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Early Ordovician (Tremadocian) Graptolites from the Mungok Formation, Yeongwol, Korea: Biostratigraphy and Correlation

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Abstract: Early Ordovician graptolites from the Mungok Formation of Yeongwol area, Korea comprise seven species belonging to six genera: *Callograptus curvithecalis*, *Callograptus sinicus*, *Aspidograptus lotolatzensis*, *Dendrograptus suni*, *Dictyonema uniforme*, *Adelograptus* cf. *tenellus*, and *Psigraptus jacksoni*. Two graptolite zones with three subzones are recognized in the eight sections of the Mungok Formation. The *Adelograptus* Zone is correlated with (1) La 1b of the Lancefield Formation of Victoria, Australia, (2) the *Adelograptus-Clonograptus* Zone of the Yehli Formation of Jilin, China, and (3) the *Adelograptus* Zone of the Road River Formation of Yukon, Canada. It suggests that the upper part of the Mungok Formation corresponds to early Late Tremadocian of Early Ordovician.

Keywords: graptolite, biostratigraphy, Ordovician, Mungok Formation, Yeongwol

Introduction

The Early Ordovician Mungok Formation in Yeongwol area is well known to yield fairly diverse invertebrate fossils (Yosimura, 1940; Kobayashi and Kimura, 1942; Kobayashi, 1960; Choi et al., 1994), conodont faunal assemblages (Won and Lee, 1977; Lee and Lee, 1999), and trace fossils (Kim et al., 1994).

Lee and Lee (1999) have tentatively established the conodont biostratigraphy with four informal conodont assemblage zones, namely Assemblage Zone (AZ) 1 (= *Semiacontiodus nogamii* - *Cordylodus lindstroemi* - *Utahconus beimadaoensis* Zone), AZ 2 (= *Rossodus manitouensis* - *Chosonodina herfurthi* Zone), AZ 3 (= *Scolopodus quadraplicatus* - *Paroistodus proteus* - *Drepanoistodus forceps* Zone), and AZ 4 (= *Paracordylodus gracilis* Zone). However, it seems to be desirable to establish a precise biostratigraphic correlation based on a more refined restudy for additional fossil collections (Lee and Lee, 1999).

Kim and Choi (2000b) proposed the trilobite biostratigraphy of the Mungok Formation (Park et al., 1994; Choi et al., 1994; Kim and Choi, 1995, 1999, 2000a), which is based on a total of twenty trilobite species procured from the three stratigraphically separated intervals of the formation. In spite of the previous biostratigraphy of the Mungok Formation on the basis of the conodonts (Won and Lee, 1977; Choi, 1993; Lee and Lee, 1999) and trilobites (Kobayashi, 1960; Kim and Choi, 2000b), it still remains to establish a more refined biostratigraphy of the formation and to correlate it based on the graptolites.

Since Kobayashi and Kimura (1942) first described two species of Early Ordovician graptolites, *Dictyonema* cf. *flabelliforme* and *Clonograptus* sp. from the formation on the basis of few fragmental specimens, any paleontological studies on the graptolites had not been carried out. Recently, numerous and diverse graptolite specimens have been collected from the upper Member of the Mungok Formation of the Yeongwol area, Korea (Jin, 2002; Cho, 2003; Kim et al., 2006). Aside from these collections, eight graptolite localities in the upper part of the formation have been recognized. This paper aims to describe the graptolites from the Mungok Formation, to establish formally the graptolite biostratigraphy of the formation, and to correlate the graptolite biozones with coeval ones elsewhere.

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Geologic setting

The Cambro-Ordovician strata of South Korea, the Choseon Supergroup, are exposed in northeastern part of the Okcheon Belt and comprise predominantly calcareous sedimentary rocks with subordinate interbeds of siliciclastics. The supergroup was divided into five types of sequences in accordance with distinct lithologic succession and geographic distribution; i.e., the Tuwibong, Yeongwol, Chongseon, Pyongchang, and Mungyeong types of the Choseon Supergroup (Kobayashi et al., 1942; Kobayashi, 1966). Choi (1998) proposed new nomenclatures in view of the International Stratigraphic Guide (Hedberg, 1976; Salvador, 1994) for the Cambrian-Ordovician sequences of South Korea; the Taebaek, Yeongwol, Yongtan, Pyongchang, and Mungyeong groups of the supergroup.

The sedimentary rocks of the Yeongwol Group are presumably unconformably underlain by the Precambrian basement and in turn overlain unconformably by the Carboniferous sedimentary rocks. The Yeongwol Group is composed of the Sambangsan, Machari, Wagok, Mungok and Yeonghung formations in ascending order (Yosimura, 1940). The lower three formations are assigned to the Cambrian and the upper two to the Ordovician (Kobayashi, 1966; Choi, 1998).

The Mungok Formation rests conformably on the Wagok Formation and is overlain by the Middle

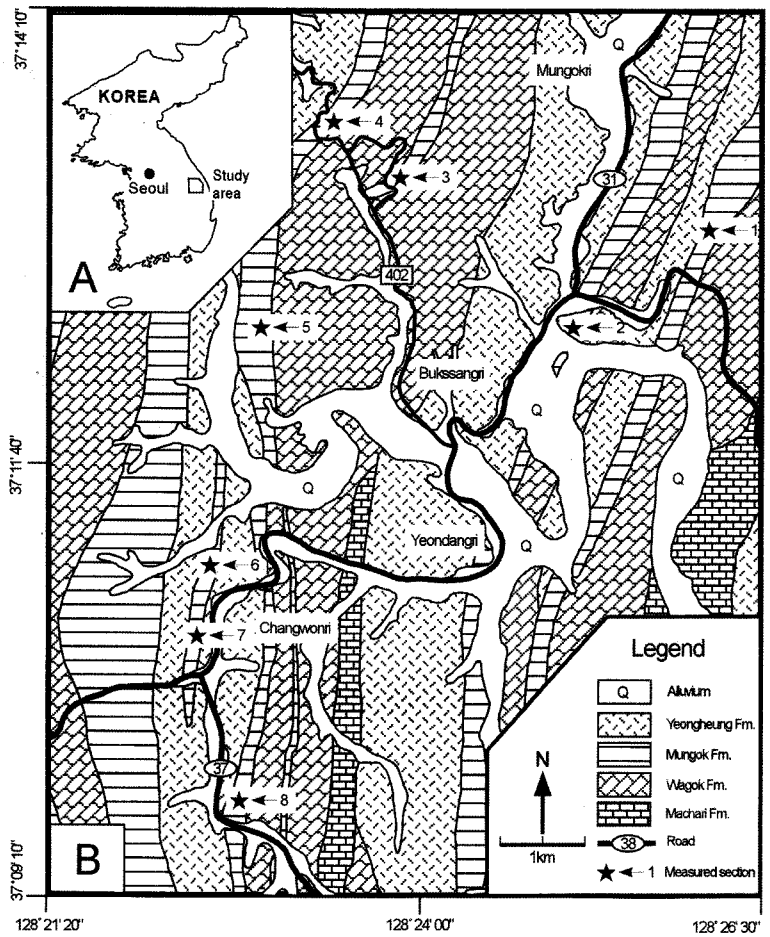

Fig. 1. Locality maps. (A) Map of the Korean Peninsula showing study area, and (B) geologic map of the Yeongwol area showing eight measured sections: (1) Tumok, (2) Namaeri, (3) Chommal, (4) Peiljae, (5) Hwabyung, (6) Yeonjeong, (7) Daegol, and (8) Myungjeon sections.

Ordovician Yeonghung Formation. The Mungok Formation is an approximately 200 m thick carbonate succession, representing a supratidal to subtidal environment (Paik et al., 1991; Choi et al., 1993). The formation was subdivided into four members based on dominant lithofacies and fossil collections; the basal, lower, middle, and upper members in ascending order (Park et al., 1994; Kim and Choi, 2000b). The Mungok Formation mainly strikes N30°E and dips 40°NW, which is repeatedly distributed due to the faults in the Yeongwol area (Fig. 1).

Graptolite biostratigraphy

The sections yielding graptolites were measured up to 50 m in thickness, in the eight sections of the Mungok Formation, including the Tumok, Namaeri, Chommal, Peiljae, Yeonjeong, Hwabyung, Daegol, and Myungjeon sections (Figs. 1 and 2). The Early Ordovician (Tremadocian) graptolite fauna is confined within the middle to upper part of the upper Member of the Mungok Formation. A total of seven graptolite species belonging to six genera were procured from the two intervals of the Mungok Formation; four species from the low interval and two from the upper interval of the upper Member with one coexisting species. They are herein referred to the *Adelograptus* and *Callograptus curvithecalis-Dendrograptus* zones, respectively (Fig. 2). The *Adelograptus* Zone comprises three subzones; the lower *Adelograptus*, *Psigraptus*, and upper *Adelograptus* subzones in ascending order (Fig. 2). The graptolite zones of the Mungok Formation correspond to the upper part of the *Shumadia pellizzarii* Zone (Kim, 1999; Kim and Choi, 2000b) of the trilobite fauna and the upper part of the Assemblage Zone 3 (= *Scolopodus quadraplicatus-Paroistodus*

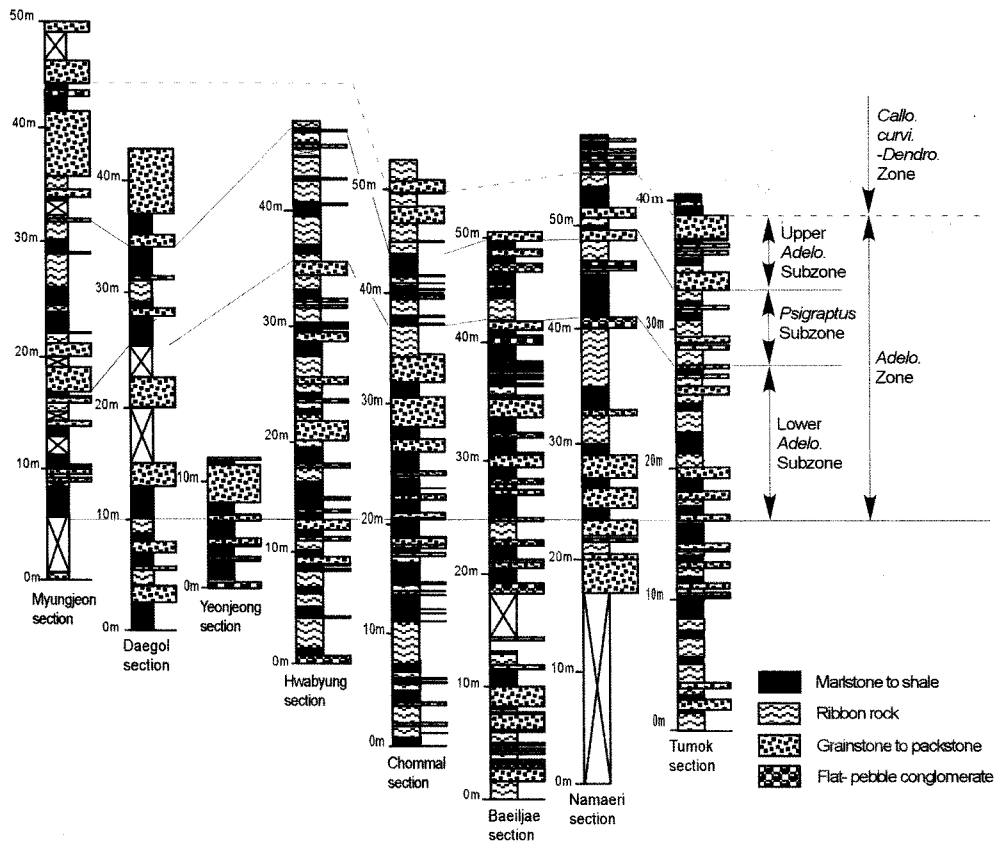

Fig. 2. Correlation of the measured sections of the Mungok Formation in Yeongwol area showing the graptolite zones. *Callo.*, *Callograptus*; *curvi.*, *curvithecalis*; *Dendro.*, *Dendrograptus*; *Adelo.*, *Adelograptus*.

	Adelograptus zone			*Callograptus curvithecalis-Dendrograptus* Zone
	Lower *Adelograptus* Subzone	*Psigraptus* Subzone	Upper *Adelograptus* Subzone	
Callograptus sinicus	○	○		
Callograptus curvithecalis				○
Dendrograptus lotolatzensis	○			
Dendrograptus suni	○		○	○
Dictyonema uniforme				○
Adelograptus cf. tenellus	○	○	○	
Psigraptus jacksoni		○		

Fig. 3. Occurrence of graptolite taxa in the biozones of the upper part of the Mungok Formation.

proteus-Drepanoistodus forceps Zone) and the Assemblage Zone 4 (= *Paracordylodus gracilis* Zone) of the conodont fauna (Lee and Lee, 1999) of the formation.

Adelograptus Zone

Composition: The *Adelograptus* Zone corresponds to the stratigraphic range of *Adelograptus* and yields *Adelograptus* cf. *tenellus*, *Psigraptus jacksoni*, *Callograptus sinicus*, *Aspidograptus lotolatzensis*, and *Dendrograptus suni* (Fig. 3). The zone is composed predominantly of *Adelograptus* and subordinately of *Psigraptus* and *Dendrograptus*. The occurrence of *Psigraptus* from the middle part of the *Adelograptus* Zone allows this zone to be subdivided into three subzones: i.e., the lower *Adelograptus*, the *Psigraptus*, and the upper *Adelograptus* subzones in ascending order (Fig. 2).

Stratigraphic occurrence: Graptolites are collected from the marlstone to shale and grainstone to packstone beds of the middle part of the Upper Member of the Mungok Formation: 16-33.4 m (Tumok section), 15-50 m (Namaeri section), 22-49 m (Chommal section), 25-45 m (Baeiljae section), 13-45.5 m (Hwabyung section), 7-8.7 m (Yeonjeong section), 8.3-44.4 m (Myungjeon section), and 13-38.9 m (Daegol section) above the base of the Tumok Member, respectively.

Correlation: The first appearance of *Adelograptus* cf. *tenellus* has been generally taken as the boundary between the lower and upper Tremadocian (Stubblefield and Bulman, 1927; Cooper, 1999). In Rock River section of the Road River Formation, Yukon, Canada, the *Adelograptus* cf. *tenellus* Biozone begins with *A.* cf. *tenellus*, followed by *Psigraptus arcticus* and *P. lenzi* overlain by the long-ranging *A.* cf. *tenellus* (Jackson, 1974; Jackson and Lenz, 2003). This succession, that is the interval of *Adelograptus* cf. *tenellus* intervened by *Psigraptus*, is similar with that of Yeongwol. The *Psigraptus* intervals in Canada and NE China is short range about 5-10 m (Jackson and Lenz, 2003; Zhang and Erdtamnn 2004), but in Yeongwol, these intervals are comparatively long range maximum about 15 m.

The *Psigraptus* interval includes within *Adelograptus* cf. *tenellus* Zone not as a zonal nomenclature in the Road River Formation of Yukon, Canada (Jackson and Lenz, 2003), and is erected as a zonal status of the *Psigraptus jacksoni* Zone of the Yehli Formation, Jilin, China (Zhang and Erdtmann, 2004). The La 1.5 Zone of the Lancefield sequence of Victoria, Australia represents the appearance of *Clonograptus* and *Adelograptus* with not common genus of *Psigraptus* (Cooper, 1979; Cooper and Stewart, 1979; Vandenberg and Cooper, 1992). The zone is also correlated with the global graptolite chronozone 5 (*Adelograptus* Zone) of Cooper (1999) based on the appearance of abundant *Adelograptus* with *Psigraptus*.

Lower *Adelograptus* Subzone

Composition: The lower *Adelograptus* Subzone includes *Adelograptus* cf. *tenellus*, *Callograptus sinicus*,

<table>
<tr><td></td><td colspan="3">1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td></td><td colspan="3">Korea</td><td>China</td><td>Australia</td><td>Canada</td><td>Global</td></tr>
<tr><td rowspan="4">Late Tremadoc</td><td colspan="2" rowspan="2">Callograptus curvithecalis
-Dendrograptus Zone</td><td rowspan="2">Y5: Adelograptus-
Clonograptus Zone
(Callograptus? taizehoensis Zone)</td><td>La 2
(Assemblage 4)</td><td>Adelograptus antiquus Zone</td><td>Paradelograptus antiquus Zone (6)</td></tr>
<tr><td rowspan="3">Adelograptus
Zone</td><td>Upper Ad.
Subzone</td><td rowspan="3">La 1.5
(Assemblage 3)
Psigraptus-
Clonograptus</td><td rowspan="3">Adelograptus cf.
tenellus Zone</td><td rowspan="3">Adelograptus
Zone (5)</td></tr>
<tr><td>Psigraptus
Subzone</td><td>Y4: Psigraptus
jacksoni Zone</td></tr>
<tr><td>Lower Ad.
Subzone</td><td>Y3: Dendrograptus
Bed</td></tr>
<tr><td rowspan="4">Early Tremadoc</td><td colspan="2" rowspan="3"></td><td rowspan="2">Y2: Anisograptus
richardsoni Zone</td><td rowspan="2">La 1
(Assembalge 2)</td><td rowspan="2">Anisograptus
richardsoni Zone</td><td>Rhabdinopora
flabelliformis
anglica Zone (4)</td></tr>
<tr><td>Anisograptus
matanensis Zone (3)</td></tr>
<tr><td rowspan="2">Y1: Dictyonema parabola
-Staurograptus
dichotomous Zone</td><td rowspan="2">(Assemblage 1)</td><td>Staurograptus
tenuis Zone</td><td>Rhabdinopora
flabelliformis
parabola Zone (2)</td></tr>
<tr><td>Dictyonema
flabelliforme/
Radiograptus Zone</td><td>Rhabdinopora
praeparabola
Zone (1)</td></tr>
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Fig. 4. Correlation of the graptolite zones of the Mungok Formation with coeval ones elsewhere. Columns 1-5 are followings: 1, Mungok Formation, Yeongwol, Korea (this study); 2. Yehli Formation, Jilin, China (Zhao et al., 1988; Zhang and Erdtmann, 2004); 3, Lancefield Formation, Victoria, Australia (Cooper, 1979; Cooper and Stewart, 1979; Vandenberg and Cooper, 1992); 4, Road River Formation, Yukon, Canada (Jackson, 1974; Barnes et al., 1981; Jackson and Lenz, 2003); 5, Global chronozones (Cooper, 1999). *Ad.*, *Adelograptus*.

and *Aspidograptus lotolatzensis* (Fig. 3). Other associated fossils are brachiopods, *Asaphellus* sp., and *Sphenothallus* sp.

Stratigraphic occurrence: Graptolite collections are restricted to the grainstone to packstone beds of the middle part of the Upper Member of the Mungok Formation; 16-16.8 m (Tumok section), 15-35 m (Namaeri section), 22-30.3 m (Chommal section), 25-33 m (Peiljae section), 13-17.1 m (Hwabyung section), 7-8.7 m (Yeonjeong section), 13-16 m (Daegol section), and 8.3-11.4 m (Myungjeon section) above the base of the Tumok Member of the Mungok Formation, respectively (Fig. 2).

Correlation: This subzone is correlatable with the lower part of the *Adelograptus* cf. *tenellus* Zone (Jackson, 1974; Barnes et al., 1981; Jackson and Lenz, 2003; Fig. 4) of Yukon, Canada containing *Adelograptus* cf. *tenellus*, which occurred earlier in age than *Psigraptus*. The subzone also corresponds to the *Dendrograptus*-bearing beds (Y3 or X2) from the Yehli Formation in Jilin, China based on only dendroid of *Callograptus sinicus* (Zhao et al., 1988; Fig. 4).

Psigraptus jacksoni Subzone

Composition: This subzone is defined by the occurrence of *Psigraptus*. It is characterized by the abundance of *Psigraptus jacksoni* with some *Adelograptus* cf. *tenellus* and *Callograptus sinicus* (Fig. 3). The graptolites are commonly associated with trilobites *Asaphellus* sp.

Stratigraphic occurrence: Graptolites are recovered from the marlstone to shale and grainstone to packstone beds of the middle part of the Upper Member: 30-33.4 m (Tumok section), 45-50 m

(Namaeri section), 38-44 m (Chommal section), 43-45 m (Peiljae section), 35-45.5 m (Hwabyung section), 28.2-37.6 m (Daegol section), and 16.9-31.6 m (Myungjeon section) above the base of the Upper Member, respectively (Fig. 2).

Correlation: The La 1.5 (*Psigraptus* and *Clonograptus* Zone) of the Lancefield Formation, Victoria and Tasmania, Australia (Cooper, 1979; Cooper and Stewart, 1979; Rickards and Stait, 1984; VandenBerg and Cooper, 1992) contains *Psigraptus* together with various species of *Adelograptus*. La 1.5 is well correlated with the *Psigraptus* Subzone of the Mungok Formation in faunal assemblage including *Psigraptus jacksoni* and *Adelograptus* cf. *tenellus* (Fig. 4). Jackson (1974) reported the occurrence of *Psigraptus lenzi* from the Road River Formation of Yukon, Canada. However, he did not designate the detailed horizon of the *Psigraptus* bed though denoted the genus occurred within the *Adelograptus antiquus* Subzone. His supplementary study designated the *Psigraptus* horizon at the base of the *Adelograptus antiquus* Subzone, in which the genus is associated with *Adelograptus* sp. (Jackson, 1975). Barns et al. (1981) erected the *Psigraptus* Zone between the *Clonograptus aureus* Zone and *Adelograptus antiquus* Zone, and correlated it with the upper Middle Tremadocian ones. The subzone is equivalent to the *Psigraptus* (Wang and Erdtmann, 1986) and *Muenzhigraptus-Psigraptus* zones (Y4; Zhao et al., 1988) of the Yehli Formation, Jilin, China based on the appearance of the zonal representative *Psigraptus*. *Muenzhigraptus* is the junior synonym of *Psigraptus* (Rickards and Stait, 1984; Wang and Erdtmann, 1986; Rickards et al., 1991; Kim et al., 2006) and the zone of Zhao et al. (1988) is only dominated by *Psigraptus*.

Upper *Adelograptus* Subzone

Composition: The base of this subzone is defined by the disappearance of *Psigraptus* and the upper boundary by the last appearance of *Adelograptus* cf. *tenellus*. The subzone is recognized by *Adelograptus* cf. *tenellus*, and includes *Dendrograptus suni* (Fig. 3).

Stratigraphic occurrence: Graptolites are discovered from grainstone to packstone and ribbon rock beds of the middle part of the Upper Member: 48-49 m (Chommal section), 37.6-38.9 m (Daegol section), and 34.3-44.4 m (Myungjeon section) above the base of the member, respectively (Fig. 2).

Correlation: The subzone is characterized by the occurrence of *Adelograptus* cf. *tenellus*, and the absence of the preceding zonal taxon *Psigraptus jacksoni*. The same situation is shown in the upper part of the *A.* cf. *tenellus* Zone of the Road River Formation, Yukon, Canada (Jackson, 1974; Jackson and Lenz, 2003).

Callograptus curvithecalis-Dendrograptus Zone

Composition: This zone is mainly recognized by the common occurrences of dendroids including *Callograptus curvithecalis* and *Dendrograptus suni*, in subordinate association with *Dictyonema uniforme* (Fig. 3).

Stratigraphic occurrence: The zone is recognized approximately 50 m above the base of the upper Member of the Mungok Formation in the Chommal and Tumok sections. The upper limit of the zone cannot be determined due to the lack of the outcrop in the sections. Graptolites occurr in the grainstone to packstone and ribbon rock beds of the upper part of the Upper Member: 50-51.5 m (Chommal section) and 49.7-50 m (Tumok section) above the base of the member, respectively (Fig. 2).

Correlation: Correlation of this zone is difficult because the dendroid graptolites have rarely been reported from other areas. However, *Callograptus curvithecalis*, *Dendrograptus suni* and *Dictyonema uniforme* reported from the Yehli Formation of Liaoning, China (Mu, 1953, 1955) lead the *Callograptus curvithecalis-Dendrograptus* Zone of the Mungok Formation to be correlatable to the Y5 Zone (the *Adelograptus* and *Clonograptus* Zone or *Callograptus? taizehoensis* Zone) of Wang and Erdtmann (1987) and Zhao et al. (1988) (Fig. 4).

Systematic Paleontology

The criteria for classification of graptolites herein follow those of Bulman (1970), Erdtmann (1982), and Fortey and Cooper (1986). All materials treated in this paper are housed in the Paleontological Laboratory of Department of Earth Science Education, Korea National University of Education. Abbreviations are: KNUE, Korea National University of Education and CA, *Callograptus*.

Order Dendroidea Nicholson, 1872
Family Dendrograptidae Roemer *in* Frech, 1897
Genus *Callograptus* Hall, 1865

Type species: *Callograptus elegans* Miller, 1889
Diagnosis: See Bulman (1970).

Callograptus curvithecalis Mu 1955
Fig. 5A.
1955 *Callograptus curvithecalis* Mu; p. 45, pl. 4, figs. 12-16.
Diagnosis: See Mu (1955).
Material examined: Five well-preserved or fragmented specimens; figured specimen: KNUE-CA 1012a.
Description: Rhabdosome conical or flabellate, 60 mm high and 50 mm wide. The rooting stipe in the proximal area might be more than 0.7 mm in thickness, from which lateral stipes originated by dichotomous biradiation up to 15th order. The rooting stipe tends to be rapidly thinning down up to 0.3 mm in width and not differentiated with lateral stipes except near main stipes of the proximal part. Branching is regular near the proximal part of the rahbdosome and tend to be decrease its regularity distally, resulting in forming clear branching zones near the proximal, while the zones are not recognized in the distal part. Stipes fairly close together but never overlapped, 13 in 10 mm transversely, parallel to subparallel each other, and sparse dissepiments connecting them. Thecae inconspicuous probably due to the ventral view, but in terms of the apertural traces of thecae recognized 16 in 10 mm.
Remarks: The main difference between *Dendrograptus* and *Callograptus* is that the former has stipes diverging steadily and lack dissepiments altogether, and the latter has parallel stipes closely spaced and occasionally connected by dissepiments (Chapman et al., 1996). It is thought to be a complete morphological gradation from disordered *Dendrograptus* through *Callograptus* to highly regular *Dictyonema* spp., and thus it is very useful in distinguishing between *Callograptus* and *Dictyonema*

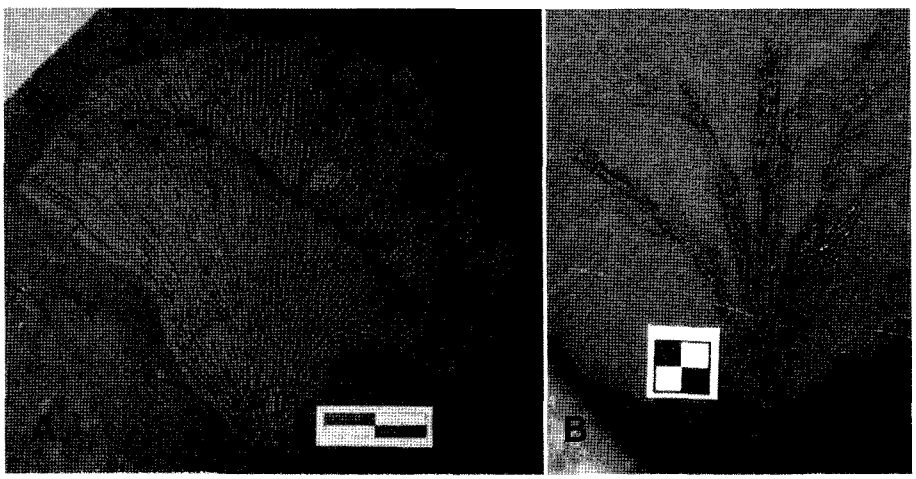

Fig. 5. A. *Callograptus curvithecalis*. *A*, KNUE-CA1012a. B. *Callograptus sinicus*. *B*, KNUE-CA2010. Scale of 5A, 5 mm, and 5B, 2 mm.

(Bulman, 1934; Chapman et al., 1996). Sparse dissepiments and parallel alignment of stipes of the present material seem better assignable to *Callograptus* than *Dendrograptus* or *Dictyonema*. Flabellate rhabdosome and dichotomously biradiated stipes which arranged in parallel and connected transversely by infrequent dissepiments correspond to *Callograptus curvithecalis* (Mu, 1955).

Occurrence: The *Callograptus curvithecalis-Dendrograptus* Zone of the Mungok Formation at the Chommal Section.

Callograptus sinicus Mu, 1955

Fig. 5B.

1955 *Callograptus sinicus* sp. nov.; Mu, pl. 3, fig. 9.

Diagnosis: See Mu (1955).

Material examined: Eight carbonized specimens in shale with partial relief; figured specimen: KNUE-CA 2010.

Description: Rhabdosome at least 45 mm long and 20 mm wide flabellate or probably conical in form with many stipes up to at least seventh order, with a thick main stem to the proximal part from which lateral stipes are serially given off. Stipes show dichotomous branching with dissepiments, width ca. 0.09-0.11 mm, occasionally coming out, and flexible to the distal, and closely arranged of 16-18 in 10 mm transversely. Stipe width, ca. 0.60 mm, becomes slender distally because of probably cortical overgrowth in the proximal part. The space between stipes is ca. 0.65-0.85 mm near to the proximal part, but it becomes to be narrow as ca. 0.35-0.45 mm in the distal parts. It also proves that it needs to accommodate many stipes in conical or flabellate rhabdosome distally. Thecae are ca. 20 in 10 mm, with apertural spine of denticles. Stipes branching is somewhat irregular, not forming branching zone. Branching intervals are very short, 1.0 mm, near the main stem and increase progressively up to more than 7.0 mm in the distal.

Remarks: The present material shows close resemblance to the Chinese ones (Mu, 1955) in the number of stipe arrangement per unit length and irregular branching of the stipes, sparse dissepiments, and entire rhabdosome size.

Occurrence: The *Psigraptus* Subzone and the lower *Adelograptus* Subzone the *Adelograptus* Zone of the Mungok Formation at the Myeongjeon and Chommal sections, respectively.

Order Graptoloidea Lapworth (in Hopkinson and Lapworth, 1875)

Family Anisograptidae Bulman, 1950

Genus *Adelograptus* Bulman, 1941

Type species: *Bryograptus? hunnebergensis* Moberg (= *Dichograptus tenellus* Linnarsson, 1871)

Diagnosis: See Maletz and Erdtmann (1987).

Adelograptus cf. *tenellus* (Linnarsson, 1871)

Figs. 6A-F.

1991 *Adelograptus* cf. *A. tenellus* (Linnarsson); Williams and Stevens, p. 33-34, pl. 2 figs. 2-3, text-fig. 13A-J.

2002 *Adelograptus* sp. A; Jin, p. 143-150, text-fig. 17; pl. 6, figs. A-G, pl. 7, figs. A-G, pl. 8, figs. A-I, pl. 9, figs. A-D.

2002 *Adelograptus* sp. C; Jin, p. 105-106, text-fig. 19, pl. 12, figs. B-E, H-I.

Remarks: The present materials are characterized by the small size of rhabdosome, short primary stipes and unique regularity of the second stipes arrangement. The two second stipes on the opposite side in a rhabdosome are respectively same in length each other, but each of which is different from neighbored stipes. This species resembles Linnarsson's original material *Dichograptus? tenellus* from Nygård, Hunneberg in appearance, but is different from the original in the lengths of the stipes and sicula.

Occurrence: The *Adelogratus* Zone of the Mungok Formation.

Genus *Psigraptus* Jackson, 1967

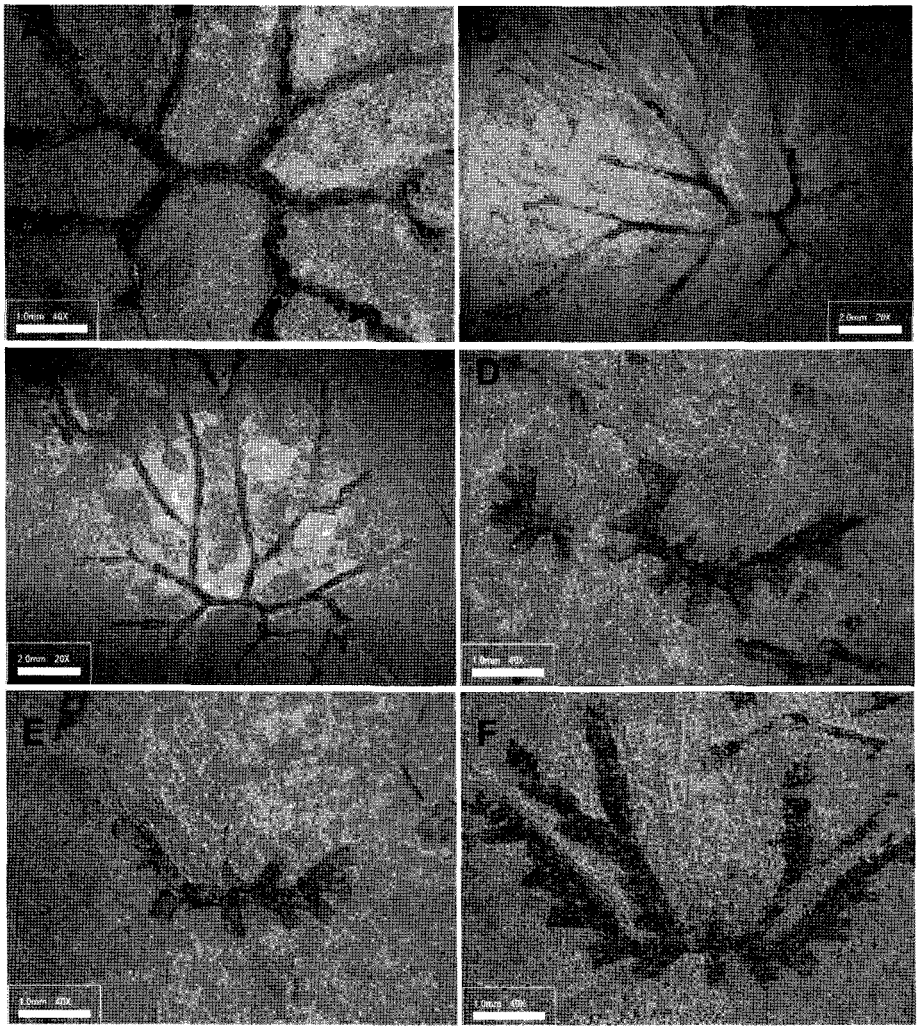

Fig. 6. A-C. *Adelograptus* cf. *tenellus*. *A*, KNUE-AD1021. *B*, KNUE-AD1026. *C*, KNUE-AD1028. D-F. *Psigraptus jacksoni*. *D*, KNUE-PS1042. *E*, KNUE-PS1044. *F*, KNUE-PS1046. Scale of 6A, 6D-6F, 1 mm, and 6B-6C, 2 mm.

Type species *Psigraptus arcticus* Jackson 1967
Diagnosis See Kim et al. (2006).

Psigraptus jacksoni Rickards and Stait 1984
Figs. 7A-F.

1984 *Psigraptus jacksoni* sp. nov.; Rickards and Stait, p. 104-110, figs. 2-6.

1986 *Psigraptus jacksoni* Rickards and Stait; Wang and Erdtmann, p. 17-18, pl. 2, fig. 10.

1987 *Psigraptus jacksoni* Rickards and Stait; Wang and Erdtmann, p. 250-252, pl. 2, fig. 10.

1991 *Psigraptus jacksoni* Rickards and Stait; Rickards et al., p. 250-253, fig. 2, 7.

2002 *Psigraptus arcticus* Jackson; Jin, p. 161-172, pl. 15-20.

2003 *Psigraptus jacksoni* Rickards and Stait; Cho, p. 117-126, pl. 7-11.

2006 *Psigraptus jacksoni* Rickards and Stait; Kim et al., p. 15-18, figs. 2-5.

Diagnosis: See Kim et al. (2006).

Remarks: Taxonomy among the species of *Psigraptus* is controversial since the first report of Jackson (1967). Main taxonomic criterion is the

number of the first-order stipes: i.e., *P. arcticus* is *biradiate*, *P. lenzi* triradiate and *P. jacksoni* tri- or quadri-radiate (Jackson, 1967; Lin, 1981; Rickards and Stait, 1984). Wang and Chen (1996) described *P. jacksoni* as the adolescent to mature morphs of *P. arcticus*, whereas *P. lenzi* would represent an astogenic gerontic transitional form towards *P. arcticus*. Lin (1981) defined *Yukonograptus* for *P. lenzi* and Zhao and Zhang (1985) erected some new genera such as *Muenzhigraptus*, *Diphygraptus*, *Hunjiangograptus*, and *Holopsigraptus* from the Yehli Formation, Jilin, China. However, all of them were considered to be a junior synonym of *Psigraptus* (Wang and Erdtmann, 1987; Rickards et al., 1991; Jackson and Lenzi, 1999; Kim et al., 2006). Three species of *Psigraptus* including *P. arcticus*, *P. lenzi* and *P. jacksoni* were generally accepted. Recently, Kim et al. (2006) suggested two species of the genus: *P. arcticus* and *P. jacksoni*.

Occurrence: The *Psigraptus* Subzone of all sections of the Mungok Formation.

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References

Barnes, C.R., Norford, B.S., and Skevington, D., 1981, The Ordovician system in Canada. International Union of Geological Sciences Publication, 28, 210 p.

Bulman, O.M.B., 1934, On the graptolites prepared by Holm 6, structural characters of some *Dictyonema* and *Desmograptus* species from the Ordovician and Silulian rocks of Sweden and the east Baltic region. Arkiv f. Zoologie, 26A (5), 1-52.

Bulman, O.M.B., 1941, Some dichograptids of the Tremadocian and Lower Ordovician. Annals and Magazine of Natural History, 11 (7), 100-121.

Bulman, O.M.B., 1950, Graptolites from the *Dictyonema* Shales of Quebec. Quarterly Journal of the Geological Society, 106, 63-99.

Bulman, O.M.B., 1970, Graptolithina. Treatise on Invertebrate Paleontology, Part V, Graptolithina with sections on Enteropneusta and Pterobranchia. 2nd ed., Geological Society of America and University of Kansas Press, 163 p.

Chapman, A.J., Durman, P.N., and Rickards, R.B., 1996, A provisional classification of the graptolite Order Dendroidea. Palaeontological Zoology, 70 (1/2), 189-202.

Cho, H.S., 2003, Early Ordovician Graptolites from the Mungok Formation of Yeongwol Area, Korea. Unpublished Master dissertation, Korea National University of Education, Chungbuk, 127 p.

Choi, D.K., 1998, The Yongwol Group (Cambrian-Ordovician) redefined: a proposal for the stratigraphic nomenclature of the Choson Supergroup. Geosciences Journal, 2, 220-234.

Choi, D.K., Park, G.H., and Kim, D.H., 1994, Tremadocian trilobites from the Mungok Formation, Yeongweol area, Korea. Journal of Paleontoogical Society of Korea, 10, 209-226.

Choi, J.Y., 1993, Conodont biostratigraphy and paleoecology of the Lower Paleozoic Mungok Formation in the Yeongwol-gun and Pyungchang-gun, Korea. Unpublishing MS dissertation, Yonsei University, 124 p.

Cooper, R.A., 1979, Sequence and correlation of Tremadoc graptolite assemblages. Alcheringa, 3, 7-19.

Cooper, R.A., 1999, Ecostratigraphy, zonation and global correlation of earliest planktic graptolites. Lethaia, 32, 1-16.

Cooper, R.A. and Stewart, I., 1979, The Tremadoc graptolite sequence of Lancefield, Victoria. Palaeontology, 22, 767-797.

Erdtmann, B.-D., 1982, A reorganization and proposed phylogenetic classification of planktic Tremadoc (early Ordovician) dendroid graptolites. Norsk Geologisk Tidsskrift, 62, 121-144.

Fortey, R.A. and Cooper, R.A., 1986, A phylogenetic classification of the graptoloids. Palaeontology, 29, 631-653.

Hall, J., 1851, New genera of fossil corals. American Journal of Science, 2, 398-401.

Hall, J., 1865, Graptolites of the Quebec Group. Geological Survey of Canada, Canadian organic remains, Decade, 2, 1-151.

Hedberg, H.D. (ed.), 1976, International Stratigraphic Guide-a guide to stratigraphic classification, terminology, and procedure: John Wiley and Sons, New York, 200 p.

Hopkinson, J. and Lapworth, C., 1875, On new British graptolites. Annals and Magazine of National History, 5, 149-177.

Jackson, D.E., 1967, *Psigraptus*, a new genus from the Tremadoc of Yukon, Canada. Geological Magazine, 104, 311-315.

Jackson, D.E., 1974, Tremadoc graptolites from Yukon territory, Canada. In Rickards, R.B., Jackson, D.E., and Hughes, C.P. (eds.), Graptolite studies in honour of O.M.B. Bulman, Special Paper in Palaeontology, 13, 35-58.

Jackson, D.E., 1975, New data on Tremadoc graptolites from Yukon, Canada. Palaeontology, 18, 883-887.

Jackson, D.E. and Lenz, A.C., 1999, Occurrence of *Psigraptus* and *Chigraptus* gen. nov. in the Tremadoc of the Yukon Territory, Canada. Geological Magazine, 136 (2), 153-157.

Jackson, D.E. and Lenz, A.C., 2003, Taxonomic and biostratigraphical significancd of the Tremadoc graptolite fauna from northern Yukon Territory, Canada. Geological Magazine, 140 (2), 131-156.

Jin, Y.P., 2002, Biostratigraphy and Paleontology of the early Ordovician graptollites from the Mungok Formation, Yeongwol, Korea. Unpublished Ph.D. dissertation, Korea National University of Education, Chungbuk, 172 p.

Kim, D.H., 1999, Stratigraphy and Paleontology of the Lower Ordovician Mungok Formation, Yongwol, Korea. Unpublished Ph.D. dissertation, Seoul National University, Seoul, 263 p.

Kim, D.H. and Choi, D.K., 1995, *Kainella* (Trilobita, Early Ordovician) from the Mungok formation of Yeongweol area and its stratigraphic significance. Journal of the Geological Society of Korea, 31, 579-582.

Kim, D.H. and Choi, D.K., 1999, Occurrence of *Leiostegium* (Trilobita, Early Ordovician) from the Mungok Formation. Journal of the Paleontological Sociey of Korea, 15, 109-114.

Kim, D.H. and Choi, D.K., 2000a, *Jujuyaspis* and associated trilobites from the Mungok Formation (Lower Ordovician), Yongwol, Korea. Journal of Paleontology, 74, 1031-1042.

Kim, D.H. and Choi, D.K., 2000b, Lithostratigraphy and biostratigraphy of the Mungok Formation (Lower Ordovician), Yongwol, Korea. Geosciences Journal, 4, 301-311.

Kim, J.Y., Hwang, K.S., and Park, S.I., 1994, Trace fossils and storm-influenced deposits of the Mungok Formation (Early Ordovician), Yeongwol, Korea. Journal of the Korean Earth Science Society, 15, 115-125.

Kim, J.Y., Cho, H.S., and Erdtmann, B.-D., 2006, *Psigraptus jacksoni* from the Early Ordovician Mungok Formation, Yeongwol area, Korea: taxonomy and development. Alcheringa, 30, 11-22.

Kobayashi, T., 1960, The Cambrian-Ordovician formations and faunas of South Korea, Part , Palaeontology . Journal of the Faculty of Science, 2 (3), 217-275.

Kobayashi, T., 1966, Stratigraphy of the Chosen Group in Korea and South Manchuria and its relation to the Cambro-Ordovician Formations of other areas, section A, The Chosen Group of South Korea. Journal of the Faculty of Science, 2 (16), 1-84.

Kobayashi, T. and Kimura, T., 1942, A discovery of a few Lower Ordovician graptolites in south Chosen with a brief note on the Ordovician zones in eastern Asia. Japanese Journal of Geology and Geography, 18, 307-311.

Kobayashi, T., Yosimura, I., Iwaya, Y., and Hukasawa, T., 1942, The Yukusen geosyncline in the Chosen period: brief notes on the geologic history of the Yukosen orogenic zone, 1. Proceedings of the Imperial Academy of Tokyo, 18, 579-584.

Lee, B.S. and Lee, J.D., 1999, Conodonts from the Mungog Formation (Lower Ordovician), Yeongweol. Journal of the Paleontological Society of Korea, 15, 21-42.

Linnarsson, J.G.O., 1871, Om nåra försteningar från Sveriges och Norges. Öfversigt af Kongl Vetenskaps-Akademiens Förhandlingar, 6, 789-796.

Maletz, J. and Erdtmann, B.D., 1987, *Adelograptus tenellus* (Linnarsson 1871): Its astogenetic development and its stratigraphical and palaeogeographical distribution. Bulletin of the Geological Society of Denmark, 35, 179-190.

Miller, S.A., 1889, North American geology and palaeontology. Western Methodist Book Concern, Ohio, 664 p.

Mu, A.T., 1953, A preliminary study on the graptolites in Taitzeho valley, Laiotung. Acta Palaeontologica Sinica, 1 (1), 23-35.

Mu, A.T., 1955, The new materials of the dendroid graptolites of China. In Lee, J.S., Young, C.C., Sze, S.C., Sun, Y.C., Yin, T.S., Yu, C.C., and Chen, H., (eds.), Palaeontologia Sinica, Whole Number 138, New Series, B (5), 33-62.

Nicholson, H.A., 1872, Monograph of British Grpatolites. Edinberg and London, 133 p.

Paik, I.S., Woo, K.S., and Chung, G.S., 1991, Stratigraphic, sedimentologic and paleontologic investigation of the Paleozoic sedimentary rocks in Yeongweol and Gabsan areas: depositional environments of the Lower Ordovician Mungog formation in the vicinity of Yeongwol. Journal of the Geological Society of Korea, 27, 357-370.

Park, K.H., Choi, D.K., and Kim, J.H., 1994, The Mungog Formation (Lower Ordovician) in the northern part of Yeongwol area: lithostratigraphic subdivision and trilobite faunal assemblages. Journal of the Geological Society of Korea, 30, 168-181.

Rickards, R.B. and Stait, B.A., 1984, *Psigraptus*, its classification, evolution and zooid. Alcheringa, 8, 101-111.

Rickards, R.B., Partridge, P.L., and Bank, M.R., 1991, *Psigraptus jacksoni* Rickards and Stait-systematics, reconstruction, distribution and preservation. Alcheringa, 15, 243-254.

Roemer, F., 1897, Lethaea geognostica; Theil 1, Lethaea palaeozoica, 1. Bd., Graptolithiden: (Lief. 1-2 by Roemer, F.; Lief. 3 continued by Frech, F.), 544-684.

Salvador, A. (ed.), 1994, International Stratigraphic Guide-a guide to stratigraphic classification, terminology, and

procedure. International Union of Geological Sciences and the Geological Society of America, Inc., Colorado, 214 p.

Stubblefield, C.J. and Bulman, O.M.B., 1927, On the Shineton Shales of the Wrekin district. Quarterly Journal of Geological Society of London, 83, 96-146.

Vandenberg, A.H.M. and Cooper, R.A., 1992, The Ordovician graptolite sequence of Australasia. Alcheringa, 16, 33-85.

Wang, X. and Erdtmann, B.-D., 1986, The earlist Ordovician graptolite sequence of Hunjiang, Jilin province, China. Acta Geologica Sinica, 60 (3), 13-27.

Wang, X. and Erdtmann, B.-D., 1987, Zonation and correlation of the earliest Ordovician graptolites from the Hunjang, Jinlin province, China. Bulletin of the Geological Society of Denmark, 35, 245-257.

Wang X. and Wang C., 2001, Tremadocian (Ordovician) graptolite diversification events in China. Alcheringa, 25, 155-168.

Williams, S.H. and Stevens, R.K., 1991, Late Tremadoc graptolites from western Newfoundland. Palaeontology, 34, 1-47.

Won, M.Z. and Lee, H.Y., 1977, Age and biostratigraphy of the Mungog (Samtaesan) Formation by means of the condont fauna. Journal of the Geological Society of Korea, 13, 97-107.

Yosimura, I., 1940, Geology of the Neietsy (Yeongwol) district, Kogendo (Kangwondo), Chosen. Journal of the Geological Society of Japan, 47, 113-122.

Zhang, Y. and Erdtmann, B.-D., 2004, Tremadocian (Ordovician) biostratigraphy and graptolites at Dayangcha (Baishan, Jilin, NE China). Paläontologische Zeitschrift, 78 (2), 323-354.

Zhao, X.L., Lin, Y.K., and Zhang, S.X., 1988, Xinchangian (early Ordovician) graptolite sequence in Hunjiang area of Jilin with comments on Cambrian-Ordovician Boundary. Acta Palaeontologica Sinica, 27 (2), 188-204.

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