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Kayseraspis (Trilobita) from the Mungok Formation in Yeongwol area and its significance for the Lower Ordovician biostratigraphy and chronostratigraphy of the Taebaeksan Basin, Korea

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ABSTRACT: This study reports the occurrence of a trilobite *Kayseraspis* from the uppermost part of the Mungok Formation, Yeongwol Group, Korea. This genus has been known to occur in the upper part of the Dumugol Formation of the Taebaek Group and in the lower part of the Yeongheung Formation of the Yeongwol Group, and to indicate the lowermost Floian in the Taebaeksan Basin. However, the occurrence of *Kayseraspis* from the Mungok Formation and the comparison between the biostratigraphy of trilobites and graptolites suggest that the *Kayseraspis*-bearing faunas in Korea can be assigned to the upper Tremadocian. Accordingly, it is plausible that the base of the Floian may be positioned in the overlying strata, the Yeongheung Formation of the Yeongwol Group and the Makgol Formation of the Taebaek Group. In order to consolidate the Lower Ordovician chronostratigraphy of the Taebaeksan Basin, additional integrative studies on trilobites, graptolites, and conodonts are required.

Key words: *Kayseraspis*, Taebaeksan Basin, Ordovician, biostratigraphy, correlation

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1. INTRODUCTION

Trilobites have played a crucial role in establishing biostratigraphic schemes of the lower Paleozoic Joseon Supergroup (Cambrian Stage 4 to Darriwilian) of the Taebaeksan Basin, Korea (Choi et al., 2016). Nineteen and 22 trilobite biozones have been established respectively for the Yeongwol and Taebaek groups of the Joseon Supergroup. The boundaries of the biozones from the Wuliuan Stage of Cambrian to the Tremadocian Stage of Ordovician are well correlated with those of the international chronostratigraphic units. In contrast, the boundaries of the biozones overlying the Tremadocian ones do not well correspond to those of the chronostratigraphic units due to the relative paucity of trilobite occurrences (Choi et al., 2016). The base of the Floian has been suggested to be roughly coincident with the base of the *Kayseraspis* Zone of the Taebaek and Yeongwol groups.

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Kobayashi (1934) recognized the *Asaphellus* and *Protopliomerops* zones in the Dumugol Formation and the *Clarkella* Zone in the overlying "Jikdong Limestone (= lower part of the current Makgol Formation)" of the Taebaek Group. Although the latter was established based on the occurrence of the eponymous brachiopod genus, Kobayashi (1966) emphasized that the five trilobite species of *Kayseraspis* and associated taxa are crucial for biostratigraphy and international correlation of the Lower Ordovician strata. Kim et al. (1991) re-defined the *Clarkella* Zone into the *Kayseraspis* Zone, and concluded that it is assignable to the upper part of the Dumugol Formation and to the lower Arenigian (= Floian). Choi (1998a) reported a *Kayseraspis*-bearing trilobite faunule from the Yeongwol Group in Danyang area, and correlated it to the lower Floian *Kayseraspis* Zone of the Dumugol Formation. In the Yeongwol Group, three trilobite biozones underlying the *Kayseraspis* Zone were established in the Mungok Formation, the *Yosimuraspis*, *Kainella*, and *Shumardia* zones in ascending order (Kim and Choi, 2000). Kim and Choi (2000) suggested that the entire Mungok Formation was assignable to the Tremadocian based on no occurrence of *Kayseraspis*.

As a result, *Kayseraspis* is crucial for determining the boundary between the Tremadocian and Floian in the Joseon Supergroup.

This study aims to report the occurrence of *Kayseraspis* for the first time from the Mungok Formation of the Yeongwol Group, to discuss its biostratigraphic significance, and to reevaluate the geologic age of the *Kayseraspis*-related faunas of the Joseon Supergroup.

2. GENERAL GEOLOGY, FOSSIL LOCALITY, AND MATERIAL

The Taebaeksan Basin, a tectonic province located in the mid-eastern part of the Korean Peninsula, mainly comprises the lower Paleozoic Joseon Supergroup and disconformably overlying upper Paleozoic Pyeongan Supergroup. The Taebaeksan Basin was located in the northeastern margin of the Sino-Korea Platform (Chough et al., 2000; Choi and Chough, 2005; Kwon et al., 2006; Choi, 2014). The Joseon Supergroup (Cambrian–Ordovician) consists of the mixed carbonate-siliciclastic sequences, and is subdivided into three groups based on their unique lithologic succession and geographic distribution: namely, Taebaek, Yeongwol, and Mungyeong groups (Choi, 2014; Choi et al., 2016). Of the three groups, the Taebaek and Yeongwol groups have been intensively studied in terms of paleontology, sedimentology, and stratigraphy.

The Taebaek Group consists of ten formations: Jangsan (or Myeonsan, the lateral equivalent), Myobong, Daegi, Sesong, Hwajeol, Dongjeom, Dumugol, Makgol, Jigunsan, and Duwibong formations in ascending order. The Cambrian–Ordovician boundary lies within the lower part of the Dongjeom Formation. The stratigraphy of the Taebaek Group is well established (Choi et al., 2004; Choi and Chough, 2005). The Yeongwol Group is distributed in the western half of the Taebaeksan Basin, and consists of the Sambangsan, Machari, Wagok, Mungok, and Yeongheung formations in ascending order (Yosimura, 1940; Kobayashi, 1966; Choi, 1998b; Kwon and Kwon, 2020). The lower three formations are assigned to the Cambrian and the upper two to the Ordovician (Kobayashi, 1966; Choi, 1998b). Although there have been controversies on the paleogeographic locations of the Taebaek and Yeongwol groups due to lithologic and stratigraphic differences (e.g., Cluzel et al., 1991; Yin and Nie, 1993), the two groups are generally considered to have been deposited in carbonate platforms within the Sino-Korea Platform (Choi, 2009; Kwon, 2012). Trilobite studies also represent strong paleogeographic proximity between the Taebaek and Yeongwol groups (Choi et al., 2016).

The Mungok Formation consists mainly of limestone with occasional intercalation of shale beds, and is up to 200 m in thickness and subdivided into four members: Garam, Baeiljae, Jeommal, Dumok members in ascending order (Kim and Choi, 2000). The *Yosimuraspis* and *Kainella* zones were established for

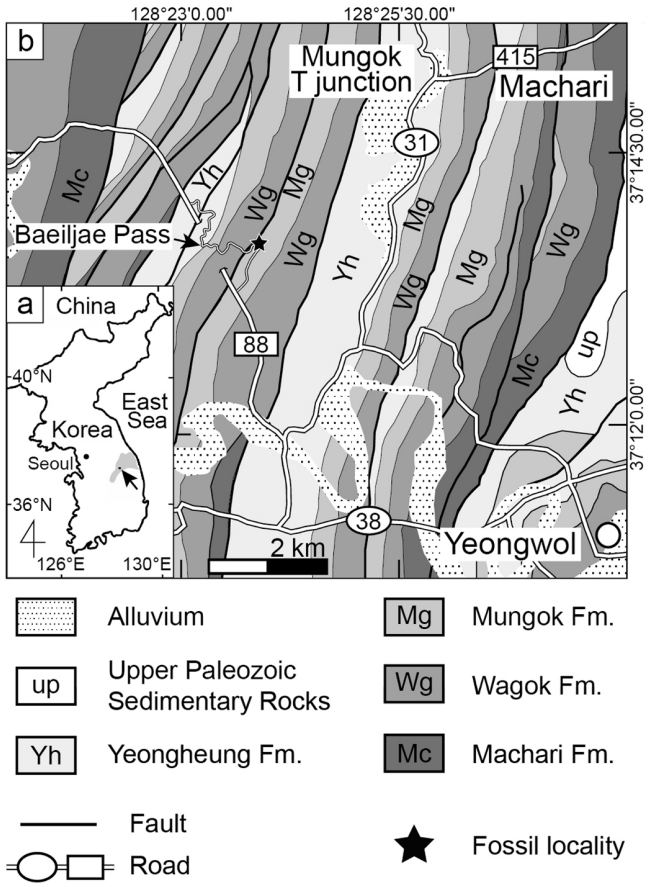

Fig. 1. Locality map. (a) Location of the Taebaeksan Basin in the Korean Peninsula (shaded area) and the study area indicated by an arrow, (b) geologic map showing fossil locality (modified from Hong, 2014, fig. 1).

the basal part of the Garam and Jeommal members, respectively, and the *Shumardia* Zone for the lower to middle part of the Dumok Member. The lithostratigraphy of the Mungok Formation can be found in Kim and Choi (2000) and Kim et al. (2014).

The present specimen of *Kayseraspis* was found in a locality immediately south of a small crop field along an abandoned road of the Baeiljae Pass at Bukssang-ri, Nam-myeon, Yeongwol-gun (N37°13′39.21″, E128°23′52.70″) (Fig. 1). The fossil-yielding interval consists of greenish-gray shale intercalated by thin marlstone layers. This interval corresponds to the uppermost part of the Chommal-II section of Kim and Choi (2000, fig. 4), which is correlated to the upper part of the Dumok Member of the Mungok Formation. In the outcrop, the Dumok Member is overlain by the Wagok Formation probably with a thrust fault contact, with no exposure of 15 to 20 m-thick interval between the two formations.

The fossil-bearing slab is a thin greenish-gray shale with a dimension of 12 × 10 cm long. Two trilobite fossils are preserved on one surface: an internal mold of a pygidium of *Kayseraspis* sp. and a poorly preserved external mold of a pygidium of an

unidentifiable asaphid. This material is deposited in the fossil arthropod collection (prefix KIGAM-9H) of the Geological Museum, Korea Institute of Geoscience and Mineral Resources, Daejeon, South Korea.

3. SYSTEMATIC PALEONTOLOGY

Class Trilobita Walch, 1771
Order Asaphida Salter, 1864
Family Asaphidae Burmeister, 1843
Kayseraspis Harrington, 1938
Type species: *Kayseraspis asaphelloides* Harrington, 1938 from the San Bernardo Formation, Salta, Argentina (Floian, Ordovician).

Kayseraspis sp.
Fig. 2
Material: One pygidium (KIGAM-9H-355)

Description: Pygidium subtriangular in outline with a short terminal axial spine; sagittal length 13.5 mm (57%) and maximum width 13.5 mm excluding axial spine. Pygidial spine 3.6 mm long, 4.4 mm wide anteriorly, strongly tapering backward, and very weakly convex. Conical axis narrow, weakly convex, and 4.4 mm wide occupying 19% of pygidial maximum width, reaching to posterior border furrow; axial rings not well defined. Pleural field with a convex anterior band of the anteromost pleural rib defined by well incised first pleural furrow; rest of pleural and interpleural furrows faintly defined. Border concave, separated from pleural field by distinct break in slope; width of border more or less uniform, 35% of pygidial length sagittally; doublure as wide as border.

Remarks: This specimen is characterized by a short terminal axial spine. Although incompletely preserved, the outer margin of the pygidium is clearly deflected near the posteromost end, indicating the presence of an axial spine. No information on cranidium precludes the further assessment down to species level.

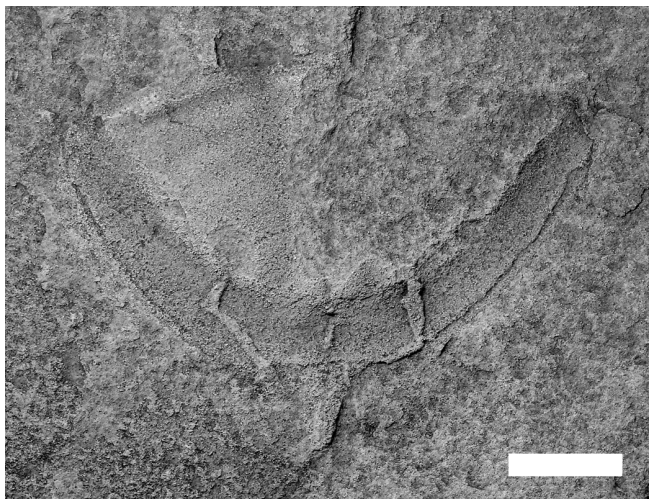

Fig. 2. Internal mold of a pygidium of *Kayseraspis* sp. from the uppermost part of the Mungok Formation, KIGAM-9H-355. Scale bar is 5 mm wide.

4. DISCUSSION

4.1. Importance of the Occurrence of *Kayseraspis* in the Mungok Formation

In Korea, *Kayseraspis* was first reported from the Taebaek Group (Kobayashi, 1966; Kim et al., 1991; Cheong et al., 1993). Kim et al. (1991) established the *Kayseraspis* Zone based on the dominant occurrence of *Kayseraspis laticauda* in association with *Asaphopsis nakamurai* in the upper part of the Dumugol Formation. The *Kayseraspis* Zone was assigned to the Arenigian (= Floian) on the ground of that the eponymous genus has been known mostly from the Arenigian strata of many other paleocontinents, except for the Tremadocian occurrence in North China. The faunal assemblage is closely similar to the constituents of the Floian *Asaphopsis* trilobite biogeographic province recognized by Whittington and Hughes (1973). It should be mentioned that this study follows Jell and Stait (1985) who transferred all but the type species of *Asaphopsis* to *Asaphopsoides*.

Subsequently, *Kayseraspis* was reported from Maepo, Danyang area in association with *Asaphellus*? sp., *Kayseraspis* sp. cf. *K. laticauda*, *Asaphopsoides maepoensis*, indeterminate asaphid trilobite, and some gastropods and ostracods (Choi, 1998a). The Danyang area is generally regarded as the southwestward extension of the Yeongwol Group, although the strata are strongly deformed (Choi, 2014). The *Kayseraspis*-bearing fauna of this area was correlated with the *Kayseraspis* Zone of the Dumugol Formation of the Taebaek Group on the basis of the strong similarity between the two trilobite assemblages characterized by the common occurrences of *Kayseraspis* and *Asaphopsoides* (= *Asaphopsis*) species, and was assigned to the Floian (Choi, 1998a). Later, the Danyang fauna was with hesitation included in the Yeongheung Formation because the lithologic succession of the fossil-occurring interval is not comparable to any part of the typical Mungok Formation and the faunal assemblage has not been reported from the Mungok Formation (Choi et al., 2016).

Consequently, the base of the Floian Stage in the Taebaeksan Basin has been placed at the base of the *Kayseraspis* zones in the upper part of the Dumugol Formation of the Taebaek Group and with some doubt, the basal part of the Yeongheung Formation of the Yeongwol Group (Choi et al., 2016, fig. 8). However, the occurrence of *Kayseraspis* in the upper part of the Mungok Formation in this study suggests that the uppermost part of the Mungok Formation may be assigned to the Floian or the *Kayseraspis*

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zones previously assigned to the lower Floian should be reassigned to the upper Tremadocian, both of which are incompatible with the current chronostratigraphic scheme of the Joseon Supergroup. Otherwise, the occurrence of *Kayseraspis* from the Mungok Formation can be simply regarded as the oldest (late Tremadocian) record of *Kayseraspis* in the Taebaeksan Basin, while the other *Kayseraspis-Asaphopsoides* associations belong to the Floian. Hence, to test these possibilities, it is necessary to reevaluate the Tremadocian–Floian boundary of the Joseon Supergroup by incorporating the biostratigraphy and international correlation based on fossils other than trilobites.

4.2. Reassessment of the Age of the *Kayseraspis*-bearing Faunas in the Taebaeksan Basin

The Global Stratotype Section and Point (GSSP) of the Floian Stage was defined by the first appearance of the graptolite *Tetragraptus approximatus* at the Diabasbrottet section in southwestern Sweden (Bergström et al., 2004). The absolute age of the boundary was estimated as 477.7 ± 1.4 Ma (Ogg et al., 2016). The first appearance datum of *T. approximatus* is consistent with the base of the *T. phyllograptoides* Zone of the Scandinavian graptolite biozonation and was close to the base of the conodont *Oelandodus elongatus-Acodus deltatus deltatus* Subzone of the *Paroistodus proteus* Zone and the trilobite *Megitaspis* (*Paramegitaspis*) *planilimbata* Zone (Bergström et al., 2004).

However, as Bergström et al. (2004) pointed out, it is somewhat problematic to use the Baltoscandian fossil assemblages for the correlation of the strata deposited near the paleoequator because the Early Ordovician trilobites and conodonts display a strong provincialism, while the graptolite *T. approximatus* shows a cosmopolitan distribution. Since the Taebaeksan Basin was located in the peri-equatorial region during the early Paleozoic (Choi et al., 2001), the comparison of biostratigraphic schemes based on trilobites and graptolites may provide more reliable age of the *Kayseraspis*-bearing faunas in the Taebaeksan Basin.

Although graptolites are not known to occur in the Dumugol Formation of the Taebaek Group, they have been relatively well studied in the Mungok Formation of the Yeongwol Group (Kim et al., 2006a, 2006b; Cho and Kim, 2007a, 2007b; Kim et al., 2009). Cho and Kim (2007a) established five Tremadocian graptolite biozones in the interval spanning from the Jeommal Member of the Mungok Formation to the lower part of the overlying Yeongheung Formation, namely the *Anisograptus matanensis*, *Adelograptus* cf. *tenellus*, *Callograptus* spp., *Paradelograptus antiquus*, and *Aorograptus victoriae* zones in ascending order (Fig. 3). The lower three graptolite biozones were correlated with the trilobite *Shumardia* Zone of Kim and Choi (2000), indicating that the base of the Floian should be placed within the Yeongheung Formation. This assignment is supported by the correlation with the graptolite biostratigraphy of the Diabasbrottet GSSP, Britain, and Australasia (Fig. 3). Two graptolite specimens were observed in the outcrop adjacent to the *Kayseraspis* sp.-yielding interval, which are identified as *Callograptus* sp. and *Dictyonema*

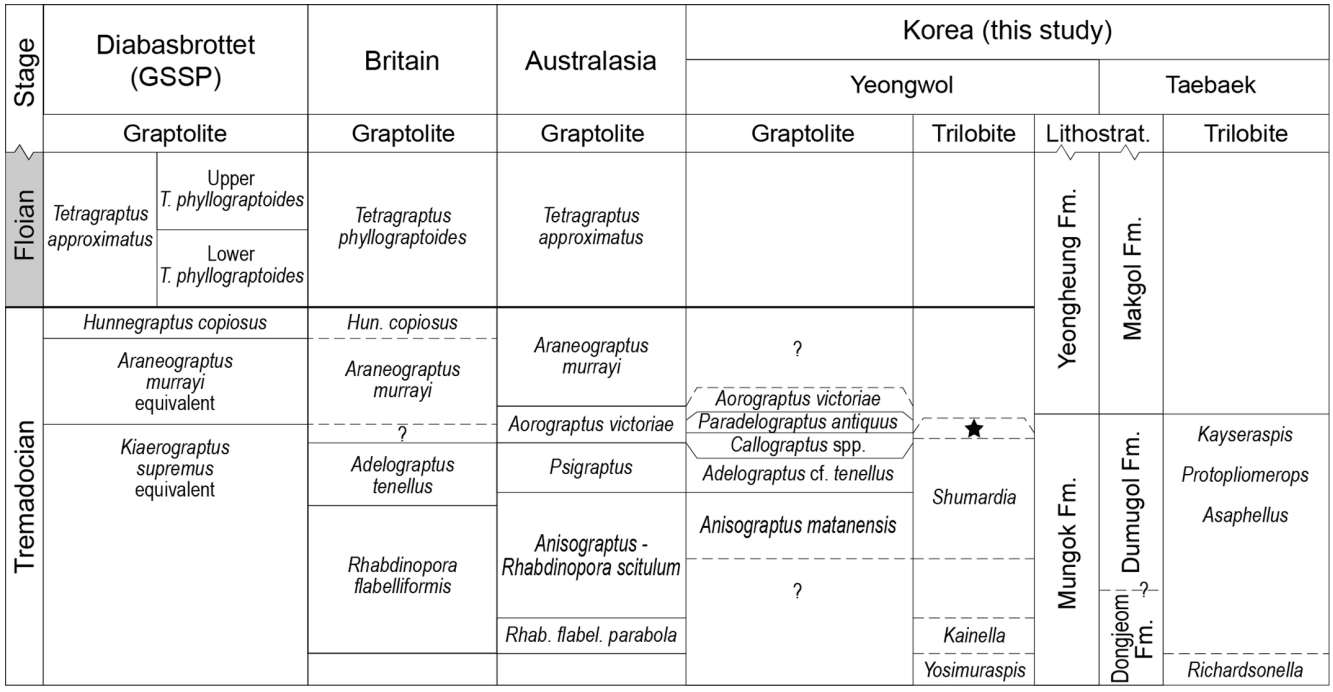

Fig. 3. Correlation of the Tremadocian to the early Floian graptolite and trilobite biozones, compiled from Bergström et al. (2004) for Diabasbrottet section, Ogg et al. (2016) for Britain and Australasia, Cho and Kim (2007a) and Kim and Choi (2000) for the Mungok Formation, and Kim et al. (1991) for the Dumugol Formation. An asterisk indicates the stratigraphic position of *Kayseraspis* from this study.

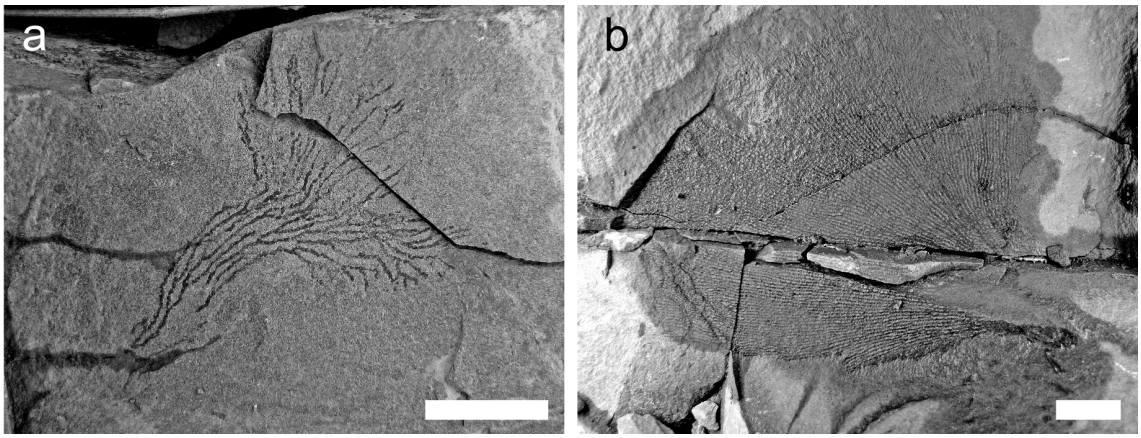

Fig. 4. Tremadocian graptolites from the outcrop in the vicinity of the *Kayseraspis*-yielding interval. (a) *Callograptus* sp., (b) *Dictyonema* sp. Scale bars are 10 mm wide.

sp. respectively (Fig. 4). Such dendroid graptlites are common members of the *Callograptus* spp. Zone of the Mungok Formation, and *Callograptus* are commonly found in the *Aorograptus victoriae* Zone of North China (Zhang and Erdtmann, 2004) to the lower part of which the *Callograptus* spp. Zone is correlated (personal communication with Dr. Cho, H.S.). This association of *Kayseraspis* and dendroid graptolites leads to conclude that the occurrence of *Kayseraspis* sp. can be assigned to the *Callograptus* spp. Zone above the *Shumardia* Zone (Fig. 3). Thus, the interval yielding *Kayseraspis* from the uppermost part of the Mungok Formation, Yeongwol area, is most likely to be the late Tremadocian in age.

The upper Tremadocian occurrence of *Kayseraspis* in the Mungok Formation of the Yeongwol Group does not necessarily indicate that the other *Kayseraspis* zones of Taebaek and Danyang area should also be assigned to the Tremadocian. The occurrence of a single specimen of *Kayseraspis* in Yeongwol area, which is not assignable to the specific level, hampers direct faunal correlation with the other *Kayseraspis* zones within the Taebaeksan Basin. No record of *Asaphopsis* (= *Asaphopsoides*), the constituent of the Floian *Asaphopsis* province, in the Mungok Formation of Yeongwol area suggests that the *Kayseraspis-Asaphopsoides* assemblages in Taebaek and Danyang areas may be younger.

Nevertheless, the assignment of the *Kayeraspis* Zone in the Taebaek and Danyang areas to the upper Tremadocian is still plausible on the basis of the following two reasons (Fig. 3). Firstly, *Kayseraspis* has been known to occur in the Tremadocian of North China (Zhou and Fortey, 1986) and Australia (Shergold, 1991), although it has been reported from the Floian of Canada (Kobayashi, 1955), Argentina (Harrington, 1938; Harrington and Leanza, 1957), and Australia (Legg, 1976; Laurie and Shergold, 1996). The species of *Asaphopsis* (= *Asaphopsoides*) also have been reported from the upper Tremadocian strata in China as noted by Kim et al. (1991). Based on the close paleobiogeographic relationship addressed by Choi et al. (2001), the Tremadocian occurrence of these genera in North China lends support to the upper Tremadocian age of *Kayseraspis* zones of the Taebaeksan Basin. In addition, since the trilobite faunal similarity has been known to be stronger between the Yeongwol and Taebaek groups in the Lower Ordovician than in the Cambrian (Choi et al., 2001; Choi, 2009; Choi et al., 2016), it seems reasonable to consider the appearance of *Kayseraspis* synchronous than diachronous across the Taebaeksan Basin that was a relatively small local basin in the Sino-Korea Platform.

Secondly, the global conodont biostratigraphic correlation of the Dumugol Formation of Yeongwol–Taebaek area by Seo et al. (1994), which was favored by Choi (1998a) to assign the *Kayseraspis* Zone to the Floian, should be reassessed in reference to the recent studies. Seo et al. (1994) established four conodont biozones in the Dumugol Formation, namely the *Chosonodina herfurthi-Rossosdus manitouensis*, *Glyptoconus quadraplicatus*, *Paracordylodus gracilis*, and *Triangulodus dumugolensis* zones in ascending order. The Tremadocian–Floian boundary was placed within the *Glyptoconus quadraplicatus* Zone. Later, Seo and Lee (2010) correlated these four biozones to those below the *Serratognathus bilobatus* Zone of North America and North China. It is noteworthy that the base of the *S. bilobatus* Zone is regarded as consistent with the base of Floian in the Jiangnan Slope Belt of South China and the North China Platform (e.g., Zhen et al., 2015; Wang et al., 2019). It implies that the entire Dumugol Formation, including the *Kayseraspis* Zone, can be assigned to the Tremadocian.

5. CONCLUSION

It is necessary to evaluate the local biostratigraphic schemes in accordance with the GSSP criteria to facilitate international stratigraphic correlation. In the lower Paleozoic Joseon Supergroup of Korea, the Ordovician biostratigraphy and chronostratigraphy

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have been relatively poorly understood compared to the Cambrian. The occurrence of a trilobite *Kayseraspis* from the Mungok Formation in Yeongwol area shows that the *Kayseraspis*-bearing faunas in the Taebaeksan Basin may be assignable to the late Tremadocian rather than the Floian. This interpretation is based on the comparison of the graptolite biostratigraphy to the trilobite faunal succession in relation to the GSSP criteria. Although it seems now more complicated to define the Tremadocian–Floian boundary in the Taebaeksan Basin, the base of Floian can be drawn somewhere above the *Kayseraspis* zones or the genus-bearing intervals in the Taebaekan Basin, i.e., within the Yeongheung Formation of the Yeongwol Group and the Makgol Formation of the Taebaek Group. As in this study, the integrative and comparative approach using different fossil groups will facilitate more reliable Tremadocian–Floian boundary in the Taebaeksan Basin. Since biostratigraphically valuable taxa such as trilobites, graptolites, and conodonts are relatively diverse and abundant in the Lower Orodivician than in the Middle Ordovician, multidisciplinary studies are required for the Mungok and Yeongheung formations of the Yeongwol Group and for the Dumugol and Makgol formations of the Taebaek Group in order to establish more precise chronostratigraphy of the Joseon Supergroup in the Taebaeksan Basin.

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REFERENCES

Bergström, S.M., Löfgren, A., and Maletz, J., 2004, The GSSP of the Second (Upper) Stage of the Lower Ordovician Series: Diabasbrottet at Hunnenberg, Province of Västergötland, Southwestern Sweden. Episodes, 27, 265–272.

Burmeister, H., 1843, Die Organisation der Trilobiten. Georg Reimer, Berlin, 148 p.

Cheong, C.H., Kim, B.K., and Choi, D.K., 1993, Invertebrate fossils from the upper part of the Dumugol Formation (Lower Ordovician) of Dongjeom area, Korea. Journal of the National Academy of Sciences, Republic of Korea (Natural Sciences), 32, 1–21.

Cho, H.S. and Kim, J.Y., 2007a, Graptolite biostratigraphy and its correlation of the Mungok and Yeonghung formations at Yeongwol area, Korea. Geosciences Journal, 11, 23–38.

Cho, H.S. and Kim, J.Y., 2007b, A new graptolite species *Adelograptus brevibrachiatus* from the Mungok Formation of Yeongwol area, Korea. Journal of the Korean Earth Science Society, 28, 563–571.

Choi, D.K., 1998a, An Early Ordovician trilobite faunule from the Choson Supergroup, Maepo, Tanyang area, Korea. Geosciences Journal, 2, 235–242.

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

Choi, D.K., 2009, Trilobite faunal assemblages of the Taebaeksan Basin and their importance in reconstructing the early Paleozoic paleogeography and paleoenvironments of Korean Peninsula. Journal of the Paleontological Society of Korea, 25, 129–148. (in Korean with English abstract)

Choi, D.K., 2014, Geology and Tectonic Evolution of the Korean Peninsula. Seoul National University Press, Seoul, 277 p. (in Korean with English summary)

Choi, D.K. and Chough, S.K., 2005, The Cambrian–Ordovician stratigraphy of the Taebaeksan Basin, Korea: a review. Geosciences Journal, 9, 187–214.

Choi, D.K., Kim, D.H., and Sohn, J.W., 2001, Ordovician trilobite faunas and depositional history of the Taebaeksan Basin, Korea: implications for palaeogeography. Alcheringa, 25, 53–68.

Choi, D.K., Lee, J.G., Lee, S.-B., Park, T.-Y., and Hong, P.S., 2016, Trilobite biostratigraphy of the lower Paleozoic (Cambrian–Ordovician) Joseon Supergroup, Taebaeksan Basin, Korea. Acta Geologica Sinica (English edition), 90, 1976–1999. https://doi.org/10.1111/1755-6724.13016

Choi, D.K., Chough, S.K., Kwon, Y.K., Lee, S.-B., Woo, J., Kang, I., Lee, H.S., Lee, S.M., Sohn, J.W., Shinn, Y.J., and Lee, D.-J., 2004, Taebaek Group (Cambrian–Ordovician) in the Seokgaejae section, Taebaeksan Basin: a refined lower Paleozoic stratigraphy in Korea. Geosciences Journal, 8, 125–151.

Chough, S.K., Kwon, S.T., Ree, J.-H., and Choi, D.K., 2000, Tectonic and sedimentary evolution of the Korean peninsula: a review and new view. Earth-Science Reviews, 52, 175–235.

Cluzel, D., Lee, B.J., and Cadet, J.P., 1991, Indosinian dextral ductile fault system and synkinematic plutonism in the southwest of the Ogcheon belt (South Korea). Tectonophysics, 194, 131–151.

Harrington, H.J., 1938, Sobre las faunas del Ordoviciano Inferior del Norte Argentino. Revista del Museo de la Plata (new series), 1, 109–289.

Harrington, H.J. and Leanza, A.F., 1957, Ordovician trilobites of Argentina. Department of Geology, University of Kansas, Special Publication, 1, 276 p.

Hong, P.S., 2014, Cambrian Series 3 trilobites from the lower part of the Machari Formation, Deoksang section, Yeongwol, Korea. Ph.D. Thesis, Seoul National University, Seoul, 108 p. (in English with Korean abstract)

Jell, P.A. and Stait, B., 1985, Tremadoc trilobites from the Florentine Valley Formation, Tim Shea area, Tasmania. Memoirs of the Museum of Victoria, 46, 1–34. https://doi.org/10.24199/j.mmv.1985.46.01

Kim, D.H. and Choi, D.K., 2000, Lithostratigraphy and biostratigraphy

of the Mungok Formation (Lower Ordovician), Yongwol, Korea. Geosciences Journal, 4, 301–311.

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

Kim, J.Y., Cho, H.S., and Jin, Y.P., 2006b, Early Ordovician (Tremadocian) graptolites from the Mungok Formation, Yeongwol, Korea: biostratigraphy and correlation. Journal of the Korean Earth Science Society, 27, 745–756.

Kim, J.Y., Choi, S.K., Jin, Y.P., and Kim, K.S., 2009, Late Tremadocian graptolites from the Mungok Formation of the Namaeri and Baeiljae Sections at Yeongwol, Korea. Journal of the Korean Earth Science Society, 30, 646–659.

Kim, K.H., Choi, D.K., and Lee, C.Z., 1991, Trilobite biostratigraphy of the Dumugol Formation (Lower Ordovician) of Dongjeom area, Korea. Journal of the Paleontological Society of Korea, 7, 106–115.

Kim, Y.-H.G., Rhee, C.W., Woo, J.S., and Park, T.-Y.S., 2014, Depositional systems of the Lower Ordovician Mungok Formation in Yeongwol, Korea: implications for the carbonate ramp facies development. Geosciences Journal, 18, 397–417.

Kobayashi, T., 1934, The Cambro-Ordovician formations and faunas of South Chosen, Palaeontology, Part II, Lower Ordovician faunas. Journal of the Faculty of Science (Imperial University of Tokyo), Section II, 3, 1–84.

Kobayashi, T., 1955, The Ordovician fossils from the McKay Group in British Columbia, Western Canada, with a note on the Early Ordovician palaeogeography. Journal of Faculty of Science, University of Tokyo, Section 9, 355–493.

Kobayashi, T., 1966, The Cambro-Ordovician formations and faunas of South Korea, Part 10, Stratigraphy of the Chosen Group in Korea and South Manchuria and its relation to the Cambro-Ordovician formations and faunas of other areas, Section A, The Chosen Group of South Korea. Journal of the Faculty of Science (University of Tokyo), Section II, 16, 1–84.

Kwon, Y.J. and Kwon, Y.K., 2020, Sequence stratigraphy in the Middle Ordovician carbonate successions (Yeongheung Formation), mid-east Korea: paleogeographic implications for a land-detached ramp-type platform. Journal of Asian Earth Sciences, 193, 104263.

Kwon, Y.K., Chough, S.K., Choi, D.K., and Lee, D.-J., 2006, Sequence stratigraphy of the Taebaek Group (Cambrian–Ordovician), mid-east Korea. Sedimentary Geology, 192, 15–55.

Laurie, J.R. and Shergold, J.H., 1996, Early Ordovician trilobite taxonomy and biostratigraphy of the Emanuel Formation, Canning Basin, Westem Australia (Part 1 and 2). Palaeontographica Abteilung A, 240, 65–103.

Lee, S.-B. and Choi, D.K., 2007, Trilobites of the *Pseudokoldinioidia* fauna (uppermost Cambrian) from the Taebaek Group, Taebaeksan Basin, Korea. Journal of Paleontology, 81, 1454–1465.

Legg, D.P., 1976, Ordovician trilobites and graptolites from the Canning Basin, western Australia. Geologica et Paleontologica, 10, 1–58.

Ogg, J.G., Ogg, G.M., and Gradstein, F.M., 2016, A Concise Geologic Time Scale 2016. Elsevier, 240 p.

Salter, J.W., 1864, A Monograph of the British Trilobites. Palaeontographical Society Monograph, London, 16, 83 p.

Seo, K.-S. and Lee, B.-S., 2010, Conodonts from the Early Ordovician Dumugol Formation in Seckgaejae area, Bonghwagun, Kyungsangbukdo, Korea. Journal of the Paleontological Society of Korea, 26, 59–69.

Seo, K.-S., Lee, H.-Y., and Ethington, R.L., 1994, Early Ordovician conodonts from the Dumugol Formation in the Baegunsan Syncline, eastern Yeongweol and Samcheog areas, Kangweon-do, Korea. Journal of Paleontology, 68, 599–616.

Shergold, J.H., 1991, The Pacoota Sandstone, Amadeus Basin, Northern Territory: stratigraphy and palaeontology. Bulletin – Australia, Bureau of Mineral Resources, Geology and Geophysics, 237, 93 p.

Walch, J.E.I., 1771, Die Naturgeschichte der versteinerungen zur erläuterung der Knorrischen Sammlung von Merkwürdigkeiten der Natur. Dritter Theil, Paul Jonathan Felßecker, Nürnberg, 235 p.

Wang, Z.-H., Zhen, Y.Y., Bergström, S.M., Wu, R.-C., Zhang, Y.-D., and Ma, X., 2019, A new conodont biozone classification of the Ordovician System in South China. Palaeoworld, 28, 173–186.

Whittington, H.B. and Hughes, C.P., 1973, Ordovician trilobite distribution and geography. In: Hughes, N.F. (ed.), Organisms and Continents through Time: A Symposium. Special Papers in Palaeontology, 12, p. 235–240.

Yin, A. and Nie, S., 1993, An indentation model for the north and south China collision and development of the Tan-Lu and Honam fault systems, Eastern Asia. Tectonics, 12, 810–813.

Yosimura, I., 1940, Geology of the Neietsu District, Kogendo, Tyosen (Korea). Journal of the Geological Society of Japan, 47, 112–122. (in Japanese)

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

Zhen, Y.Y., Percival, I.G., and Zhang, Y.-D., 2015, Floian (Early Ordovician) conodont-based biostratigraphy and biogeography of the Australasian Superprovince. Palaeoworld, 24, 100–109.

Zhou, Z.Y. and Fortey, R.A., 1986, Ordovician trilobites from North and Northeastern China. Palaeontographica Abteilung A, 192, 157–210.

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