Mineral assemblages and heavy minerals of sandstones from the Pyeongan Group in Taebak area, Korea

Kang-Min Yu* and Eung-Seok Lee*

Mineral assemblages pelites of sandstones support the stratigraphic division of the Pyeongan Group. In the Upper Member of Gobangsan Formation, sandstones are characterized by acidic volcanic rock fragments (17% on average of total constituents). The Nogam Formation contains abundant potash feldspar ranging from 2 to 22% (11% on average). The Hongjeom, and Sadong Formations and the Lower and Middle Members of the Gobangsan Formation comprise quartzose arenite/wacke. The result of heavy mineral constituents are coincident with the results of mineral assemblages of the sandstones of Pyeongan Group in differentiating the stratigraphic division. Tourmalines in the Pyeongan Group were derived from Li-poor granitoids, pegmatites and aplites, or Ca-poor metapelites and metapsammites. The garnets in the Nogam Formation were derived from medium- to high-grade metamorphic rocks.

The provenance of sandstones in the Hongjeom Formation, Sadong Formation, and in the Lower and Middle Members of Gobangsan Formation is supposed to be mainly quartzite and quartzose sandstone. The provenance of sandstones in the Upper Member of Gobangsan Formation was probably andesite and granodiorite which could supply plagioclase and acidic volcanic rocks as well as quartzite and quartzose sandstone. The provenance of sandstones in the Nogam Formation was granite, granitic gneiss, pegmatite and amphibolite which supplied potash feldspar as well as quartzite and quartzose sandstone.

Key words: mineral assemblage, heavy mineral, sandstone, Pyeongan Group, Taebak area.

Introduction

The Pyeongan Group comprises Hongjeom, Sadong, Gobangsan and Nogam Formations in ascending order (Shiraki, 1930). Based on lithology and fossil contents the group has been divided into the seven formations, i.e., the Manhang, Geumcheon, Jangseong, Hambacgsan, Dosagog, Gohan and Donggo formations (Cheong, 1969, 1974). Suh et al., (1979) did the good work for

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geologic map of 1 : 25,000 scale including the study area. This paper follows Suh et al., (1979) for geologic boundary of the formations, and follows Shiraki (1930) for the name of the formations (Table 1).

There are many researches on sandstone petrology (Dickinson 1970; Dickinson and Suczek, 1979; Ingersoll et al., 1984; Kiminami et al., 1992). Concerning to the research on mineral assemblages of sandstones fo the Pyeongan Group, there were two reports in 1960’s, at first report (Cho, 1966; Kim, 1968). Recently some papers were added to the study on sandstones in the Pyeongan Group (Yu, 1985; Lee et al., 1986;
Table 1 Stratigraphic correlation of the Samcheong Coalfield including the study area.

<table>
<thead>
<tr>
<th>System</th>
<th>GICTR (1962)</th>
<th>Cheong (1969)</th>
<th>Suh et al. (1979)</th>
<th>This Paper</th>
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<td>Great Limestone</td>
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</table>

GICTR: Geologic Investigation Corps of Tabaeegsan Region. Fm: Formation. Mb: Member. Ls: limestone.

Yu and Lee, 1987, 1992). Lee (1990) reported the absence of feldspar in sandstones from the Manhang and Yobong Formations. Choi et al., (1991) found the volcanogenic sediments in the Nogam Formation. Concerning to the research on heavy minerals of sandstones, there are Hubrt (1962) for ZTR index, Morton (1985, 1987) for provenance study by electron microprobe and lysis of detrital garnets, Statteger (1987) for provenance, and Adachi (1977) for stratigraphic significance. And there are some papers on heavy minerals in sandstone from Korean Peninsula (Koh, 1986; Yu and Lee,1987; Yu and Kim, 1988; Yu et al., 1992). This paper treats the mineral assemblages and heavy minerals of sandstones in the Pyeongan Group, and differentiates the each formation of Pyeongan Group by the petrographic results.

Geologic setting

The study area mainly comprises the Pyeongan Group of Carboniferous to Triassic age, a part of the Choseon Supergroup of Cambrian to Early Silurian age and the Kyeongsang Supergroup of Cretaceous age (Fig. 1).

Choseon Supergroup

The Maggol Limestone which is the uppermost formation of Choseon Supergroup is distributed in the study area, surrounding the Pyeongan Group. It consists mainly of well-bedded limestone and dolomitic limestone which intercalate calcareous shale and intraformational breccias. The thickness and ratio of dolomitic limestone increases upward in the formation. The age of the formation is Canadian–Chazyan of Ordovician (Lee, 1976). Paik (1985) found the casts of evaporite minerals, and interpreted it as the shallow marine environments under arid climate with a periodically humid setting. This formation is 300 to 400 m thick.

Pyeongan Group

This group unconformably overlies the Maggol Limestone of Choseon Supergroup in the southern part of study area, but in fault contact with the latter in the eastern and western parts of
study area (Fig. 1). The Pyeongan Group is divided into four formations by lithological characters, namely Hongjeom, Sadong, Gobangsan and Nogam Formations in ascending order (Table 1).

**Hongjeom Formation**

The Hongjeom Formation is the lowermost formation of the Pyeongan Group and unconformably overlies the Choseon Supergroup at an outcrop which locates about 200 meters away to southeast from the gate of Jangseong Coal Company. The formation is mainly composed of pebble-bearing coarse-grained quartzose sandstone, medium- to coarse-grained quartzose sandstone and shale (Fig. 2). Limestone beds are interbedded with sandstone in some localities. The pebble clasts of pebble-bearing coarse-grained sandstone are quartzite and shale, ranging from 3 mm to 12 mm in size. The formation was deposited in shallow marine environment, and its age is assigned to Carboniferous by fossils (Cheong, 1969). The formation is 150 to 300 m thick.

**Sadong Formation**

It is divided into the Lower and the Upper Members. The Lower Member corresponds to the Geumcheon Formation, and the Upper Member to the Jangseong Formation by Cheong (1969). Dark gray fine-grained sandstone of the Lower Member conformably overlies the Hongjeom Formation. This member is mainly composed of black shale and dark gray fine-grained sandstone, intercalating medium- to coarse-grained sandstone (Fig. 2). Limestone and coal bed are interbedded with sandstone in some localities. The member is 50 to 100 m thick.

The Upper Member is composed of black shale and dark gray medium- to coarse-grained sandstone, intercalating fine-grained sandstone and coal seams. This member is a major coal measure of the Samcheog Coal Field. Cheong
Fig. 2 Columnar sections of the part of Pyeongan Group in the study area. The locations of all columnar sections shown in Fig. 1.

Ho: Hongjeom Formation, S1 and S2: Sadong Formation, G1 to G6: Gobangsan Formation, N1 to N6: Nogam Formation. 1-32: Sample number of sandstones analysed for mineral assemblage, H1-H14: Sample number of sandstones analysed for heavy mineral assemblage, Ch: Hongjeom Formation, Csl: Lower Member of Sadong Formation, Psu: Upper Member of Sadong Formation, Pgu: Upper Member of Gobangsan Formation, TRn: Nogam Formation, sh: shale, f: fine-grained sandstone, m: medium-grained sandstone, co: coarse-grained sandstone, p: pebble-bearing sandstone.
(1969) reported 4 cyclothems which consist of 4-5 beds of sandstone and shale and 3-4 coal seams. Medium- to coarse-grained sandstone of the Upper Member is roughly distinguishable from the fine-grained sandstone of Lower Member (Fig. 2). The member varies 100 to 150 m in thickness.

**Gobangsan Formation**

It is divided into three members, i.e., Lower, Middle and Upper Members corresponding to the Hambaegsan, Dosagog and Gohan formations by Cheong (1969), respectively. This formation shows some graded bedding and abundant cross bedding. Milky white coarse- to very coarse-grained quartzose sandstone of the Lower Member of Gobangsan Formation conformably overlies the Upper Member of Sadong Formation. The Lower Member is mainly composed of milky white coarse-grained and pebble-bearing coarse-grained quartzose sandstone, and is intercalated with shale and medium-grained quartzose sandstone (Fig. 2). The pebbles are mostly quartzite, and the size is about 1 cm. The member is 200 to 250 m thick.

The Middle Member is composed of coarse-grained and pebble-bearing quartzose sandstone, and shale (Fig. 2). This member is very similar to the Lower Member of Gobangsan Formation in lithology, however this member has more frequent intercalation of shale bed. The pebbles of pebble-bearing sandstone are quartzite and greenish shale, and the sizes range from 2 mm to 3 cm. The member is 250 to 300 m thick.

The Upper Member is composed of fine- to coarse-grained sandstone and shale, associated with pebble-bearing sandstone. This member is characterized by lithic sandstone and more predominance of fine-grained sandstone. The fine- to coarse-grained lithic sandstone of the Upper Member is distinguished from the sandstone of Middle Member of Gobangsan Formation (Fig. 2). The geologic age of the Upper Member of Gobangsan Formation is supposed to be Permian (Chang, 1972). This member is 150 to 300 m thick.

**Nogam Formation**

This formation corresponds to the upper portion of Nogam Formation by the Geological Investigation Corps of Taebaegsan Region (1962), and corresponds to Donggo Formation named by Cheong (1969). Sandstone of the Nogam Formation is distinguished from the sandstone of Gobangsan Formation by the abundant potash feldspar. The formation is mainly composed of greenish fine- to medium-grained feldspathic sandstone, intercalating pebble-bearing sandstone and conglomerate. The gravels of pebble-bearing sandstone are quartzite and greenish shale, and the size is mostly less than 1 cm. Clasts of conglomerate are tuff, granite, sandstone and shale (Plate 1-A). The clast is rounded to well rounded, and ranges from 2 cm to 20 cm in diameter. The formation shows graded bedding, ripple mark, and abundant cross bedding. Although no fossil was found, the formation has been inferred to be late Permian or early Triassic by its stratigraphic position. This formation has been supposed to be non-marine sediments. Clear evidence, needs for sedimentary environment at this moments. This formation has about 1000 m thick in the study area.

**Kyeongsang Supergroup**

The Kyeongsang Supergroup is distributed in the northern part of the study area. The supergroup is divided into the Jeoggagri and Heungjeon Formations. The Jeoggagri Formation overlies unconformably the Pyeongan Group. The formation is composed of conglomerate and mudstone. In the huge outcrop at Miin Fall near Tongri Town, clasts of conglomerate are composed of quartzite, limestone, sandstone and shale. The formation is 200 to 300 m thick. The Heungjeon Formation is composed of tuff of 200 m thick, and conformably overlies the Jeoggagri Formation.

**Method**

For analysis of mineral assemblage of sandstones, forty thin sections were made oriented parallel to bedding plane. Medium- to coarse-
grained sandstones were selected for mineral assemblage. Potash feldspars were stained by sodium cobaltinitrite according to the procedure by Bailey and Stevens (1960). The analysis of mineral assemblage was counted by the traditional method, and the counted points were over than 300 points with an interval of 0.5 mm. The classification of sandstone follows the Okada’s scheme (Okada, 1971), and fifteen per cent of matrix is adopted for boundary between arenite and wacke.

For analysis of heavy mineral of sandstones, sixteen samples were selected, and extracted heavy minerals by using bromoform. About fifteen hundreds of heavy minerals were examined by polarized, reflected microscope and electron probe microanalyser (EPMA). Sampling localities are shown in Fig. 1.

Results

Mineral assemblage

Table 2 Mineral assemblage frequency per cent of the sandstones from the Pyeongan Group. The sampling localities are shown in Fig. 2 and Fig. 3.

<table>
<thead>
<tr>
<th>Formation Name</th>
<th>Sample Number</th>
<th>Mono Quartz</th>
<th>Poly Quartz</th>
<th>Total Quartz</th>
<th>Plagioclase</th>
<th>K-Feldspar</th>
<th>Total Feldspar</th>
<th>Acidic Lv.</th>
<th>Inter. Lv.</th>
<th>Chert</th>
<th>Calcite</th>
<th>Shale</th>
<th>Other R.F.</th>
<th>Total R.F.</th>
<th>Acc Min.</th>
<th>Matrix</th>
<th>Grain size</th>
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Mineral assemblages of sandstones from the Pyeongan Group are summarized in Table 2.

In the Hongjoom Formation, major mineral constituent of sandstone is quartz which ranges from 65 to 70% of the total constituents and 67.22% on average. Average content of monocrystalline quartz is 60.5%, and that of polycrystalline quartz is 5.4%. Feldspar content ranges from zero to 2% of total constituents. Rock fragments range from 7 to 9%, and 8% on average.

In the Lower Member of Sadong Formation, quartz ranges from 62 to 72%, and 68.8% on average. Average content of monocrystalline quartz is 64.7%, and that of polycrystalline quartz is 4.1%. Feldspar content ranges from zero to 1%. Rock fragments range from 5 to 12%, and 7.4% on average. In the Upper Member of Sadong Formation, quartz ranges from 61 to 71%, and 67.1% on average. Average content of monocrystalline quartz is 59.4%, and that of polycrystalline quartz is 7.8%. Feldspar content is
zero on point counting. Feldspar is rarely recognized in thin section.

In the Lower Member of Gobangsan Formation, quartz content ranges from 64 to 80%, and 73.3% on average (Plate 1-B). Average content of monocrystalline quartz is 66%, and that of polycrystalline quartz is 7.3%. Feldspar content ranges from zero to 0.3%. Rock fragment content ranges from 5 to 10%, and 8.3% on average. In the Middle Member of Gobangsan Formation, quartz content ranges from 73 to 82%, and 78.5% on average. Average content of monocrystalline quartz is 72.4%, and that of polycrystalline quartz is 6.1%. Feldspar content ranges from zero to 1%. Rock fragment content ranges from 5 to 12%, and 8.7% on average.

In the Upper Member of Gobangsan Formation, quartz content ranges from 40 to 51%, and 45.5% on average. Average content of monocrystalline quartz is 42.8%, and that of polycrystalline quartz is 2.7%. Plagioclase content ranges from 10 to 12%, and 11.2% on average. Plagioclase content is remarkably abundant. Potash feldspar content ranges from 0.3 to 1.3%, and 1% on average. Potash feldspar firstly appears in this member. From the Hongjeom Formation to the Middle Member of Gobangsan Formation, there is no potash feldspar. Acidic volcanic rock fragment (Plate 1-C) content ranges from 15 to 17% of total constituents, and 16.9% on average. This remarkable content of acidic volcanic rock fragment enable to distinguish the sandstone in the Upper Member of Gobangsan Formation from the other sandstones in the Pyeongan Group.

In the Nogam Formation, quartz content ranges from 42 to 59%, and 51% on average. Average content of monocrystalline quartz is 48%, and that of polycrystalline quartz is 3%. Plagioclase content ranges from 5 to 15%, and 10.1% on average. Average content of plagioclase of the formation is almost same as that of the Upper Member of Gobangsan Formation. Potash feldspar content ranges from 2 to 22%, and 10.9% on an average. The Nogam Formation is characterized by the abundance of potash feldspar (Plate 1-D). Acidic volcanic rock content ranges from zero to 16% of the total constituents, and 5% on average.

There is a clear difference in mineral assemblage of sandstone between the lower part and upper part of the Pyeongan Group. The lower part consists of the Hongjeom Formation, Sadong Formation, and the Lower and Middle Members of the Gobangsan Formation. The upper part is the Upper Member of the Gobangsan Formation and the Nogam Formation. The compositional variety of quartz, plagioclase, potash feldspar and acidic volcanic rock in the sandstones from the Pyeongan Group are shown in Fig. 3. Average content of quartz from the lower part of Pyeongan Group is 71.3%, and that of polycrystalline quartz is 6.3%. However, average content of

![Fig. 3 Variation diagram of quartz, potash feldspar, plagioclase and acidic volcanic rock fragment of the sandstones from the Pyeongan Group.
1-40: Sample number of the sandstone.](image)
quartz in the upper part of Pyeongan Group is 50.3%, and that of polycrystalline quartz is 3.0%. Content of plagioclase shows an abrupt increase in the Upper Member of Gobangsan Formation and Nogam Formation (Fig. 3). The content of potash feldspar

Fig. 4 Quartz–feldspar–rock fragment ternary diagram of sandstones from the Pyeongan Group.
Q: quartz, F: Feldspar, R: rock fragment, Fm: Formation, Cs1: Lower Member of Sadong Formation, Psu: Upper Member of Sadong Formation, Pgl: Lower Member of Gobangsan Formation, Pgm: Middle Member of Gobangsan Formation, Pgu: Upper Member of Gobangsan Formation.

Fig. 5 Quartz–plagioclase–potash feldspar ternary diagram of the sandstones from the Pyeongan Group.
Q: quartz, P: plagioclase, K: potash feldspar. Symbols are same as those in Fig.4.

Fig. 6 Variation of heavy mineral amount of sandstones among the formations of the Pyeongan Group. The values are arithmetic means of heavy minerals for each formation.
shows abrupt increasing in the Nogam Formation. The content of acidic volcanic rock is 1.2% on average from the upper part of Pyeongan Group. However, the amount of acidic volcanic rock shows an abrupt increase in the upper part of Pyeongan Group is in variable in amount (Fig. 3). Intermediate volcanic rocks are rarely found in the Upper Member of Gobangsan Formation.

These contents of each mineral assemblage are well coincident with the formation and member boundary of the Pyeongan Group. Mineral assemblages of the sandstones from Pyeongan Group are plotted in QFR (quartz-feldspar-rock fragment) ternary diagram (Fig. 4). Sandstones in the Hongjeom Formation, Sadong Formation, and Lower and Middle Members of Gobangsan Formation are classified as quartzose arenite/wacke. The sandstones in the Nogam Formation are classified as feldspathic arenite/wacke. Ratio of quartz, plagioclase and potash feldspar are plotted in QPK ternary diagram (Fig. 5). They can be a separation between the sandstones of the Upper Member of Gobangsan Formation and those of the Nogam Formation.

Heavy Mineral

Heavy mineral constituents of the sandstones from Pyeongan Group are zircon, tourmaline, rutile, sphene, epidote, muscovite, biotite, pyrite, garnet, ilmenite and hematite (Table 3). Zircon, tourmaline and rutile are the main heavy mineral constituents of the Pyeongan Group.

In the Hongjeom Formation, the amount of tourmaline ranges from 60 to 86% of the total constituents, and 73.2% on an average. Tourmaline content is 55%, and rutile content is 15% in the Lower Member of Sadong Formation. Tourmaline content is 15%, and rutile content is 53% in the Upper Member of the Sadong Formation. Heavy mineral constituents between the Lower and Middle Members of Gobangsan Formation are mainly tourma-line, rutile and zircon, and inclu-de mica and opaque mineral. The Upper Member of Gobangsan Formation has garnet of 8.5%. The Nogam Formation has

Table 3 Heavy mineral frequency per cent of the sandstones from the Pyeongan Group. The numbers of total are identified heavy mineral.

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<th>Sample Number</th>
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<th>Sphene</th>
<th>Epidote</th>
<th>Muscovite</th>
<th>Biotite</th>
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<th>Garnet</th>
<th>Ilmenite</th>
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Mb: Member.

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considerable amount of sphene, epidote and garnet (Table 3).

Vertical variation of heavy mineral content of whole sequence of the Pyeongan Group is shown in Fig. 6. From the lower part of Pyeongan Group, heavy mineral content are almost same (Fig. 6). Heavy mineral content of the upper part of Pyeongan Group is different from the lower part of Pyeongan Group (Fig. 6). This result supports to the result of the mineral assemblage of the sandstones of the Pyeongan Group in dividing the Pyeongan Group into the formations.

In theory, tourmaline offers good opportunity for distinguishing provenance, because of its ultrastable nature. However, accurate analyses of tourmaline are less easy than those of garnet, because of the presence of boron in the structure (Morton, 1985). In this study, selected samples of tourmaline and garnet were quantitatively analysed by EPMA.

The data are plotted on Ca–Fe–Mg ternary diagram (Fig. 7; Henry and Guidotti, 1985), and the data show that the tourmalines are derived from Li-poor granitoids, pegmatites and aplites, or Ca-poor metapelites and metapsammmites. This result is the same as the judgement on Al–Fe–Mg ternary diagram (Fig. 8; Henry and Guidotti, 1985). The difference among the formations of Pyeongan Group can not be recognized in this study.

The garnets have wide variety of potential compositions in sedi-
ment with seven principal end-members, i.e., pyrope, almandine, spessartine, grossular, andradite, uvarovite and hydrogrossular, and possible further substitution by Ti, Zr, and U (Morton, 1985). The garnet is the most useful mineral to study the provenance. Twenty garnet grains from the Nogam Formation were analysed by EPMA. The analysed data are plotted on Pyrope(Mg)-Almandine(Fe)+Spessartine(Mn)-Grossular(Ca) ternary diagram (Fig. 9; Morton, 1985). The data show that the garnets are almandine rich garnets which have grossular (< 9.9%) and spessartine (< 12.7%). Pyrope content ranges from 4.9 to 28.7%. The garnets are supposed to be derived from medium-to high-grade metamorphic rocks.

Provenance

The sandstones of the Hongjeom Formation, Sadong Formation, Lower Member and Middle Member of Gobangsan Formation have almost same mineral assemblage. Major mineral constituent of sandstone is quartz which ranges from 61 to 82%. Matrix content ranges from 5 to 23%. The large amount of quartz means that the provenance of sandstones is supposed to be the rocks which include quartzite and quartzose sandstone which could supply quartz sufficiently. The large amounts of matrix suggests that the provenance was not far from the depocenter.

The sandstones of the Upper Member of Gobangsan Formation are mainly composed of quartz, plagioclase and acidic volcanic rocks. Provenance of sandstones in this member is supposed to be derived from andesite, granodiorite which could supply plagioclase and acidic volcanic rocks as well as quartzite and quartzose sandstone. Acidic volcanic rock fragments from the Upper Member of Gobangsan Formation and Nogam Formation, are mostly rounded with some angular grains. The rounded grains are supposed to be derived from the preexisted acidic volcanic rock and the angular shaped grain has the possibility from the syndepositional acidic volcanic eruption. This opinion is same to Lee (1990) and Choi et al., (1991).

In the Nogam Formation, clasts of acidic volcanic and granitic rocks are also found in conglomerate, and high amount of plagioclase, potash feldspar and acidic volcanic rocks are found in the sandstones. Specially, potash feldspar content is 10.9% on average. Provenance of sandstones in the Nogam Formation is supposed to be derived from granite, granitic gneiss and amphibolite which could supply potash feldspar as well as quartzite and quartzose sandstone. And this formation is partially influenced by acidic volcanic rocks. Acidic volcanic rock content is become the useful criteria to distinguish the sandstones from the Pyeongan Group.

Heavy mineral sphene is found in the Nogam Formation, and sphene is supposed to be derived from plutonic rock. Garnet from the Nogam Formation is supposed to be derived from metamorphic rocks. Tourmaline of the Pyeongan Group is supposed to be derived from Li-poor granitoids, pegmatites and aplites, or Ca-poor metapelite and metapsammites.

Conclusion

1. Mineral assemblage of sandstones changes
well concordantly with the stratigraphic division of the Pyeongan Group. The sandstones of the Hongjeom Formation, Sadong Formation, Lower and Upper Members of Gobangsan Formation are classified as quartzose arenite / wacke. The sandstones of the Upper Member of Gobangsan Formation is classified as lithic arenite / wacke. The sandstones of the Nogam Formation are mostly classified as feldspathic arenite / wacke.

2. There is a difference of mineral assemblage of sandstone between the Upper Member of Gobangsan Formation and Nogam Formation. The sandstones of the Upper Member of Gobangsan Formation are characterized by acidic volcanic rock fragment content ranging from 15 to 17% of total constituents, and 16.9% on average. The sandstones of the Nogam Formation are characterized by potash feldspar content ranging from 2 to 22%, and 10.9% on average.

3. The result of heavy mineral constituents is support to the result of the mineral assemblage of sandstones of Pyeongan Group in differentiating the formations. Heavy mineral content of the Upper Member of Gobangsan Formation and Nogam Formation are clearly differentiated from the lower part of Pyeongan Group.

4. The tourmalines analysed quantitatively by EPMA were derived from Li-poor granitoids pegmatites and aplites, or Ca—poor metapelite and metapsammites. The garnets of Nogam Formation were derived from medium- to high-grade metamorphic rocks.

5. Provenance of the sandstones in the Hongjeom Formation, Sadong Formation and Lower and Middle Members of Gobangsan Formation is supposed to be mainly quartzite and quartzose sandstone. Provenance of the sandstones in the Upper Member of Gobangsan Formation is supposed to be andesite, granodiorite and acidic volcanic rocks as well as quartzite and quartzose sandstone. Provenance of the sandstones in the Nogam Formation is supposed to be granite, granitic gneiss, pegmatite and amphibolite as well as quartzite and quartzose sandstone.

Acknowledgments

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References


MORTON, A. C., 1985: A new approach on provenance studies: electron microprobe analysis of detrital garnets from Middle Jurassic sandstones of the northern North Sea. Sedimentology, 32, 553–566.


Explanation of Plate

A: Conglomerate bed in the Nogam Formation. Scale which rounded ten won coin of 22 mm in diameter, shown by arrow.
T: tuff, G: granitic rock, S: shale.

B: Photomicrograph of quartzose sandstone of the Lower Member of Gobangsan Formation. Scale is 0.4mm.

C: Photomicrograph of lithic sandstone of the Upper Member of Gobangsan Formation showing typical acidic volcanic rock fragments. Scale is 0.2mm.
Lv: acidic volcanic rock fragment, Q: quartz.

D: Photomicrograph of feldspathic sandstone of the Nogam Formation showing abundant potash feldspars stained by sodium cobalt nitrite solution. Scale is 0.4mm.
K: potash feldspar.