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A New Graptolite Species *Adelograptus brevibrachiatus* from the Mungok Formation of Yeongwol Area, Korea

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Abstract: *Adelograptus brevibrachiatus* sp. nov. is erected for materials previously referred to as *Adelograptus* cf. *tenellus* from the circum-Pacific area. The species shares many morphological characteristics with *Adelograptus tenellus* from Europe but differs from it by possessing typically short stipe lengths throughout rhabdosome due to less thecal density along the stipes. Taxonomic characteristics of *A.* cf. *tenellus* reported from circum-Pacific area are compared with each other. The paleogeographic distribution of *A. tenellus* seems to be restricted within Europe, while that of *A. brevibrachiatus* within circum-Pacific area.

Keywords: *Adelograptus*, graptolite, Ordovician, Yeongwol, Korea

Introduction

Taxonomy of the adelograptids has been for a long time complicated due to a wide range of diagnosis on *Adelograptus tenellus* (Linnarsson, 1871; Cooper, 1979; Maletz and Erdtmann, 1987; Jackson and Lenz, 2000, 2003). Based on Hutt's (1974) observation that *Clonograptus tenellus* and *Adelograptus hunnebergensis* share identical proximal development patterns, Maletz and Erdtmatnn (1987) transferred *C. tenellus* to *Adelograptus* and showed that the species is very variable. One of the main characteristics on the taxonomic identification of graptolites is influenced by the post-mortem orientation and mode of rhabdosome burial (Maletz and Erdtmatnn, 1987). Since the first report of *C. tenellus* from Australasia (Hall, 1899), many studies of the species from the circum-Pacific area have been carried out (Benson and Keble, 1935; Hsü, 1936; Harris and Thomas, 1938; Mu, 1955; Berry, 1960; Jackson and Lenz, 1962; Braithwaite, 1976; Jackson, 1974; Cooper, 1979; Cooper and Stewart, 1979; Williams and Stevens, 1991; Jackson and Lenz, 2003; Jackson and Norford, 2004; Zhang and Erdtmann, 2004). When compared with *C. tenellus* from Europe, the species from the circum-Pacific area exhibits a similar proximal development patterns and rhabdosomal appearance but is different by a shorter first-order stipe and more closely spaced branching (Williams and Stevens, 1991; Jackson and Lenz, 2003). Although application of the British Arenig and Tremadoc series to sequences from the outside of Britain is not straightforward, there is a big gap in the stratigraphic occurrences of the species between the Atlantic and circum-Pacific areas: Early Tremadocian in Atlantic and Late Tremadocian in circum-Pacific areas. Moreover, many graptolitists doubted the records of the species from late Tremadoc strata in circum-Pacific area (Bulman and Cooper, 1969; Maletz and Erdtmann, 1987; Williams and Stevens, 1991).

Recently, Lower Ordovician (Tremadocian) Mungok Formation has been reported to yield abundant graptolites including adelograptid (Jin, 2002; Cho, 2003; Kim et al., 2003, 2006). Adelograptids from the formation are able to identify its characteristics in detail and to compare it with coeval ones elsewhere. This paper aims to report *A. brevibrachiatus* sp. nov. from the formation and to discuss its stratigraphical and taxonomic meanings.

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Geologic Setting and Fossil Localities

The Lower Ordovician (Tremadocian) Mungok Formation distributed in Yeongwol area (Fig. 1) is composed of ca. 200 m thick carbonate rocks, representing a supratidal to subtidal environment (Paik and Lee, 1989; Paik et al., 1991) and high energy storm-influenced deposits (Kim et al., 1994; Moon and Martin, 1994). Four conodont assemblage biozones (Lee and Lee, 1999), three trilobite biozones; the *Yosimuraspis vulgaris*, *Kainella euryrachis* and *Shumadia pellizzarii* zones in ascending order (Kim and Choi, 2000), and two graptolite biozones; the *Adelograptus* spp. and *Callograptus curvithecalis* zones in ascending order (Cho, 2003) were established in the formation. The formation is dated to be the early Early to early Late Tremadocian (Jin, 2002; Cho, 2003; Kim et al., 2003, 2006).

The Myeongjon Section is exposed along the local road 533 at Myeongjon village, 3.5 km southwest of Yeongwol Town. This section measures ca. 48 m in thickness, with strike N20°E and dip 40°NW. Graptolites were collected from two intervals of the section (Fig. 1). The lower interval graptolite bed 1 to 3 (Fig. 1), ca. 8 m to 11 m above the base of the measured section, yield *Adelograptus brevibrachiatus* associated with *Psigraptus jacksoni* Rickards and Stewart, 1984 and many dendroids, and the upper interval graptolite bed 4 (Fig. 1), ca. 34 m to 43 m above the base of the measured section, also contains the species.

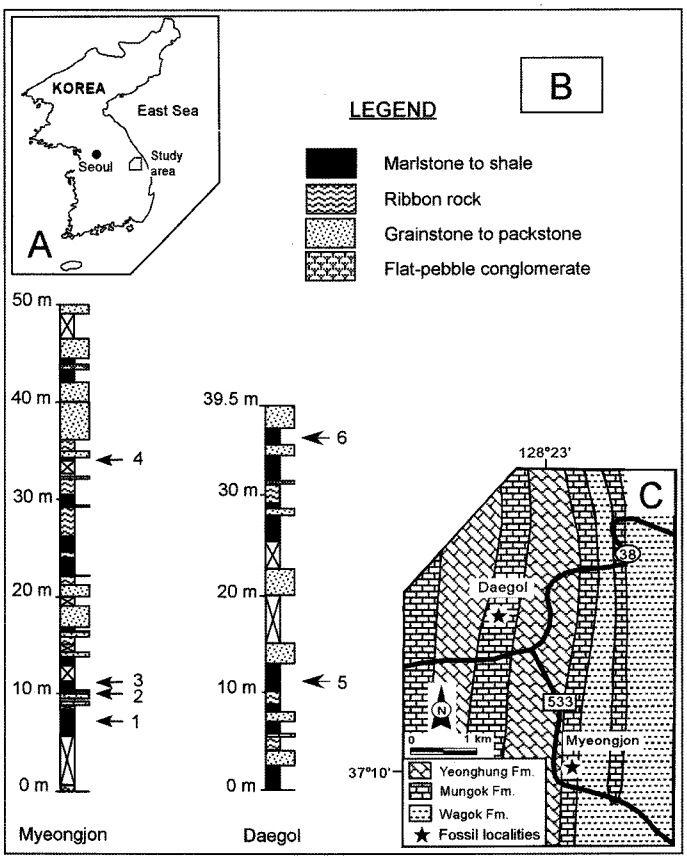

Fig. 1. Geologic map of the study area and stratigraphic distribution of graptolites. A, Korean peninsula showing study area. B, Stratigrapthic columns of the measured sections showing *Adelograptus brevibrachiatus* bearing beds. C, Geologic map of the study area and fossil localities.

The Daegol Section is exposed along the national road 38 in the vicinity of the Changwon village, 3.0 km southwest of Yeongwol Town. This measured section is ca. 40 m in thickness, with strike N32°E and dip 40°NW. Graptolites were collected from two intervals in the section (Fig. 1). The lower interval graptolite bed 5 (Fig. 1), ca. 10 m to 14 m above the base of the measured section, yields *Adelograptus brevibrachiatus* also associated with *P. jacksoni*, and the upper interval graptolite bed 6 (Fig. 1), ca. 36 m to 38 m above the base of the measured section, also contains the species.

Distribution of Adelograptids

Adelograptus tenellus was first described by Linnarsson (1871) from Hunneberg Mountain of Västergöland, Sweden. Since that time, the species has been reported from the *Dictyonema* Shales, between the zones of *Rhabdinopora flabelliformis flabelliformis* Eichwald and *R. f. norvegica* Kjerulf, of several of Atlantic areas (Maletz and Erdtmann, 1987). Cooper (1999) placed the Zone of *Adelograptus* including *A. tenellus* and *Psigraptus* in the base of the Late Tremadocian. The stratigraphic position of *A. tenellus* is late Early Tremadocian or early Late Tremadocian in Europe (Maletz and Erdtmann, 1987; Cooper, 1999). However, some materials related to the species (=*A.* cf. *tenellus*) frequently reported from middle Late Tremadocian in the outside of Europe: *Aorograptus victoriae* Zone of Newfoundland (Williams and Stevens, 1991), *Kiaerograptus pritchardi* Zone of Yukon (Jackson and Lenz, 2003), and *Aorograptus victoriae* Zone of North China (Zhang and Erdtmann, 2004). *A. brevibrachiatus* (=*A.* cf. *tenellus*) from the outside of Europe shows relatively longer zonal range and younger than *A. tenellus* of Europe: from the early Late Tremadocian *Adelograptus tenellus* Zone to middle Late Tremadocian *Aorograptus victoriae* Zone.

Since Hall (1899) reported *Clonograptus rigidus* var. *tenellus* (Linnarsson) from the Lancefield beds of Victoria, Australasia, many materials related to *A. tenellus* have been known: *Bryograptus hunnebergensis* Moberg, *C. tenellus* var. *callavei* (Lapworth), and *Clonograptus tenellus* var. *kingi* Benson and Keble from Fiordland of New Zealand (Benson and Keble, 1935), *Clonograptus tenellus* var. *callavei* from the Tanchiachiao Shale of South Anhui, China (Hsü, 1936), *Clonograptus tenellus* var. *problematica* Harris and Thomas from Victoria of Australia (Harris and Thomas, 1938), *Clonograptus tenellus* var. *callavei* from the Yinchupu Shale of western Zheijiang, China (Mu, 1955), *C.* cf. *tenellus* from the Marathon region of Texas, USA (Berry, 1960), *C. tenellus* from the Road River Formation of Yukon, Canada (Jackson and Lenz, 1962), *Adelograptus hunnebergensis* from the Martin Point of Newfoundland, Canada (Erdtmann, 1971), *C. tenellus* from the Xinchang Formation in Taishan of Guangdong, China (Wang et al., 1979), *C. tenellus* from the Lower Ordovician Maoping Formation of Chongyi, Jiangxi, China, *C. t.* var. *callavei* from the upper part of the Yehli Formation of Hunyuan, Datong, Shanyin districts, Shanxi (Lin, 1981), *Adelograptus* cf. *tenellus* from Newfoundland (Williams and Stevens, 1991), from Yukon (Jackson and Lenz, 2003), and from Jilin (Zhang and Erdtmann, 2004).

As Bulman and Cooper (1969) have noted no resemblance between the materials of New Zealand and north-west European counterpart, especially considering a conspicuously short funicle of the New Zealand materials, the adelograptids related to *tenellus* from the circum-Pacific area are, in morphological and stratigraphical view, different from *A. tenellus* of Europe. As shown in Fig. 2, the geographic distribution of *A. tenellus* (Linnarsson) *sensu stricto* seems to be restricted within Europe (Bulman, 1971), while that of *A. brevibrachiatus* (=*A.* cf. *tenellus*) within Yukon of Canada, Lancefield of Australia, Jilin of North China, and Yeongwol of Korea. The postulation is supported by the distribution of *Psigraptus jacksoni* frequently associated with *A. brevibrachiatus* (Fig. 2).

Systematic Paleontology

Order Graptoloidea Lapworth, 1875

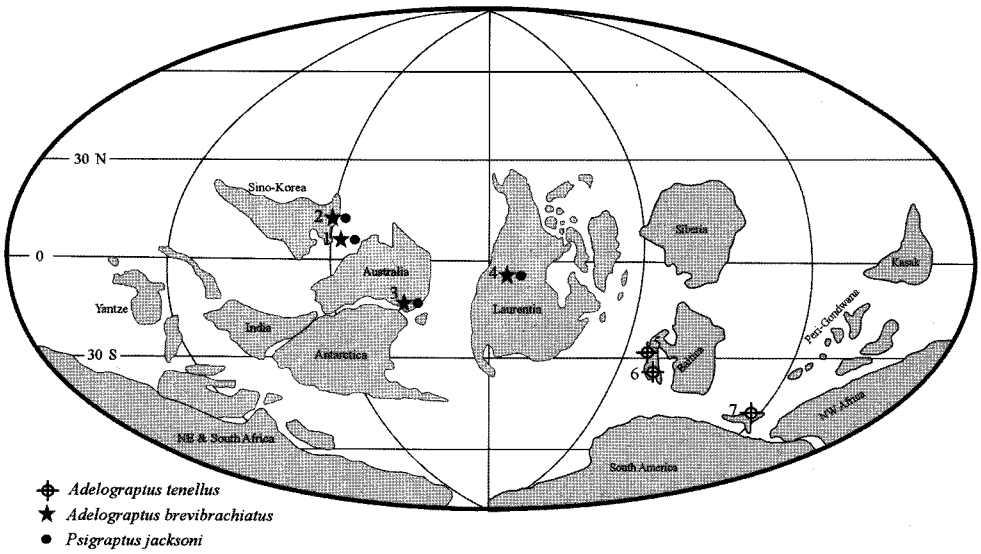

Fig. 2. Early Ordovician paleogeographic map showing the occurrence of *Adelograptus tenellus*, *Adelograptus brevibrachiatus*, and *Psigraptus jacksoni*, modified from Scotese and McKerrow (1990) and Zhang and Erdtmann (2004). 1, Yeongwol (this study). 2, Jilin (Wang and Erdtmann, 1986, 1987; Zhang and Erdtmann, 2004). 3, Lancefield (Cooper and Stewart, 1979). 4, Yukon (Jackson and Norford, 2004). 5, Hunneberg (Linnarsson, 1871; Moberg, 1892; Maletz and Erdtmann, 1987). 6, Oslo (Monsen, 1925; Bulman, 1954; Erdtmann, 1965). 7, Great Britain (Bulman and Rushton, 1973).

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: The confusion in separation of *Adelograptus* from *Bryograptus* comes from their similar characteristics: sub-symmetrical, pendent or declined, and dendroid morphology. According to Lapworth's (1875) original diagnosis, the 1st-order stipes of *Bryograptus* are two. Bulman (1941), however, showed the evidence of three 1st-order stipes (Westergård, 1909), and he thought that the two 1st-order stipes in Lapworth (1875) were probably due to concealment of the third (central) stipe by matrix. And he proposed that *Bryograptus* should be restricted to the species identical with the genotype in possessing three 1st-order stipes, and those species with only two 1st-order stipes should be transferred to the new genus *Adelograptus* (Bulman, 1941).

After Bulman's (1941) proposal, it was still remained other problems in distinction between *Adelograptus* and *Clonograptus*. So far the distinction of two genera especially in relation to *Adelograptus tenellus* is still equivocal as shown in terms of *Clonograptus tenellus* Group (Lin, 1981) and in the doubt about Maletz and Erdtmann's (1987) *Adelograptus tenellus*. The differences of these two genera are sub-horizontal and declined rhabdosomes, more irregular branching, more variable lengths in *Adelograptus*, and its strictly horizontal rhabdosome, symmetrical first order stipes with only one theca in *Clonograptus*. Jackson (1973) and Braithwaite (1976) thought that bithecae is present in *Adelograptus* but not in *Clonograptus*.

In this view, based on the presence of bithecae, Maletz and Erdtmann (1987) proposed to include *Clonograptus* within the graptoloid family Dichograptidae and to retain *Adelograptus* as the bithecae-bearing ancestor in the dendroid family Anisograptidae. These genera are classified according to the stratigraphical distinction; the more primitive dendroid *Adelograptus*

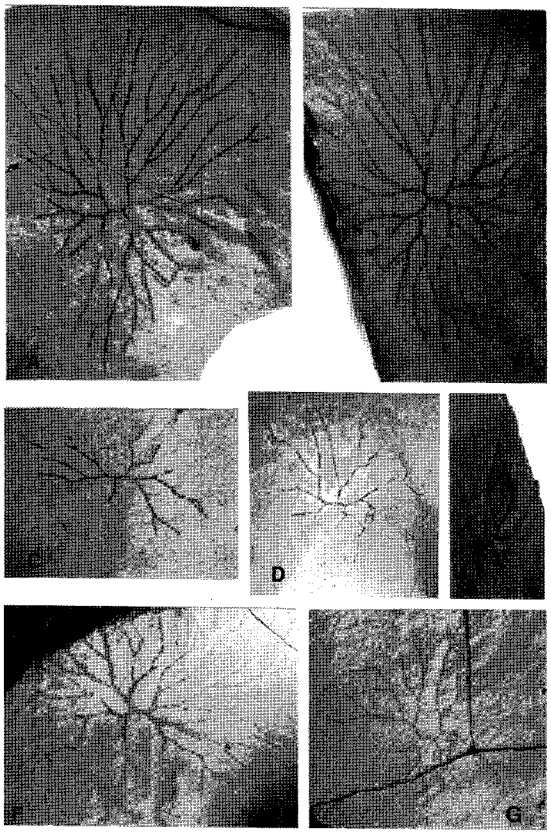

Fig. 3A-E. *Adelograptus brevibrachiatus* from the Mungok Formation of Yeongwol area. *A*, K/Y-MJ2001a. *B*, K/Y-MJ2001b, counter part of K/Y-MJ2001a. *C*, K/Y-2004. *D*, K/Y-MJ2012. *E*, K/Y-MJ2010. *F*, K/Y-MJ2002. *G*, K/Y-MJ2020. All figures ×1.8.

in the Tremadoc, the more advanced graptoloid *Clonograptus* in the upper boundary strata of the Tremadoc and in the Scandinavian Hunneberg Substage (originally Early Arenig; Erdtmann, personal communication in 2002). *Clonograptus aureus* Jackson, 1973 reported from early Late Tremadocian in circum-Pacific area (Jackson, 1973; Jackson and Lenz, 2003; Jackson and Norford, 2004) is only one exception.

Adelogratpus brevibrachiatus sp. nov.
Fig. 3. A-E

1979 *Clonograptus tenellus* (Linnarsson) *sensu lato*; Cooper and Stewart, p. 785-786. text-fig. 8 m.

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

2003 *Adelograptus* cf. *A. tenellus* (Linnarsson); Jackson and Lenz, p. 140-141, Figs. 9i, j, l-o; 11f, g.

2004 *Adelograptus* cf. *tenellus* (Linnarsson); Zhang and Erdtmann, p. 343-345, Figs. 7D, 13F.

Derivation of the name: *Adelograptus* characterized by short stipe, *brevis* (=short) and *brachium* (=branch).

Diagnosis: *Adelograptus* with short stipe lengths, especially ca. 1.0-1.5 mm on first order stipes. Sicula has 0.9-1.5 mm long and 0.5 mm wide across the aperture. Autothecae is slender, inclined slightly towards apertures about 18-20, and 8 to 9 in 10 mm. Sicula bitheca seen; bithecae seen throughout rhabdosome. Four second-order stipe lengths are diagonal or identical.

Material: Many carbonized specimens: K/Y-MJ 2001a, b, 2002, 2003, 2004, and 2006a, b from the Myeongjon Section and K/Y-DG 2001 from the Daegol Section of the Mungok Formation. All materials are deposited in the Paleontological Laboratory of Korea National University of Education. K/Y, Korea/Yeongwol; MJ, Myeongjon; DG, Daegol.

Description: First order stipe lengths are ca. 1.3-2.2 mm. The 2nd order stipe lengths are: the shorter one, ca. 0.70-1.12 mm (average 0.95 mm), and the longer one, ca. 1.62-1.92 mm (average 1.79 mm). It shows a significant difference as 0.84 mm in stipe length between two kinds of stipes. Four second-order stipe lengths are diagonal or identical. The other stipe lengths are: 3rd order stipes, ca. 1.05-2.85 mm; 4th order stipes, ca. 1.5-6.4 mm; 5th order stipes, 3.42-8.25 mm; 6th order stipes, 6.75 mm; 7th order stipes, unbifurcated. This demonstrates the stipes are lengthened distally (Table 1, 2; Fig. 4, 5).

The stipe widths are ca. 0.22-0.45 mm (average 0.34 mm) in proximal part and ca. 0.12-0.30 mm (average 0.21 mm) in distal part. This suggests cortical overgrowth in the proximal part, that is, more slender distally, but one specimen (K/Y-MJ2003) has a

Table 1. Biometric data of *Adelograptus brevibrachiatus* from the Mungok Formation. MJ: Myeongjon, DG: Daegol, L_s: Sicula length (mm), L_1: Combined 1st-order stipe length (mm), L_2: 2nd-order stipe length (mm), L_3: 3rd-order stipe length (mm), L_4: 4th-order stipe length (mm), W_s: stipe width (la: lateral, dv: dorso-ventral, p: proximal, d: distal) (mm), I_{th}: Thecal interval in 10 mm, O_b: Branching order

		MJ2001	MJ2002	MJ2003	MJ2004	MJ2005	MJ2006	MJ2007	DG2001
L_1		1.72	1.80	1.52	1.33	2.22	1.40	1.52	1.50
L_2		1.02, 1.83	0.80, 1.62	0.92, 1.03	1.03, 1.18	1.10, 1.85	1.12, 1.73	1.05, 1.20	0.70, 1.92
L_3		1.52-1.82	1.60-2.03	1.22-2.10	1.52-1.88	2.10-2.85	1.32-1.74	1.05	2.40-2.52
L_4		1.72-3.43	2.42-5.02	2.43-3.70	1.50-4.03	3.42-3.64	2.12-2.24	1.72	2.72-6.43
L_5		3.42-8.25	-	3.42-4.20	-	3.42-4.83	-	-	-
L_6		6.75	-	-	-	-	-	-	-
W_s	la	-	-	-	-	-	-	-	-
	dv	0.40 (p) 0.22 (d)	0.37 (p) 0.20 (d)	0.30 (p&d)	0.28 (p) 0.18 (d)	0.45 (p) 0.20 (d)	0.42 (p) 0.21 (d)	0.22 (p) 0.12 (d)	0.43 (p) 0.20 (d)
I_{th}		8	-	8	8	-	-	-	-
O_b		7th	5th	6th	5th	6th	5th	5th	5th

Table 2. Comparison of the biocharacters of *Adelograptus brevibrachiatus* and *A. tenellus*. 1, Yeongwol (this paper). 2, Yukon (Jackson and Norford, 2004). 3, Lancefield (Cooper and Stewart, 1979). 4, Jilin (Zhang and Erdtmann, 2004). a, Maletz and Erdtmann (1987). In sicula measurements, the dimensions of the cauda are not included. od.-order

		A. brevibrachiatus (mm)				*A. tenellus*[a] (mm)
		1	2	3	4	
Length (mm)	sicula	1.2-1.38	1.1-1.4	1	1.2	1.0-1.2
	funicle	1.3-2.2	2.0	3	3.0	3.0-6.0
	2nd od.	0.7-1.9	1.0-2.1	-	0.7-1.0	3.0-12.0
	3rd od.	1.1-2.85	2.4-3.5	-	-	5.0-10.0
	4th od.	1.5-6.4	~3.0	-	-	7.0-12.0
	5th od.	3.4-8.2	-	-	-	>15
	6th od.	6.8	-	-	-	-
Stipe width		0.2-0.45	0.35-0.5	0.2-0.4	0.4	0.3-0.5
Thecae in 10 mm		8	8	8	-	10

specific feature, almost constant width throughout rhabdosome. One specimen (K/Y-MJ2001) displays maximum 7th order branching of a complete rhabdosome. The species generally expresses rigid features, but one specimen (K/Y-DG2001) shows very flexible post-mortem morphology. Sicula has 1.2-1.38 mm long and 0.5 mm wide across the aperture. Sicula bitheca seen; bithecae seen throughout rhabdosome. Autothecae are slender, inclined slightly towards apertures about 18-20, and 8 to 9 in 10 mm (K/Y-MJ 2001, 2003, 2004).

Remarks: Bulman and Cooper (1969) concluded, after comparing coeval New Zealand graptolites (*C. tenellus*, Hall, 1899; *C. tenellus* and *C. tenellus callavei*, Hall, 1914; *C. tenellus*, Benson and Keble, 1935) with European ones (*C. tenellus*, Moberg, 1892; *A. hunnebergensis*, Stubblefield, 1929), that *Adelograptus hunnebergensis* and *Clonograptus tenellus* previously described from New Zealand are potential synonyms. This confusion seems to be come from the ambiguity of Linnarsson's (1871) original description. He described a brief morphological comment based upon three fragments (Linnarsson, 1871, p. 794-796, pl. 16, figs. 13-15). Many authors adopted the illustration of Moberg (1892) as criteria (Westergård, 1909; Bulman and Cooper, 1969), and also admitted many variations of *C. tenellus* (Elles and Wood, 1902; Westergård, 1909; Stubblefield, 1929; Bulman and Rushton, 1973; Cooper and Stewart, 1979).

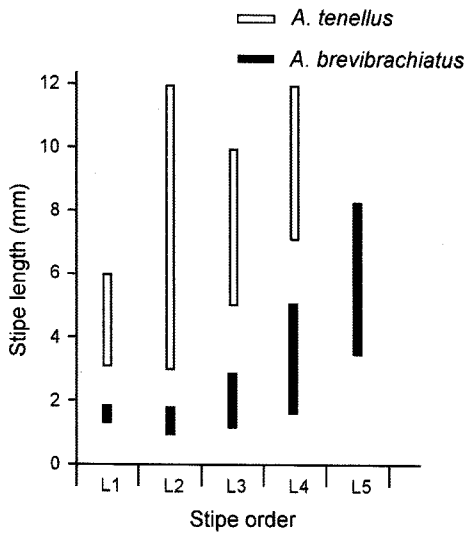

Fig. 4. Comparison of stipe lengths of *Adelograptus tenellus* and *A. brevibrachiatus*.

The main characteristics of *Clonograptus tenellus* are the extreme tenuity and the mucronate thecal apertures (Elles and Wood, 1902). The rigidity and flexibility have been considered as biostratinomical features (Wang and Erdtmann, 1986, 1987; Maletz and Erdtmann, 1987; Rickard et al., 1991), and the former is not sufficient. The latter is only visible in the well-preserved specimens, or in the more distal stipes in true profile view, and it is desirable to identify the distal part of this species. The criteria to identify the species are indispensable to the proximal part and the general aspect of the species. The diagnosis of *A. brevibrachiatus* is based on the length of the stipe and the sicula, thecal features and density, and the relationship among the second-order stipes.

Adelograptus brevibrachiatus from the Mungok Formation of Yeongwol, differs from *Adelograptus tenellus* (Linnarsson) *sensu stricto* previously reported from Europe. The funicle length of *A. brevibrachiatus* is shorter than *A. tenellus*: ca. 2.0-3.0 mm of *A. brevibrachiatus* and ca. 3.0-6.0 mm of *A. tenellus*. The successive stipe lengths of the species are also too short (Table 1, 2; Fig. 4, 5). The thecal density of the species is lower than *A. tenellus*: 8 in 10 mm of *A. brevibrachiatus* and 10 of *A. tenellus*. In this regard, it needs to describe a new species for the Yeongwol

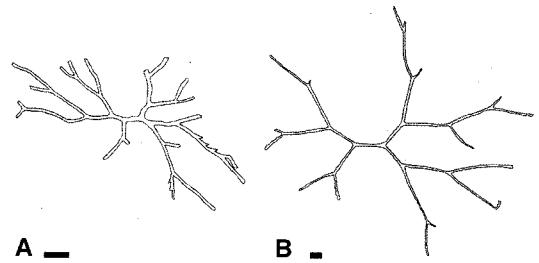

Fig. 5. Comparison of adelograptids. A, specimen from Yeongwol, K/Y-MJ 2004. B, specimen from Hunneberg, Sweden, SGU 4497b. All scale bars indicate 2 mm.

specimens of the adelograptids: *Adelograptus brevibrachiatus* sp. nov. And in the morphological and characteristic view, it is available to separate *A. brevibrachiatus* from *A. tenellus*. The materials previously reported from the circum-Pacific area are well consistent with the Yeongwol one, even though the branching orders of the stipes differ from each other (Jackson and Norford, 2004; Zhang and Erdtmann, 2004; Table 2). The thecal density of the materials is same as eight thecae in 10 mm except the Jilin material (Table 2).

Some *tenellus* group reported from the outside of Britain differs from *A. brevibrachiatus* due to following reasons: *C. rigidus* var. *tenellus* Hall, 1899 and *C. tenellus kingi* Benson and Keble, 1935 from the Lancefield, Victoria, Australasia showing extremely high thecal density as 10-11 in 10 mm of Hall and 17-21 of Benson and Keble. The species related to *A. tenellus* reported by Hall (1899) and Benson and Keble (1935) differ from each other and may be the separated taxa. The Newfoundland materials are not bifurcated because of the juvenile stage. The younger growth stage of the Newfoundland material may show its lower thecal density as 6-7 thecae in 10 mm (Williams and Stevens, 1991).

Acknowledgments

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