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Graptolite Biostratigraphy of the Mungok Formation (Early Ordovician) in the Hwabyung Area, Yeongwol, Korea

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강원도 영월 화병 지역의 전기 오르도비스기 문곡층의 필석 생물층서

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요 약: 강원도 영월 화병 지역의 문곡층 상부에서 4속 5종의 필석 화석을 *Dendrograptus* sp., *Callograptus curvithecalis* Mu 1955, *Adelograptus tenellus* Linnarsson, 1871, *Adelograptus* sp. 그리고 *Psigraptus jacksoni* Rickards and Stait, 1984로 분류하여 기재하였다. 이들의 대부분은 한국에서 두 번째 보고되는 것이며 특히, *Psigraptus*는 캐나다 유콘(Yukon), 오스트레일리아의 빅토리아(Victoria)와 태스메니아(Tasmania), 중국의 질린과(Jilin) 허베이(Hebei)에 이어 세계에서 6번째 보고이다. 문곡층 상부에서 산출된 화석에 의해 *Adelograptus*대, *Callograptus-Dendrograptus*대 및 *Psigraptus*대로 세 개의 필석 생물대가 인지된다. 이들 필석 생물대는 오스트레일리아 란스필드 지역에 분포하는 란스필드층(Lancefield Formation)의 La 1.5대와 캐나다 유콘 지역의 로드리버층 (Road River Formation)의 *Psigraptus*대 및 북중국 질린 지역의 엘리층(Yehli Formation)의 *Psigraptus*대와 대비된다. 화병 지역에 분포한 문곡층 상부에서 산출되는 필석 화석은 이 층의 상부가 후기 트레마독(Tremadoc)의 초기임을 지시한다.

주요어: 필석, 오르도비스기, 문곡층, 영월, 한국

Abstract: Five species of graptolites belonging to four genera were described from the upper part of the Mungok Formation in the Hwabyung area of Yeongwol, Korea. They are *Dendrograptus* sp., *Callograptus curvithecalis* Mu 1955, *Adelograptus tenellus* Linnarsson, 1871, *Adelograptus* sp., and *Psigraptus jacksoni* Rickards and Stait, 1984. Most of them are reported for the second time in Korea, and the occurrence of *Psigraptus* is the sixth time ever in the world, following the Yukon Territory of Canada, the Victoria and Tasmania areas of Australia, and the Jilin and Hebei areas of China. Based on the graptolites, three biozones were recognized from the upper part of the Mungok Formation in the Hwabyung area: the *Adelograptus* Zone, the *Callograptus-Dendrograptus* Zone, and the *Psigraptus* Zone, in ascending order. These graptolite zones are correlated with the La 1.5 Zone (*Psigraptus* and *Clonograptus* Zone or Assemblage 3) of Victoria, Australia, the *Psigraptus* Zone of the Road River Formation in Yukon, Canada, and the *Psigraptus* Zone of the Yehli Formation of Hunjiang, Jilin, north China. Therefore, according to the graptolites and their biozones, the age of the upper part of the Mungok Formation is assigned to be early Late Tremadoc.

Keywords: graptolite, Tremadoc, Ordovician, Mungok Formation, Yeongwol.

Introduction

Graptolites of Korea were first introduced by Shiraki (1922) from the Jikunsan Shale in Hwangjidong, Taebaek, Gangwondo. Kobayashi (1934) described two species belonging to two genera from the Jikunsan Shale in Makgol, Sangdong and Hwangji, Taebaek, Gangwondo. Shimizu and Obata (1935) documented three species belonging to three genera of graptolites from the Jikunsan Shale of Dumugol and Makgol, Sangdong, Gangwondo. Subsequently, without any illustration or

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description. Kobayashi and Kimura (1942) described *Dictyonema* cf. *flabelliforme* and *Clonograptus* (?) sp. from the Mungok Formation. Recently, Jin (2002) described nineteen species belonging to six genera of graptolites from the Mungok Formation in the Jeommal, Dumok Valley and Yeonjeong sections of Yeongwol area and erected three graptolite zones in the formation.

The main purpose of this study is to describe the graptolite fossils from the Mungok Formation of the Hwabyung area, and to correlate biozones erected herein with those of other countries.

Geological Setting

The Cambro-Ordovician sedimentary rocks of South Korea, the Joseon Supergroup, are exposed in northeastern part of the Okcheon Belt. The Yeongwol type Joseon Supergroup which is widely distributed in the Yeongwol area was divided into five lithostratigraphic units, namely, the Sambangsan, Machari, Wagok, Mungok and Yeongheung formations in ascending order (Yosimura, 1940). Thrust movement during the Devonian-Early Carboniferous Okcheon Orogeny (Cluzel, 1992; Cluzel et al., 1990, 1991) resulted in N-S and NW-SE trending belt-like distribution of the Joseon Supergroup in the Yeonweol area (Fig. 1).

The Mungok Formation of the Yeongwol area has been known to yield relatively diverse invertebrate fossils (Kobayashi, 1960). The Mungok Formation, about 200 m in thickness, rests conformably on the Wagok Formation and is overlain by the Yeongheung Formation.

The Mungok Formation is characterized by the alternation of diverse 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). Yosimura (1940) subdivided the formation into three parts. The basal part consists of greenish shale and marl, and bluish gray limestone. The lower part is mainly composed of gray massive dolomitic limestone with occasional intercalation of black chert lenses and red sandy limestone beds. The upper part consists generally of alternations of bluish gray limestone, marl and greenish shale.

Recently Kim (1999) subdivided the Mungok Formation into four lithostratigraphic members according to the assemblages of predominant lithofacies: i.e., the Garam, Baeiljae, Jeommal and Dumok members in ascending order. The lowermost Garam Member is characterized by alternations of ribbon rock and grainstone to packstone with intercalations of thin intraformational congrlomerate beds and chert layers. The Baeiljae Member is represented by a monotonous sequence of light gray to gray, massive to crudely bedded dolostone. The Jeommal Memeber consists of alternations of ribbon rock and intraformational conglomerate beds with occasional intercalations of grainstone to packstone beds. The uppermost Dumok Member comprises marlstone to shale, particularly greenish fissile shale. This present graptolite materials were obtained from the Dumok Member of the Mungok Formation (Kim, 1999).

The Mungok Formation yields diverse fossil faunas including trilobites, brachiopods, graptolites, ostracods and some unidentified fossils. The age of the formation has been somewhat controversial. Based on about fifty species of invertebrate fossils, Kobayshi (1960) stated that the formation is dated as Tremadoc to Arenig in age. This formation was correlated with the Dongjeom Formation, the Dumugol Formation and the lower part of the Makgol Formation of the Duwibong type of the Lower Paleozoic Erathem (Kobayashi, 1960, 1966). Through conodont study, Won and Lee (1977) and Lee and Lee (1999) assigned the age of the formation is the early Tremadoc to early Arenig. Kim (1999) and Kim and Choi (2000) also suggested that the age of the formation is early Tremadoc to late Tremadoc through the trilobite study.

According to investigation of Woo et al. (1990), the carbonate rocks of the Mungok Formation have

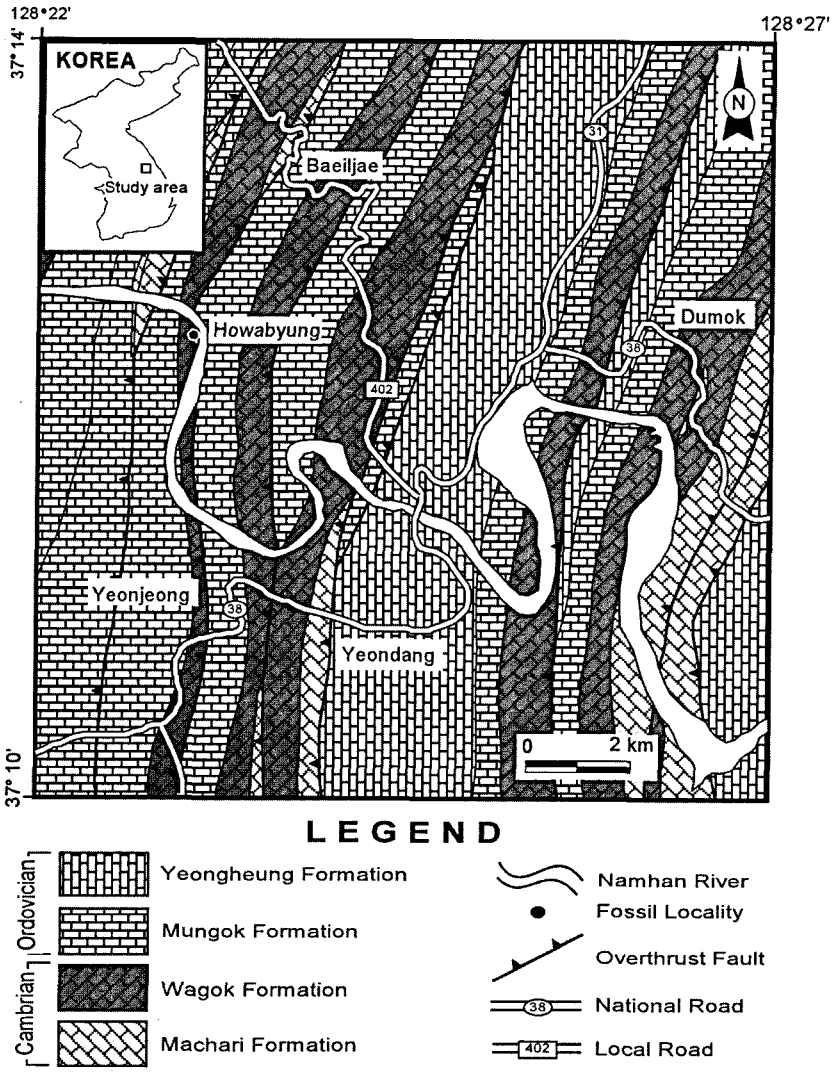

Fig. 1. Geologic map of the study area and fossil locality (after Lee, 1995).

been subjected to complicated shallow marine, meteoric, and burial diagenesis. Sedimentological and paleontological studies have shown that the Mungok Formation was deposited in tidal-flat environment (Paik et al., 1991), and high energy storm-influenced environment (Kim et al., 1994; Moon and Martin, 1994). Paik and Lee (1989) described that storm activities played an important role in deposition of the Mungok Formation. Choi et al. (1993) recognized eight lithofacies within the formation and proposed that the Mungok sediments were deposited in a somewhat deeper shallow ramp to basinal environment.

Biostratigraphy and Correlation

The graptolites are found on the upper to middle parts of the Dumok Member of the Mungok Formation in Hwabyung area. Thickness of graptolite yielding beds is about 45 m. Graptolites are occurred from the eight beds comprising marlstone to shale and ribbon rock (Fig. 2). Of the five species of graptolites, *Adelograptus tenellus* Linnarsson, 1871, *Adelograptus* sp., *Callograptus*

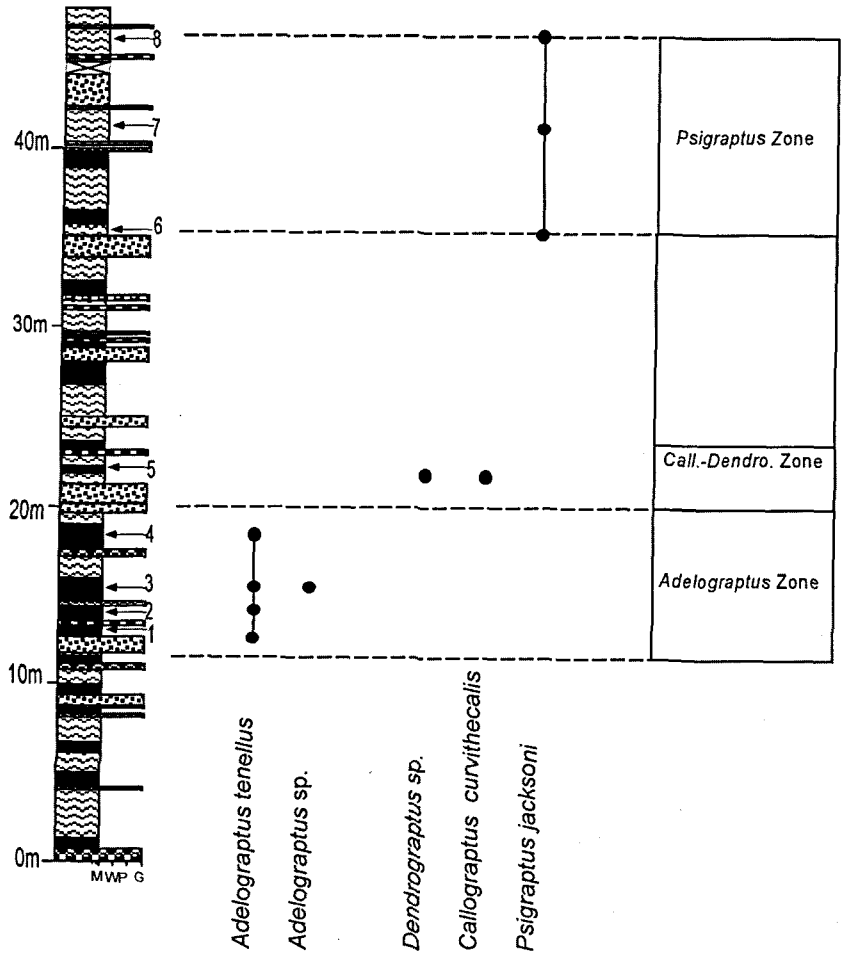

Fig. 2. Stratigraphic column showing graptolite beds and zonation of graptolite taxa from the Dumok Member of the Mungok Formation in the Hwabyung Section of the Yeongwol area. Numbers right on the column represent graptolite beds.

curvithecalis Mu, 1955, and *Callograptus* sp. are occurred from marlstone to shale, and *Psigraptus jacksoni* Rickards and Stait, 1984 are found from ribbon rock.

On the basis of occurrence of graptolites, three graptolite zones are erected in the measured section of the Dumok Member (Fig. 2). They are *Adelograptus* Zone, *Callograptus-Dendrograptus* Zone, and *Psigraptus* Zone in ascending order.

Adelograptus Zone

The *Adelograptus* Zone is recognized by the occurrence of *Adelograptus tenellus* Linnarsson, 1871, and it includes the Graptolite Beds 1 to 4 of the Hwabyung Section which is about 4.4 m thick (Fig. 2). The zone ends with the first occurrence of denroid graptolites. The zone was recognized from 13 m to 17.1 m above the base of the Dumok Member in the Hwabyung Section.

The zone is composed of *Adelograptus tenellus*, *Adelograptus* sp., *Spenothalus ruedenmani* and *Lingulellar*, which are restricted to marlstone to shale, *Adelograptus tenellus* is a dominant species of this zone.

Reclined *Adelograptus* is restricted to the Bed 3, and *Lingulellar* sp. and *Spenothalus ruedenmani* are sometimes associated with the *Adelograptus* on the same bedding surface.

Correlation: *Adelograptus tenellus* was reported for the first time from the Lancefield beds of Victoria, Australasia (Vandenberg and Cooper, 1992). Nowadays *A. tenellus* is regarded as one of the Tremadoc index fossils. According to the recent studies, however, the first appearance of *Adelograptus tenellus* group has been generally taken as the boundary between the Early and Late Tremadoc (Stubblefield and Bulman, 1927; Cooper, 1999), and so it is reasonable to take the base of the zone as the boundary between the Early and Late Tremadoc in the Mungok Formation in the Hwabyung Section.

Cooper (1979) and Cooper and Stewart (1979) reported that *Clonograptus tenellus* (other name of *Adelograptus tenellus*), *Adelograptus* sp., *Psigraptus lenzi* 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). Therefore, this zone of the Mungok Formation in the Hwabyung Section can be correlated with the *Adelograptus* Zone of the Hunneberg Sweden and Central Great Britain, and La 1.5 Zone (*Psigraptus* and *Clonograptus* Zone or Assemblage 3) of Victoria, Australia.

The *Clonograptus aureus* Subzone (Jackson, 1974) containing *Adelograptus tenellus* types in the Yukon Territory, Canada can be correlated with the *Adelograptus* Zone of the present study.

This zone of the Hwabyung section is correlated with the Lower *Adelograptus* Zone of the Jeommal Section in the Yeongwol area (Jin, 2002).

Callograptus-Dendrograptus Zone

This zone is recognized from the Graptolite Bed 5 of the Hwabyung Section by the common occurrences of dendroids including *Callograptus curvithecalis*, *Dendrograptus* sp. and *Spenothalus ruedenmani*.

The zone is 22 m apart from the base of the Dumok Member of the Mungok Formation in the Hwabyung Section. The upper limit of the zone can not be clearly designated, because the exposure is cut by a road.

Correlation: The correlation of this zone is difficult because of the only occurrences of dendroid graptolites. However, *Callograptus curvithecalis* was reported from *Callograptus Taitzehoensis-Dictyomema flabelliforme erientale* Zone Yehli Formation, northern China (Lin, 1992) and the zone corresponds to La 1.5 Zone (or Assemblage 3) of Victoria, Australia, *Clonograptus aureus* Subzone (Jackson, 1974) Yukon Territory, Canada (Lin, 1992, Table 1).

The *Callograptus-Dendrograptus* Zone of the Mungok Formation can be correlated with the *Callograptus Taitzehoensis-Dictyomema flabelliforme erientale* Zone of the Yehli Formation, northern China (Lin, 1992).

Psigraptus Zone

The lower and upper boundaries of the *Psigraptus* zone can be demarcated by the first appearance and disappearance of *Psigraptus jacksoni*. The zone includes Graptolite Bed 6 to 8 of the Hwabyung section and it is recognized between 35 m and 45 m from the base of the Dumok Member. *Psigraptus jacksoni* is the only graptolite occurred in this zone.

Correlation: A species *Pisgraptus jacksoni* was reported by Rickards and Stait (1984) from the Pontoon Hill Siltstone Member in Tasamia, Australia. They noted that *P. jacksoni* occurred at the same time as *P. arcticus* and *P. lenzi*, of perhaps appeared a little earlier. This is confirmed by Wang and Erdtmann (1986) who recorded all three forms from the *Psigraptus* Zone of Hunjiang. Thus, *Psigraptus* species provides a powerful stratigraphical tool for recognition of the middle Tremadoc.

Wang and Erdtmann (1987) proposed the *Psigraptus* Zone on the basis of *P. lenzi*, *P. arcitus*, and *P. jacksoni* in the Yeili Formation of Hunjiang, Jilin Province, China. The zone is easily correlated with the La 1.5 *Psigraptus-Clonograptus* Zone of

Table 1. The correlation of the graptolite zones of the Dumok Member of the Mungok Formation with those of other countries.

Korea Yeongwol This Study			Australia Lancefield, Victoria Cooper, 1979; Cooper and Stewart, 1979			Canada Yukon Jackson, 1974; Barnes et al., 1981	Northern China Jilin Zhao et al., 1988			Global Chronozones Cooper, 1999		
MUNGOK FORMATION	D		LANCEFIELDIAN	La 2	(Assemblage 4) *A. victoriae* *Clonograptus* *Temnograptus* *K. prichardi* *K. antiquus* *T. decipiens* *D. macgillivrayi*	*Adelograptus antiquus* Zone *A. victoriae* *C. tenellus* type *Kiaerograptus* *T. decipiens* *D. macgillvrayi*	YEHLIFORMATION	Y5	*Adelograptus* -*Clonograptus* Zone (*Callograptus*? *taizehoensis* Zone)	*H. copiosus* Zone (9)	LATE	TREMADOC
										A. murrayi- *A. pulchellus* Zone (8)		
										Kiaerograptus Zone (7)		
										P. antiquus Zone (6)		
		Psigraptus Zone		La 1.5	(Assemblage 3) *Psigraptus* -*Clonograptus*	*Psigraptus* Zone		Y4	*Muenzhigraptus* -*Psigraptus* Zone	*Adelograptus* Zone (5)		
		Callo.-Dendro. Zone						Y3	*Dendrograptus* Bed			
		Adelograptus Zone										
	J			La 1	(Assembalge 2) *D. scitulum* *A. compactus* *A. delicatulus*	*Clonograptus aureus* Zone *Anisograptus richardsoni* Zone	MATION	Y2	*Anisograptus richardsoni* Zone	*R. f. anglica* Zone (4)	EARLY	
	B									*Anisograptus matanensis* Zone (3)		
	G				(Assemblage 1)	*Staurograptus tenuis* Zone		Y1	*Dictyonema parabola* -*Staurograptus dichotomous* Zone	*Rhabdinopora f. parabola* Zone (2)		
						D. flabelliforme/ *Radiograptus* Zone				*R. praeparabola* Zone (1)		

D: Dumok Member, J: Jeommal Member, B: Baeiljae Member, G: Garam Member, A: *Adelograptus*, K: *Kiaerograptus*, T: *Temnograptus*, D: *Dendrograptus*, H: *Hunnegraptus*, P: *Psigraptus*

Victoria, Australia, and which indicates early Late Tremadoc age. Zhao et al. (1988) also correlated *Muenzhigraptus-Psigraptus* Zone (Y4) with La 1.5 *Psigraptus-Clonograptus* Zone of Victoria, Australia, the Pontoon Hill Siltstone Member in Tasamia, Australia and the lower part of the *Kiaerograptus antiquus* Zone of Yukon, Canada on the basis of *Muenzhigraptus* species (that it is known as *Psigraptus jacksoni*) and other *Psigraptus*.

Jackson (1974) reported the occurrence of the *Psigraptus lenzi* from the Road River Formation in Yukon, Canada. *Psigraptus lenzi* and *Psigraptus arcticus* were reported from the Road River Formation in Yukon, Canada by Barns et al. (1981) who erected the *Psigraptus* Zone between the *Clonograptus aureus* Zone and *Adelograptus antiquus* Zone. They assigned the age of these zones as the upper Middle Tremadoc (Table 1).

Therefore, this *Psigraptus* Zone of the Mungok Formation in Howagbyung Section is well correlated with *Psigraptus* Zone and *Muenzhigraptus-Psigraptus* Zone of the Yeili Formation of Hunjiang, Jilin Province, China, La 1.5 *Psigraptus-Clonograptus* Zone of Victoria, Australia, the Pontoon Hill Siltstone Member in Tasamia, Australia, and *Psigraptus* Zone of the Road River Formation in Yukon, Canada. The age of these zones was known as Middle Tremadoc or early Late Tremadoc. Also this zone is well matched with *Psigraptus* Subzone of the Mungok Formation in the Jeommal Section (Jin, 2002).

Systematic Paleontology

Systematic studies on graptolites had been achieved by Bulman (1970), Mu (1974), Erdtmann (1982), Fortey and Cooper (1986), etc. Graptolite classification has traditionally been based upon grade groups reflecting general levels of evolutionary complexity (Fortey and Cooper, 1986). Fortey and Cooper (1986) introduced phylogenetic classification of graptolites, which produces a more objective classification of taxa that are diagnosable.

This study follows the taxonomic categories of Fortey and Cooper (1986) and Erdtmann (1982). All materials treated in this study are housed in the Paleontological Laboratory of the Department of Earth Science Education, Korea National University of Education.

Phylum HEMICHORDATA Bateson, 1885
Class GRAPTOLITHINIA Bronn, 1849
Order DENDROIDEA Nicholson, 1872
Family Dendrograptidae Roemer in Frech, 1897
Genus *Dendrograptus* Hall, 1858

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

Diagnosis: Generally robust, shrub-like in habit. More or less irregular stipe divisions occur and lead to stipe orientation in any plane above the holdfast or stem (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 subspecies of *D. hallianus*. The rhabdosome has clear indications of bithecae and autothecae in the axis of the branching points (Rickard et al., 1990). Typically rhabdosome is dendroid and stipes are usually divergent and unconnected. Stem is well developed, with basal attachment. Autothecae is denticulate, spined or with apertural processes.

Dendrograptus sp.
(Fig. 3-F)

Material: Four compressed specimens on bedding surface. HB01080104C, HB01080104C1, HB01080108C-1, HB01080108C-2.

Description: Rhabdosome rigid dendroid form, of medium size with a very short basal stem, attaining a length of 5.4 mm and a width of 2.8 mm. Branches fairly straight throughout, of rigid appearance, 0.1-0.2 mm wide, bifurcating infrequently at intervals of 3-5 mm, under angles of about 30°. The intervals between branching zones increase distally.

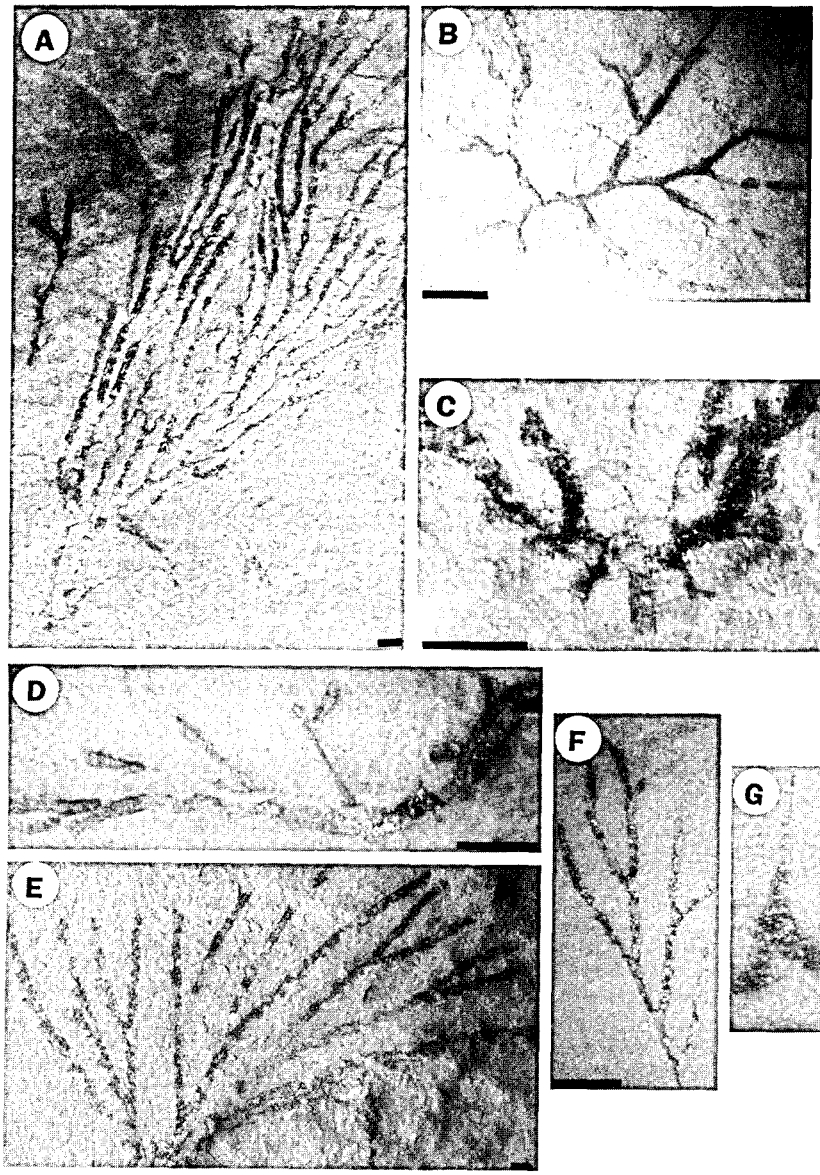

Fig. 3. Graptolites from the Dumok Member of the Mungok Formation in the Hwabyung Section of the Yeongwol area. A. *Callograptus curvithecalis* Mu, 1955, B. *Adelograptus tenellus* Linnarsson, 1871, C. Juvenile rhabdosome of *Psigraptus jacksoni* Rickards and Stait, 1984, Note slender nema at prosicula tip, D. *Adelograptus* sp., E. *Psigraptus jacksoni* Rickards and Stait, 1984, F. *Dendrograptus* sp., G. Sicula of *Adelograptus tenellus* Linnarsson, 1871 with first one thecae, Note slender nema at prosicula tip. Scale bars indicate 1mm.

Both autothecae and bithecae are not seen even in the distal stipes probably due to the ventro-dorsal preservation of the stout rhabdosome. Dissepiment clearly absent throughout the rhabdosome.

Remarks: The present specimen is closely similar in whole configuration and branching habit, to the *Dendrogaptus grabaui* described from the Yehli Formaion of north China (Lin, 1992) though *D. grabaui* has slightly longer and wider rhabdosome. Also this is similar with *D. suni*, which was reported from the Yehli Formation of north China but it is different from the latter in having a long

rigid main stem in the proximal part of the rhabdosome. *Dendrogaptus* sp. is similar in rhabdosome and branching habit to the *Dendrograptus* sp. A from the Mungok Formation in Jeommal Section, but *Dendrograptus* sp. A has disc-like holdfast in the proximal tip of the rhabdosome, which can not find in this species (Jin 2002). Species identification is not possible due to the extremely poor preservation of the fragment.

Occurrence: The *Callograptus Dendrograptus* Zone (Graptolite Bed 5) of the Dumok Member of the Mungok Formation in the Hwabyung Section.

Genus *Callograptus* Hall, 1865

Type species: *Callograptus elegans* Hall, 1865 (subsequentliy designated Miller, 1889)

Diagnosis: Rhabdosome conical, flabellate or irregular, with thecate stem, or, more commonly, thickened nonthecate stem or disc-like holdfast; dichotomous, more or less regular branching of the stipes which are parallel to subparallel, sporadically connected by anastomosis or dissepiments; authothecae denticulate, sometimes distally isolate (Bulman, 1970).

Remarks: *Callograptus* was erected by Hall in 1865 for dendroid forms intermediate in habitus between *Dictyonema* and *Dendrograptus*. It is distinguished from *Dictyonema* in that the latter has far more dissepiments, less anastomosis, much more regular stipe divisions, and has, as a rule, more loosely spaced autothecae (Ricards et al., 1990). The main difference between an ordered *Dendrograptus* and a *Callograptus* is that former has stipes which diverge steadily and lack dissepiments altogether (Chapman et al., 1996). Stipes of *Callograptus* are parallel or subparallel and are rarely anastomosed or united by dissepiments.

Callograptus curvithecalis Mu, 1955
(Fig. 3-A)

1955 *Callograptus curvithecalis* Mu; Palaenontologia Sinica, Whole No.138, New Series B. No. 5, p. 45, Pl. Ⅳ, figs. 12-16.

Diagnosis: Rhabdosome is flabellate. Stipes are dichotomously biradiated and arranged parallelly and connected transversely by rare dissepiments (Mu, 1955).

Material: Two well-preserved specimens (HB0202267045-1 and HB0202267045-2) and many fragmented specimens.

Description: The rhabdosome is flabellate, 35 mm high and 18 mm wide. Stipes close together but never overlapped, 0.3-0.4 mm wide, subparallel to parallel each other, 0.1-0.8 mm apart, and sparse dissepiments connecting them. Dissepiments 0.1-0.2 mm wide, sparsely distributed, and perpendicular or nearly perpendicular to axis of stipe. Branching is dichotomous, regular near the proximal part and tend to be decrease its regularity to the distal of the rahbdosome, the angle of divergence is between 10 and 40°. There is 14 stipes within 10 mm width in average. Lateral stipes originated by dichotomous biradiation up to averaging 15th order from proximal stipe. There are 16-17 thecae in 10 mm. Thecae is inconspicuous probably due to the ventral view, but thecae can be observed only in the ventral view as depressional scar having 0.3-0.5 mm in diameter, in terms of the depressional traces of thecae recognized 15 in 10 mm.

Remarks: *C. curvithecalis* Mu, 1995 resembles *C. undosus* Kraft, 1973 recorded from the Ordovician strata of Bohemia. However, it differs from the latter in the lower angle of divergence and possessing nonwave-shaped stipes. This species may be distinguished from *C. rokycanensis* Boucek, 1956 especially by the more many number of sipes in 10 mm, and lower angle of divergence.

Occurrence: The Graptolite Bed 5 of the *Callograptus-Dendrograptus* Zone of the Hwabyung Section.

Order GRAPTOLOIDEA Lapworth, 1875
Suborder VIRGELLINA Fortey and Cooper, 1986
Family ANISOGRAPTIDAE Bulman, 1950
Subfamily ADELOGRAPTINAE Mu, 1974
Genus *Adelograptus* Bulman, 1941

Type species: *Dichograptus tenellus* Linnarsson, 1871.

Diagnosis: Rhabdosome biradiate multiramous horizontal or declined, commonly somewhat lax and flexuous; branching principally dichotomous at mainly irregular and infrequent interval. Autothecae slender of moderate to low inclination and overlap (Maletz and Erdtmann, 1987).

Remarks: The revision of *Adelograptus* permits incorporation of many slender regularly branching taxa previously accommodated within the rather unsatisfactory genus *Clonograptus* (Williams and Stevens, 1991). And several multiramous graptolites with sub-horizontal to declined rhabdosomes have been allotted to *Adelograptus*. *Clonograptus* with horizontal rhabdosome is distinguished from *Adelograptus* with more irregular branching. The proximal part of *Clonograptus* is symmetrical and both first order stipes consist of one thecae, whereas in *Adelograptus* the length of the first order stipes is more various and even both first order stipes may be of different length (Maletz and Erdtmann, 1987). Later dichotomies take place at greatly variable and irregular distances in both genera.

Adelograptus has been found in the Tremadoc, whereas the more advanced graptoloid *Clonograptus* has been observed above the upper boundary of the Tremadoc Series and Scandinavian Hunneberg Substage (i.e., lower Arenig). So *Adelograptus* is more primitive than the *Clonograptus* (Maletz and Erdtmann, 1987).

Adelograptus tenellus Linnarsson, 1871
(Fig. 3-B, G)

1871 *Dichograptus*? *tenellus* n. sp., Linnarsson, p. 794. pl. 16, figs. 13-15.

1892 *Clonograptus tenellus* var. *hians* n. var., Morberg: p. 92. fig. 4.

1892 *Bryograptus*? *sarmentosus* n. sp., Morberg: p. 95. pl 1. figs. 10-12.

1892 *Clonograptus tenellus* Linnarsson., Morberg: p. 89. pl. 1. figs. 1-3. ?4.

1902 *Clonograptus tenellus*, Elles and Wood, p. 83, pl. 11, fig. 2 a-c.

1973 *Clonograptus aureus* sp. Jackson, p. 708, text-figs. A-C.

1974 *Clonograptus tenellus* Linnarsson., Hutt: p. 79, figs. 1-4.

1979 *Adelograptus* sp. nov. Cooper and Stewart p. 789, text-figs. a-c, j.

1979 *Clonograptus* sp. 1 Cooper and Stewart; Palaeont. vol. 22, Pt. 4, p. 786, pl. 103. fig. 11, text-fig. 6a.

1979 *Clonograptus* sp. 3 Cooper and Stewart; Palaeont. vol. 22, Pt. 4, p. 789, pl. 103. fig. 14, text-figs. 6g, h, i, 7i.

1987 *Adelograptus tenellus* Linnarsson, Maletz and Erdtmann, p. 180, p. 1-2, text-figs. 1-2.

2002 *Adelograptus* sp. A Jin, p. 101. pl. VI. figs. A-G; pl. VII. figs. A-G. pl. VIII. figs. A-I; pl. IX. figs. A-D.

2002 *Adelograptus* sp. B Jin, p. 104. pl. XI. figs. A-D; pl. XII. figs. F-G.

2002 *Adelograptus* sp. C Jin, p. 105. pl. XII. figs. B-E, H-I.

Diagnosis: Rhabdosome with several stipes formed by delayed dichotomous branching from two primary stipes, biradiate multiramous, horizontal to declined. The length of second stipes are diagonally identical, but stipes neighboured are different from each other (Maletz and Erdtmann, 1987).

Material: Thirty specimens and many fragments.

Description: Rhabdosome biradiate multiramous, up to 6th order delayed bifurcations, horizontal to declined. The largest rhabdosome seen has a diameter of about 20 mm. The sicula observed in specimens that are laterally preserved, measures averaging 0.7 mm in length and possesses a long slender nema. The first authotheca grows away from the sicula at or near a right angle.

Each first order stipe contains of two or three thecae, or rarely only of one. Younger specimens show first order stipes with an angle of about 110-150°, in the more mature rhabdosomes they form a straight line. Thecal outline is rarely seen owing to

preservation, and conservational stipe width is consistent, 0.2 mm in dorsal view, then sometimes in large specimens the rhabdosome shows a tapering width of stipes. First order stipe length is 0.3 mm and the higher order dichotomies are gradually delayed with the stipes of the same order being of subequal length (i.e. the length of subsequent orders increases progressively). Whole rhabdosome appears to be slender and little flexuous.

The thecae of the proximal parts is vanished by the secondary overgrowth. The thecae are simple straight, sometimes curved, 0.5 mm long in proximal part, whereas in terminal parts they are not observed. Bithecae of *Adelograptus tenellus* can not be observed.

Remarks: Jin (2002) divided species of *Adelograptus* from the Mungok Formation into *Adelograptus* sp. A, *A.* sp. B and *A.* sp. C on the basis of stipes length in proximal part and morphology. Maletz and Erdtmann (1987) revised *A. tenellus* and they selected a neotype and thoroughly discussed the morphological variation found within the species. In the treatise, the length of the first order stipes of *Adelograptus* is more various and even both first order stipes may be of different length. Variety of stipe length in *A. tenellus* was recognised (Maletz and Erdtmann, 1987) who interpreted all species as *A. tenellus*. Therefore, *Adelograptus* sp. A, *A.* sp. B and *A.* sp. C (Jin, 2002) should be regarded as one species *Adelograptus tenellus*.

Materials from the Mungok Formation in Hwabyung area differ from the holotype material in having a shorter funicle and smaller rhabdosome, and various width of stipes.

Occurrence: *Adelograptus* Zone of the Dumok Member of the Mungok Formation at Hwabyung section.

Adelograptus sp.
(Fig. 3-D)

Material: Four compressed specimens on bedding surface. HB02101105, HB02101105, HB0106031, HB05277.

Description: Rhabdosome biradiate multiramous, reclined. The largest rhabdosome seen has a diameter of about 8mm. The sicula observed in specimens that are laterally preserved, measures 0.4 in length.

Thecal outline is rarely seen owing to preservation, and conservational stipe width is consistent, 0.2 mm in dorsal view. First order stipe length is 0.35 mm and the higher order dichotomies are gradually delayed with the stipes of the same order being of subequal length (i.e. the length of subsequent orders increases progressively).

The thecae are simple straight, sometimes curved, 0.5 mm long in proximal part and can not be measured in terminal part because they are unobserved.

Remarks: This species is closely similar in whole configuration and branching habit, to the *Adelograptus tenellus* Linnarsson, 1871. However are remarkably differnt from *A. tenellus* which has horizontal to declined *Adelograptus* rhabdosome. *Adelograptus* sp. is similar in general morphology to reclined reported from the Mungok Formation in the Jeommal section (Jin, 2002).

Occurrence: The *Adelograptus* Zone (Graptolite Bed 3) of the Hwabyung Section.

Subfamily ANISOGRAPTINAE Erdtmann, 1982
Genus *Psigraptus* Jackson 1967

Type species: *Psigraptus arcticus* Jackson, 1967

Diagnosis: Nematophorus rhabdosome siculate, reclined stipes, conical. Autothecae curved with isolated aperture. The degree of autothecae isolation gradually decrease towards the distal end of each stipe in the adolescent to mature rhabdosome owing to the increase of branching number. Bithecae present through the rhabdosome (Wang and Chen, 1996).

Remarks: Three species of *Psigraptus* including *P. arcticus* Jackson, *P. lenzi* Jackson, and *P. Jacksoni* Richards and Stait have been known up to now.

The main basis for erecting *Muenzhigraptus*,

Hunjiangorapdtus, *Diphygraptus* and Holo*psigraptus* (Zhao and Zhang, 1985) as well as *Yukonograptus* (Lin, 1981) are only the number of branches and isolation or denticulate of the distal autothecae of rhabdosome. It was, however, ignored that the relationship of the number of branches, controlled by the position and ability of dicalycal thecae, and the isolated degree of authothecae with the astogenetic nature progress of a single species within *Psigraptus*, and the influence of preservation upon the disposition and number of stipes (Wang and Chen, 1996).

Yukonograptus originally defined by Lin (1981) for *Psigraptus lenzi* Jackson was considered to be a junior synonym of *Pisgraptus* (Rickards and Stait, 1984). Rickards et al. (1991) regarded *Muenzhigraptus*, *Diphygraptus*, *Hunjiangograptus*, and *Holopsigraptus* as junior synonyms of *Pisgraptus*.

Psigraptus jacksoni Richards and Stait, 1984
(Fig. 3-C, E)

1980 *Psigraptus* cf. *arcticus* Jackson; Stait and Laurie, P. 205, fig. 3.

1984 *Psigraptus jacksoni* sp. nov., Rickards and Stait; p. 107, figs. 2-6.

1985 *Muenzhigraptus sinicus* (gen. et sp. nov.); Zhao and Zhang, p. 18, pl. 2. figs. 1-8.

1985 *Muenzhigraptus paucibranchiatus* (gen. et sp. nov); Zhao and Zhang, p. 18-19; pl. 2, figs. 9-11.

1985 *Muenzhigraptus*? *symmetricus* (gen. et sp. nov); Zhao and Zhang, p. 19, pl. 1, figs. 5-10; text fig. 3.

1985 *Diphygraptus reclinatus* (gen. et sp. nov); Zhao and Zhang, p. 19-20, pl. 3, figs. 4-6.

1985 *Hunjiangoraptus typicus* (gen. et sp. nov.); Zhao and Zhang, p. 20, pl. 3, figs. 4-6.

1985 *Holopsigraptus hungiangensis*? (gen. et sp. nov.); Zhao and Zhang, p. 21, pl. 4, figs. 3.

1985 *Holopsigraptus furcatus* (gen. et sp. nov.); Zhao and Zhang, p. 21, pl. 4, figs. 4-7.

1985 *Clonograptus* (*Neoclonograptus*) *gracilis* (subgen. et sp. nov.) Zhao and Zhang, p. 21, pl. 3, figs. 9-10, text fig. 4.

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

1988 *Muenzhigraptus paucibranchiatus* Zhao and Zhang; Zhao et al., pl. 3, fig. 11.

1988 *Muenzhigraptus*? symmetricus Zhao and Zhang; Zhao et al., pl. 3, fig. 12.

1988 *Muenzhigraptus rigidus* Zhao and Zhang; Zhao et al., pl. 3, fig. 17.

1991 *Psigraptus jacksoni* Rickards and Stait; Rickards et al., p. 248-253, text-figs. 2, 7.

1996 form-species *Psigraptus jacksoni* Rickards and Stait; Wang and Chen, p. 101-102, text-figs. 13.1-13.2.

2002 *Psigraptus arcticus* Jackson; Jin, p. 108-113, pl. XV, figs. a-h; pl. XVI, figs. a-e; pl. XVII , figs. a-h; pl. XVIII, figs. a-f; pl. XIX, figs. a-f; pl. XX, figs. a-d.

Diagnosis: Small sicular reclined rhabdosome, consisting of two primary stipes and one or two rapidly developing pseudo-primary stipes, dichotomously branching; curvature of funicular region more open; bithecae present throughout; mature rhabdosomes have an upright; autothecae curved, aperturally isolated in proximal part (Rickards et al., 1991).

Material: More than seventy specimens.

Description: The sicula has a short but conspicuous nema. Rhabdosome consisting of two primary stipes and one or two rapidly developed pseudo-primary stipes, strongly reclined conical shape. Dichotomous branching of rhabdosome has been detected to the 5th order, branching to 7th or 8th order colony was not found in the present material. Rhabdosom about 5.5 mm long with a maximum width of 3 mm. The branching of the second stipes so regular but to 3rd-5th order with irregular. There is a distal increase in length of higher orders. The first order (that between the sicula and first dichotomy) is 0.5-0.8 mm between the sicula and first pseudo-primary stipes. Some specimens, a minority, show only three main stipes

near the origin (i.e. two primaries and one pseudo-primary) and sometimes show only two stipes.

Sicula 1.2 mm long, 0.2 mm wide in aperture, with slender long nema has been detected to up to 1.5 mm long. The first autothecal tube, 0.8-1 mm long, is isolated at proximal part of rhabdosome and it decreases distally to become denticulate along the stipes. The apertural region of this first autotheca is about 0.25 mm in diameter.

Remarks: Three species of the *Psigraptus* including *P. arcticus*, *P. lenzi* and *P. jacksoni* are generally accepted to the graptologists in the world. Jackson (1967) first reported *Psigraptus* from Yukon, Canada of which *Psigraptus arcticus* has two branches while *P. lenzi* has three as proximal stipes.

Jin (2002) reconstructed *Psigraptus* rhabdosome and according to number of stipes, divided it into six types on the basis of the investigation of the Yeongwol specimens. And he mentioned that varied forms of *Psigraptus* rhabdosome are the just superficial appearance on the bedding surface of the 3-dimensional conical rhabdosome. On the basis of the reconstruction model, the three species of *Psigraptus* including *P. arcticus*, *P. lenzi* and *P. jacksoni* are regarded as the superficially different morphology on the bedding surface of the conical *Psigraptus* rhabdosome. That is, Jin (2002) analyzed 3 species of genus *Psigraptus* into varied form of *Psigraptus arcticus* in the Mungok Formaion Yeongwol, Korea. *Psigraptus arcticus* (biradiate) and *P. lenzi* (biradiate with two or four second stipes) differ from *P. jacksoni* principally in the possession of "monoform" strongly isolated matathecae (autothecae) and a virtually scandent orientation of the two first and 2 or 4 second order stipes, additional higher order dichotomies appear to be lacking (Wang and Chen, 1996). That is, *Psigraptus arcticus* has nearly scandent orientation of stipes and has autothecae isolated from proximal to disital part. On the other hand, *Psigraptus* that is occurred in Mungok Formation has reclined orientation of stipes, and the degree of autothecae isolation gradually decreases towards the distal end of each stipe (towards the distal, autothecae denticulate). Therefore, *Psigraptus arcticus* described from the Mungok Formation by Jin (2002) is regarded as *P. jacksoni*.

Occurrence: *Psigraptus* Zone of the Hwabyung Section (Graptolite Bed 6-8).

Summary

Five species belonging to four genera of graptolite of the early Late Tremadoc found on the upper to middle parts of Dumok Member of the Mungok Formation in Hwabyung area, Yeongwol, Korea are herein described as *Adelograptus tenellus* Linnarsson, 1871, *Adelograptus* sp., *Dendrograptus* sp., *Callograptus curvithecalis* Mu 1955, *Psigraptus jacksoni* Richards and Stait 1984.

Eight graptolite beds were recognized from the Hwabyung Section. The Graptolite Beds 1 to 4 yield commonly *Adelograptus tenellus* and *A.* sp. this interval is named as the *Adelograptus* Zone. The Graptolite Bed 5 containing *Dendrograptus* sp. and *Callograptus curvithecalis* is designated as the *Callograptus-Dendrograptus* Zone. The Graptolite Beds 6 to 8 yield commonly *Psigraptus jacksoni*; this interval is named as the *Psigraptus* Zone.

The *Adelograptus* Zone corresponds to the *Adelograptus* Zone of the Hunneberg Sweden and Central Great Britain, *Clonograptus aureus* Subzone of the Yukon Territory, Canada, La 1.5 Zone (*Psigraptus* and *Clonograptus* Zone or Assemblage 3) of Victoria, Australia, and the Lower *Adelograptus* Zone of the Jeommal Section Yeongwol, Korea. The *Callograptus-Dendrograptus* Zone can be correlated with the *Callograptus taitzehoensis-Dictyomema flabelliforme erientale* Zone of the Yehli Formation, northern China. The *Psigraptus* Zone is correlated with *Psigraptus* Zone and *Muenzhigraptus-Psigraptus* Zone of the Yehli Formation of Hunjiang, Jilin Province, China, La 1.5 *Psigraptus-Clonograptus* Zone of Victoria, Australia, Pontoon Hill Siltstone Member in Tasamia, Australia, and *Psigraptus* Zone of the Road River

Formation in Yukon, Canada.

Based of occurrence of graptolites, the age of the upper part of the Mungok Formation in the Hwabyung section is regarded as early Late Tremadoc.

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