Geosciences Journal
Vol. 10, No. 4, p. 391 – 402, December 2006

Early evolution of the Duwibong Unit of the lower Paleozoic Joseon Supergroup, Korea: A new view

Yongin Kim[1]
Yong Il Lee*
School of Earth and Environmental Sciences, Seoul National University, Seoul 151-747, Korea

ABSTRACT: This study proposes the revised stratigraphy of the lower part of the Duwibong Unit of the lower Paleozoic Joseon Supergroup that the Myobong Formation is the lowermost stratum. The Jangsan Formation, which has long been regarded as the lowermost stratum of the Unit, is likely to be of late Proterozoic in age. It is also proposed that the Myeonsan and Myobong formations are of coeval age and that the Myeonsan Formation formed in the early stage is interpreted to be the local proximal facies which was overlain by the Myobong Formation in the late stage. This new interpretation is based on the presence of the unconformity between the Jangsan and Myobong formations observed in two areas (Dongjeom area, Taebaek City and Deogam area, Imgye-Myeon, Jeongseon-Gun). Sandstone facies in the topmost part of the Myeonsan Formation is gradually overlain by siltstone to mudstone facies of the Myobong Formation. In addition, Myobong mudstone is geochemically similar to Myeonsan mudstone. The similarity in lithologies among Jangsan sandstone, quartzarenite gravelly clasts in the Myeonsan Formation and the newly defined late Proterozoic stratum (Kim and Lee, 2003a) immediately underlying the Myeonsan Formation provides additional evidence that the Jangsan Formation is not the lowermost stratum of the Duwibong Unit but the source rocks of quartzarenite gravelly clasts of the Myeonsan Formation.

Key words: lower Paleozoic, Joseon Supergroup, Taebaeksan Basin, Jangsan Formation, Myobong Formation

1. INTRODUCTION

The Joseon Supergroup, distributed in eastern central Korea, ranges from Early Cambrian to Late Ordovician in age (Cheong, 1969; Lee, 1988). It overlies unconformably Precambrian granitic gneiss and metasedimentary rocks, and is unconformably overlain by the upper Paleozoic-early Mesozoic Pyeongan Supergroup which is mainly composed of thick clastic succession of marginal marine to non-marine facies containing economically important coal measures (Cheong, 1969). The Joseon Supergroup consists predominantly of carbonate rocks with minor interbedded siliciclastic rocks. Development of thick carbonate platform deposits in the lower Paleozoic sequence indicates that the Joseon Supergroup was deposited in a stable setting such as passive margin or craton interior (Lee and Lee, 2003). The Joseon Supergroup is conventionally subdivided into five types of sequence based on distinct lithologic successions and geographic distribution: namely, Duwibong, Yeongweol, Jeongseon, Pyeongchang and Mungyeong units (Kobayashi et al., 1942). The Duwibong Unit consists of 10 stratigraphic formations: the Jangsan, Myeonsan, Myobong, Daegi, Hwajeol, Dongjeom, Dumugol, Makgol, Jigunsan and Duwibong formations with decreasing age (Cheong, 1969) (Fig. 1).

The Jangsan and Myeonsan formations have been regarded to be age equivalent, forming the lowermost strata of the Duwibong Unit (Kim and Cheong, 1987). The two formations are in fault contact (Fig. 2). The Myeonsan Formation is distributed in the eastern side of the fault (the Dongjeom Fault), while the Jangsan Formation in the western side (Kim and Cheong, 1987). Both strata are known to overlie unconformably the Precambrian basement rocks. Lithologically, the two formations are different. The Myeonsan Formation consists of basal conglomerate, Fe-Ti oxide-bearing sandstone (placer deposit), siltstone and shale, and is 90 m thick on average (Kim, 1991). The Myeonsan Formation has abundant sedimentary structures such as horizontal stratification, small-scale cross-bedding, herring-bone cross-bedding, ripple marks, flaser bedding, mud cracks and trace fossils. Kim (1991) interpreted that the Myeonsan Formation was deposited in a tide-dominated shallow marine environment. In contrast, the Jangsan Formation comprises mostly milky white quartzose rocks and is about 40 to 200 m thick (Yun, 1978). The Jangsan Formation shows only few sedimentary structures such as small-scale cross-bedding and horizontal stratification. It has been interpreted to be deposited in shallow marine environment (Yun, 1978). Both of the Jangsan and Myeonsan formations are considered to be conformably overlain by the Myobong Formation, which is about 100 to 200 m thick. The lower part of the Myobong Formation consists of mudstone, siltstone, fine to coarse sandstone and pebbly sandstone, whereas mudstone dominates in the upper part of the formation with intercalated thin-bedded limestones such as wackestone, packstone and grainstone (Park et al., 1994). Kobayashi (1966) interpreted that the Myobong Formation was deposited in intertidal environments. Yun (1978) reinterpreted that the Myobong

*Corresponding author: lee2602@plaza.snu.ac.kr
[1]Present address: The Reseach Institute for International Affairs, Seoul 463-27, Korea

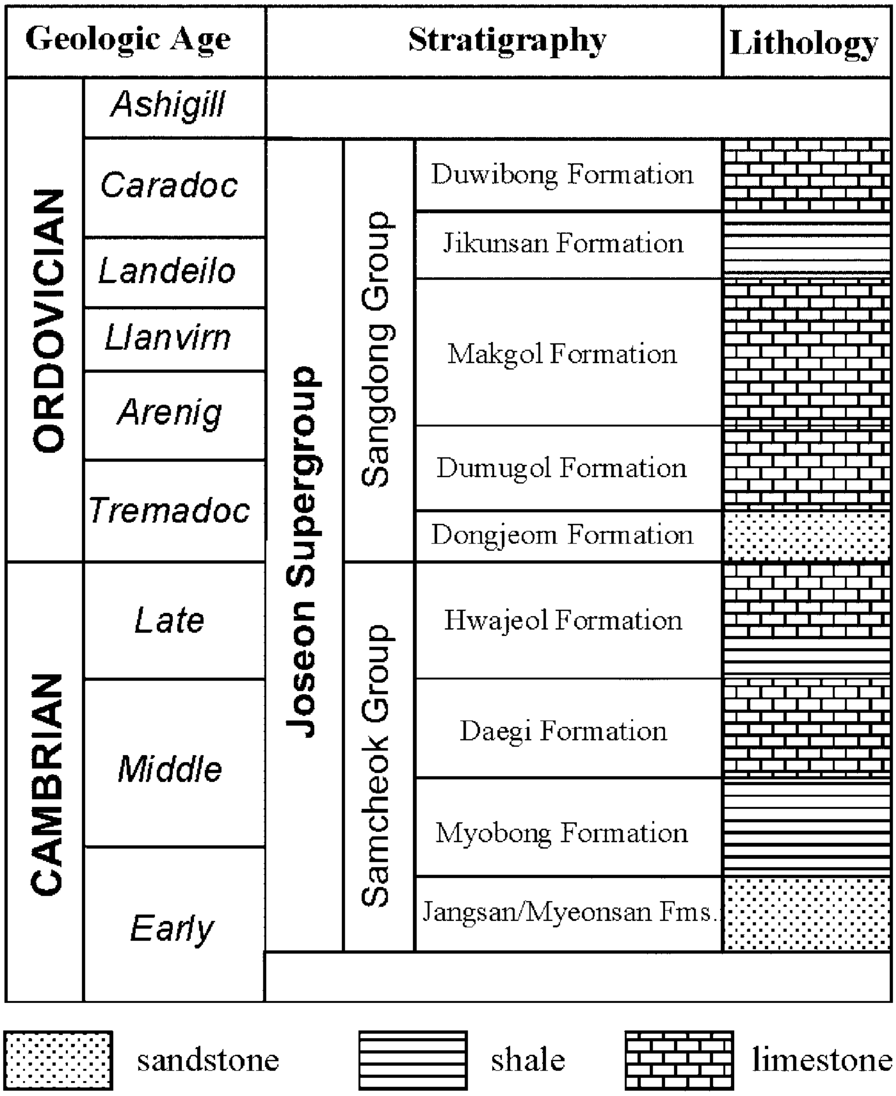

Fig. 1. Stratigraphic subdivision of the Duwibong Unit of the Joseon Supergroup (modified after Cheong, 1969; Lee, 1988).

Formation was deposited in an open shelf setting based on petrographic and geochemical studies. Park et al. (1994) reported that the Myobong Formation consists of 12 lithofacies and four facies associations, and interpreted that the depositional environments changed up sequence from outer shelf to inner shelf, and to carbonate platform.

The purpose of this study is to re-evaluate the stratigraphic relationships among the Jangsan, Myobong and Myeonsan formations. Based on the finding of the unconformity between the Jangsan and Myobong formations, this study presents a new interpretation on the early evolution of the Duwibong Unit of the Joseon Supergroup, the type sequence of the lower Paleozoic in the southern Korean Peninsula. We provide evidence that the lowermost strata of the Duwibong Unit of the Joseon Supergroup are not the Jangsan and Myeonsan formations as commonly thought, but the Myeonsan and Myobong formations. This study also reveals that lithology of the Jangsan Formation is very similar to that of a newly defined late Proterozoic stratum (NDPS) (Kim and Lee, 2003a) which is regarded as a source rock of the Myeonsan Formation.

2. METHODS

To characterize the stratigraphic relationships among the Jangsan, Myeonsan and Myobong formations, detailed field works were carried out at four sections near the Dongjeom Fault (Fig. 3). These sections were studied in detail in terms of lithology, texture, grain size, and sedimentary structures. More than 150 samples were collected from the sections representing the Myeonsan and Jangsan formations, and rock slabs and thin sections were made from them. Boundary between the Jangsan and Myobong formations was examined in the Dongjeom area, Taebaek City (Fig. 3①) and Deogam area, Imgye-Myeon, Jeongseon-Gun (County) (Fig. 3②). Conglomerates in the lower part of the Jangsan Formation

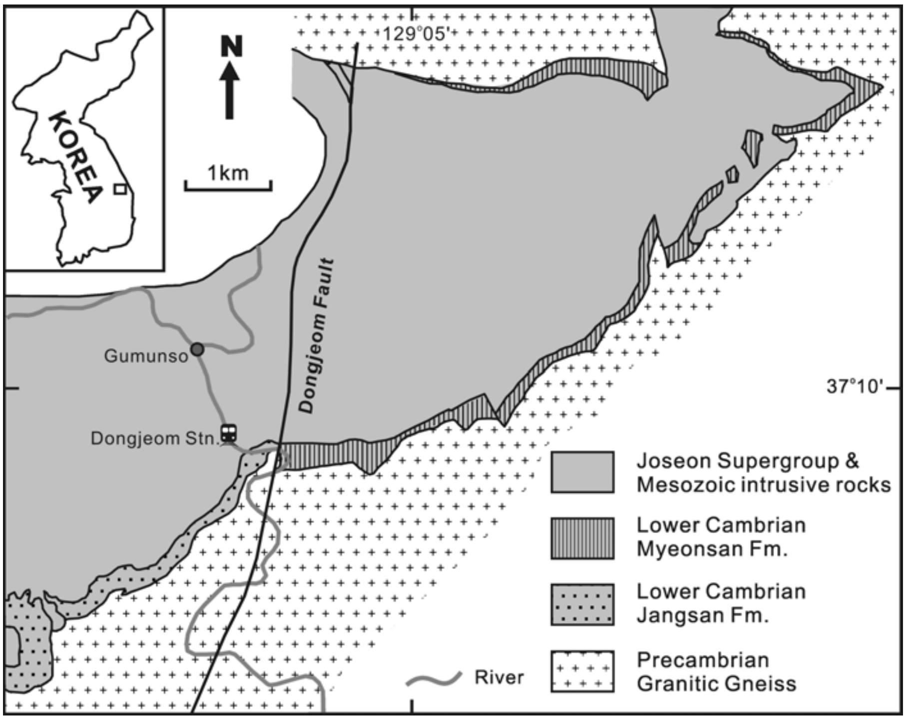

Fig. 2. Simplified geological map of the Dongjeom area, Taebaek City showing the distribution of the Jangsan and Myeonsan formations (modified after Kim and Cheong, 1987). Both formations are in contact by the Dongjeom fault.

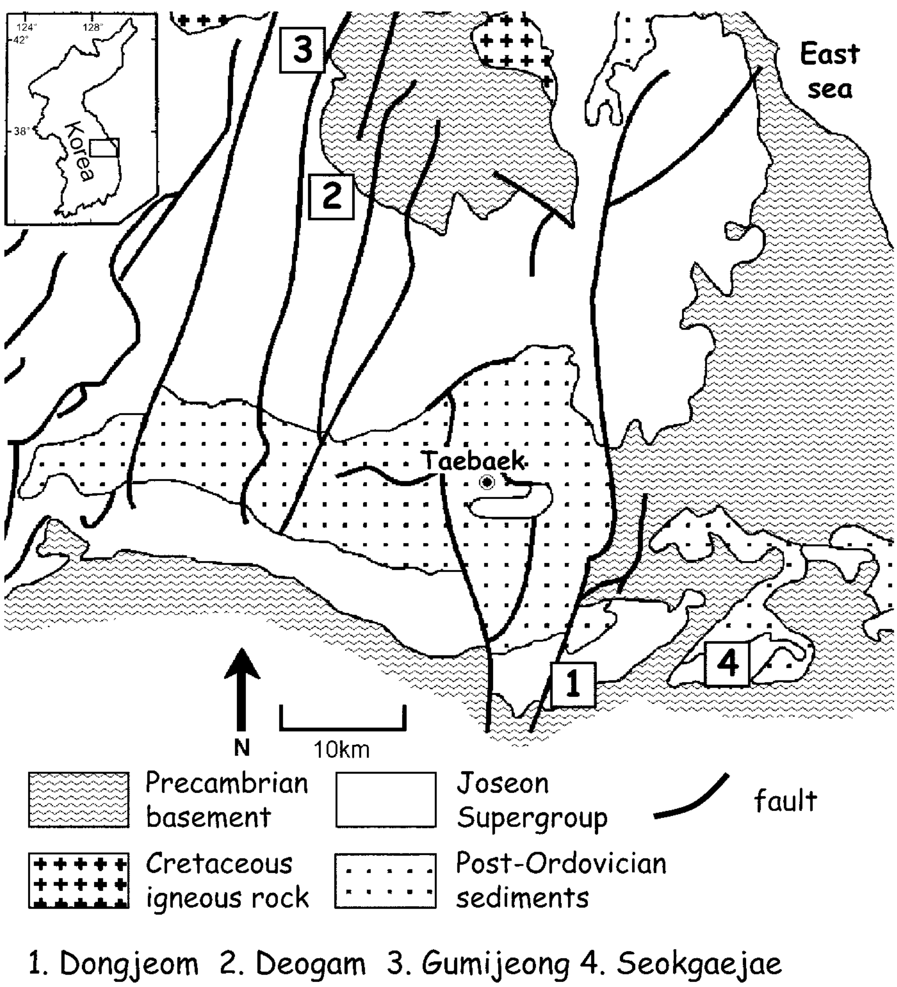

Fig. 3. Simplified geological map of the central eastern Korea where the Duwibong Unit of the Joseon Supergroup is distributed (modified after GICTR, 1962). The locations of studied sections are ① Dongjeom area and Yeonhwa-2 Mine, Taebeck City, ② Deogam area, Imgye-Myeon, Jeongseong-Gun, ③ Gumijeong, Imgye-Myeon, Jeongseon-Gun, and ④ Seokgaejae, Bonghwa-Gun.

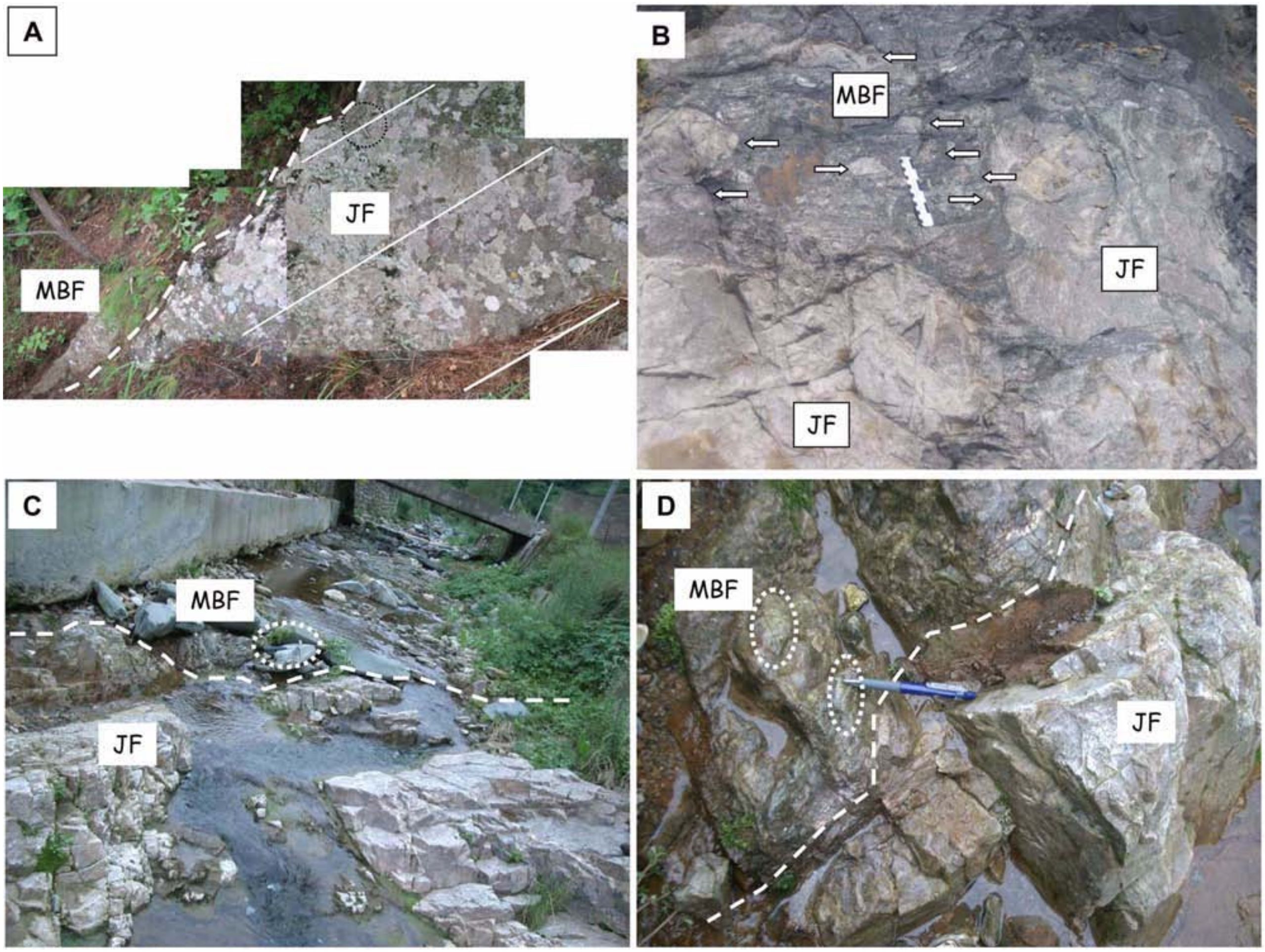

Fig. 4. (A) The unconformable boundary (marked by broken line) between the Jangsan and the Myobong formations observed on the hill near the former Yeonhwa-2 Mine, Taebaek City. Dark colored thin conglomerate bed of the Myobong Formation (MBF) overlies unconformably the Jangsan Formation (JF). Thin parallel lines indicate the bedding planes of the Jangsan Formation. Scale is in dot-lined circle. (B) Photograph showing the irregular boundary between the Jangsan Formation below and the Myobong Formation above, which is exposed on the Naktong River bottom near the Dongjeom Station, Taebaek City. Note the occurrence of quartzite pebbles (arrows) in the Myobong Formation immediately above the boundary. (C) The boundary between the Jangsan and Myobong formations at Deogam site, Imgye-myeon, Jeongseon-gun. Hammer for scale in the dotted ellipsoid. (D) Close-up of the boundary below the dotted area in C showing that clasts in conglomerate of the Myobong Formation are lithologically very similar to the immediately underlying Jangsan sandstone (JF: Jangsan Formation; MBF: Myobong Formation).

was studied at Gumijeong, Imgye-Myeon, Jeongseon-Gun (Fig. 3③). The Myeonsan and Myobong formations were also studied at Seokgaejae, Bonghwa-Gun, Gyeongsangbuk-Do (Province) (Fig. 3④) and at former Yeonhwa-2 Mine area, Taebaek City (Fig. 3①). To characterize the clasts of basal conglomerates of the Myeonsan Formation, a total of 2533 clasts were analyzed according to their size, lithology and roundness in the field. Clasts were divided into seven lithologic categories: milky white granitic gneiss, dark granitic gneiss, coarse quartzarenite, medium quartzarenite, fine quartzarenite, dark fine-grained meta-pelite, and milky white vein quartz. Rare earth elements (REEs) were analyzed for mudstones of the Myeonsan Formation as well as mudstones of the Myobong Formation that is overlying both the Jangsan and Myeonsan formations by a Perkin Elmer Elan6100 ICP-MS at the Korea Basic Science Institute and Korea Polar Research Institute (see Jarvis, 1988). Analytical precision for REEs is better than 5%.

3. RESULTS

3.1. Relationship between the Jangsan and Myobong formations

It has long been regarded that the Jangsan Formation forms the lowermost stratum of the Duwibong Unit and that the Jangsan Formation is conformably overlain by the Myobong Formation. However, this study reports newly that

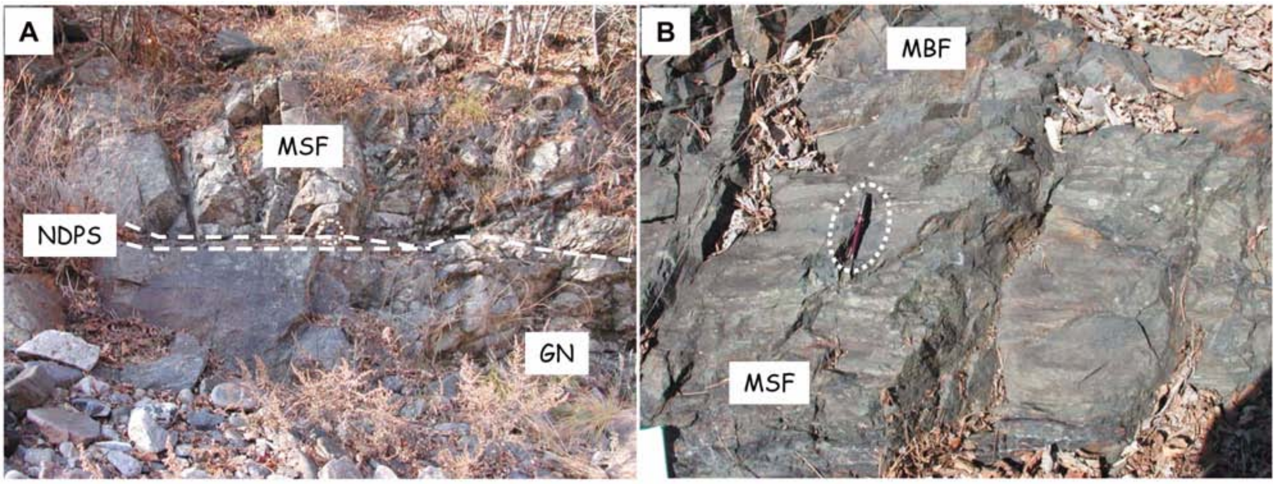

Fig. 5. (A) The boundary between the Precambrian basement rock and the Myeonsan Formation in Dongjeom area, Taebaek City. Scale is in dot-lined circle. MSF: the Myeonsan Formation; NDPS: the newly defined upper Proterozoic stratum (Kim and Lee, 2003a) and GN: the Precambrian granite gneiss. (B) Photograph showing the lowermost Myobong Formation (MBF) in Dongjeom area, Taebaek City, which overlies conformably small cross-bedded sandstone of the Myeonsan Formation. The boundary between the two formations is placed at the top of the ball-point pen for scale.

both formations are in unconformable contact based on the following lines of evidence. Firstly, in the Dongjeom area, Taebaek City, the Myobong Formation overlies unconformably the Jangsan Formation on the hill southwest of the former Yeonhwa-2 Mine (Fig. 4A). The uppermost part of the Jangsan Formation consists of medium to coarse sandstone, which is milky white to pink in color. The lowermost part of the Myobong Formation is composed of gravelstone, which is exposed along the boundary about 1 m lateral distance. It is gray to dark gray in color and is overlain by horizontally stratified siltstone. The boundary between the Jangsan and Myobong formations is irregular, and dark-colored Myobong gravelstone truncates the underlying milky white Jangsan coarse sandstone (Fig. 4A). The very irregular boundary between the Jangsan and Myobong formations is also exposed on the Nakdong River bottom near the Dongjeom Station when the water level is low (Fig. 4B). The irregular surface of the fine-grained white quartzarenite of the Jangsan Formation is stained with iron oxides, and the hollow areas are filled with various sizes of gravels of fine-grained white quartzarenite which is lithologically very similar to the immediately underlying Jangsan Formation.

At Deogam site, Imgye-Myeon, Jeongseon-Gun, the Jangsan Formation occurs less than 25 m in thickness. The Jangsan Formation has a two-meter thick basal conglomerate layer, which is deformed. Clasts in the basal conglomerate are mostly milky white meta-quartzites. The upper part of the Jangsan Formation consists of milky white to pale green sandstones. The Myobong Formation overlies unconformably the Jangsan Formation (Fig. 4C). The lowermost pebbly sandstone of the Myobong Formation truncates the underlying Jangsan sandstones (Fig. 4D), and some clasts of which reach up to 10 cm in length. The clast composition of the basal Myeonsan Formation is very similar to that of the immediately underlying Jangsan sandstone.

3.2. Relationship between the Myeonsan and Myobong formations

In the eastern part of the Dongjeom Fault, the Myeonsan Formation is distributed with about 120 m thickness. The basal conglomerate of the Myeonsan Formation overlies unconformably the Precambrian basement rocks such as granite gneiss and quartzarenite (NDPS) (Fig. 5A; Kim and Lee, 2003a). The Myeonsan Formation is conformably overlain by the Myobong Formation (Fig. 5B). The Myeonsan Formation consists of five fining-upward cyclic sequences (Kim, 2004). The basal facies of each sequence is characterized by either gravelstone in the lowermost sequence or coarse to very coarse sandstone in the rest. This facies

Table 1. Classification of clasts in the basal conglomerate of the Myeonsan Formation (Kim and Lee, 2003a).

Lithology	number	%
Milky white granitic gneiss	134	5.3
Dark granitic gneiss	177	7.0
Coarse-grained quartzarenite	1555	61.4
Medium-grained quartzarenite	353	13.9
Fine-grained quartzarenite	280	11.1
Dark fine-grained meta pelite	29	1.1
Milky white vein quartz	5	0.2
Total	2533	100.0

Maximum size: 87 cm; mean size: 7 cm

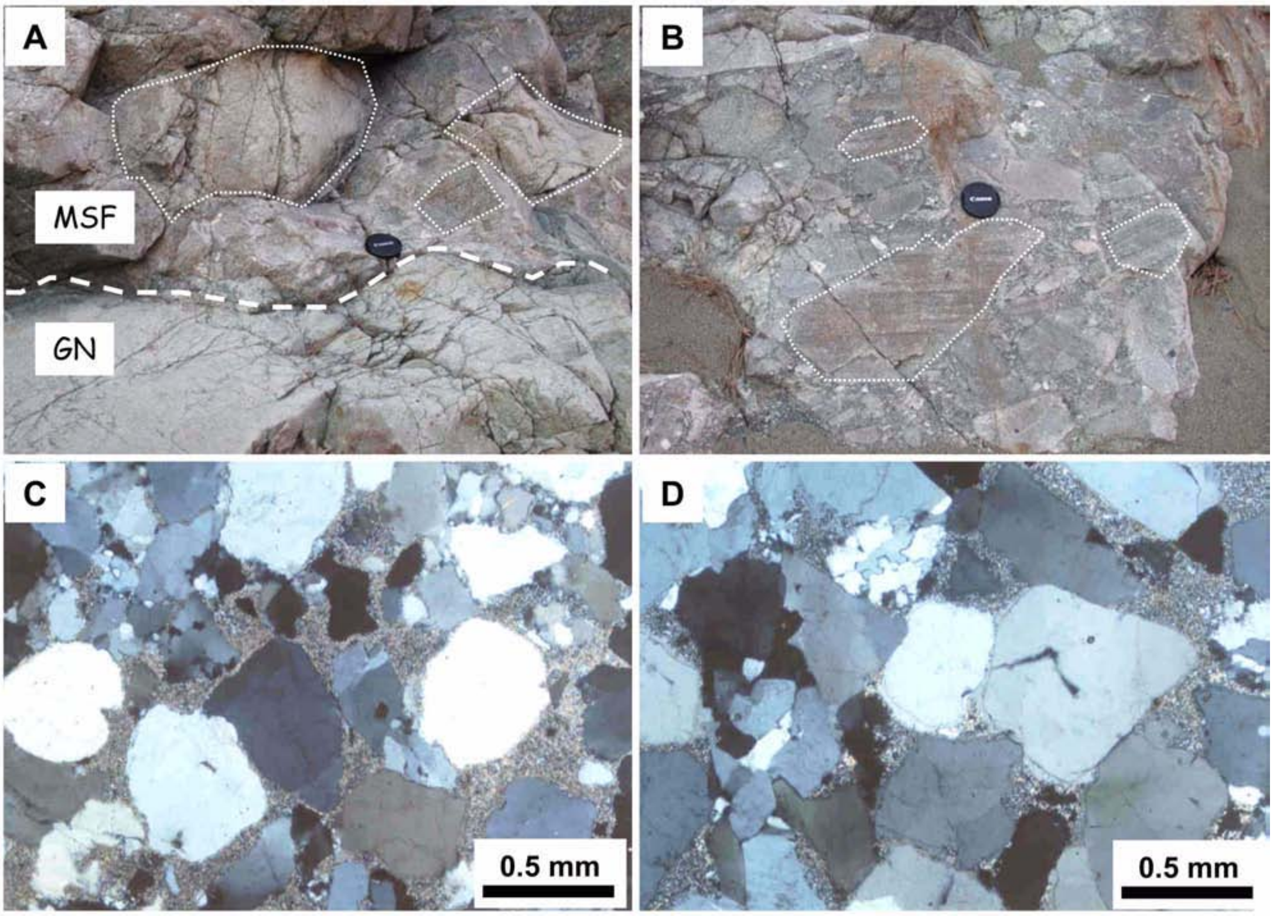

Fig. 6. (A) The boundary between the Precambrian granite gneiss (GN) and the Myeonsan Formation (MSF) in Dongjeom area, Taebaek City. Metamorphic clasts (marked by dotted line) in basal conglomerate of the Myeonsan Formation are very similar to the underlying basement rock. (B) Photograph showing the quartzarenite gravelly clasts in the basal conglomerate of the Myeonsan Formation. Some clasts show well-developed planar lamination. (C) Photomicrograph of quartzarenite gravelly clast in the basal conglomerate of the Myeonsan Formation. Cross polarized-lights. (D) Photomicrograph of the newly defined upper Proterozoic stratum (NDPS) by Kim and Lee (2003a). Cross polarized-lights. Note that the texture is very similar to that of quartzarenite gravelly clasts in the basal conglomerate of the Myeonsan Formation, like shown in C.

changes to mudstone facies through alternating sandstone and siltstone facies. Each sequence is interpreted to represent rising of relative sea-level at the beginning. In addition, the average grain size of the basal facies of the five cycles decreases upwards in the Myeonsan Formation. In the top sequence, thin cross-bedded sandstone gradationally changes to dark gray siltstone to mudstone that is regarded as the lowermost part of the Myobong Formation (Fig. 5B).

3.3. Clast Composition in Basal Conglomerates of the Myeonsan Formation

Table 1 shows the proportion of gravelly clast lithologies in basal conglomerate of the Myeonsan Formation. Maximum clast size is about 87 cm long. The majority of clasts (92%) are less than 15 cm long. Milky white and dark gray micaceous granitic gneiss clasts are derivatives of the Taebaeksan Gneiss complex that is immediately underlying the Myeonsan Formation (Fig. 6A). Dark fine-grained metapelite clasts seem to be derivatives of the Yuli Group (the Taebaeksan Schist complex) that underlies unconformably the Jangsan Formation in the Sangdong area, Yeongweol-Gun, west of the study area. Quartzarenite gravelly clasts are milky white or light pinkish. They show well-developed sedimentary structures such as planar lamination (Fig. 6B). Under a petrographic microscope, quartzarenite contains some matrix and hence is generally poorly sorted (Fig. 6C). The size of clasts derived from basement rocks (granitic gneiss and dark metamorphic rock) is commonly larger than that of quartzarenite clasts, whereas the latter is more rounded than the former. Among the clast lithologies the proportion of quartzarenite clasts is 86.4% of the total clasts and that of basement rock-derived clasts is 13.4%. Kim and Lee (2003a) reported a new Proterozoic stratum, less than

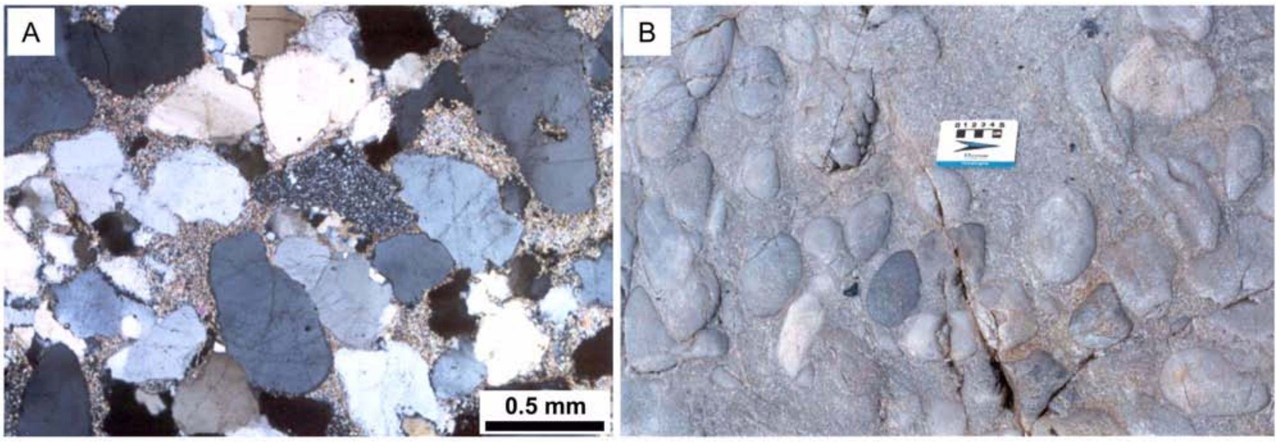

Fig. 7. (A) Photomicrograph of Jangsan sandstone. Note that it shows textural inversion (see text for details). Cross polarized-lights. (B) Photograph showing well-rounded meta-quartzite gravelly clasts in the Jangsan Formation distributed at Gumijeong, Imgye-myeon, Jeongseon-gun.

10 cm thick, that was formerly known as the lowermost part of the Myeonsan Formation. Lithologically, it is different from the Myeonsan Formation, but is similar in petrographical and geochemical characteristics to quartzarenite clasts in the basal conglomerate of the Myeonsan Formation (Fig. 6C, D). This stratum is interpreted to be a source rock of quartzarenite clasts in the Taebaeksan Basin and of late Proterozoic in age, and correlative with the Guhyeon System in North Korea (Kim and Lee, 2003a).

3.4. Petrography of the Jangsan Formation

The Jangsan Formation consists of fine to coarse sandstone with minor gravelstone. The Jangsan Formation shows a lithologic variety according to the position in the basin. In the northern part of the basin, Jangsan sandstones are mostly metamorphosed and show a strained foam texture. The Jangsan Formation is milky white to pale green in color. In contrast, the Jangsan Formation in the southern part preserves depositional textures and is milky white to pink in color. This study focuses on the Jangsan sandstones distributed in the southern part of the basin. The Jangsan Formation has been known to be composed of supermatured, quartzose sandstone, and thus it was first named the Jangsan Quartzite (Kobayashi, 1966). However, this study reports that the Jangsan Formation consists of submatured and poorly to moderately sorted sandstones. Detrital grains are mostly composed of quartz with minor feldspar. They are moderate- to well-rounded. Considerable amounts of matrix such as mixture of microcrystalline quartz and illite/mica are present in sandstones, showing textural inversion (Fig. 7A). Quartz overgrowths are developed on some detrital quartz grains. Most gravelly clasts scattered in the basal part of the Jangsan Formation are meta-quartzite at all studied sections (Fig. 7B). It was previously reported that the Jangsan Formation includes quartzarenite clasts in basal conglomerate, Dongjeom area, Taebaek City (Yun, 1978). However, this basal conglomerate of the Jangsan Formation at the Dongjeom section was reinterpreted to be the basal conglomerate of the Myeonsan Formation (Kim and Lee, 2003a).

3.5. Mudstone Composition of the Myeonsan and Myobong Formations

The REE compositions of mudstones of the Myeonsan Formation and mudstones of the Myobong Formation that are overlying both the Myeonsan and Jangsan formations are shown in Table 2. The major characteristics in patterns

Table 2. Rare earth element compositions of Myeonsan and Myobong mudstones (ppm).

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
Myeonsan Fm-1	33.21	53.40	6.65	21.34	4.48	0.71	4.06	0.65	3.78	0.84	2.37	0.37	2.02
Myeonsan Fm-2	35.82	68.66	8.89	30.78	7.49	1.89	7.18	1.28	7.26	1.46	3.96	0.61	3.59
Myobong Fm-1	57.81	103.54	11.72	34.15	6.08	1.14	5.23	0.84	4.90	1.00	2.86	0.41	2.51
Myobong Fm-2	53.12	91.70	11.01	35.13	6.52	1.48	6.44	1.01	6.23	1.29	3.66	0.56	3.15
Myobong Fm-3	56.13	100.63	13.46	47.25	11.67	2.52	10.59	1.70	8.96	1.74	4.41	0.65	3.62
Myobong Fm-4	71.53	125.95	14.82	45.13	7.86	1.76	7.54	1.24	7.02	1.51	4.02	0.63	3.58

Myobong Fm-1 & 2: Myobong mudstone overlying the Myeonsan Formation; Myobong Fm-3 & 4: Myobong Formation overlying the Jangsan Formation

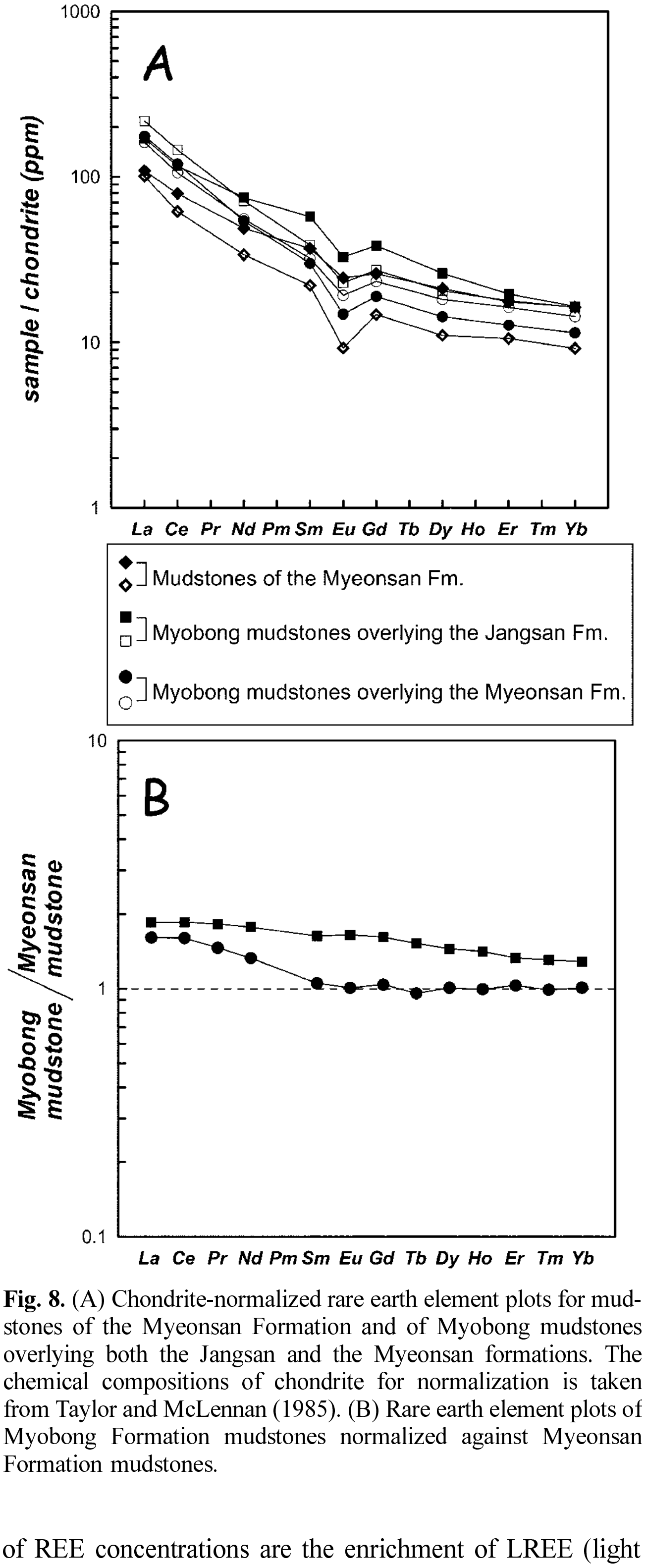

Fig. 8. (A) Chondrite-normalized rare earth element plots for mudstones of the Myeonsan Formation and of Myobong mudstones overlying both the Jangsan and the Myeonsan formations. The chemical compositions of chondrite for normalization is taken from Taylor and McLennan (1985). (B) Rare earth element plots of Myobong Formation mudstones normalized against Myeonsan Formation mudstones.

of REE concentrations are the enrichment of LREE (light rare earth element) over HREE (heavy rare earth element), and near flat HREE patterns. The average europium anomaly, Eu/Eu* (where Eu*=Eu_n/[(Sm)(Gd)1/2]), of both Myeonsan and Myobong mudstones ranges from 0.51 to 0.79, close to that of post-Archean average shale (PAAS) (0.66). The chondrite-normalized La/Yb ratio varies from 6.8 to 15.7, which indicates that mudstones are fractionated similar to PAAS (9.2; Taylor and McLennan, 1985). Chondrite-normalized pattern of mudstones of the Myeonsan Formation is very similar to those of mudstones of the Myobong Formation overlying both the Myeonsan and the Jangsan formations (Fig. 8).

The lower diagram of Fig. 8 shows the REE patterns of the average Myobong Formation mudstones overlying both the Jangsan and Myeonsan formations normalized against the Myobong mudstone. Both Myobong mudstones are very slightly LREE-enriched compared to the Myeonsan mudstone, suggesting some mixing of the fractionated compoents with Myeonsan Fomation sediments.

4. DISCUSSION

4.1. Source rocks of the Myeonsan Formation

From the study of gravelly clasts in basal conglomerate it can be inferred that gravels of the Myeonsan Formation were largely sourced from quartzose sedimentary rocks as well as from metamorphic basement rocks. Both metamorphic clasts and quartzarenite clasts were originated from the underlying gneisses and NDPS, respectively (Kim and Lee, 2003a). In Myeonsan placer sandstones, the average contents of framework grains are 40% quartz, 40% Fe-Ti oxide mineral, 17% feldspar and 3% rock fragments (Kim, 1991). The presence of abundant Fe-Ti oxide minerals in sand fraction (Fig. 9A) suggests that Fe-Ti oxide deposits also supplied detrital grains to the Myeonsan Formation. However, at present no Fe-Ti oxide deposits are observed in the Korean Peninsula. Fe-Ti oxide grains can be originated from various kinds of mafic rocks. However, the presence of relatively large amount of Fe-Ti oxide grains and thick placer deposits in the Myeonsan Formation suggests that Fe-Ti oxide grains might have been derived from Fe-Ti oxide ore deposits such as sedimentary placer deposits or Fe-Ti oxide deposits related to igneous activity. In the Korean Peninsula there occur two Fe-Ti oxide ore deposits of igneous origin. One is the ilmenite ore deposits related to anorthosite, which is located in the central southern Korea. The other is a small-scale Fe-Ti oxide ore deposit related to igneous activity, which is located in Yeoncheon-Gun, western central Korea. However, the Fe-Ti oxide minerals in these ore deposits show different texture from that of the Fe-Ti oxide grains of the Myeonsan Formation. Both Fe-Ti oxide ore deposits have no or weak exsolution texture, whereas the Fe-Ti oxide grains in the Myeonsan Formation show well-developed exsolution texture (Fig. 9B). Well-developed exsolution texture occurs commonly in orthomagmatic Ti ores, related much to anorthosite or gabbroic rocks. In addition, volcanic rock fragments are occasionally observed in Myeonsan sandstones. These observations suggest that

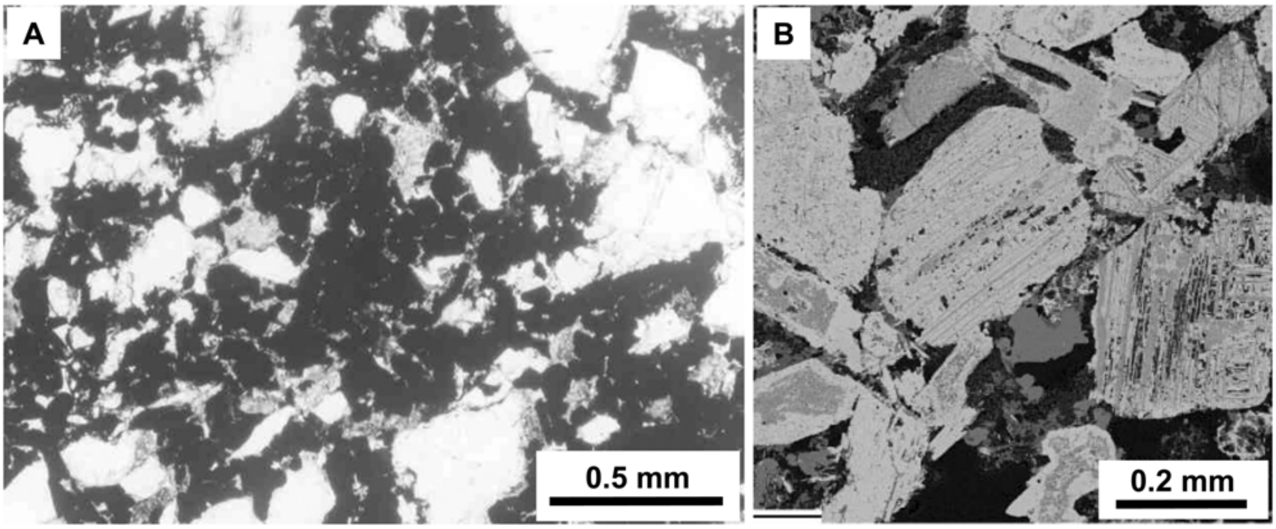

Fig. 9. (A) Photomicrograph of a placer sandstone in the Myeonsan Formation. Dark grains are Fe-Ti oxides. Crossed nicols. (B) Back-scattered electron (BSE) image showing exsolution texture in Fe-Ti oxide grains of the Myeonsan Formation.

source Fe-Ti oxide deposit was formed by igneous activity.

Possible former existence of mafic igneous rocks can be inferred from a recent study. A large 1839±10 Ma rapakivi granite batholith has been reported from northeastern Gyeonggi massif (Zhai et al., 2005). The rapakivi granites are usually known to be associated with gabbro, leucogabbro and anorthosite representing an anorogenic magmatism in an extensional setting (Haapala and Rämö, 1990, 1999; Windley, 1995). Although the rapakivi granite in the Gyeonggi massif is associated with orthogneiss, amphibolite and metasedimentary rocks (Lee and Kim, 1968; Kim, 1977), the presence of the rapakivi granite may suggest the former existence of gabbro, leucogabbro or anorthosite that are commonly associated with this type granite. The occurrence of rapakivi granite is yet reported from the Yeongnam massif. Although precautious, it can be assumed that these mafic rocks might have existed and been exhumed in the source area for the Myeonsan Formation and that we now observe abundant detrital Fe-Ti oxide grains in the Myeonsan Formation as the only evidence of their former existence.

Many quartzite beds are present in the Precambrian sequences of the southern Korean Peninsula: they are Euiam Quartzite, Yongmunsan Quartzite, Anyang Quartzite, Seosan Quartzite and Geumsusan Quartzite (Kim and Lee, 2003b). These Precambrian quartzites show mostly high-grade metamorphic textures (Kim and Lee, 2003b), different from quartzarenite texture observed in Myeonsan Formation gravelly clasts, and are located geographically in far distance from the Taebaeksan Basin. The size of the gravelly clasts in the Myeonsan basal conglomerate indicates that the source rocks were located not far from the place where the Myeonsan Formation was deposited. Therefore, the Precambrian quartzites listed above can be ruled out as source rocks for the Myeonsan Formation. Rather, a new late Proterozoic quartzite stratum (Kim and Lee, 2003a) is regarded as possible quartzarenite source for the Myeonsan Formation. Accordingly, the Myeonsan Formation was sourced from various kinds of igneous, metamorphic and sedimentary rocks.

4.2. The Jangsan Formation: a source rock of the Myeonsan Formation?

The lithological characterisitcs of Jangsan sandstones (Fig. 7A) are very similar to those of quartzarenite gravelly clasts in the Myeonsan Formation (Fig. 6C) and of NDPS (Fig. 6D). This observation suggests that the Jangsan Formation could be a source rock for the Myeonsan Formation. If this interpretation is accepted, the Jangsan Formation may not be the lowermost stratum of the Duwibong Unit of the lower Paleozoic Joseon Supergroup. This interpretation is supported by the presence of the unconformity between the Jangsan and Myobong formations (Fig. 4). The gravelly clasts in the basal conglomerate of the Myobong Formation (Fig. 4D) are most likely to have been originated from the underlying Jangsan sandstone. This observation indicates that Jangsan sandstones had been buried, lithified, uplifted, and exposed to the surface before the deposition of the Myobong Formation. The Myobong Formation was dated to be the late Early to early Middle Cambrian (Kobayashi, 1966). Thus, the Jangsan Formation, which had been already lithified before the deposition of the Myobong Formation, is likely to be of Precambrian in age. The newly reported Proterozoic stratum (NDPS) that is underlying the Myeonsan Formation was interpreted to be correlative with the Guhyeon System in North Korea (Kim and Lee, 2003a). The Guhyeon System is in either conformable or uncon-

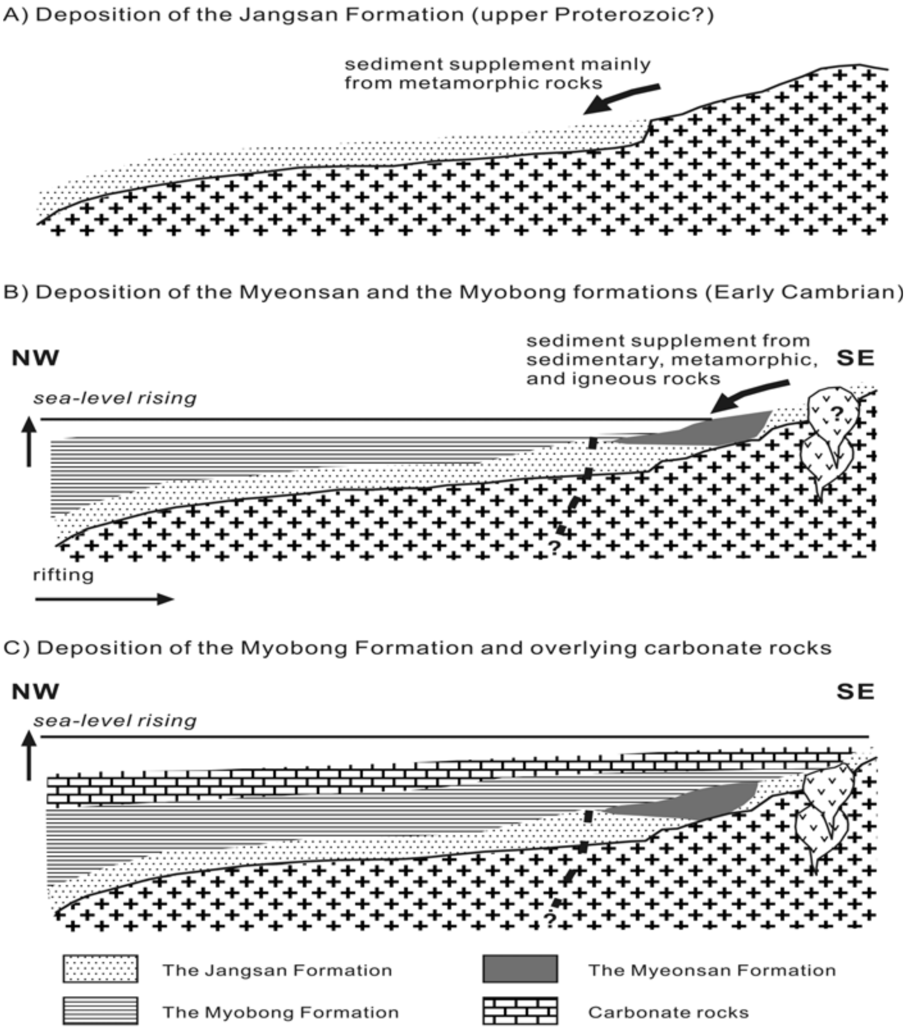

Fig. 10. Reconstruction of the early evolution of the Duwibong Unit, the Joseon Supergroup. The subvertical dashed line represents the future Dongjeom Fault.

formable contact with the lower Paleozoic Hwangju System (Supergroup) depending on the distribution area (Ri and Om, 1996). The lithology of the NDPS is very similar to that of the Jangsan Formation (Fig. 5D vs. 6A). Accordingly, the above lines of evidence favor that the Jangsan Formation may be correlative with the upper Proterozoic Guhyeon System in North Korea.

4.3. Early evolution of the Duwibong Unit

The conformable contact between the Myeonsan and Myobong formations indicates that both strata were continuously deposited. The similarity of mudstone geochemical compositions in two formations also suggests that they shared similar provenance characteristics, probably in a same depositional setting. The southeastern part of the Taebaeksan Basin has been regarded to be proximal to source area, where the basin was unconformably developed on the Yeongnam massif. Thus, the Myeonsan Formation is interpreted to be the coeval stratum with the Myobong Formation as a laterally equivalent facies. Consequently, this study proposes to redefine that the lowermost strata of the Duwibong Unit of the Joseon Supergroup are the Myobong Formation in the basinal area and the Myeonsan Formation in the proximal area. Fig. 10 shows schematically the early evolution of the Duwibong Unit of the lower Paleozoic Joseon Supergroup. The Jangsan Formation was probably deposited during the late Proterozoic (Fig. 10A). After burial and uplift, the Jangsan Formation was exposed and eroded during the Early Cambrian. In the early stage of the Taebaeksan Basin development, the Myobong Formation was deposited in the basin side of the basin, and the laterally coeval Myeonsan Formation was deposited in the proximal part of the basin (Fig. 10B). As relative sea level rose during the Early to Middle Cambrian concurrent with 'eustatic' sea level rise (Hallam, 1984; Vail et al., 1977), fine fractions such as siltstone to mudstone were dominated in the Taebaeksan Basin, resulting in the expansion of the Myobong Formation deposition on the Myeonsan Formation (Fig. 10C). With time, the basin changed from siliciclastic shelf to carbonate platform, and the carbonate rocks of the overlying Daegi Formation were deposited on the Myobong Formation (Fig. 10C).

5. CONCLUSIONS

This study deals with the early evolution of the Duwibong Unit of the lower Paleozoic Joseon Supergroup, which represents the type stratigraphy of the early Paleozoic in the southern Korean Peninsula. The Jangsan Formation has long been regarded as the lowermost stratum of the Duwibong Unit. However, this study presents some new lines of evidence that the Jangsan Formation does not belong to the Joseon Supergroup, and is of late Proterozoic in age. The Jangsan Formation is interpreted to be correlative with the upper Proterozoic Guhyeon System in North Korea. This interpretation is based on the discovery of the unconformity between the Jangsan and Myobong formations present at two sections, each in Dongjeom area, Taebaek City and in Deogam area, Imgye-Myeon, Jeongseon-Gun. In addition, similarity in lithologies among Jangsan sandstones, quartzarenite gravelly clasts in the Myeonsan Formation and a newly reported late Proterozoic stratum underlying the Myeonsan Formation provides additional evidence that the Jangsan Formation is not the lowermost stratum of the Duwibong Unit, but acted as source rocks for the Myeonsan Formation in the earliest stage. Topmost sandstone facies of the Myeonsan Formation changes gradually to siltstone to mudstone facies of the overlying Myobong Formation. Also, the Myobong mudstone is geochemically very similar to the underlying Myeonsan Formation mudstone. Therefore, it is proposed that the Myeonsan and Myobong formations are of coeval age, and form the lowermost strata of the Duwibong Unit of the lower Paleozoic Joseon Supergroup.

ACKNOWLEDGMENTS: This study was supported by the Korea Research Foundation (KRF-2004-015-C00588) and partly by the BK 21 program through SEES, SNU. The manuscript benefited much from constructive comments by two anonymous reviewers. Dr. S.D. Hur, Korea Polar Research Institute is thanked for help in analyses of the rare earth and trace elements on some mudstone samples. The authors are also indebted to Messrs. K.S. Ham and S.H. Lee for their assistance in the field and laboratory. We thank Messrs. K.H. Shin and G.S. Son at Korea Resources Corporation for guidance to the Deogam site, Imgye-Myeon, Jeongseon-Gun, and M.S. Sim and Y.J. Joo for drawing some diagrams.

REFERENCES

Cheong, C.H., 1969, Stratigraphy and paleontology of the Samcheog coalfield, Gangweondo, Korea. Journal of Geological Society of Korea, 5, 13–56.

GICTR, 1962, Geologic Atlas of Taebaegsan Region. Geological Investigation Corps of Taebaegsan Region.

Haapala, I. and Rämö, O.T., 1990, Petrogenesis of the Proterozoic rapakivi granites of Finland. Geological Society of America Special Paper 246, 275–286.

Haapala, I. and Rämö, O.T., 1999, Rapakivi granites and related rocks: an introduction. Precambrian Research, 95, 1–7.

Hallam, A., 1984, Pre-Quaternary sea level changes. Annual Review of Earth and Planetary Scineces, 12, 205–243.

Jarvis, K.E., 1988, Inductively coupled plasma mass spectrometry: a new technique for the rapid or ultra-trace level determination of the rare-earth elements in geological materials. Chemical Geology, 68, 31–39.

Kim, H.S., 1977, Mineralogy and petrology of the Precambrian iron deposits. Journal of Geological Society of Korea, 13, 191–211.

Kim, J.Y., 1991, Stratigraphy of the Myeonsan Formation in Samcheoggun, Kangwondo and Ponghwagun, Kyeongsangbukdo. Journal of the Geological Society of Korea, 27, 225–245.

Kim, J.Y. and Cheong, C.H., 1987, The Precambrian-Cambrian boundary in the east of the Dongjeom fault, Gangweon-do, Korea. Journal of the Geological Society of Korea, 23, 145–158.

Kim, Y., 2004, Sedimentary evolution of siliciclastic rocks in the Duwibong unit of the lower Paleozoic Joseon Supergroup, Korea. Ph. D. Thesis, Seoul National University, 322p.

Kim, Y. and Lee, Y.I., 2003a, A new Late Proterozoic stratum in South Korea. Geosciences Journal, 7, 47–52.

Kim, Y. and Lee, Y.I., 2003b, Characterization of quartzites in the southern Korean Peninsula. Gondwana Research, 6, 729–742.

Kim, Y. and Lee, Y.I., 2004a, Diagenesis of shallow marine sandstones, the Lower Ordovician Dongjeom Formation, Korea: Response to relative sea-level changes. Journal of Asian Earth Sciences, 23, 235–245.

Kim, Y. and Lee, Y.I., 2004b, Origin of quartz cement in the Lower Ordovician Dongjeom Formation, Korea. Journal of Asian Earth Sciences, 24, 327–335.

Kobayashi, T., 1966, The Cambro-Ordovician formations and faunas of South Korea. Part X. stratigraphy of Chosen Group in Korea and south Machuria and its relation to the Cambro-Ordovician formation of other areas. Sect. A. The Chosen Group of South Korea. Jornal of Science, University of Tokyo, 16, 1–84.

Kobayashi, T., Yosimura, I., Iwaya, Y. and Hukasawa, T., 1942, The Yukusen Geosyncline in the Chosen Period. Brief notes on the geologic history of the Yukosen Orogenic Zone, 1. Proc. Imp. Acad. Tokyo, 18, 579–584.

Lee, H.Y., 1988, Paleozoic Eratherm. In: Lee, D.S. (Ed.), Geology of Korea. Kyohak-sa, Seoul, pp. 49–156.

Lee, S.M. and Kim, H.S., 1968, Petrogenesis of the syenite in the Yangyang mine district, Kwangwon Province. Journal of Geological Society of Korea, 4, 199–214.

Lee, Y.I. and Lee, J.I., 2003, Paleozoic sedimentation and tectonics in Korea: A review. Island Arc, 12, 162–179.

Park, B.K., Ryu, C.S. and Cheong, D.K., 1994, Sedimentary facies and depositional settings of Lower Cambrian Myobong Formation in Choseon Supergroup, Taebaeg area, Korea. Journal of Geological Society of Korea, 30, 435–454.

Ri, S.R. and Om, H.Y., 1996, Section 3: Middle-Upper Proterozoic Era. In: Paek, R.J., Kang, H.G. and Jon, G.P. (Eds.), Geology of Korea. Foreign Languages Books Publishing House, Pyongyang, pp. 52–79.

Taylor, S.R. and McLennan, S.M., 1985, The Continental Crust: Its Composition and Evolution. Blackwell, 312 p.

Vail, P.R., Mitchum, R.M., Jr. and Thompson, S., III, 1977, Seismic stratigraphy and global changes of sea level, 4: Global cycles of relative changes of sea level. In: Payton, C.E. (Ed.), Seismic

Stratigraphy – Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists Memoir 26, pp. 83–97.

Windley, B. F., 1995, The Evolving Continent, 3rd Edition. John Wiley and Sons, Chichester, 526p.

Yun, S., 1978, Petrology, chemical composition, and depositional environments of the Cambro-Ordovician sedimentary sequences in the Yeonhwa 1 mine area, southeastern Taebaegsan region, Korea. Journal of the Geological Society of Korea, 14, 145–174.

Zhai, M., Ni, Z., Oh, C.W., Guo, J. and Choi, S. G., 2005, SHRIMP zircon age of a Proterozoic rapakivi granite batholith in the Gyeonggi massif (South Korea) and its geological implications. Geological Magazine, 142, 23–30.

Manuscript received April 3, 2006
Manuscript accepted August 29, 2006