrian-Ordovician boundary intervals in Australia have been known to be well represented (Druce and Jones, 1971;Jones et al., 1971;Nicoll and Shergold, 1991). Recently, Shergold and Nicoll (1992) examined the Cambrian-Ordovician boundary interval at Black Mountain region and recognized nine successive conodont zones in the interval : i. e., *Teridontus nakamurai, Hispidodontus resimus, Hispidodontus appressus, Hispidodontus discretus, Cordylodus proavus, Hirsutodontus simplex, Cordylodus prolindstromi, Cordylodus lindstromi,* and *Chosonodina herfurthi-Cordylodus angulatus* zones in ascending order (Fig. 4, column 5). They recommended the Cambrian-Ordovician boundary at the base of the *Cordylodus lindstromi* Zone.

The conodont assemblages of the *Cordylodus intermedius-Utahconus beimadaoensis* and *Chosonodina herfurthi-Rossodus manitouensis* zones of Korea (Choi, 1993;Seo et al., 1994) are closely comparable to *Cordylodus lindstromi* and *Chosonodina herfurthi-Cordylodus angulatus* zones of Australia, respectively. Meanwhile, the *Fryxellodontus inornatus-Monocostodus sivierensis-Semiacontiodus lavadamensis* Zone of the Hwajeol Formation (Lee, 1992) cannot be equated with the *Cordylodus lindstromi* Zone of Australia with certainty, as all the elements of the former occur in the *Cordylodus prolindstromi* Zone or below in Australia.

North America

It is difficult to correlate the Late Cambrian-Early Ordovician trilobite faunas of Korea with those of North America, as a few taxa occur commonly in both regions. As described above, *Jujuyaspis borealis* occurs within the *Symphysurina bulbosa* Zone in the western Rocky Mountains, Canada (Norford, 1969;Dean, 1989;Loch et al., 1993), which allows correlation of the strata bearing this genus with those of the western United States (Winston and Nicholls, 1967;Stitt and Miller, 1987). Loch et al. (1993, fig. 4) placed the Cambrian-Ordovician boundary at the base of *Missisquoia depressa* Subzone, well below the first appearance of *Jujuyaspis borealis* (Fig. 3, column 6).

In the western Texas, *Jujuyaspis borealis* is associated with a conodont faunal assemblage of the lower part of Fauna B (=*Cordylodus lindstromi* Zone in Miller, 1988) (Stitt and Miller, 1987);identified taxa are *Cordylodus drucei, C. intermedius, C. lindstromi, C. prion, C. proavus, Iapetognatus preaengensis, Monocostodus sevierensis, Utahconus utahensis, Acontiodus proinquus* and *Semiacontiodus nogamii.* Therefore, the *Jujuyaspis*-bearing trilobite faunas and associated conodont assemblages in North America can be correlated with those of the basal part of the Mungog Formation.

DISCUSSION

Henningmoen (1973) noted that three horizons were justifiable for serving the Cambrian-Ordovician boundary ; namely the base of the Tremadoc Series, the base of upper Tremadoc, and at the base of Arenig Series. Subsequently, the Cambrian-Ordovician Boundary Working

Group has been accepted the base of the Tremadoc Series as the base of the Ordovician Period. However, it has not been resolved yet what faunal features can serve as the base of the Tremadoc.

In the traditional type area of the Tremadoc Series in North Wales, it has been known that there is a hiatus in the faunal record between the Tremadoc and underlying Olenid Series (Henningsmoen, 1973;Rushton, 1982). In the Baltic region, the base of the Tremadoc Series has been frequently taken at a horizon marked by the sudden immigration of early planktonic *Dictyonema* graptolites. For instance, an olenid trilobite *Boeckaspis hirsuta* occurs slightly below and within the range of planktonic *Dictyonema* and this trilobite has been regarded as a typical Tremadoc trilobite at Naersnes section of Norway (Henningsmoen, 1957;Bruton et al., 1982).

In North America, the base of the Ordovician has frequently been placed at the base of the Canadian (=Ibexian) Series, lying within the *Hirsutodontus hirsutus* Subzone at the base of the *Cordylodus proavus* Zone on the conodont biostratigraphic scheme and at the *Missisquoia depressa* Subzone on the trilobite scheme (Miller et al., 1982;Stitt, 1977). In the mean time, the base of the Tremadoc tends to be placed progressively higher during the last decade. Fortey et al. (1982) suggested that the base of the Tremadoc should be younger, lying above the *Missisquoia typicalis* Subzone and close to the base or within the *Symphysurina* Zone. Landing (1988) also placed the base of the Tremadoc close to the base of Fauna B (=*Cordylodus lindstromi* Zone of Miller, 1988) and within the *Symphysurina brevispicata* Subzone. Landing (1993) further favored the Cambrian-Ordovician boundary to be placed at the lowest occurrence of *Dictyonema flabelliforme* assemblage within an interval with lower Fauna B-aspect conodonts.

In Australia, Jones et al. (1971) originally considered that the first appearance datum of conodonts belonging to the *Cordylodus proavus* Zone could have defined the base of the Datsonian Stage, which in turn formed the hase of the Ordovician. The Cambro-Ordovician condont biostratigraphy has been well established (Shergold and Nicoll, 1992), while contemporaneous trilobites are poorly known in the Black Mountain region. Shergold and Nicoll (1992) revised the Cambrian-Ordovician conodont biostratigraphy of the Black Mountain region and recommended the Cambrian-Ordovician boundary at the first appearance of *Cordylodus lindstromi*, i. e., the base of the Warendian Stage in Australia, thus drastically modifying the previous concept of Cambrian-Ordovician boundary in Australia.

The Cambrian-Ordovician boundary intervals in North China have been intensively studied as the Xiaoyangqiao section at Dayangcha yields diverse faunal assemblages of conodonts, graptolites, and trilobites (Chen et al., 1985;Chen et al., 1988). Chen et al. (1988) recommended four biostratigraphic horizons for the potential Cambrian-Ordovician boundary stratotype : namely, 1) the first appearance datum (FAD) of *Cordylodus intermedius*, 2) FAD of *Hirsutodontus simplex-Cordylodus drucei-Albiconus postcostatus*, 3) FAD of *Semiacontiodus lavadamensis-Utahconus utahensis-Monocostodus sevierensis*, and 4) FAD of *Cordylodus lindstromi* in ascending order. They favored the FAD of *Hirsutodontus simplex-Cordylodus drucei-Albiconus postcostatus* within the *Cordylodus intermedius* Zone as the Cambrian-Ordovician boundary stratotype.

In summary, the comparatively well-studied sections across the Cambrian-Ordovician boundary interval described above reveal that at least four biostratigraphic horizons may have been considered as having potential for standardizing the boundary point : namely, the base of *Cordylodus proavus* Zone, the base of the *Cordylodus intermedius* Zone, the base of *Cordylodus lindstromi* Zone (cf. Miller, 1988), and the lowest occurrence of nematophorous dendroids of the *Rhabdinopora flabelliformis*-type within an interval with lower Fauna B-aspect conodonts (Landing, 1988, 1993).

The base of *Cordylodus proavus* Zone is the lowest horizon among the boundary point candidates and has long considered as the base of the Ordovician in Australia (Jones et al., 1971). It is characterized by the extinction of *Proconodontus* and *Cambrooistodus* and the appearance of *Cordylodus proavus* and species of *Hirsutodontus.* Slightly above the *Cordylodus proavus* Zone, there is another potential boundary point, the base of the *Missisquoia depressa* Zone, which also marks the base of Canadian (or Ibexian) in North America (Stitt, 1977;Ludvigsen, 1982;Loch et al., 1993). The base of the *Cordylodus intermedius* Zone received little support for the boundary point. In North China the Cambrian-Orodvician boundary has been favored within the *Cordylodus intermedius* Zone, however.

The base of *Cordylodus lindstromi* Zone is the youngest conodont zone under consideration for the boundary point and appears to have been increasingly favored by members of the Working Group of the Cambrian-Ordovician boundary. However, the validity *Cordylodus lindstromi* as a species has been distrusted by conodont specialists (cf. Landing, 1993). In addition, Landing (1993) demonstrated that the conodont distributions are controlled by depostitional environments and the lowest local occurrences of euconodonts may have been diachronous, and subsequently recommended that the Cambrian-Ordovician boundary should be defined by the lowest occurrence of nematophorous dendroids of the *Rabdinopora flabelliformis*-type within an interval with lower Fauna B-aspect conodonts.

Although the currently avaiable biostratigraphic data do not permit the selection of the global stratotype that can provide a guide for the definition of the Cambrian-Ordovician boundary, it seems worthwhile to discuss two biostratigraphic intervals in Korea which are apparently close to the Cambrian-Ordovician boundary. One is the *Fryxellodontus inornatus-Monocostodus sivierensis-Semiacontiodus lavadamensis* Zone which occupies the uppermost part of the Hwajeol Formation (Lee, 1992). The stratigraphic ranges of the conodont species reported from the *Fryxellodontus inornatus-Monocostodus sivierensis-Semiacontiodus lavadamensis* Zone overlap the ranges of the *Cordylodus proavus, C. intermedius,* and *C. lindstromi* Zone in western North American platform strata (Miller, 1988, fig. 2), North China (Chen et al., 1988, fig. 6) and Australia (Shergold and Nicoll, 1992, fig. 2). Therefore, there is a good possiblity that the Cambrian-Ordovician boundary in the Duwibong sequence lies within the uppermost part of the Hwajeol Foramtion. The other is the *Cordylods intermedius-Utahconus beimadaoensis* Zone at the basal part of the Mugog Formation. This zone is correlatable with the *Cordylodus lindstromi* Zone established elsewhere, most likely with the upper part of the *Cordylodus lindstromi* Zone. The occurrence of *Jujuyaspis* along with the lower Fauna B-aspect conodonts in the interval is also consistent with the results from North America (Loch et al., 1993), China (Zhou and Zhang, 1984), and Norway (Bruton et al., 1988). Although the base of the *Cordylodus intermedius-Utahconus beimadaoensis* Zone has yet to be determined, the trilobite and conodont data suggest that the Cambrian-Ordovician boundary in the Yeongweol sequence may lie slightly below the base of the Mungog Formation.

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우리나라 태백산 지역의 캄브리아-오르도비스계 경계 검토

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요 약

우리나라에서 캄브리아-오르도비스계의 경계는 일반적으로 두위봉형 조선누층군의 경우 화절층과 동점규암층 사이에 그리고 영월형 조선누층군의 경우 와곡층과 문곡층사이에 존재하는 것으로 인정되어 왔다. 최근 국제적으로 활발하게 진행되어 온 캄브리아-오르도비스계 경계부에 대한 연구와 발맞추어 이 연구에서는 캄브리아-오르도비스계 경계 규명에 가장 중요한 화석인 코노돈트와 삼엽충 화석군에 대한 자료를 바탕으로 우리나라에서의 캄브리아-오르도비스계 경부에 대한 논의를 하였다. 아직 캄브리아-오르도비스계의 경계에 대한 정의가 국제적으로 확립되지 않았기 때문에 명확한 결론을 내릴 수는 없지만, 현재까지 알려진 생층서대 중 두 개의 구간에서 캄브리아-오르도비스계 경계부의 화석군 특징을 보여주는 점에서 주목된다. 하나는 두위봉형 조선누층군의 화절층 최상부에서 인지된 *Fryxellodontus inornatus-Monocostatus sevierensis-Semiacontiodus lavadamensis*대이며, 다른 하나는 문곡층 최하부에서 알려진 하부 화석군이다. 문곡층의 하부 화석군은 *Yosimuraspis, Jujuyaspis,* 및 *Pseudokainella*등 삼엽충 화석 산출에 의하여 특징지을 수 있으며, 코노돈트 화석에 의한 *Cordylodus intermedius-Utahconus beimadaoensis*대에 대비될 수 있다. 이들 화석군의 특징에 의하면, 우리나라에서의 캄브리아-오르도비스계 경계는 두위봉형 조선누층군에서는 화절층 최상부에 그리고 영월형 조선누층군에서는 와곡층과 문곡층 경계보다 하위에 존재할 가능성이 큰 것으로 생각된다.

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