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Late Tremadocian Graptolites from the Mungok Formation of the Namaeri and Baeiljae Sections at Yeongwol, Korea

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Abstract: The early Ordovician graptolites from the upper part (Tumok Member) of the Mungok Formation of the Namaeri and Baeiljae sections at Yeongwol consist of five species belonging to five genera. They are *Adelograptus* cf. *tenellus*, *Callograptus* sp., *Dendrograptus suni*, *Dictyonema* sp., and *Psigraptus jacksoni*. Of these 5 species, *Psigraptus* is the most excellent index fossil for international correlation with the early Ordovician strata. *Adelograptus* cf. *tenellus* from the Mungok Formation of the Namaeri and Baeiljae sections is also recognized with especially short stipe relative to *Adelograptus tenellus*. Three graptolite zones (such as *Adelograptus*, *Psigraptus*, and Dendroid type zones) are correlated with those of Canada, Australia, and China, respectively. The upper part of the Mungok Formation is assigned to the late Tremadocian.

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

Introduction

The first occurrence of graptolites was reported by Shiraki (1922) from the Ordovician of the Jikunsan Shale in Hwangjidong, Taebaek, Korea. Subsequently, Shimizu and Obata (1935) recognized three species belonging to three genera of graptolites from the Jigunsan Shale of Makgol village in Sangdong area. Kobayashi and Kimura (1942) also introduced two species belonging to two genera of the early Ordovician graptolites, *Dictyonema* cf. *flabelliforme* and *Clonograptus* (?) sp., from the Mungok Formation, Yeongwol area. Based on the macrofossils containing three species of graptolites, Kobayashi (1966) stated that the Mungok Formation is dated as Tremadocian to Arenigian in its age. Recently, Jin (2002) described nineteen species belonging to six genera of the early Ordovician graptolites from the Mungok Formation of the Yeongwol area and erected three graptolite zones in the formation. Graptolites from the Mungok Formation of Yeongwol area were recently investigated by Kim et al. (2006), Cho and Kim (2007), and Cho et al. (2009). The purposes of this study are to describe early Ordovician graptolites from the Mungok Formation and to establish graptolite biostratigraphy and biocorrelation.

Geological Setting

The Cambrian-Ordovician Choseon Supergroup is mainly composed of carbonates with less amounts of shale and sandstone. This supergroup is widely distributed in the northeastern part of the Okcheon Belt in South Korea. The sedimentary rocks of the Yeongwol type Choseon Supergroup are unconformably underlain by the Precambrian basement and in turn overlain unconformably by the Carboniferous sedimentary rocks. These strata are comprised of the Sambangsan, Machari, Wagok, Mungok, and Yeonghung formations in the ascending order (Yosimura, 1940). The lower three formations of the Yeongwol type Choseon Supergroup are assigned to the Cambrian, while the upper two to the Ordovician (Kobayashi, 1966; Choi, 1998).

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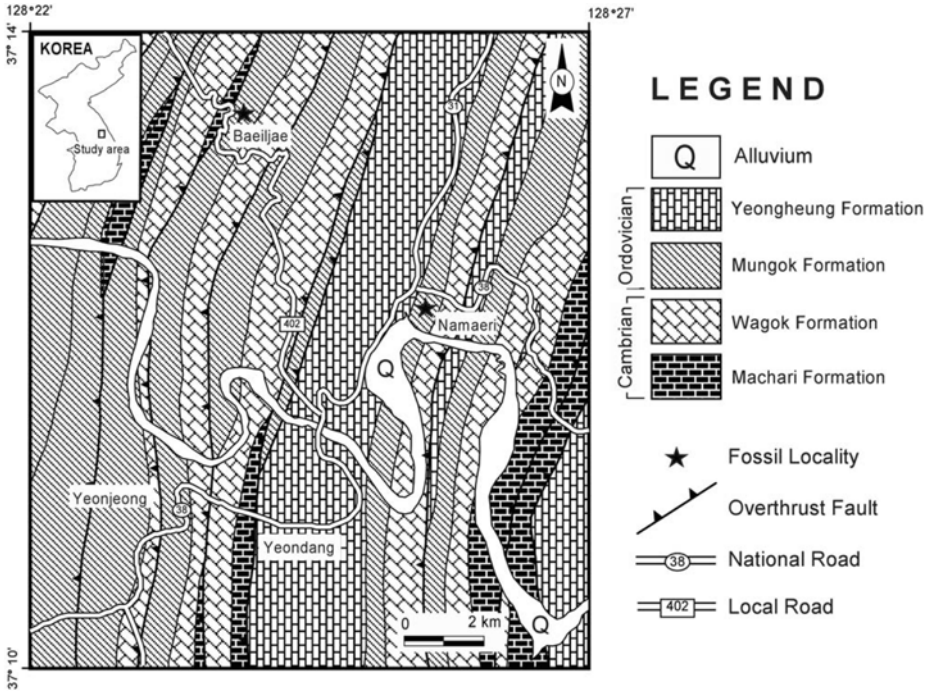

Fig. 1. Geological map of the study area and fossil localities (Lee, 1995; Kim and Choi, 2000).

The Mungok Formation rests conformably on the Wagok Formation and is overlain by the Yeonghung Formation (Fig. 1). This formation is characterized by the distinctive lithofacies such as ribbon rock, grainstone to packstone, marlstone to shale, and flat-pebble conglomerate facies (Paik and Lee, 1989; Paik et al., 1991; Choi et al., 1993; Park et al., 1994; Kim, 1999). The lower and near the uppermost part of the Mungok Formation includes chert beds which can be useful as a marker beds (Paik et al., 1991; Park et al., 1994). Kim (1999) subdivided the Mungok Formation into four lithostratigraphic members according to the assemblages of predominant lithofacies: i.e., the Karam, Peiljae, Chommal, and Tumok members in the ascending order.

The Mungok Formation yields diverse and abundant fossils such as trilobites, graptolites, brachiopods, ostracods, conodonts, and some unidentified fossils. The age of the formation has been somewhat controversial. Based on the fifty species of invertebrate fossils, Kobayashi (1966) stated that the Mungok Formation is dated as Tremadocian to Arenigian in its age. The formation was also correlated to the early Tremadocian to the early Arenigian on the basis of conodonts assemblages (Won and Lee, 1977; Lee and Lee, 1999). Kim (1999) and Kim and Choi (2000) also suggested that the age of the formation can be dated to the early Tremadocian to the late Tremadocian through the trilobite study.

Paik et al. (1991) and Chung et al. (1993) regarded that the Mungok Formation was deposited in a tidal flat environment developed on the carbonate platform with patches of oolitic shoals. In addition, it was suggested that the formation was deposited in high energy storm-influenced environments on the basis of ichnofacies analysis (Kim et al., 1994; Moon and Martin, 1994), and somewhat deeper, shallow ramp to basinal environment based on the eight lithofacies (Choi et al., 1993). Woo et al. (1990) investigated the diagenetic history of the carbonates in the Mungok Formation and delineated that the diagenesis occurred under shallow marine, meteoric, and burial environments.

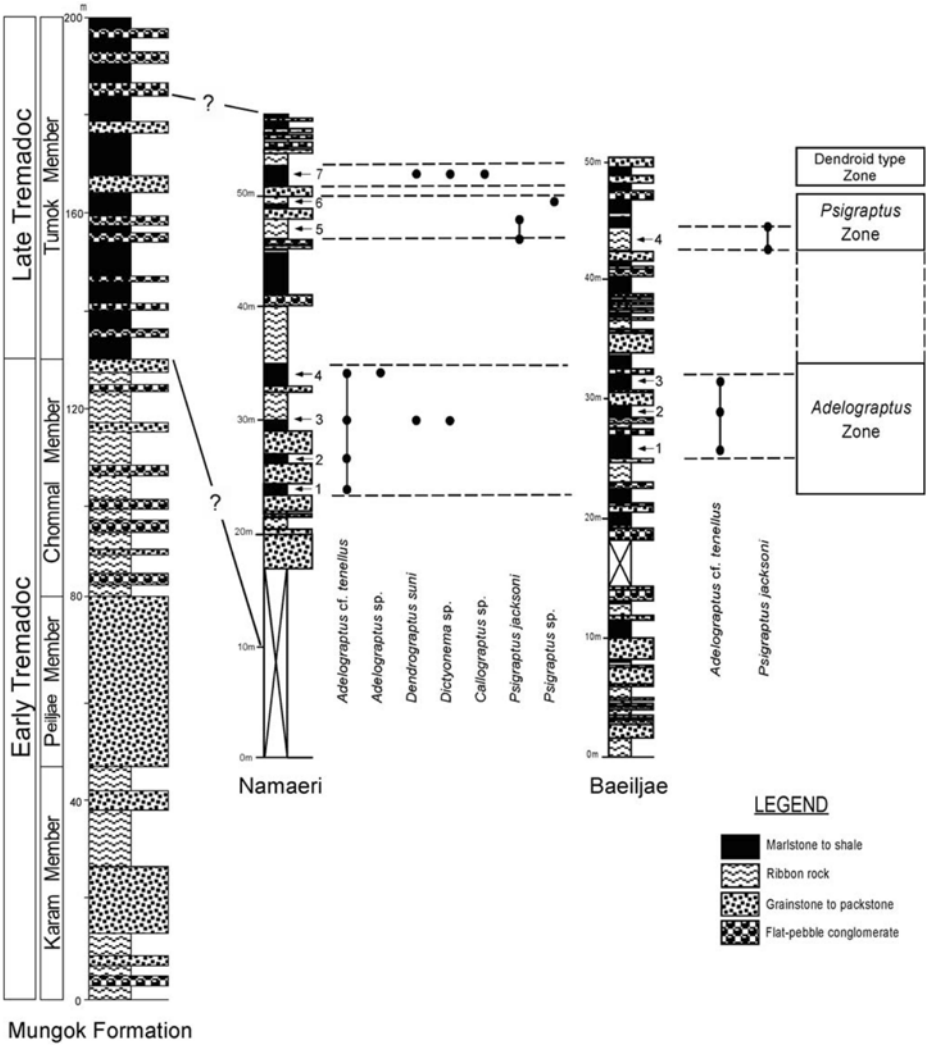

Fig. 2. Stratigraphic distribution and zonation of graptolite taxa from the Namaeri and Baeiljae sections. Numbers right on the column represent Graptolite Beds.

Biostratigraphy and Correlation

Five species belonging to five genera of graptolites are collected from the upper part (Tumok Member) of the Mungok Formation in the two localities of Yeongwol area. They are described herein as *Adelograptus* cf. *tenellus* (Linnarsson), 1871, *Callograptus* sp., *Dendrograptus suni*, Mu, 1955, *Dictyonema* sp., and *Psigraptus jacksoni* Rickards and Stait, 1984 (Fig. 2).

Well preserved graptolites in this study are collected in two sections: the Namaeri and Baeiljae sections (Fig. 1). The Namaeri section is composed of seven graptolite beds which are well exposed along the Seogang (Fig. 2). The *Adelograptus* cf. *tenellus* occurred from the Graptolite Bed 1, 2, 3, and 4 of the section. The Graptolite Bed 5 and 6 also contain *Psigraptus jacksoni* which is very important to establish biostratigraphy and paleogeography. The Graptolite Bed 7 of the section yields commonly dendroid graptolites including *Callograptus*, *Dendrograptus*, and *Dictyonema*.

On the other hand, the Baeiljae section consists of four graptolite beds and *Adelograptus* bed is obvious

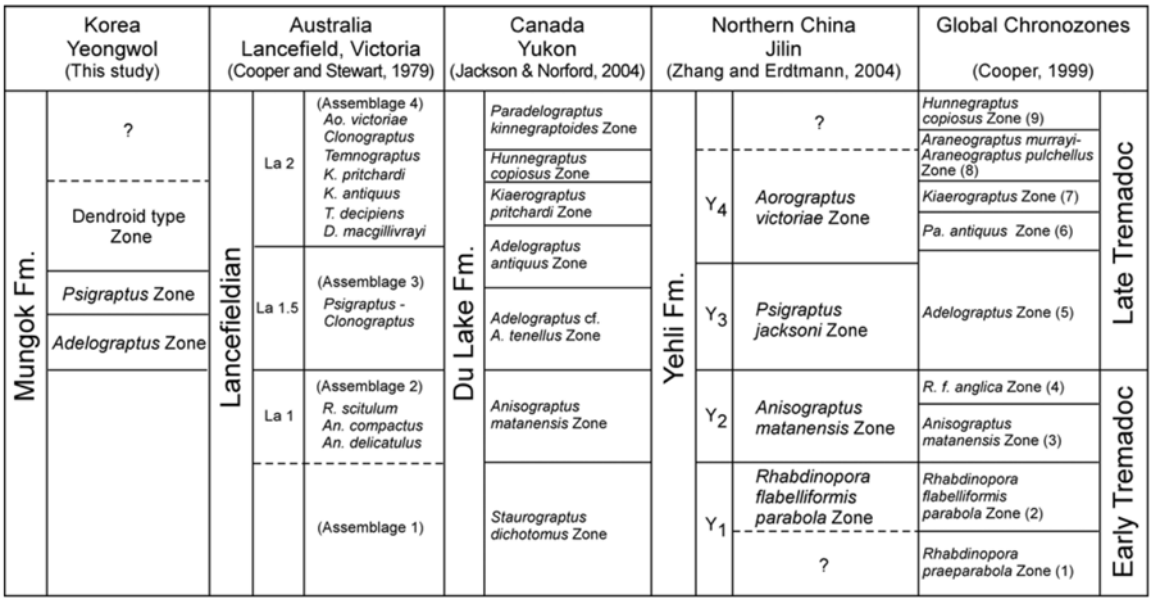

Fig. 3. The correlation of the graptolite zones of the Tumok Member of the Mungok Formation with those of other countries (*An: Anisograptus, Ao: Aorograptus, K: Kiaerograptus, T: Tetragraptus, D: Dictyonema, R: Rhabdinopora, Pa: Paradelograptus, f: flabelliformis*).

within deeply weathered interval zone of this section. Although graptolite fauna is not diverse, well preserved rhabdosome of *Adelograptus* occurs from the Graptolite Bed 2 and 3 of the Baeiljae section. Compared with the Baeiljae section, the Namaeri section is characterized by the Dendroid type Zone which contains *Callograptus*, *Dendrograptus*, and *Dictyonema* (Fig. 2). The *Adelograptus* and *Psigraptus* zones recognized in the Namaeri and Baeiljae sections, and Dendroid Zone observed in the Namaeri section are described herein.

The *Adelograptus* Zone

Composition: *Adelograptus* cf. *tenellus* (Linnarsson), 1871.

Stratigraphic occurrence: This zone starts with appearance of *Adelograptus* cf. *tenellus* which is observed from the Graptolite Beds 1 to 4 of the Namaeri section and the Graptolite Beds 1 to 3 of the Baeiljae section from the Mungok Formation in the study area (Fig. 2). *Adelograptus* Zone is recognized from 15 m above base of the Tumok Member of the upper part Mungok Formation in the Namaeri section. This zone is about 10 m thick and graptolites were mainly collected from deeply weathered shale. The Graptolite Bed 4 of this zone from the Namaeri section contains *Adelograptus* associated with a few dendroid type graptolites. This zone also designated from 15 m above base of the Tumok Member is about 7 m thick and includes *A.* cf. *tenellus* from the Graptolite Beds 1 to 3 of the Baeiljae section (Fig. 2).

Correlation: Cooper (1979) and Cooper and Stewart (1979) reported that *Clonograptus tenellus* (other name of *Adelograptus tenellus*), *Adelograptus* sp., *Psigraptus lenzi* Jackson 1967, and *Clonograptus* spp. were found from the La 1.5 Zone (or Assemblage 3) of Victoria, Australia. This zone was also recognized within the beds of Hunneberg, Sweden and Central Great Britain area where *A. tenellus* was yielded (William and Stevens, 1991). Lately, Jackson and Lenz (2003) and Jackson and Norford (2004) suggested that *Adelograptus* cf. *tenellus* Zone including *Ancoragraptus bulmani* Spjeldnaes 1963, *Psigraptus arcticus* Jackson 1967, and *Psigraptus lenzi*

at Yukon of Canada. Therefore, this zone of the Mungok Formation from the Namaeri and Baeiljae sections can be correlated with the *Adelograptus* Zone of Hunneberg, Sweden and Central Great Britain, La 1.5 Zone (*Psigraptus* and *Clonograptus* Zone or Assemblage 3) of Victoria, Australia, and *Adelograptus* cf. *tenellus* Zone at Yukon, Canada (Fig. 3).

The *Psigraptus* Zone

Composition: *Psigraptus jacksoni* Rickards and Stait 1984

Stratigraphic occurrence: The base of this zone is defined by the first appearance (FAD) of the *Psigraptus jacksoni,* the fourth report in the world after Canada, Australia, and China. The Graptolite Bed 5 and 6 of the Namaeri section is about 4 m and 2 m thick respectively, and the Graptolite Bed 4 of the Baeiljae section belongs to this zone. The lithology of this zone is characterized by the ribbon rock and lime mudstone with very thin argillaceous laminae (Fig. 2).

Correlation: Wang and Erdtmann (1987) proposed the *Psigraptus* Zone on the basis of *P. lenzi*, *P. arcticus*, and *P. jacksoni* in the Yehli Formation of Hunjiang, Jinlin Province, China. The zone is easily correlated with the La 1.5 *Psigraptus-Clonograptus* Zone of Lancefieldian Sequence of Lancefield, Victoria, Australia, and it indicates early late Tremadocian. Zhao et al. (1988) also correlated *Muenzhigraptus-Psigraptus* Zone of Jilin, China with La 1.5 *Psigraptus-Clonograptus* Zone of Victoria, the Pontoon Hill Siltstone Member in Tasmania, Australia, and the lower part of the *Adelograptus antiquus* Zone of Yukon, Canada on the basis of *Muenzhigraptus* species (that it is known as *P. jacksoni*) and other *Psigraptus*. Jackson (1974) reported the occurrence of the *P. lenzi* from the Road River Formation in Yukon, Canada. *P. lenzi* and *P. arcticus* were reported from the Road River Formation in Yukon, Canada by Barnes et al. (1981) who erected the *Psigraptus* Zone between the *Clonograptus aureus* Zone and *Adelograptus antiquus* Zone. Recently, Zhang and Erdtmann (2004) reported the occurrence of the *P. jacksoni* from the Yehli Formation of the Laotougou and Xiaoliaohuangdi sections in Dayangcha, North China.

According to the stratigraphic occurrences mentioned above, the *Psigraptus* Zone of the Mungok Formation from the Namaeri and Baeiljae sections corresponds to the *Psigraptus-Clonograptus* Zone (La 1.5) of the Lancefieldian Sequence at Victoria, Australia, and *P. jacksoni* Zone from the Yehli Formation of the Laotougou and Xiaoliaohuangdi sections in Dayangcha, North China (Fig. 3).

The Dendroid type Zone

Composition: *Callograptus* sp., *Dendrograptus suni* Mu, 1955, and *Dictyonema* sp.

Stratigraphic occurrence: This zone is only designated from the Graptolite Bed 7 of the Namaeri section. The interval of the Dendroid type Zone is about 3 m thick, 42 m above from base of the Tumok Member of the Mungok Formation. It is located nearly above the *Psigraptus* Zone of the Namaeri section (Fig. 2). The outcrop of this zone is bluish gray to gray, deeply weathered, and well laminated shale. The Dendroid type Zone is 2 m in thickness and contains dendroid type graptolites such as *Callograptus*, *Dictyonema*, and *Dendrograptus*.

Correlation: The dendroid type graptolites such as *Callograptus curvithecalis*, *Dendrograptus suni,* and *Dictyonema uniforme* were reported from the Tremadocian Yehli Formation, Liaoning, northern China (Mu, 1953, 1955). However, the correlation of this zone is difficult because of a few occurrences of dendroid type graptolites. The Dendroid type Zone of the Mungok Formation in the Namaeri section can be correlated with the *Adelograptus antiquus* Zone of Yukon, Canada and Y_4 Zone (*Aorograptus victoriae* Zone) of the Yehli Formation at Jilin, northern China (Fig. 3).

Systematic Paleontology

The taxonomic categories herein mainly follow Erdtmann (1982) and Fortey and Cooper (1986). All specimens investigated in this study are housed in the Paleontological Lab. of the Department of Earth Science Education, Korea National University of Education.

Class GRAPTOLITHINA Bronn, 1846
Order DENDROIDEA Nicholson, 1872
Family Dendrograptidae Roemer in French, 1897

Genus *Dendrograptus* Hall, 1858

Type species: *Graptolithus hallianus* Prout, 1851; by subsequent designation of Hall (1862).

Diagnosis: See Bulman (1970).

Remarks: The original description of Prout (1851) gave little detailed information about type species, and Ruedemann (1947) did not comment upon bithecae in his redescription except in *Dendrograptus hallianus* subspecies. The rhabdosome has clear indications of bithecae and autothecae in the axis of the branching points.

Dendrograptus suni Mu, 1955
Fig. 4-A

Diagnosis: See Mu (1955).

Material: Two specimens (NE 02207, NE 02210) with incompletely preserved in distal part.

Description: None of the rhabdosome is complete but main stipe 20 mm long in Fig. 3-A has been observed. The thickness of stipe is about 0.4-0.6 mm and the proximal stem is thicker than that of the distal part (Fig. 4-A). Both autothecae and bithecae are not seen because of poor preservation of rhabdosome.

Remarks: This species were firstly reported by Mu (1955) from the *Callograptus*? *taizehoensis* Zone of the Tremadocian Yehli Formation in Liaoning, which contains *Dictyonema uniforme*, *Callograptus*? *taizehoensis*, *Dendrograptus sinensis*, *D. suni*, and *D. y-wangi*.

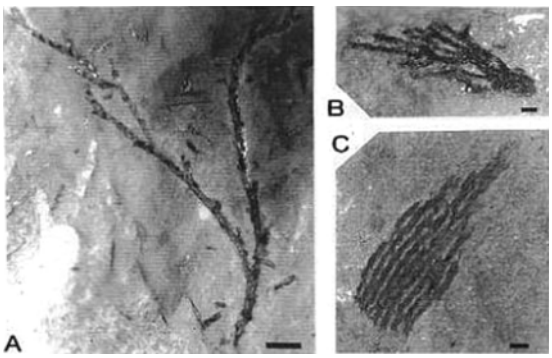

Fig. 4. Graptolites from the Tumok Member of the Mungok Formation in the Namaeri section of the Yeongwol area. A: *Dendrograptus suni* Mu, 1955, B: *Callograptus* sp., C: *Dictyonema* sp. All scale bars indicate 1.0 mm.

Occurrence: The Graptolite Bed 3 and 7 of the Namaeri section (Fig. 2).

Genus *Callograptus* Hall, 1865

Type species: *Callograptus elegans* (Miller, 1889)

Diagnosis: See Bulman (1970).

Remarks: According to Bulman's (1927-67) monograph of British dendroid graptolites, anastomosis is regulated to a minor role, yet several illustrated specimens show considerable anastomosis. *Callograptus* is distinguished from *Dictyonema* in that the latter has far more dissepiments, less anastomosis, much more regular and zoned stipe divisions, and has, as a rule, more loosely spaced autothecae. Rickards et al. (1988) reported that there is a morphological series of *Dictyonema-Callograptus-Desmograptus* which might be a broad evolutionary series.

Callograptus sp.
Fig. 4-B

Material: Two distal specimens (NE 02218, NE 02309).

Description: Rhabdosome elongated; 5.5-8 mm in length and 12-15 mm in width. Rhabdosome has thicker stipe in the proximal part than distal stem. Stipes sinuous and subparallel to one another are connected by conspicuous dissepiments. Dissepiment

is thin, about 0.3-0.4 mm wide, sparse, almost straight with irregularity (Fig. 4-B).

Occurrence: The Graptolite Bed 7 of the Namaeri section (Fig. 2).

Genus *Dictyonema* Hall, 1851

Type species: *Gorgonia retiformis* Hall, 1843; by subsequent designation of Miller (1889).

Diagnosis: See Bulman (1970).

Remarks: *Dictyonema* is one of the benthic dendroid graptolites which ranged from the Late Cambrian to early Late Carboniferous. Rhabdosome is mostly incomplete without proximal portions. Such forms must be often regarded as having been attached by their proximal ends, either because they are commonly found with other dendroid species whose sessile benthic nature is secure or because of the synecological situation in general (Palmer and Rickards, 1991).

Erdtmann (1982) proposed that planktic *Dictyonema flabelliforme* is differentiated from the benthic *Dictyonema* which is regarded as ancestral to all the planktic family Anisograptidae. Furthermore, genus *Rhabdinopora* Eichwald, 1855 belongs to the family Anisograptidae and *Anisograptus* and *Dictyonema* were differentiated from the *Dendrograptus* by having numerous dissepiments (Erdtmann, 1982).

Only one specimen dealt with in this study is preserved in rhabdosome without proximal portion which is also occurred in association with other sessile dendroids of *Dendrograptus* and *Callograptus* in the Mungok Formation.

Dictyonema sp.
Fig. 4-C

Material: One specimen (NE 02217) without proximal part.

Description: The rhabdosome is not complete but fragmented portion. The interval of the neighborhood stipes seems like a little wide shape from proximal part to distal, and it is approximately 0.3-0.4 mm wide. Stipes are connected by irregularly spaced dissepiments in some area, spacing is every 2 mm, whereas connections may be by anastomosis. Stipe widths are approximately 0.2-0.3 mm. Branching zones are roughly every 2-4 mm whose length increases from proximal to distal part. The zones are slightly more widely spaced distally than proximal stem (Fig. 4-C).

Occurrence: The Graptolite Bed 7 of the Namaeri section (Fig. 2).

Order GRAPTOLOIDEA Lapworth, 1875
Family ANISOGRAPTIDAE Bulman, 1950

Genus *Adelograptus* (Bulman, 1941)

Type species: *Bryograptus? hunnebergensis* Moberg 1892 (=*Dichograptus*? *tenellus* Linnarsson, 1871).

Diagnosis: See Maletz and Erdtmann (1987).

Remarks: Bulman (1941) showed the evidence of three first order stipes but he thought that two first order stipes in Lapworth's paper (1875) are probably due to concealment of the third (central) stipes by matrix. Also, he proposed to restrict *Bryograptus* to the genotype in possessing three first order stipes and to transfer those species with only two first order stipes to the new genus *Adelograptus* (Bulman, 1941).

After Bulman's (1941) proposal, the problems of classification between *Adelograptus* and *Clonograptus* arose. The differences of these two genera are; sub-horizontal and declined rhabdosomes, more irregular branching, more variable lengths in *Adelograptus*, and strictly horizontal rhabdosome, symmetrical first order stipes with only one theca in *Clonograptus*. The presence or absence of bithecae in *Clonograptus* has been also controversial. Erdtmann et al. (1987) insisted presence, and Braithwaite (1976) and Jackson (1973), however, insisted absence. In this view, based on the presence of bithecae, Maletz and Erdtmann (1987) proposed to include *Clonograptus* within the graptoloid family Dichograptidae and retain *Adelograptus* as the bithecae-bearing ancestor in the dendroid family Anisograptidae.

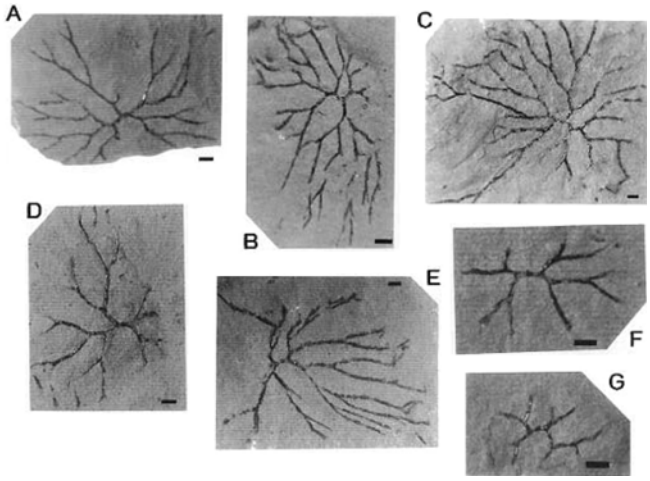

Fig. 5. Graptolites from the Tumok Member of the Mungok Formation in the Baeiljae section of the Yeongwol area. A-G: *Adelograptus* cf. *tenellus*. All scale bars indicate 1.0 mm.

Adelograptus cf. *tenellus* (Linnarsson, 1871)
Figs. 5-A-G; Figs. 6-C-F

Material: Several hundreds of well preserved specimens from the Baeiljae section of the Mungok Formation.

Description: This form has nearly horizontal stipe disposition. The sicula varies in length from ca. 0.75 mm to 1.6 mm (0.9 mm average) and funical lengths, about 0.6-2.0 mm (1.06 mm average), have relatively short length compared with *Adelograptus tenellus* (Table 1 and 2). Rhabdosome is characterized by stipe bifurcations. The length of stipes are 0.5-1.6 mm in second order, 1.2-2.6 mm (1.67 mm average) in third order, and 1.8-4.4 mm (2.78 mm average) in fourth order (Table 2). These stipes branch, usually dichotomously, near the aperture of theca 1^2 and approximately 5-7 mm in diameter throughout the rhabdosome. Data from a large number of specimens show that the second stipes normally diverge at a low angle ranging from about 40° to 135° (86° average). However, several specimens are preserved with high angle from 90° to 135°, and they show the reclined graptolites (Figs. 5-B-C and Figs. 6-C-E). The width of stipes are ca. 0.15-0.26 mm (0.19 mm average) in proximal part (Table 1) and ca. 0.2-0.3 mm (0.24 mm average) in distal part, this proves the cortical overgrowth in the proximal part.

Remarks: Several multiramous graptolites with subhorizontal to declined rhabdosomes formerly had been assigned to *Adelograptus*. Stubblefield and Bulman (1927) recorded *Dictyonema flabelliforme* (Eichwald, 1840), *Clonograptus tenellus*, *C. tenellus* var. *callavei* Elles and Wood 1902, and *Bryograptus hunnebergensis* (Moberg, 1892) from the Transition Beds. After, then, Bulman and Cooper (1969) reported that *Adelograptus hunnebergensis* and *Clonograptus tenellus* which are potential synonyms based on the previously description from the New Zealand graptolites (Hall, 1899), and other *Clonograptus* (Hall, 1914; Benson and Keble, 1935). Hutt (1974) explained that the development of *Clonograptus tenellus* and *Adelograptus hunnebergensis* is described for the first time. Her study showed that the mode of development and the internal stolon system suggested by Bulman (1949) had been confirmed, and early growth stages were compared with those of *Rhabdopleura compacta*.

Maletz and Erdtmann (1987) proposed that the proximal part of *Clonograptus* is symmetrical with both first order stipes consisting of one theca only. Whereas, in *Adelograptus*, the lengths of the first order stipes are more variable and even both first order stipes may be different length. Bithecae are present in *Adelograptus*, but have not been found in

Table 1. Biometric data of proximal part of *Adelograptus* cf. *tenellus* from the Mungok Formation

Specimen No.	Funicle length (mm)	Sicula length (mm)	Stipes width (mm)
BJ 02415	1.2	0.8	0.2
BJ 02321a,b	1.1	0.75	0.2
BJ 02103	1.6	0.83	0.2
BJ 02310	0.86	0.8	0.23
BJ 02114	-	0.76	0.2
BJ 02105	0.9	0.83	0.15
BJ 02405	2.0	1.6	0.25
BJ 02417	-	1.0	0.23
BJ 02213	1.4	1.0	0.25
BJ 02206	1.0	1.0	0.15-0.26
BJ 02311	-	0.6	0.2
BJ 02307	0.85	0.76	0.17
BJ 02409	-	1.0	0.16

Table 2. Comparison of *Adelograptus tenellus* with *A.* cf. *tenellus* from the Mungok Formation

Graptolites dimensions	*A. tenellus* (Maletz and Erdtmann, 1987)	*A.* cf. *tenellus* (This study)
Sicula length (mm)	1.0-1.2	0.75-1.6
Funicle length (mm)	3.0-6.0	0.6-2.0
2nd order stipes length (mm)	3.0-12.0	0.5-1.6
3rd order stipes length (mm)	5.0-10.0	1.2-2.6
4th order stipes length (mm)	7.0-12.0	1.8-4.4
Stipes width (mm)	0.3-0.5	0.15-0.3

Clonograptus (Jackson, 1973). Based on this fact, *Clonograptus tenellus* was transferred to *Adelograptus* as *A. tenellus*.

Occurrence: The Graptolite Bed 1-4 of the Namaeri section and the Graptolite Bed 1-3 of the Baeiljae section (Fig. 2).

Genus *Psigraptus* Jackson 1967

Type species: *Psigraptus arcticus* Jackson, 1967

Diagnosis: See Kim et al. (2006).

Remarks: The simplification of graptolite rhabdosome pointed out by Elles (1922, 1923, 1933) and Bulman (1933, 1955, 1958) is one of the most important trends in evolution of graptoloids. It is true that in many graptolites especially in the *Psigraptus* fauna, the reduction of proximal stipes is considerably remarkable.

Psigraptus was first introduced as a new graptolite genus by Jackson (1967), who described two-stiped *P. arcticus* and the three-stiped associated species *P. lenzi* on the basis of a study of compressed specimens collected probably in the *Adelograptus antiquus* Subzone at Rock River, Yukon Territory, Canada (Jackson, 1974).

The Tremadocian *Psigraptus jacksoni* is considered stratigraphically and evolutionarily intermediate between *Rhabdinopora* or *Staurograptus* and *Psigraptus* species in later (Rickards and Stait, 1984). The first documentation of the genus outside Canada was by Cooper and Stewart (1979), who recorded a three or four-stiped form of *P. lenzi*, together with *Clonograptus* at a stratigraphic level between La 1 and La 2 zones in Stauro Gully, Victoria, Australia. Cooper and Stewart (1979) reported the high variability of rhabdosome and thecal morphology occurred from irregularities introduced during flattening and burial on the sea floor, and subsequent tectonic distortion.

Rickards and Stait (1984) described a third new species called *Psigraptus jacksoni* from Florentine Valley, Tasmania in Australia. Subsequently, as a

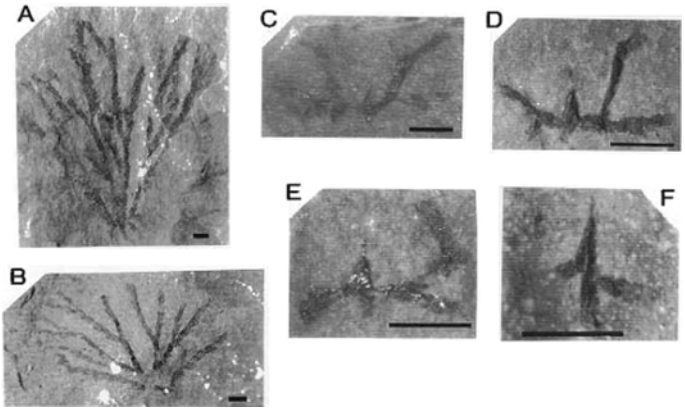

Fig. 6. Graptolites from the Tumok Member of the Mungok Formation in the Namaeri and Baeiljae sections of the Yeongwol area. A and B: *Psigraptus jacksoni* Rickards and Stait, 1984, C-E: Reclined *Adelograptus* cf. *tenellus*., F: Proximal part of *Adelograptus* cf. *tenellus*. All scale bars indicate 1.0 mm.

result of their study with *Psigraptus jacksoni*, they concluded that there was so much morphological variation as to render meaningless any classification based on the number of terminal stipes.

Lin (1981) proposed for the three-stiped *P. lenzi* and the Family Psigraptidae, because it was indistinguishable from the Family Anisograptidae. Zhao and Zhang (1985, 1986) proposed four new genera of psigraptids, based on the degree of isolation of autothecae and orders of branching, such as *Muenzhigraptus*, *Diphygraptus*, *Hunjiangograptus*, and *Holopsigraptus* from the Yehli Formation in Jilin, northeast China. However, Wang and Erdtmann (1986, 1987) reported that their taxonomy on basis of the morphology of theca and the capacity of dichotomy was misled from misconception of preservation process.

Jin (2002) suggested that the three species of *Psigraptus* (*P. arcticus*, *P. lenzi,* and *P. jacksoni*), including psigraptids of the several species from the China, should be affiliated to *P. arcticus*. According to his study, there were synchronously lots of the forms of *Psigraptus* rhabdosome on the identical bedding surfaces such as *P. arcticus*, *P. lenzi*, and *P. jacksoni* (Jin, 2002). Consequently, these psigraptids are the same species in spite of different morphology according to the preservational condition.

Psigraptus jacksoni Rickards and Stait, 1984

Figs. 6-A and B

Diagnosis: See Kim et al. (2006).

Material: Several hundred specimens.

Description: The length of stipe increases distally though it varies considerably. The lengths of stipes are 0.5-0.8 mm in first order when measured between the sicula and the first branching part, 0.45-0.8 mm in 2nd order, 0.75-2.5 mm in 3nd order, 0.9-3.2 mm in 4th order, 1.1-3.7 mm in 5th order, and 1.8-3.6 mm in 6th order.

The whole size of rhabdosome is diverse in graptolite collection. Maximum size of the reclined colony is about 20 mm long and circumscribes a reclined cone of some 12 mm at its widest. The general form of mature rhabdosome is upright, but juvenile rhabdosome is somewhat curved shape. The free meta-thecae are well-developed at proximal part of rhabdosome and decrease distally to become denticulate along the stipes (Figs. 6-A and B).

Remarks: *Psigraptus* appears to contain diverse shapes because of soft sedimental matrix and a flexible rhabdosome (Rickards et al., 1991). The specimens from the Mungok Formation are similar to Chinese graptolites. Based on the degree of thecal isolation and of the reclination of the stipes, most of the *Psigraptus* of China appears to be a single species even though considering the preserved variability. At

present only three species are known; *P. arcticus*, *P. lenzi*, and *P. jacksoni*. Lin (1981) made *P. lenzi* the type species of new genus *Yukonograptus*, which differs from *Psigraptus* only in having 'three primary stipes' as opposed to *P. arcticus* and *P. jacksoni*.

P. jacksoni clearly shows that greater rhabdosomal variation is possible in this group, particularly when mature specimens are at hand, and for this reason both the genus *Yukonograptus* and the new family Psigraptidae erected by Lin (1981) on graptodendroids (Rickards and Stait, 1984) should be rejected. However, it is difficult to be sure of the demanded specific differences of these new genera because thecal spacing, stipe dimensions, and stipe dispositions are almost identical. All of these were also considered to be a junior synonym of *Psigraptus* in later (Wang and Erdtmann, 1987; Rickards et al., 1991; Jackson and Lenz, 1999).

Occurrence: The Graptolite Bed 5 and 6 of the Namaeri section and the Graptolite Bed 4 of the Baeiljae section (Fig. 2).

Conclusions

Five species belonging to five genera of the early Ordovician graptolites from the Mungok Formation of the Namaeri and Baeiljae sections, Yeongwol are described as *Dendrograptus suni*, *Adelograptus* cf. *tenellus*, *Callograptus* sp., *Dictyonema* sp., and *Psigraptus jacksoni*. Especially, *Psigraptus* is one of the most powerful index fossils for correlation of the early Ordovician strata. *Adelograptus* cf. *tenellus* from the Mungok Formation has similar characteristics to *A. tenellus* except for short-stipe length.

Eleven graptolite beds were recognized from the Namaeri and Baeiljae sections. The Graptolite Beds 1 to 4 of the Namaeri section and the Graptolite Beds 1 to 3 of the Baeiljae section yield commonly *Adelograptus* cf. *tenellus*, which are named the *Adelograptus* Zone. The *Psigraptus jacksoni* is commonly collected from the Graptolite Beds 5 to 6 of the Namaeri section and the Graptolite Bed 4 of the Baeiljae section; this interval is named the *Psigraptus* Zone. The Graptolite Bed 7 of the Namaeri section containing *Callograptus*, *Dendrograptus*, and *Dictyonema* is designated as the Dendroid type Zone.

On the basis of the graptolite fossils, the upper part (Tumok Member) of the Mungok Formation is Tremadocian correlated to late Tremadocian Lancefield Formation of Lancefield, Australia, the Yehli Formation of Jinlin, China, and the Road River Formation of Yukon, Canada.

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