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Heavy Mineral Analysis of the Cretaceous Hayang Group Sandstones, Northeastern Gyeongsang Basin

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ABSTRACT : The northeastern part of the Gyeongsang Basin is widely covered by the Cretaceous Hayang Group (Aptian to Albian). The Hayang Group consists of the Iljig, Hupyeongdong, Jeomgog, and Sagog formations. Heavy mineral analysis was carried out to define the possible source rocks of the Hayang Group sandstones. Heavy minerals separated from Iljig, Hupyeongdong, and Jeomgog sandstones are hematite, ilmenite, leucoxene, magnetite, pyrite, actinolite, andalusite, apatite, biotite, chlorite, epidote, garnet, hornblende, kyanite, monazite, muscovite, rutile, sphene, spinel, staurolite, tourmaline, and zircon. Based on their close association and sensitiveness, the heavy mineral assemblages can be classified into 6 suites: 1) apatite-green tourmaline-sphene-colorless/yellowish zircon; 2) colorless garnet-epidote-rutile-brown tourmaline; 3) rounded purple zircon-rounded tourmaline-rounded rutile; 4) augite-hornblende-colorless zircon; 5) epidote-garnet-sphene; and 6) blue tourmaline. The possible source rocks corresponding to each assemblage are 1) granitic rocks; 2) metamorphic rocks (schist and gneiss); 3) older sedimentary rocks; 4) andesitic rocks; 5) metamorphosed impure limestone; and 6) pegmatite, respectively. Previous paleocurrent data suggest that the sediments of the study area were mainly derived from the northeastern to southeastern directions. Thus, the most possible source areas would be the east extension part of the Sobaegsan metamorphic complex to the northeast and the Cheongsong Ridge to the southeast.

Key words : Gyeongsang Basin, Hayang Group, sandstone, heavy mineral, source rock

INTRODUCTION

The northeastern part of the Gyeongsang Basin is widely covered by the Cretaceous Hayang Group (Fig. 1). The Hayang Group has been well studied on stratigraphy and structural geology (e.g., Kim *et al.*, 1970; Park, 1977; Chang *et al.*, 1977, 1978). In order to understand the evolution of the sedimentary basin with relation to the tectonic evolution of the east Asian continental margin during Cretaceous time, further detailed studies on sedimentology and petrology of the Hayang Group have been needed.

Previous data on paleocurrent in the northwestern part of the Gyeongsang Basin suggests that the paleocurrent direction is toward southeast at 120° with a standard deviation of ±71° (Chang and Kim, 1968). In contrast, the northeastern part is toward the northwest direction at 290° with a standard deviation of ±68° (Lee, 1995). These paleocurrent data suggest that the source rocks of the Hayang Group in the northeastern part is different from those of the northwestern part.

This study is focused on the heavy mineral analysis to deduce the source rocks of the Hayang Group in the northeastern part of the Gyeongsang Basin.

GEOLOGICAL SETTING

The Gyeongsang Basin is located in the sou-

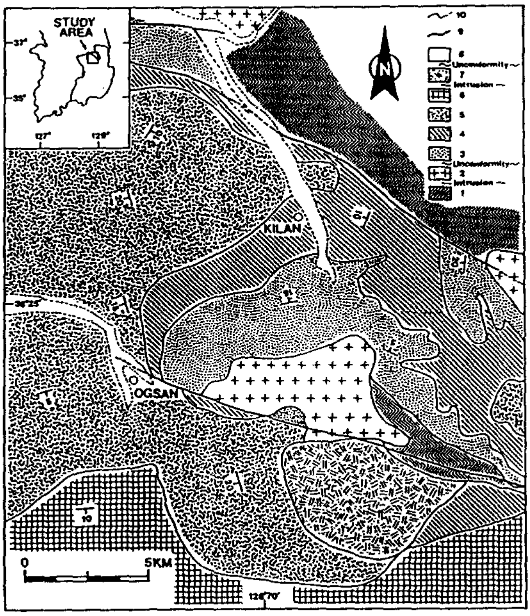

Fig. 1. Geologic map of the study area. 1: Precambrian basement rocks, 2: Jurassic granite, 3-6: Cretaceous strata (3: Iljig Fm., 4: Hupyeongdong Fm., 5: Jeomgog Fm., 6: Sagog Fm.), 7: Cretaceous quartz porphyry, 8: Quaterary alluvium, 9: Fault boundary, 10: Geologic boundary (after Kim *et al.*, 1970; Chang *et al.*, 1978).

theastern part of the Korean peninsula. During Cretaceous time, Korean peninsula was placed at the eastern continental margin of the Eurasian plate. Thus, the eastern margin of the Asian continent was characterized by active convergent plate margin (Seno and Maruyama, 1984). During the time, a large sinistral strike-slip fault system was produced at the eastern margin of the Eurasian continent. The oblique subduction accompanied intense extensional or compressional events and shear deformation (Okada, 1993). By these processes, many non-marine sedimentary basins such as Gyeongsang Basin were formed during Cretaceous time.

The Hayang Group is underlain by the Sindong Group. However, in the northeastern part of Gyeongsang Basin, the Hayang strata directly overlies the basement rocks of the Precambrian gneiss and Jurassic granite without intervening the Sindong Group (Chang, 1970, 1975). Such a situation led to the idea that an eastward expansion of the basin was approximately coincident with the beginning of deposition of Hayang Group (Chang, 1970, 1975). The Hayang Group deposited in fluvio-lacustrine environments (Chang, 1988; Woo, 1989). In the study area, the Hayang strata consist of conglomerate, sandstone, shale, and marl which are intercalated with lava flows and volcanics (Chang, 1975). The Hayang Group is subdivided into the Iljig, Hupyoengdong, and Jeomgog formations in ascending order.

Iljig Formation

This formation is largely composed of abundant conglomerate, pebbly sandstone, and minor amounts of sandstone and mudstone. The thickness of the formation varying from place to place is approximately 700m in the Baegjadong area and about 400m in the Gigyeongdong area. In the northeastern part of the study area, the Iljig Formation is in contact with Precambrian granitic gneiss and amphibolite due to the Andong fault. The sedimentary strata were severely disturbed by the Andong faulting in the northern and northeastern parts. The clasts are mainly composed of granite, quartzite, granite gneiss, and schist. They are commonly moderate to well rounded and show polymodal or bimodal texture in grain size. The conglomerates are clast-or matrix-supported, commonly disorganized and locally graded, and range in thickness from several decimeters to meters.

Hupyeongdong Formation

The lower boundary of the Hupyeongdong Formation is characterized by the Gumidong conglomerate which includes chert pebbles. The formation is 100m to 500m thick and consists of coarse-to medium-grained sandstone, common fine sandstone, siltstone and purplish mudstone. In the Baebang area, the clasts of the Gumidong conglomerate of 1.5m thick comprise pebble-sized chert, fine-grained sandstone, quartzite, and granite. They show disorganized clast-supported, moderately sorted and subangular to subrounded texture.

Jeomgog Formation

This formation is about 950m thick and consists of greenish sandstone, mudstone, and minor pebbly sandstone, with intercalated tuffaceous sandstone and cherty rock. In the Gogog-dong area, the greenish sandstone contains abundant granule-sized pink feldspars and intra-formational mud chips. The sandstone beds are mainly massive, but often show crude stratification and low angle cross-bedding. In general, the Jeomgog sandstones contain trachytic rock fragments. The fine-grained sandstone beds alternate with greenish and dark gray mudstones. Mudrocks are frequent in the upper part of the formation.

ANALYTICAL METHOD

Thirty-five sandstone samples from the Hayang Group were selected for heavy mineral

Table 1. Heavy mineral frequencies of the Cretaceous Hayang Group sandstones in the northeastern part of the Gyeongsang Basin (in grain %)

Formation	Iljig Formation										
Sample No.	L-01	L-02	L-04	L-05	L-07	L-09	L-10	L-11	L-12	L-14	L-15
Others											
Altered grain	15	7	14	2	4	6	2	2	1	4	1
Opaques											
Hematite		2	2	23	9	9	+		2	3	+
Ilmenite	66	75	27	9	1	41		+	34	8	+
Leucoxene	1	+		4	1	17	13	1	6	3	21
Limonite											
Magnetite				3	+	6			3	+	27
Pyrite											
Non-Opaques	18	15	57	59	84	21	84	96	54	82	49
Total	100	100	100	100	100	100	100	100	100	100	100
Non-Opaques											
Actinolite	2										
Andalusite								1	1		
Apatite		5	4	2	1	3		2	1		5
Augite	1	3	9			1	1	4	67	1	
Biotite	20	48	2		36			3			13
Chlorite	46		61	59	41					2	28
Epidote	2	8	3			1	90	58	3	77	
Garnet(colorless)			2				1	3	15	1	1
Garnet(green tint)								1	1		
Garnet(pink tint)								1	1		
Hornblende	6										
Hypersthene			10								
Kyanite											
Monazite						4		17			
Muscovite		5	2	8	21	2		2		2	10
Rutile				1		28				1	
Sphene			1			1		1	5		
Spinel									1	1	
Staurolite							1				4
Tourmaline(blue)	1									1	
Tourmaline(brown)	16	13		1	1	34		1		2	10
Tourmaline(green)	3					5	1	1	1	2	4
Zircon(colorless)		12	4	25		6	3	1	2	5	19
Zircon(yellow tint)	3	6	1	4		12	2	2	2	1	5
Zircon(purple)			1			5	1	1		5	1
Total	100	100	100	100	100	100	100	100	100	100	100
Total counted grains	397	251	465	502	545	484	485	589	447	589	514

Note: Total counted grains are the total counted grains without carbonate. Sign+is less than 1 percent. Heavy mineral frequencies are given in grain percent and non-opaques frequencies are normalized to 100 percent of total non-opaque crops.

analysis. Heavy minerals were separated by a routine procedure (Hutchison, 1974). After cutting away weathered surface, about 200g of each sample were crushed with steel roller. 120-230 mesh (0.125-0.06 mm) fractions were separated by dry sieving, using a mechanical shaker. The separated grains were treated with 10% oxalic acid ($H_2C_2O_4 \cdot 2H_2O$) solution, as described by Leith (1950), in order to eliminate iron oxide coated on the surface. Apatite was not effected and grains turned into clear after 20 minutes of gentle boiling. After densimetric separation, the average recovery of heavy minerals is 0.08g from each 10g fraction. The heavy mineral grains (average: 480 grains) are then mounted on slide glass for optical identification.

RESULT

Heavy mineral description

Totally 35 sandstone samples from the Iljig (11), Hupyeongdong(12), and Jeomgog formations(12) were examined for heavy mineral spectra. The frequency of heavy minerals from the sandstones is firstly shown in grain % (Table 1) and then the relative abundance of

Table 1. (Continued)

Formation	Hupyeongdong Formation											
Sample No.	L-16	L-17	L-18	L-19	L-20	L-21	L-22	L-23	L-24	L-25	L-26	L-27
Others												
Altered grain	3	+	2	2	5	+	1	2	2	2	2	2
Opaques												
Hematite	18	+	4	5	2	3	2	2	2	2	17	36
Ilmenite	8	16	16	18	10	37	21	21	18	38	31	7
Leucoxene	5	4	11	14	14	7	17	5	14	2	8	18
Limonite	+					+					2	+
Magnetite	6	18	21	10	2	+	4	8	6	1	+	12
Pyrite												
Non-Opaques	59	60	46	51	66	50	74	62	58	55	39	24
Total	100	100	100	100	100	100	100	100	100	100	100	100
Non-Opaques												
Actinolite	1											
Andalusite	2			1		1			1			3
Apatite	1	9	5	9	1	1	2	23	4	4	2	3
Augite	1				1	1						
Biotite	1		1									
Chlorite		16	13	18	15	27	35	14	1	1	3	4
Epidote	1			1	1	2		1	1			1
Garnet(colorless)	4	2		1			1	1		1	8	1
Garnet(green tint)	2	26	33								30	42
Garnet(pink tint)		1										
Hornblende	1											
Hypersthene											1	
Kyanite	30			1								
Monazite					1	1	1				2	2
Muscovite	2	20	38	29	3	11	2	17	7	16	27	10
Rutile	3	1		1	8	5	4		1		3	3
Sphene	3	3	1		2	2	1	1	8	2	1	2
Spinel	6			1			1	6	1		1	
Staurolite						1						
Tourmaline(blue)			1		1		1	1		1		
Tourmaline(brown)	4	14	3	16	11	14	11	24	5	16	9	14
Tourmaline(green)	1	3	2	2	3	3	2	3		2	4	2
Zircon(colorless)	3	2	1	14	11	5	21	4	52	25	3	
Zircon(yellow tint)	21	2	2	3	24	13	6	3	15	23	6	1
Zircon(purple)	13	1		3	18	13	12	2	5	9		12
Total	100	100	100	100	100	100	100	100	100	100	100	100
Total counted grains	421	544	464	523	601	572	574	527	524	445	495	480

Table 1. (Continued)

Formation	Jeomgog Formation											
Sample No.	L-29	L-31	L-32	L-33	L-34	L-35	L-36	L-37	L-40	L-41	L-42	L-43
Others												
Altered grain	6	2	+	22	+	4	6	11	6	5	2	+
Opaques												
Hematite	12	2	7	5	2	+	+				+	+
Ilmenite	25	38	26	2	34	26	+	1	19		68	9
Leucoxene	3	5	4	19	2	2	3					2
Limonite												
Magnetite	+	5	5	+	6	10	6	16	+	1		23
Pyrite						+	30			69		
Non-Opaques	53	48	57	51	55	56	53	72	74	25	29	64
Total	100	100	100	100	100	100	100	100	100	100	100	100
Non-Opaques												
Actinolite									47	6		
Andalusite	1	1		1								
Apatite	1	6	18			18		1	1	2		8
Augite	1	4			1		1		1	3		1
Biotite	1			1		1	1			2	2	
Chlorite	17	5	19	26	4	22	15	4		29	16	15
Epidote	10		1	31	9	1	1	88	1		1	3
Garnet(colorless)	26	1		8	6		40					2
Garnet(green tint)	4		24	4	32		10					
Garnet(pink tint)	1				4		1					
Hornblende		1				1	1		24	3		
Hypersthene									1			
Kyanite	1	1										
Monazite		3								1	7	1
Muscovite	9	2	12	6	13	15	5	2		3	2	14
Rutile	1	7	1	1		1	1				1	1
Sphene	11	16		10	4	1	3		2	15	38	
Spinel			3	1	2	1	1					1
Staurolite												
Tourmaline(blue)				1						2		1
Tourmaline(brown)	7	10	12	4	12	7	6	1	6	20	5	9
Tourmaline(green)	2	1	1	1	2		1	2	9	3		3
Zircon(colorless)	3	21	2	1	3	10	3	1	4	2	12	14
Zircon(yellow tint)	3	16	4	2	6	17	7	1	3	9	15	23
Zircon(purple)	1	5	3	2	2	5	3		1		1	4
Total	100	100	100	100	100	100	100	100	100	100	100	100
Total counted grains	467	443	524	445	458	607	475	444	533	272	468	472

average heavy minerals (Table 2) is presented by the system of Peckham (1961).

The values for non-opaques are normalized to 100% of the total non-opaque crops. The identified heavy minerals are classified into others, opaques, and non-opaques. The others include altered grain and alterite, which is a very fine grained aggregate of unknown composition resulting from alteration of various minerals (Simpson, 1983). The alterites always possess exceptionally bright border line which helps to distinguish them from ordinary altered grains.

The opaques are hematite, ilmenite, leucoxene, limonite, magnetite, and pyrite. Major non-opaque heavy minerals are zircon, tourmaline, chlorite, garnet, and epidote. Muscovite, apatite, sphene, rutile, augite, biotite, monazite, actinolite, kyanite, spinel, andalusite, hypersthene, and staurolite are minor in amount. The major non-opaque heavy minerals from the Iljig, Hupyeongdong, and Jeomgog formations show similar constituents even though some irregularity is shown from garnet and epidote (Fig. 2). Zircon, tourmaline, and chlorite are dominant in the three formations. Sphene tends to increase from the Iljig through Hupyeongdong to Jeomgog formations. Apatite and monazite are constant through the three

Table 2. Relative abundance of average heavy minerals from the Hayang Group sandstones

Heavy mineral	Formation			Morphology
	Iljig	Hupyeongdong	Jeomgog	
Others	5.3%	1.9%	5.3%	
Altered grain	2	1	2	fine grained aggregate
Opaques	38.4%	44.4%	41.6%	
Hematite	2	3	2	irregular or earthy grains
Ilmenite	5	5	5	irregular shape
Leucoxene	3	3	2	irregular aggregate
Limonite				
Magnetite	2	3	2	irregular shape
Pyrite			3	cubic, authigenic
Non-opaques	56.3%	53.7%	53.1%	
Actinolite			2	slender prism
Andalusite		1		slightly rounded
Apatite	2	2	2	rounded, slender prism
Augite	3		1	stubby prismatic
Biotite	3		1	brown or yellow cleavage
Chlorite	5	4	4	green basal plate
Epidote	5	1	4	irregular shape
Garnet(colorless)	2	1	3	irregular to subrounded
Garnet(green tint)		3	3	irregular to subrounded
Garnet(pink tint)			1	rounded to subrounded
Hornblende	1		2	prismatic
Hypersthene	1			tabular
Kyanite		2		elongate prismatic
Monazite	1	1	1	rounded
Muscovite	2	4	3	colorless platy grains
Rutile	2	2	1	anhedral fractured
Sphene	1	2	3	fractured
Spinel		1	1	conchoidal breakage
Staurolite	1			irregular platy grains
Tourmaline(blue)		1		prismatic, fractured
Tourmaline(brown)	3	3	3	strong pleochroism, rounded
Tourmaline(green)	1	2	2	prismatic, irregular
Zircon(colorless)	3	3	3	prismatic, euhedral
Zircon(yellow tint)	2	3	3	prismatic, euhedral
Zircon(purple)	1	3	2	rounded

Note: To show the percentage range of each heavy mineral, the system of Peckham(1961) is employed: 1(0.5-2%), 2(2.5-6%), 3(6.5-12%), 4(12.5-20%), and 5(20.5-30%).

formations.

Zircon is characterized by lack of cleavage, very high refractive index, and elongate euhedral morphology. Zircon grains are generally small in size (0.05 mm) and occur as prismatic and euhedral crystals with often rounded terminations. Inclusions such as fluid globules, tourmaline, rutile, and opaque minerals sometimes arrange parallel to the c-axis. Zircon is subdivided into colorless, yellowish, and purple one on the basis of colour under open nicol. The colorless zircon is more rounded than other varieties (Fig. 3). Tomita and Karakida (1957) described that it may have been derived from reworked sediments and/or metasediments and its ultimate source rocks may be of Precambrian age.

Tourmalines are extremely variable in habit despite of predominance of subhedral and euhedral grains. The degree of roundness ranges from subangular to well rounded. They show short prism and become to nearly spherical as result of extreme abrasion during their reworking. They occur as long or short slender prismatic, well rounded basal, and irregular fractured grains. Brown, green, and blue colors are common (Fig. 4). Brown tourmaline is most common and blue one is rare. Source rocks are suggested from color of tourmaline: e.g., brown from pegmatized and/or injected metamorphic terranes; green from granite; and blue from pegmatitic rock (Krynine, 1946).

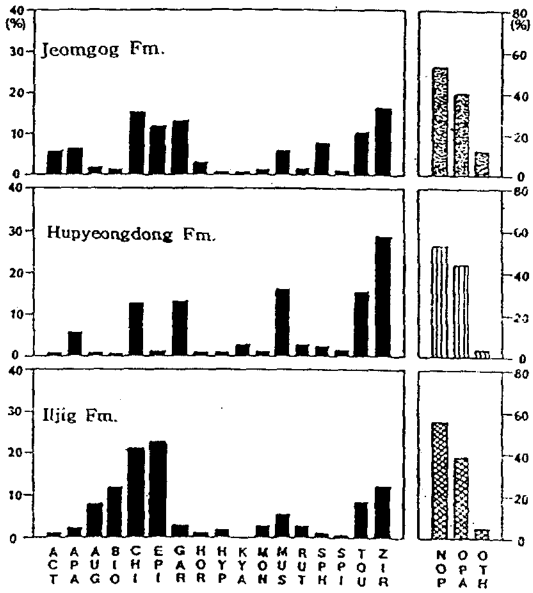

Fig. 2. Vertical variation in abundances of major heavy minerals from the Hayang Group sandstones. Right: relative abundances of opaques (OPA) and non-opaque (NOP) heavy minerals and others (OTH). Left: frequencies of non-opaque heavy minerals normalized to 100% (in grain %). ACT: actinolite, APT: apatite, AUG: augite, BIO: biotite, CHI: chlorite, EPI: epidote, GAR: garnet, HOR: hornblende, HYP: hypersthene, KYA: kyanite, MON: monazite, RUT: rutile, SPH: sphene, SPI: spinel, TOU: tourmaline, ZIR: zircon.

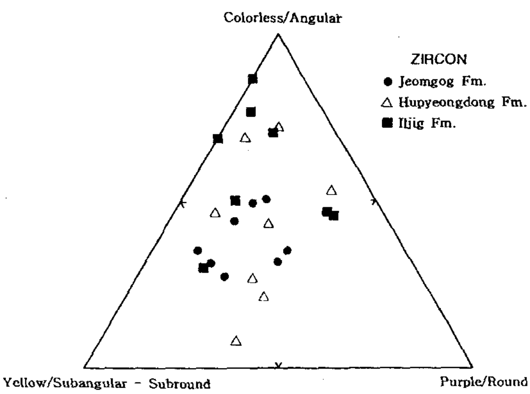

Fig. 3. Color of zircons from the Hayang Group sandstones.

Chlorite has very low interference color and slight pleochroism. Since chlorite may be detrital or formed authigenically during diagenesis, it is excluded from interpretation of source rocks.

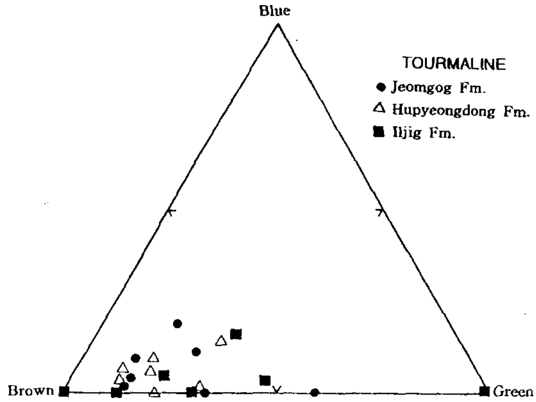

Fig. 4. Color of tourmalines from the Hayang Group sandstones.

Garnets occur as sharp irregular and moderately rounded to subrounded grains. They show etched surface which have been developed during diagenesis. Although garnets are etched through intrastratal acidic solution, they are more stable than apatite (Morton, 1984). Generally, almandine garnets show light pale pink or pale red color. Grossularite and Uvarovite garnets appear to colorless or pale green (Morton, 1986). The colorless or greenish garnets are regarded as products of contact metamorphism of calcareous sedimentary rocks (Mange and Maurer, 1992). The garnets are same as those of sandstones in the southern margin of Euiseong subbasin (Koh and Lee, 1993).

Epidote is easily diagnosed by high relief, characteristic green or yellowish green colors, and pleochroism as well as dominantly irregular morphology.

Apatite shows rounded slender prism with simple pyramidal terminations. Inclusions are zircon, magnetite, ilmenite, and minute indeterminable grains. It should be treated carefully due to its unstability in strong acid (Morton, 1986).

Rutile appears as slightly rounded prism and anhedral fractured grain with deep blood red or yellowish brown color. The content of rutile (average, 2%) is low from the three formations because the recovery of rutile grains from 120-230 mesh fraction is low (Koh, 1982).

Table 3. Possible source rocks based on the heavy mineral assemblages

Formation	Heavy mineral assemblages	Possible source rocks
Iljig	• apatite - green tourmaline - sphene - colorless/yellowish zircon	granitic rock
	• colorless garnet - epidote - rutile - brown tourmaline	metamorphic rock
	• augite - colorless zircon	andesitic rock
	• rounded purple zircon - rounded tourmaline - rounded rutile	older sedimentary rock
Hupyeong-dong	• epidote - garnet - sphene	metamorphosed impure limestone
	• apatite - sphene - green tourmaline - zircon	granitic rock
	• andalusite - rutile - spinel - brown tourmaline	metamorphic rock
	• rounded purple zircon - rounded tourmaline - rounded apatite	older sedimentary rock
	• blue tourmaline	pegmatite
Jeomgog	• apatite - sphene - green tourmaline - monazite - colorless/yellowish zircon	granitic rock
	• pinkish garnet - rutile - spinel - brown tourmaline	metamorphic rock
	• augite - hornblende	andesitic rock
	• epidote - colorless garnet - greenish garnet	metamorphosed impure limestone
	• rounded purple zircon - rounded tourmaline	older sedimentary rock

Rutile usually occurs in metamorphic rocks, particularly schist, gneiss, and amphibolite (Force, 1980).

Sphene occurs as fracture fragments and slightly rounded grains with resinous luster.

Augite shows shades of green and sometimes light green or yellowish green color. The most common morphology is stubby prismatic or granular fragments.

Spinel is colorless or pale green. Subhedral to rounded grains frequently show characteristic conchoidal breakage patterns. It is easily diagnosed by high relief morphology and isotropy.

Hornblende has a strong pleochroism and shows brown or green color. Its common morphology is prismatic, irregular or rectangular fragmental, and fibrous.

Andalusite occurs as colorless to pale pink, showing weak pleochroism. Its morphology is slightly rounded and occasionally prismatic.

Source rocks

A close investigation of the heavy mineral assemblages is an effectual approach to the interpretation of their source rocks (e.g., Hubert, 1971; Pettijohn *et al.*, 1972; Mange and Maurer, 1992). In this study, the insensitive minerals such as mica as well as authigenic minerals are excluded and non-opaque heavy mineral assemblages are only employed for analysis of provenance even though some opaque heavy minerals are recently used (Darby and Tsang, 1987; Basu and Molinaroli, 1989; Schneiderman, 1995).

The heavy mineral assemblages can be classified into 6 suites based on their close association and Table 3 is finally presented as the possible source rocks of the Hayang Group sandstones in the northeastern part of the Gyeongsang basin (Table 3).

CONCLUSION

Based on the heavy mineral assemblages, the most possible source rocks of the Hayang Group sandstones are suggested as 1) granitic rocks; 2) metamorphic rocks (schist and gneiss); 3) older sedimentary rocks; 4) andesitic rocks; 5) metamorphosed impure limestone; and 6) pegmatite.

The source rocks of the three formations are similar except andesitic rocks for the Iljig and Jeomgog formations, metamorphosed impure limestone for the Hupyeongdong and Jeomgog formations, and pegmatite for the Hupyeongdong formation. The similarity in types of source rocks indicates that the source areas were not changed during the deposition from the Iljig through Hupyeongdong to Jeomgog time. According to previous paleocurrent data of the study area, the grand vector mean calculated from the total readings of the entire study area shows 290° toward the northwest direction with a standard deviation of ±68° (Lee, 1995; Koh *at al.* 1996). This fact suggests that the sediments of the study area were mainly supplied from the source areas where located in the northeastern to southeastern directions from the study area. Thus, it can be concluded that the most possible source areas are mainly the east extension part of Sobaegsan metamorphic complex to northeast and the Cheongsong Ridge to the southeast.

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REFERENCES

Basu, A., and Molinaroli, E., 1989, Provenance characteristics of detrital opaque Fe-Ti oxide minerals, In Moron, A.C., Todd, S.P., and Haughton, P.D.W.(eds.), Developments in Sedimentary Provenance Studies: Geological SocieRy of London Special Publication, 57, 55-65.

Chang, K. H., 1970, Geology of Upper Mesozoic Strata in North Gyeongsang Province, South Korea. Journal of Geological Society of Korea, 6, 1-12.

Chang, K. H., 1988, Cretaceous stratigraphy of Southeast Korea. Journal of Geological Society of Korea, 11, 1-23.

Chang, K. H., 1988, Cretaceous stratigraphy and paleocurrent analysis of Kyongsang Basin, Korea. Journal of Geological Society of Korea, 24, 194-205.

Chang, K. H. and Kim, H. M., 1968, Cretaceous paleocurrent and sedimentation in northwestern part of Gyeongsang Basin, Southern Korea. Journal of the Geological Society of Korea, 4, 77-97.

Chang, K. H., Koh, I. S., Lee, J. Y., and Kim, S. W., 1977, Geological map of Korea (1:50,000): Gusandong Sheet. Korea Research Institute of Geoscience and Mineral Resources, 21 p.

Chang, K. H., Koh, I. S., Park, H. I., Chi, J. M., and Kim, H. M., 1978, Geological map of Korea (1:50,000): Cheongi Sheet. Korea Research Institute of Geoscience and Mineral Resources, 20 p.

Darby, D. A., and Tsang, Y. W., 1987, Variation in ilmenite element composition within and among drainage basins: implications for provenance: Journal of Sedimentary Petrology, 57,831-838.

Hubert, J. F., 1971, Analysis of heavy mineral assemblages. In (R.E. Carver ed.): Procedures in Sedimentary Petrology, Wiley, New York, 453-78.

Hutchison, C. S., 1974, Laboratory Handbook of Petrographic Technoques. John Wiley & Sons, New York, 113-132.

Kim, N. J., Kang, P. J., and Lee, H. K., 1970, Geological Map of Korea (1:50,000): Jungpyeongdong Sheet. Geological Survey of Korea, 19 p.

Koh, I. S., 1982, Sedimentary Petrology of Sandstones of the Nagdong Group. Ph.D. thesis, Seoul National University, Seoul, 92-126.(in Korean)

Koh, I. S., and Lee, Y. T., 1993, Sedimentary petrology of Cretaceous sandstones in the southern margin of Euiseong Subbasin. Journal of Geological Society of Korea, 29, 225-245.(in Korean with English abstract)

Koh, I. S., Lee, Y. T., and Shin, Y. S., 1996, Paleocurrent analysis of the Cretaceous Hayang Group in the northeastern part of Euiseong subbasin, Southeast Korea. Korean Journal of Petroleum Geology, 4, 12-19.

Krynine, P. D., 1946, The tourmaline group in sediments. Journal of Geology, 54, 65-87.

Lee, Y. T., 1950, Sedimentology and Petrology of Cretaceous Sandstones in the Northeastern part of Kyongsang Basin, Southeast Korea. Ph.D. thesis, Kyungpook National University, Taegu, 115-140.

Leith, C. J., 1950, Removal of iron oxide coating from mineral grains. Journal of Sedimentary Petrology, 20, 174-176.

Morton, A. C., 1984, Stability of detrital heavy minerals in Tertiary sandstones from the North Sea Basin. Clay minerals in Tertiary sandstones from the North Sea Basin. Clay minerals, 19, 287-308.

Morton, A. C., 1986, Dissolution of apatite in North Sea, Jurassic sandstones: Implication for the generation of secondary porosity. Clay minerals, 21, 711-733.

Mange, M. A. and Maurer, H. F. W., 1992, Heavy Minerals in Color. Chapmal and Hall, London, 147.

Okada, H., 1993, Relationship between sedimentary basins on the shelf area in the East China Sea and the Central Kyushu Rift Valley. Memoir of the Geological Society of Japan. 41, 163-173.

Okada, H. and Sakai, T., 1993, Nature and development of Late Mesozoic and Early Cenozoic sedimentary basins in Southwest Japan. Paleogeography, Paleoclimatology, Paleoecology, 105, 3-16.

Park, B. S., 1977, Type of fracturing at eastern extremity along Andong fault, Central Korea. Research Review of Kyungpook National University, 24, 315-324. (in Korean)

Peckham, A. E., 1961, Heavy minerals of the Miocene Harrison Formation in northwestern Nebraska. Journal of Sedimentary Petrology, 31, 52-62.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1972, Sand and Sandstone. Springer-Verlag, New York, 618 p.

Schneiderman, J. S., 1995, Detrital opaque oxides as provenance indicators in river Nile sediments. Journal of Sedimentary Research, A65, 668-674.

Simpson, G. S., 1983, A heavy mineral study of the sediments in some university, England, 189 p.

Son, J. D., 1989, Sedimentology of the Jinju and Iljig formations of the Cretaceous Gyeongsang Supergroup in the Gunwi area, Gyeongsangbuk-Do, Korea. Ph.D. thesis, Seoul National University, 110 p.

Seno, T. and Maruyama, S., 1984, Paleogeographic reconstruction and origin of the Philippine Sea. Tectonophysics, 102, 53-84.

Tomita, T. and Karatida, Y., 1957, Granite pebbles of the Paleozoic and Mesozoic formation in Japan: Their synthetic study of the Late Mesozoic of Japan. Mineograph, 5, 9-15.

Woo, B. G., 1989, Cretaceous Stratigraphy and sedimentation in Pyonghae-Yongdok Area, Kyongsangbuk-Do, Korea. M.Sc. thesis, Kyungpook National University, 72 p.

Xu, J., Tong, W., Zhu, G., Lin, S., and Ma, G., 1989, An outline of Pre-Jurassic tectonic framework in the east Asia. Journal of Southeast Asian Earth Science, 3, 29-45.

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경상분지 북동부 백악기 하양층군 사암의 중광물분석

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요 약 : 경상분지 북동부 안동단층 동단부의 길안지역에는 백악기 하양층군에 속하는 일직층, 후평동층, 점곡층과 사곡층이 분포하고 있다. 연구지역 사암의 기원암을 규명하기 위하여 일직층, 후평동층과 점곡층 사암에서 분리한 중광물을 해석하였다. 그 중광물 중 불투명광물은 적철석, 일메나이트, 류콕신, 갈철석, 자철석 및 황철석 등이고, 투명광물은 양기석, 홍주석, 인회석, 휘석, 흑운모, 금홍석, 스핀, 스피넬, 십자석, 전기석 및 저콘 등이다. 밀접하게 수반되고 기원암지시에 민감한 중광물들끼리 묶으면, 6개의 중광물군으로 구분된다. 1) 인회석-녹색전기석-스핀-무색/황색 저콘, 2) 무색 석류석-녹염석-금홍석-갈색 전기석, 3) 원마된 자색 저콘-원마된 전기석-원마된 금홍석, 4) 휘석-각섬석-무색저콘, 5) 녹염석-석류석-스핀, 6) 청색전기석 등이다. 각 중광물군이 지시하는 기원암은 1) 화강암질암, 2) 변성암류 (편암 및 편마암), 3) 고기 퇴적암류, 4) 안산암류, 5) 변성석회암 및 6) 페그마타이트질암 등으로 해석된다. 고수류에 관한 기존연구자료에 따르면, 퇴적물이 주로 북동부 및 남서부에 위치하였던 기원암으로부터 공급되었음을 지시하므로, 본역 하양층군의 가장 가능한 기원암은 북동부에 분포한 소백산 변성암 복합체와 남동부에 분포한 청송융기부를 이루는 화강암질 및 화산암류로 해석된다.

핵심어 : 경상분지, 하양층군, 사암, 중광물, 기원암