

Occurrence of *Changshania* (Trilobita, Cambrian) in the Taebaeksan Basin, Korea and its stratigraphic and paleogeographic significance

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Abstract

In the Cambrian the Taebaeksan Basin was a shallow marine siliciclastic–carbonate system, in which two contrasting types of lithofacies and biofacies occur in juxtaposition. The shallow marine facies (Taebaek Group) comprises diverse trilobite taxa endemic to the Sino–Korean block, whereas the deep-water oceanic facies (Yeongwol Group) is characterized by predominance of cosmopolitan and pelagic trilobites. *Changshania* is a representative Furongian trilobite genus endemic to the Sino–Korean block and has been employed as a zonal taxon for middle Furongian in North China. This article reports the occurrence of *Changshania* from the deep-water facies (Machari Formation, Yeongwol Group) of the Taebaeksan Basin, for the first time in Korea. This observation enables to correlate the *Eochuangia hana* Zone of Korea with the *Changshania–Irvingella* Zone of North China with confidence. The dominance of laminated dark gray to black shale and pandemic trilobites in the Machari Formation has been interpreted to indicate deposition in a dysaerobic deep-water environment. The occurrence of *Changshania* along with some endemic polymerid trilobites, though uncommon, in the deeper-water oceanic facies suggests that the Machari Formation was formed in the offshore region fringing the Sino–Korean block during the Cambrian.

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Keywords: Trilobites; Cambrian; Korea; North China; Paleogeography

1. Introduction

In Korea the Cambrian–Ordovician sedimentary rocks, the Joseon Supergroup, are mainly exposed in the Taebaeksan Basin, located in the central-eastern part of the Korean Peninsula (Fig. 1). The Joseon Supergroup is a mixed siliciclastic–carbonate succession displaying different lithologic successions in different areas and has been divided into the Taebaek, Yeongwol,

Mungyeong, Yongtan, and Pyeongchang groups (Choi, 1998). Of these, the Taebaek and Yeongwol groups are regionally extensive (Fig. 1b) and yield abundant and diverse invertebrate fossils, whereas the other three groups are poorly fossiliferous. Accordingly the Taebaek and Yeongwol groups have been studied intensively during the last two decades and are considered to represent the early Paleozoic environments and faunas of the Korean Peninsula (Choi and Chough, 2005).

The faunal contrast between the Taebaek and Yeongwol groups was earlier noted by Kobayashi (1966, 1967). Out of 279 trilobite species described from the Taebaeksan

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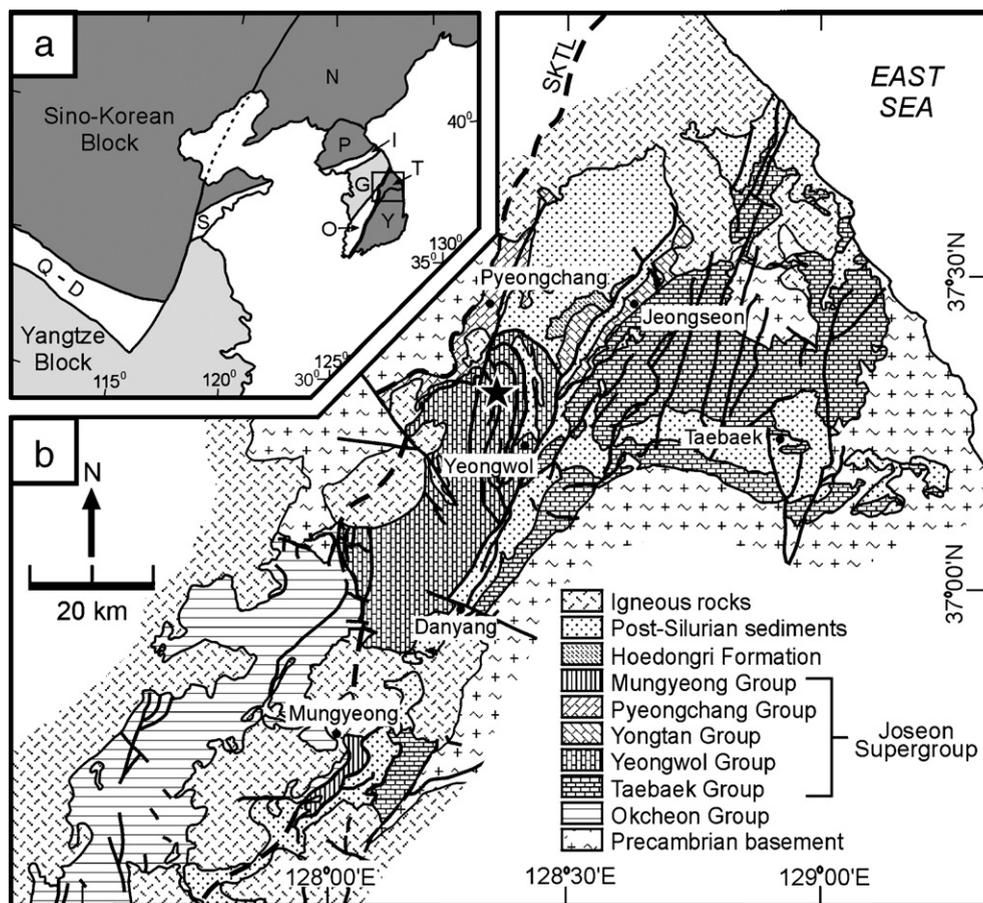


Fig. 1. Index maps. (a) A simplified tectonic map of the Korean Peninsula and adjacent region, showing the location of Fig. 1b (Abbreviations: G, Gyeonggi Massif; I, Imjingang Belt; N, Nangnim Massif; O, Okcheon Belt; P, Pyeongnam Basin; Q–D, Qinling–Dabie Belt; S, Sulu Belt; T, Taebaeksan Basin; Y, Yeongnam Massif). (b) Geologic map of the Taebaeksan Basin. A solid star represents the location of the fossil locality (Gonggiri section). SKTL (dashed line) denotes the South Korean Tectonic Line (cf. Chough et al., 2000).

Basin, the Taebaek, Yeongwol, and Mungyeong groups yield 180, 89, and 16 species respectively, whereas no trilobites have been reported from the Yongtan and Pyeongchang groups (Kobayashi, 1966; Choi, 1998). Interestingly enough, the Taebaek and Yeongwol groups have been known to share no trilobite species in the Cambrian. In a paleobiogeographic configuration of eastern Asia, Kobayashi (1967) proposed three faunal provinces during the Cambrian period: the Hwangho fauna is characterized by the dominance of endemic taxa inhabiting shallow marine environments; the Chuantien fauna is dominated by redlichiid trilobites of early to middle Cambrian age with later forms poorly represented; and the Jiangnan fauna comprises a large number of cosmopolitan and pelagic forms indicating a deep-water, oceanic setting. The Cambrian trilobites of the Taebaek Group were assigned to the Hwangho fauna, whereas those of the Yeongwol Group to the Jiangnan fauna (Kobayashi, 1967).

Recent paleogeographic studies have shown that eastern Asia was divided into the Sino–Korean (or North China) and Yangtze (or South China) blocks which were separated and behaved independently during the early Paleozoic times (Burrett, 1973; Lin et al., 1985; Scotese and McKerrow, 1990; Zhao et al., 1996; Li and Powell, 2001). The Cambrian trilobite faunal contrast between the Taebaek and Yeongwol groups apparently prompted Cluzel et al. (1991) to suggest that the Taebaek Group belonged to the Sino–Korean block, while the Yeongwol Group was part of the Yangtze block in the early Paleozoic. If this is correct, the Taebaek and Yeongwol groups must have formed in separate sedimentary basins. Meanwhile, Chough et al. (2000) discredited the hypothesis on account of that the Cambrian faunal contrast can be attested to the difference in depositional environments in a contiguous normal marine setting: viz., the Taebaek Group was deposited in the inner shelf, while the

Yeongwol Group was formed in a more offshore, deeper water environment.

Changshania Sun, 1924 is an important trilobite genus endemic to North China (see below) and has long been employed as a zonal taxon for the middle Furongian Series in China. *Changshania* has not hitherto been documented in Korea, although the trilobite faunas of the Taebaek Group show a close affinity with those of North China (Kobayashi, 1967). Part of the reasons might be attributed to the paucity of fossils in the interval of the Taebaek Group correlatable to the *Changshania* Zone. In this study, we report the occurrence of *Changshania* in the Machari Formation of the Yeongwol Group for the first time in Korea. The discovery of *Changshania* in the Yeongwol Group is very significant not only in refining the Cambrian biostratigraphic correlation of the Sino–Korean block with other parts of the world but also in providing an important evidence for early Paleozoic continental configuration of the Korean Peninsula.

2. Geology and stratigraphy

The Cambrian–Ordovician sedimentary rocks in Korea, Joseon Supergroup, are exposed in the Taebaek-san Basin located at the central-eastern part of the Korean Peninsula (Fig. 1). The Joseon Supergroup is composed of mixed siliciclastic–carbonate deposits of late early Cambrian to Middle Ordovician age, which formed in a normal marine setting fringing the Sino–Korean block in the early Paleozoic (Chough et al., 2000; Choi et al., 2001). It has been divided into five groups on the basis of unique lithologic successions and geographic distribution: namely, Taebaek, Yeongwol, Yongtan, Pyeongchang, and Mungyeong groups (Choi, 1998). The Taebaek and Yeongwol groups are stratigraphically well understood thanks to the prolific occurrence of trilobites and conodonts, whereas the stratigraphy of the latter three groups is poorly established (Choi and Chough, 2005).

The Yeongwol Group comprises in ascending order the Sambangsan, Machari, Wagok, Mungok, and Yeongheung formations (Kobayashi, 1966; Choi, 1998). The lowermost Sambangsan Formation consists exclusively of siliciclastic sediments, whereas the upper four formations are composed dominantly of carbonates. The geologic age of the group ranges from the middle Cambrian to Middle Ordovician. The Cambrian–Ordovician boundary has been drawn at the base of the Mungok Formation based on the occurrence of *Jujuyaspis* (Kim and Choi, 2000; Choi et al., 2003).

The Machari Formation has been well known to yield abundant and diverse middle Cambrian to

Furongian trilobites with some brachiopods and gastropods, the ‘Machari fauna’ (Kobayashi, 1962). The base of the formation is defined by the occurrence of dark-gray argillaceous limestone and thick-bedded bioclastic grainstone to packstone beds which yield well-preserved middle Cambrian trilobites. These beds are overlain by a succession of dark gray dolomitic limestone, shale, and lime breccia, which characterizes the lower part of the Machari Formation. The fossiliferous middle part is dominated by laminated dark gray to black shale with occasional intercalations of thin dolomitic limestone beds. The upper part is an alternating unit of thin-bedded, light gray dolomitic limestone and black shale beds, showing a conspicuous banded appearance. The banded structure becomes progressively obscure in the upper stratigraphic level and grades into massive dolostone of the Wagok Formation. The depositional environment of the Machari Formation has not been studied in detail, but the dominance of laminated black shale facies within the formation is indicative of deposition in a dysaerobic deep-water environment (Chough et al., 2000).

In a recent compilation of the stratigraphy of the Joseon Supergroup, Choi and Chough (2005) provided an updated biostratigraphy of the Yeongwol Group, in which ten trilobite biozones are recognized within the Machari Formation: they are in ascending order the *Tonkinella*, *Lejopyge armata*, *Glyptagnostus stolidotus*, *Glyptagnostus reticulatus*, *Proceratopyge tenuis*, *Hancrania brevilibata*, *Eugonocare longifrons*, *Eochuangia hana*, *Agnostotes orientalis*, and *Pseudoyuepingia asaphoides* zones. The lower three zones are assigned to the middle Cambrian, whereas the upper seven zones belong to the Furongian Series.

3. Fossil locality

All of the specimens used in this study were collected from a measured section (Gonggiri section; 128°26′29″ E and 37°18′42″ N) of the Machari Formation exposed in Yeongwol (Fig. 1b). The Gonggiri section measures about 53 m in thickness and represents the middle part of the Machari Formation. Good exposure of the section reveals that the Machari Formation is overlain conformably by the Wagok Formation to the west, while to the east exposed is a poorly-fossiliferous thick-bedded limestone succession indicating the upper part of the Machari Formation. Consequently it was inferred that the fossiliferous Gonggiri section is underlain in thrust contact by the thick-bedded upper part of the Machari Formation. The lower part of the section is composed

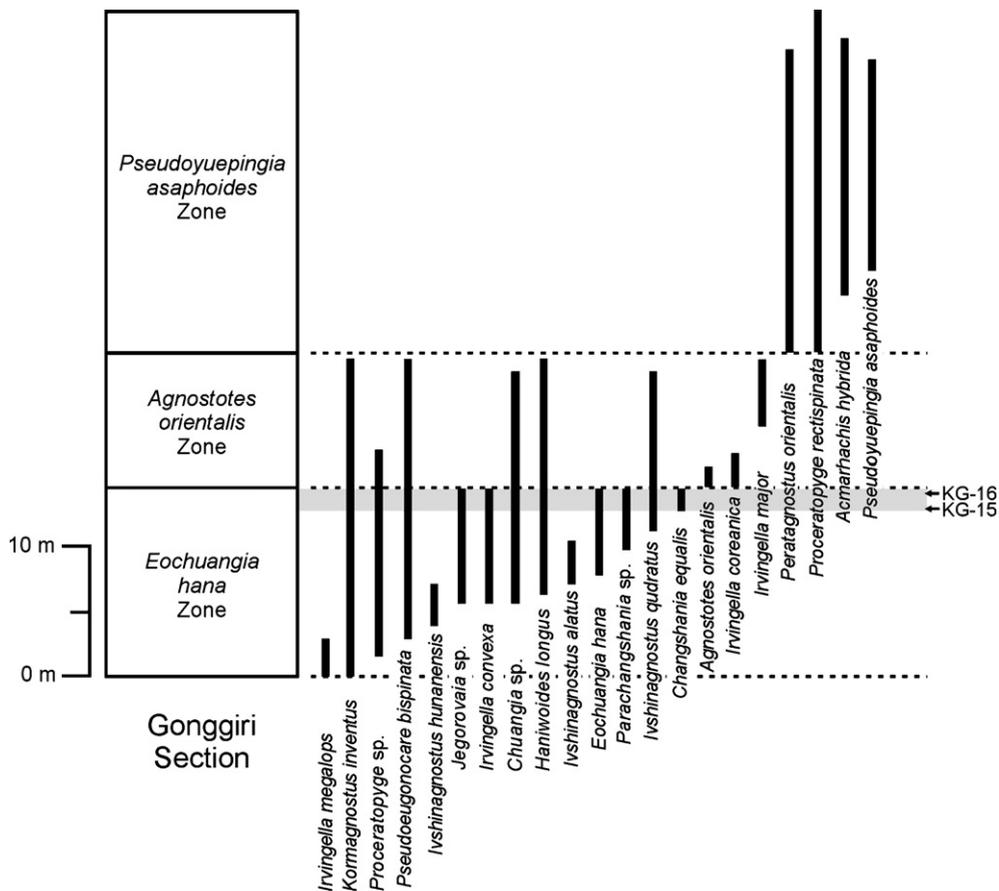


Fig. 2. Stratigraphic distribution of selected trilobite taxa from the Machari Formation of the Gonggiri section, Yeongwol, Korea. The shaded bar in the uppermost part of the *Eochuangia hana* Zone indicates the stratigraphic position of the units KG-15 and KG-16 where *Changshania equalis* was recovered.

of laminated dark gray to black argillaceous limestone, while its upper part consists largely of thinly- to medium-bedded dolomitic limestone. Massive dolostone beds (up to 50 cm thick) and thin bioclastic layers (several centimeters thick) are occasionally intercalated. A couple of weakly bioturbated beds and chert layers are also present in the upper part.

In the Gonggiri section represented are three Furongian trilobite zones: i.e., the *E. hana*, *A. orientalis* and *P. asaphoides* zones in ascending order (Fig. 2; Choi et al., 2004). The *E. hana* Zone has a high species diversity yielding twelve agnostoid and ten polymerid species. Among them, stratigraphically significant taxa are *Ivshinagnostus* spp., *E. hana*, *Irvingella megalops*, *I. convexa*, and *Changshania equalis*. The succeeding *A. orientalis* Zone includes twelve agnostoid and five polymerid species, in which the age-diagnostic taxa are *A. orientalis*, *Irvingella coreanica*, and *I. major*. The *P. asaphoides* Zone comprises seven agnostoid and two

polymerid species and has a distinct faunal assemblage different from the lower two zones (Fig. 2).

C. equalis occurs in a short interval (units KG-15 and KG-16; ca. 1 m thick) of the uppermost part of the *E. hana* Zone (Fig. 2), where associated trilobite taxa include *Homagnostus obesus*, *Micragnostus* aff. *intermedius*, *Kormagnostus inventus*, *Pseudagnostus josepha*, *Ivshinagnostus quadratus*, *Pseudorhaptagnostus tumidus*, *E. hana*, *Chuangia* sp., *Parachangshania* sp., *Irvingella convexa*, *Jegorovaia* sp. and *Haniwoides longus* (Fig. 3).

4. Systematic paleontology

Family CHANGSHANIIDAE Kobayashi, 1935

Genus *Changshania* Sun, 1924

Type species: Changshania conica Sun, 1924 from the Furongian Changshan Formation, Kaiping, Hebei Province, China.

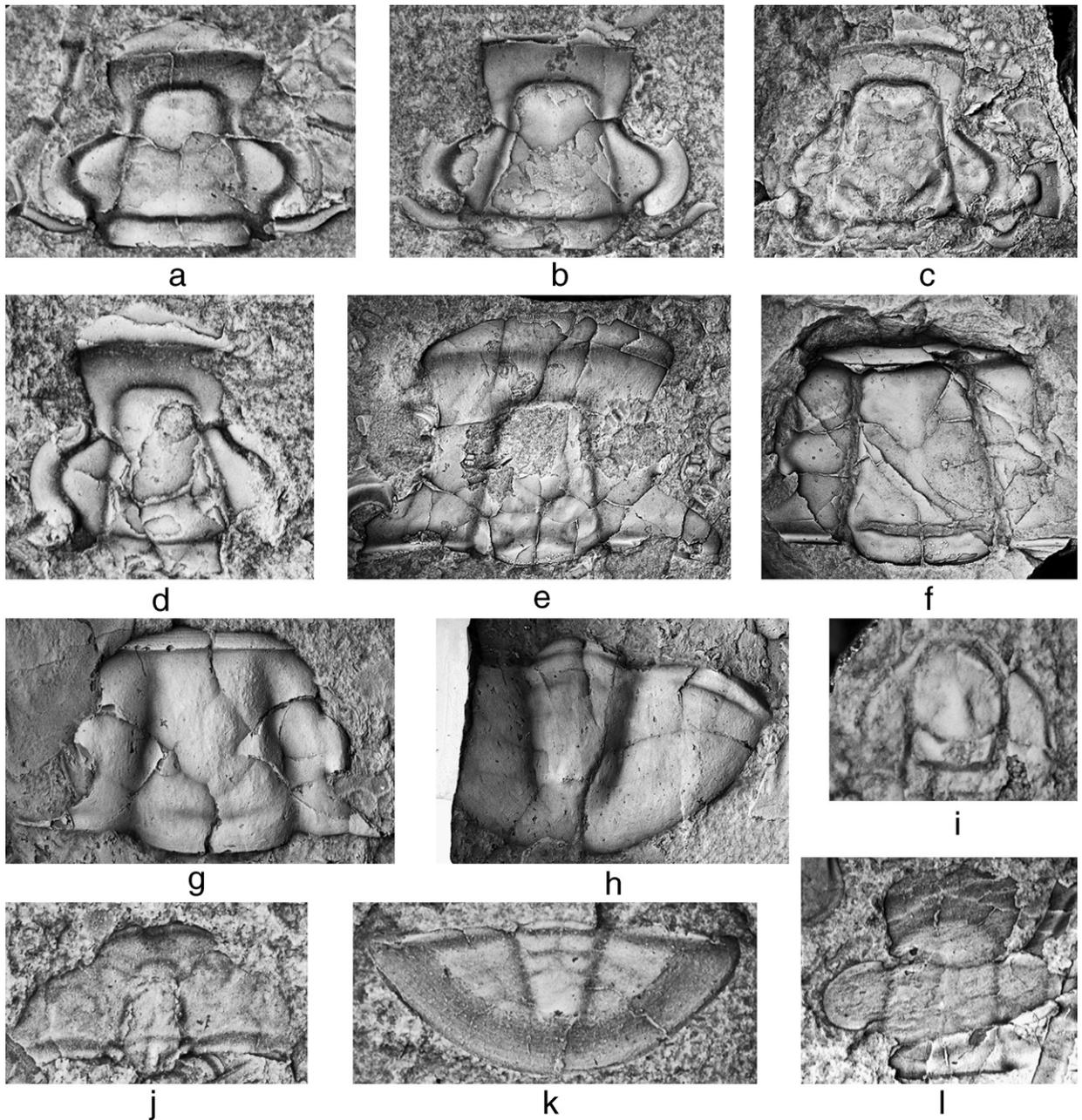


Fig. 3. Polymerid trilobites from the units KG-15 and KG-16 of the Gonggiri section, Yeongwol, Korea. (a–d) *C. equalis* Sun, 1935. (a) SNUP 783, cranidium, $\times 7$. (b) SNUP 784, cranidium, $\times 4.5$. (c) SNUP 785, cranidium, $\times 3.7$. (d) SNUP 786, cranidium, $\times 4$. (e) *Parachangshania* sp. SNUP 787, cranidium, $\times 2$. (f) *Eochuangia* sp. SNUP 788, cranidium, $\times 2.5$. (g–h) *Chuangia* sp. (g) SNUP 789, cranidium, $\times 4.7$. (h) SNUP 790, pygidium, $\times 4$. (i) *Irvingella convexa* (Kobayashi, 1935). SNUP 791, cranidium, $\times 10.5$. (j) *Jegorovaia* sp. SNUP 792, cranidium, $\times 10$. (k–l) *Haniwoides longus* Kobayashi, 1935. (k) SNUP 794, pygidium, $\times 8.5$. (l) SNUP 793, cranidium, $\times 5.5$.

Diagnosis: Cranidium rectangular to subtrapezoidal in plan view; glabella truncato-conical, clearly defined by well-incised axial and preglabellar furrows, with poorly-impressed glabellar furrows; frontal area divided into flat to concave preglabellar field and convex anterior

border; palpebral lobes large, located at level with or behind glabellar midpoint, occupying one-half to two-thirds of glabellar length, defined by well-incised palpebral furrows. Pygidium fusiform, with abaxially pointed antero-lateral corners; axis with four to five

axial rings and a terminal piece, posteriorly reaching to border furrow; pleural furrows deep and broad; interpleural furrows obsolete; border narrow, with more or less uniform width.

Discussion: Since the establishment of *Changshania* in 1924, thirteen species have been originally assigned to or later transferred to the genus: *Ptychoparia?* *bromus* Walcott, 1905, *Anomocarella baucis* Walcott, 1905, *C. conica* Sun, 1924, *C. equalis* Sun, 1935, *C. konoii* Endo in Endo and Resser, 1937, *Chelidonocephalus (Farsia) abundans kuersteni* Wolfart, 1974, *C.?* *liaotungensis* Kobayashi, 1933, *C. modesta* Endo in Endo and Resser, 1937, *C. orbiculata* Endo in Endo and Resser, 1937, *C. parallela* Endo in Endo and Resser, 1937, *Prochangshania shihuigouensis* Chu, 1960, *C.?* *truncata* Sun, 1924, and *C. yanzhouensis* Qian, 1994. *Ptychoparia?* *bromus* and *Anomocarella baucis* were assigned to *Changshania* by Lu et al. (1965) and Zhang and Jell (1987), respectively. *Prochangshania* was considered to be a junior synonym of *Changshania* by Zhang et al. (1995). *Chelidonocephalus (Farsia) abundans kuersteni* from Iran was elevated to the species level and was transferred to *Changshania* by Fortey (1994). All but *C. kuersteni* were reported from North China.

Changshania konoii and *C. parallela* are too poorly preserved to evaluate the morphological details, but are likely not to belong to *Changshania*. *Changshania orbiculata* has been transferred to *Lioparia* by Kobayashi (1962) and certainly does not belong to *Changshania*. Both *C.?* *liaotungensis* and *C.?* *truncata* are characterized by very broad subtrapezoidal glabella and hence should be excluded from *Changshania*. *Changshania shihuigouensis* was synonymized with *C. conica* by Qian (1994). *Changshania kuersteni* (Wolfart, 1974) has a very distinctive pygidium, and cannot be accommodated with the genus. Consequently, six species remain as valid members of *Changshania*: i.e., *C. bromus*, *C. baucis*, *C. conica*, *C. equalis*, *C. modesta*, and *C. yanzhouensis*.

C. equalis Sun, 1935

(Fig. 3a–d)

1935 *C. equalis* Sun, p. 42, pl. 2, Figs. 8, 9, 13–17.

1965 *C. equalis* Sun: Lu et al, p. 466, pl. 92, Figs. 7–10.

1989 *C. equalis* Sun: Zhu and Wittke, p. 227, pl. 10, Fig. 12; pl. 12, Fig. 8.

1994 *C. equalis* Sun: Qian, p.74, pl. 16, Fig. 7; pl.17, Fig. 8.

Diagnosis: A species of *Changshania* with broad trapezoidal glabella, large palpebral lobes located close to glabella and occupying exsagittally posterior

two-thirds of glabella, and medially acuminate anterior border.

Discussion: Fifteen cranidia of *C. equalis* were recovered from the units KG-15 and KG-16 of the Gonggiri section which corresponds to the uppermost part of the *E. hana* Zone. They are morphologically indistinguishable from *C. equalis* reported from North China (Sun, 1935; Zhu and Wittke, 1989; Qian, 1994), but some of the testaceous specimens in the present collection show finely granulate prosopon.

5. Stratigraphic correlation

In the past it was difficult to correlate precisely the Cambrian biozones of the Yeongwol Group with those of the Taebaek Group and coeval strata in North China, because their faunal successions are profoundly different from each other. Inevitably the correlation between the two groups has to be provisional and approximate in most cases (cf. Choi and Chough, 2005). The documentation of *Changshania* in the Yeongwol Group in this study provides a good reference point for biostratigraphic correlation of the Furongian strata between the two regions.

The Furongian trilobite biostratigraphy established in northeastern Hebei Province has long been employed as the standard for North China (Sun, 1935; Zhang, 2003): they are in ascending order the *Prochuangia*, *Chuangia*, *Changshania–Irvingella*, *Maladioidella*, *Kaolishania*, *Tsinania–Ptychaspis*, *Changia*, and *Mictosaukia* Zones. This biostratigraphic scheme can be partly traced into the Taebaek Group of Korea (Fig. 4), but it should be admitted that to date the biozonation of the Taebaek Group has been poorly resolved.

Aside from this report of *Changshania* in Korea, *Changshania* has hitherto been known to occur exclusively in North China. The *C. conica* Zone was formally established from the Changshan Formation of Hebei Province by Sun (1935), and later Lu and Dong (1953) confirmed the *Changshania* Zone in the Tangwangzhai section of Shandong Province, China. Lu and Qian (1983) proposed the *C. conica–Irvingella taitzuhoensis* Zone based on the occurrence of *Irvingella* in the *Changshania* Zone in Liaoning Province. The association of *Changshania* and *Irvingella* is very useful for biostratigraphic correlation of the Sino–Korean block with other parts of the world, as *Irvingella* is a cosmopolitan trilobite with a relatively short stratigraphic range within the Furongian (Hong et al., 2003).

In the Gonggiri section, *C. equalis* is also associated with *Irvingella convexa* in the uppermost interval of the

Age	KOREA		NORTH CHINA	SOUTH CHINA	AUSTRALIA	LAURENTIA						
	Yeongwol	Taebaek				Great Basin	Mackenzie Mt.					
FURONGIAN		<i>Kaolishania</i>	<i>Kaolishania</i>	<i>Eolotagnostus decorus</i> - <i>Kaolishaniella</i>	<i>R. claki prolatus</i> / <i>Caznaia sectatrix</i> <i>Rhaptagnostus claki patulus</i> / <i>Caznaia squamosa</i> <i>Hapidocare lilyensis</i> <i>Peichiashania tertia</i> / <i>Peichiashania quarta</i>	SUNWAPTAN	<i>Saukia</i>					
								<i>Pseudo-yuepingia asaphoides</i>	<i>Maladioidella</i>	<i>Rhaptagnostus ciliensis</i> - <i>Onchonotellus cf. kuruktagensis</i>	<i>Peichiashania secunda</i> / <i>Prochuangia glabella</i>	<i>Ptychaspis/Prosaukia</i>
								<i>Eochuangia hana</i>	<i>Changshania - Irvingella</i>	<i>Agnostotes orientalis - Irvingella angustilimbata</i>	<i>Irvingella tropica</i>	<i>Irvingella major</i>
	<i>Eugonocare longifrons</i>	<i>Chuangia</i>	<i>Chuangia</i>	<i>Corynexochus plumula</i> - <i>S. cf. kiangshanensis</i>	<i>Stigmatoda diloma</i>	SIEPTOEAN	<i>Dunderbergia</i>	<i>Olenaspella evansi</i>				
	<i>Hancrania brevilibata</i>	<i>Prochuangia</i>	<i>Prochuangia</i>	<i>Agnostus inexpectans - Proceratopyge protracta</i>	<i>Erivanium sentum</i>				<i>Olenaspella regularis</i>			
	<i>Proceratopyge tenue</i>				<i>Proceratopyge cryptica</i>					<i>Aphelaspis</i>		
	<i>Glyptagnostus reticulatus</i>				<i>Glyptagnostus reticulatus</i>						<i>Glyptagnostus reticulatus</i>	<i>Glyptagnostus reticulatus</i>
	m. CAM.	<i>Glyptagnostus stolidotus</i>	<i>Drepanura</i>	<i>Drepanura</i>	<i>Glyptagnostus stolidotus</i>	<i>Glyptagnostus stolidotus</i>	<i>Crepicephalus</i>					

Fig. 4. Correlation of the lower Upper Cambrian trilobite biozones of Korea with those of other parts of the world. Modified from Geyer and Shergold (2000) and Hong et al. (2003).

E. hana Zone (Fig. 2). Successive occurrence of four species of *Irvingella* has been well documented in the section (Hong et al., 2003): *Irvingella megalops* and *I. convexa* occur in the lower and upper parts of the *E. hana* Zone, whereas *I. coreanica* and *I. major* occupy the lower and upper parts of the *A. orientalis* Zone respectively (Fig. 2). Hong et al. (2003) demonstrated that the notable morphological change in the *Irvingella* lineage is the progressive reduction of preglabellar field and eye ridges: the stratigraphically early forms, such as *I. megalops* and *I. angustilimbata*, are characterized by the differentiated frontal area and relatively long eye ridges, whereas the younger forms have no preglabellar field and vestigial eye ridges. In the Gonggiri section, *Changshania* occurs in a much shorter stratigraphic interval than *Irvingella* does.

A close scrutiny of stratigraphic occurrences of *Changshania* in China reveals that *Changshania* also has a very short stratigraphic range, recognized in one or two horizons in North China. In recent years the association of *Changshania* and *Irvingella* has been increasingly documented in North China (Lu and Qian, 1983; Guo and Zhang, 1992; Qian, 1994; Zhang et al., 1995). The associated *Irvingella* species were identified as either *I. taitzuhoensis* or *I. flohri*, both of which were synonymized by Qian (1994). According to Hong et al. (2003), both *I. taitzuhoensis* and *I. flohri* occur stratigraphically lower than *I. major* and are comparable to *I. convexa* in terms of the morphological development in the *Irvingella* lineage. This interpretation is also consistent with the stratigraphic occurrences of *Irvingella* in North China: i.e., *I. taitzuhoensis* and *I. flohri*

were recovered from the *Changshania–Irvingella* Zone (Lu and Qian, 1983; Guo and Zhang, 1992; Qian, 1994), while *I. major* from the superjacent *Maladioidella* Zone in Liaoning Province (Guo and Zhang, 1992). It is of noteworthy that Guo and Zhang (1992) established the *Eochuangia* Zone, based on the occurrence of *E. hana* in Liaoning Province, which occupies the interval between the *Changshania* and *Maladioidella* zones in the Liaodong Peninsula. Qian (1994) on the other hand reported the presence of *Eochuangia* in the *Changshania–Irvingella* Zone of Nei Mongol.

In summary, the *E. hana* Zone of the Yeongwol Group can be best correlated with the *Changshania–Irvingella* Zone of North China, while its correlative zone has not been recognized in the Taebaek Group yet, but should be placed somewhere between the *Chuangia* and *Kaolishania* Zones (Fig. 4). The overlying *A. orientalis* Zone should be contemporaneous with the *Maladioidella* Zone of North China, as both of the zones yield *Irvingella major*. The correlation of these zones with outside the Sino–Korean block seems to be difficult, albeit broad correlation can be achieved by tracing the occurrences of *Irvingella* and *Agnostotes* (Fig. 4). The association of *Irvingella* and *Agnostotes* has been documented in the *A. orientalis–Irvingella angustilimbata* Zone of South China (Peng, 1992), *Irvingella tropica* Zone of Australia (Öpik, 1963; Shergold, 1982), and *Proceratopyge rectispinata* fauna of Mackenzie Mountains, Canada (Pratt, 1992).

6. Paleogeographic implications

Kobayashi (1967) recognized three faunal provinces in the eastern Asia during the Cambrian period: the Hwangho faunal province covers much of North China and contains many endemic trilobites representing shallow marine environments; the Chuantien faunal province is distributed in the western part of South China and is dominated by redlichiid trilobites of early to middle Cambrian; and the Jiangnan faunal province occupies the southeastern part of South China and is characterized by dominance of pandemic forms indicating deep-water oceanic settings. The trilobite faunas of the Taebaek and Yeongwol groups were included in the Hwangho and Jiangnan faunal provinces, respectively. On the other hand, the Ordovician faunal provinces display somewhat different configuration from the Cambrian ones (Kobayashi, 1969): the Ordovician cephalopod faunas of the Taebaek and Yeongwol groups show a close affinity with those of North China, but are distinct from those of South China. Whittington and Hughes (1974) analyzed the paleobiogeographic aspects

of Tremadocian trilobite faunas in that Korea and North China are linked with Australia within the tsinaniid province, but South China belongs to the olenid–ceratopygid province. These faunal contrasts between North China and South China led Burrett (1973) to propose that the Sino–Korean and Yangtze blocks were separated during the Paleozoic until they collided along the Qinling–Dabie Belt in the Triassic times (Ree et al., 1996; Meng and Zhang, 1999). The Sino–Korean and Yangtze blocks have been frequently incorporated within the Paleozoic Gondwana (Scotese and McKerrow, 1990; Laurie and Burrett, 1992), whereas recent paleogeographic models (Webby et al., 2000; Li and Powell, 2001) favored that the Sino–Korean and Yangtze blocks were isolated terranes located away from the Gondwana in the early Paleozoic (Fig. 5a).

Recent geotectonic considerations involving the Korean Peninsula (Cluzel et al., 1990, 1991; Yin and Nie, 1993) suggested that the Korean Peninsula was divided into three major parts in the early Paleozoic: namely, Nangnim, Yeongnam, and Gyeonggi massifs (Fig. 1a). The Nangnim and Yeongnam massifs were considered to occupy marginal part of the Sino–Korean block, while the Gyeonggi Massif was connected to the Yangtze block. The boundary or suture zone between the Sino–Korean and Yangtze blocks within the Korean Peninsula has been drawn along the Imjingang Belt (Cluzel, 1991; Yin and Nie, 1993; Ree et al., 1996). Cluzel et al. (1991) extended the boundary to the south within the Taebaeksan Basin, implying that the Taebaeksan Basin should represent a composite feature formed by amalgamation of tectonically different terranes. In fact, Cluzel et al. (1991) interpreted that the eastern half of the Taebaeksan Basin (Duwibong unit of Cluzel et al., 1990; Taebaek Group in Fig. 1b) was a carbonate shelf fringing the Sino–Korean block, whereas the western half (Yeongwol unit of Cluzel et al., 1990; Yeongwol Group in Fig. 1b) was part of the Yangtze block.

On the other hand, Chough et al. (2000) and Choi et al. (2001) argue against any tectonic division within the Taebaeksan Basin based on the paleobiogeographic features derived from the Cambrian–Ordovician trilobite faunas of the basin. They suggested that in the early Paleozoic the whole Taebaeksan Basin belonged to the Sino–Korean block (Fig. 5b) and was a shallow marine mixed siliciclastic–carbonate system with progressive greater depth to the west (Yeongwol area). The Cambrian trilobite faunal contrast between the Taebaek and Yeongwol groups was attributed to the difference in depositional setting: i.e., the Taebaek Group formed in a shallow marine, inner shelf environment, while the

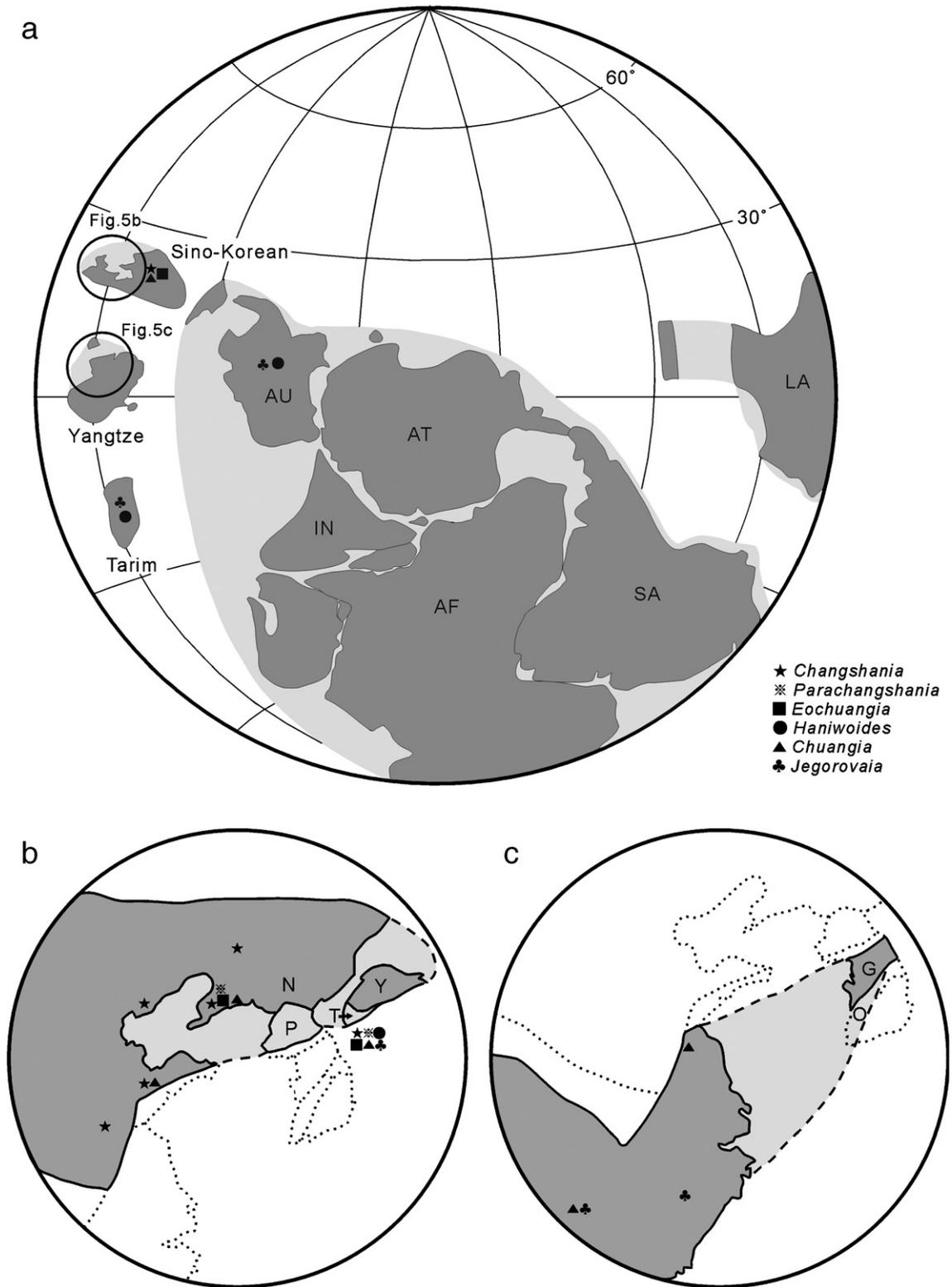


Fig. 5. Early Paleozoic paleogeographic maps, showing the occurrences of the polymerid trilobite genera which are associated with *Changshania* in the Gonggiri section, Yeongwol, Korea. (a) Paleogeographic map modified from Webby et al. (2000) and Li and Powell (2001). (Abbreviations: AF, Africa; AT, Antarctica; AU, Australia; IN, India; LA, Laurentia; SA, South America) (b) Part of Sino–Korean block. Note that *Changshania* is widespread in Korea and North China. (c) Part of Yangtze block. (Abbreviations in Fig. 5b and c are the same as those of Fig. 1a).

Yeongwol Group was deposited in a deep-water, outer shelf or slope environment. This sort of juxtaposed distribution of two contrasting lithofacies and biofacies has been employed to delineate former continental margins (Cook and Taylor, 1975; Cocks and Fortey, 1982; Fortey and Cocks, 1992). For instance, Cook and Taylor (1975) presented a paleogeographic model to explain the occurrence of two types of trilobite assemblages in the Furongian of the Great Basin, USA: one is represented by an allochthonous assemblage containing trilobite taxa typical to the *Hungatia* fauna, endemic to the Laurentia, and the other (*Hedinaspis* fauna) is characterized by the dominance of cosmopolitan taxa which are associated with the lithofacies indicating deep-water slope to basinal environments. The *Hedinaspis* fauna is a Furongian representative of the Jiangnan faunal province (Kobayashi, 1967), but was widespread in the latest Cambrian times. Cocks and Fortey (1982) and Fortey and Cocks (1992) also emphasized that the profound contrast in faunal composition alone does not indicate geographic separation unless the depositional settings are comparable, whereas the close faunal affinity does not necessarily mean the geographic proximity because planktonic and deep-water benthonic animals are widely distributed by crossing the oceanic barriers and thus have little value for paleogeographic reconstruction.

The geographic congruity of the Taebaek and Yeongwol groups can be better demonstrated by faunal similarity of their latest Cambrian and early Ordovician trilobite faunal assemblages to those of North China. A recently documented uppermost Cambrian *Fatocephalus* fauna from the Yeongwol Group (Sohn and Choi, 2002) seems to be particularly significant, as it is composed predominantly (comprising ca. 60% of the fauna in relative abundance) of an endemic species, *Fatocephalus hunjiangensis*, but also includes a considerable amount (ca. 25% of the fauna) of pandemic forms. The *Fatocephalus* fauna occurs widely in North China, thus indicating the close biogeographic link of the Yeongwol Group with North China. These faunal features were employed to interpret that the *Fatocephalus* fauna inhabited in a relatively deep-water environment along the continental margins of the Sino–Korean block. In the latest Cambrian the Yeongwol area was progressively shallower with high carbonate production evinced by a thick dolostone succession of Wagok Formation, thereby forming a widespread low-relief carbonate platform across the Taebaeksan Basin in the Ordovician. Apparently the shallow marine depositional setting in the Ordovician resulted in close faunal similarity between the trilobite assemblages of the Yeongwol Group and those of the Taebaek Group and further North China (Choi et al., 2001).

Chough et al. (2000) went on to propose the South Korean Tectonic Line along the western margin of the Taebaeksan Basin (Fig. 1b), which separates the Taebaeksan Basin and Yeongnam Massif of the Sino–Korean block (Fig. 5b) from the Okcheon Belt and Gyeonggi Massif which were connected to the Yangtze block (Fig. 5c). The discovery of *Changshania* in the Yeongwol Group strongly supports the paleogeographic interpretation of Chough et al. (2000). The lower part of the Gonggiri section, including the *E. hana* and *A. orientalis* zones, is characterized by laminated dark gray to black shale with abundant pandemic trilobites. Specifically the *Changshania*-yielding units KG-15 and KG-16 are dominated (more than 90% in relative abundance) by pandemic forms, including agnostoids, *Irvingella*, and less convincingly *Jegorovaia* and *Haniwoides* (Table 1). On the other hand, polymerid trilobites endemic to the Sino–Korean block, such as *Changshania*, *Parachangshania* and *Eochuangia*, are collectively represented by less than 10% (Table 1). These lithologic and faunal features of the Machari Formation suggest that dysaerobic deep-water environments were prevailing in the offshore Yeongwol area during that time. Although this environmental setting was favorable for pelagic and deep-water benthonic animals, the presence of *Changshania* along with some endemic taxa in this seemingly deeper-water environment indicates that the Yeongwol area must have occupied the offshore region contiguous to the Sino–Korean block, hence facilitating intermittent introduction of local faunas belonging to the Hwangho faunal province.

Table 1
Relative abundance and distribution of trilobite taxa occurring in the *Changshania*-yielding units KG-15 and KG-16 of the Gonggiri section, Yeongwol, Korea

Taxa	Number of specimens	Relative abundance (%)	Distribution
Agnostoids	284	84.3	Cosmopolitan
<i>Irvingella</i>	6	1.8	Cosmopolitan
<i>Jegorovaia</i>	3	0.9	Yangtze, Tarim, Australia, Kazakhstan
<i>Haniwoides</i>	16	4.7	Sino–Korean, Tarim, Australia
<i>Chuangia</i>	2	0.6	Sino–Korean, Yangtze
<i>Eochuangia</i>	4	1.2	Sino–Korean
<i>Parachangshania</i>	7	2.1	Sino–Korean
<i>Changshania</i>	15	4.4	Sino–Korean
	337	100.0	

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