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Origin of the Magnetite-Bearing Amphibolites from the Yangyang Iron Mine, Korea: New Geochemical Data and Interpretation

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ABSTRACT

The chemical similarity of the magnetite-bearing amphibolites of the Yangyang iron mine to mixtures of sedimentary pelites and limestone or dolomite and to the Gyeonggi para-amphibolites (So, 1974) is consistently indicated by all the chemical data of the rocks. Eight amphibolite samples were each analyzed for 18 elements, by wet chemical and emission spectroscopic methods, and these chemical data were compared with the para-amphibolites from the Gyeonggi metamorphic complex. Petrography and oxidation ratios were also considered.

1. INTRODUCTION

Yangyang Mine is the largest iron-producer in Korea with about ten million tons of total ore reserves. Studies on the ore deposit were carried out by Kim (1958) and Gil, geologist of the mine, but the magnetite-bearing amphibolites of the deposit were not studied. The iron ore in the mine is mostly contained in the amphibolites.

The objective of the present study is to determine the origin and the nature of the parent rocks of the magnetite-bearing amphibolites of the Yangyang deposit applying the geochemical methods outlined by Evans and Leake (1960) and Leake (1964), in order to contribute to an understanding of the ore genesis of the deposit.

With increasing metamorphism and metasomatism banded nature of amphibolites or association with carbonates would be invalid in determining their origin because of the chemical equivalence of the para- or ortho-amphibolites to the basaltic rocks, and Poldervaart (1958) and Wilcox (1960) and Wilcox and others (1960) concluded that no chemical distinction could be made between them. Recently Leake (1964) emphasized that although an individual analysis cannot determine the origin of an amphibolite, the nature of the trends of variation given by plotting groups of analysis and their relationship to known igneous and sedimentary trends are the most valuable distinction between ortho-and para-amphibolites. Special attention has been focused on the trace elements.

All the chemical data of the rocks studied are also compared to the para-amphibolites from the Gyeonggi metamorphic complex (So, 1974).

2. SAMPLING AND TREATMENT

Sampling was designed to obtain materials representative of all parts of the rocks. Specimens each weighing 2-3 kg were collected. Sampling localities are presented in Figure 1.

All specimens were examined petrographically, and modal analyses of approximately 1,000 counts each were done with a Swift automatic point counter. Measurements of the refractive index of hornblende were done by using standard liquids on cleavage fragments. The index of refraction of the liquid was checked on an Abbe Refractometer immediately after each match was obta-

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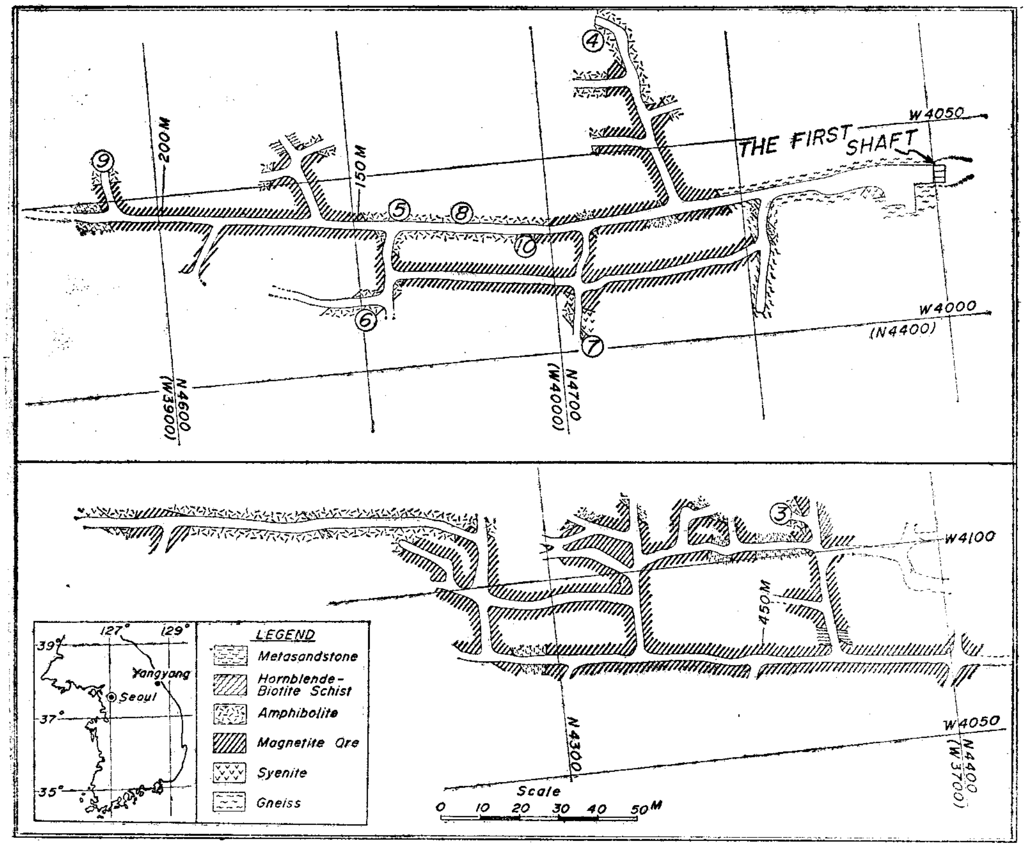

Figure 1. Underground map of the Yangyang Mine showing the sampling localities.

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Samples were prepared for chemical and spectroscopic analysis by slicing the rocks across the foliation and breaking these into 3-inch chips. The chips were broken to sand-size grains in a jaw crusher prior to being powdered in a shatter box with a tungsten carbide grinding container (100 ml). The powders were ground until all passed through a 150-mesh (105 μ) sieve.

3. ANALYTICAL METHODS

Chemical Analysis

The oxides of silicon, iron(III), calcium, magnesium and aluminum were determined by gravimetric method after alkali fusion. Ferrous oxide was extracted into saturated aqueous solution of boric acid and was titrated with permanganate solution. Determination of phosphorous was conducted by colorimetry using vanadomolybdate reagent. Potassium and sodium were analyzed by Perkin-Elmer, 303 atomic absorption spectrophotometer. Copper and molybdenum were analyzed by colorimetry. Determination of titanium was done by X-ray fluorescence spectrometry using a Philips Electronic Instrument. Major elements analyses were done with the assistance of D. G. Choi of the Geological and Mineral Institute of Korea.

Spectrochemical Analysis

Each prepared sample was mixed with a buffer (NaCl + Carbon powder SP-3) free from

Table 1. Modal Analyses

	Minerals (vol. %)									
	Hornblende	Quartz	Sphene	Calcite	Plagioclase	Apatite	Epidote	Chlorite	Pyroxene	Biotite
3	73	<1	2	20	1	—	—	—	—	1
4	77	<1	16	<1	1	5	—	—	—	—
5	56	2	17	—	7	10	—	—	—	—
6	50	7	<1	—	38	<1	—	—	—	3
7	66	<1	12	<1	1	5	14	—	—	—
8	79	—	12	—	1	4	2	—	—	—
9	79	<1	8	5	1	2	2	—	—	—
10	—	21	—	40	4	—	—	32	<1	—

	Zircon	Opaques					Counts Pointed	Traverse Sp. mm	Ref. Index of Hornblende	
		Ilmenite	Magnetite	Pyrite	Hematite	Pyrrhotite			N_α	N_γ
3	<1	0.2	0.6	0.6	0.6	—	1079	1/6×2	1.670	1.709
4	—	—	—	—	—	—	1033	1/6×2	1.674	1.689
5	—	6	1.7	0.3	—	—	1126	1/6×2	1.674	1.704
6	—	—	0.7	0.3	—	—	1000	1/6×2	1.640	1.674
7	—	0.7	—	0.3	—	—	1020	1/6×2	1.676	1.684
8	—	0.5	1.5	—	—	—	1006	1/6×2	1.672	1.684
9	—	2	—	—	—	—	1008	1/6×2	1.678	1.689
10	—	1.5	—	1.0	0.3	0.2	1006	1/6×2	1.646	1.668

spectroscopic impurities. A crater in the lower (positive) electrode (National SPK L-3703) of highest purity graphite was filled with the sample mixture. Arc spectra of the amphibolite were recorded on Eastman Kodak SA-1 plates using a 3.4 meter grating spectrograph, Jarrell-Ash Ebert mounting, with dispersion in the first order of 5.1 Ångstroms per mm. Comparison with master plate determined the qualitative presence of minor elements. Comparison with spectra of ratio powders which contain known quantities of interesting elements fixed the order of magnitude of manganese, chromium, cobalt, nickel, vanadium and strontium.

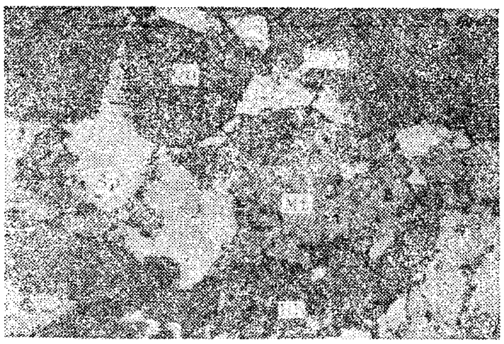

Figure 2. Photomicrograph of a polished section. Irregular intergrowth of magnetite (dark grey, with numerous inclusions of silicate gangues), pyrrhotite (light grey, decomposed partially to pyrite and marcasite) and sphalerite (with abundant oriented inclusions of chalcopyrite) all of which have penetrated silicate gangues. Two gangue minerals: Quartz (darker grey), Hornblende (darkest grey). Reflected light 28x. 1 Nicol. Sp=sphalerite, P.M =intergrowth of pyrite & marcasite, Hb=hornblende, Mt=magnetite, Qu=quartz.

4. DESCRIPTION OF THE ROCKS

The rocks distributed in the mining district are gneiss, argillite, hornblende-biotite schist and magnetite-bearing amphibolites and syenite with minor occurrences of intrusives.

The amphibolites which grade into the surrounding rocks are composed mainly of hornblende, quartz, plagioclase together with minor components such as sphene, apatite, calcite, epidote and chlorite. The grain size of hornblende ranges from 0.2mm to 0.4mm in width. Fine euhedral hornblende crystals are often included in the larger one. Chlorite, calcite and epidote are the retrograde products from hornblende. Refractive indices of hornblende range from 1.640 to 1.678 (N_{α}) and from 1.668 to 1.709 (N_{γ}). Plagioclase mostly altered to calcite and sericite are associated with quartz grains. Anhedral titanite and magnetite are intimately associated with hornblende.

Opaque minerals, in addition to magnetite, are mainly ilmenite and small amounts of pyrite, hematite and rare chalcopyrite and pyrrhotite. Ilmenite is usually decomposed into titanite and rutile. Hematite is partly exsolved from some of the ilmenite (Fig. 2).

Table 2. Chemical and Spectrographic Analyses, Niggli Values and Oxidation Ratios.

	3	4	5	6	7	8	9	10
SiO_2	45.70	40.70	39.70	52.40	42.10	39.80	39.00	39.90
Al_2O_3	10.70	18.90	26.70	22.40	22.60	22.90	19.60	15.90
Fe_2O_3	7.20	6.70	8.85	2.66	6.02	6.00	6.80	10.10
FeO	14.50	7.60	6.45	3.76	7.48	9.10	9.80	19.10
MnO	0.38	0.49	0.34	0.15	0.49	0.50	0.63	0.37
MgO	5.70	5.07	4.04	3.22	3.35	8.34	4.30	3.80
CaO	10.20	13.10	4.29	6.01	12.6	6.45	12.90	11.40
Na_2O	1.30	1.75	2.30	3.60	1.30	1.40	1.42	0.54
K_2O	1.70	1.80	3.05	3.97	1.25	2.75	1.20	0.71
TiO_2	0.28	0.75	1.20	0.65	1.00	0.88	0.80	0.20
P_2O_5	0.04	0.08	1.60	0.06	0.06	0.04	0.06	0.01
Total	97.7	96.94	98.52	98.88	98.25	98.16	96.51	102.03
Ni	10	85	40	55	5	40	10	40
Cr	13	5	25	26	46	10	20	15
Co	45	25	45	50	60	45	35	130
Cu	60	80	235	220	85	50	45	185
Sr	25	60	80	165	160	25	80	45
Mo	30	22	40	35	32	22	25	20
V	90	50	60	85	60	65	50	50
si	100.00	86.00	93.00	147.00	128.00	82.00	82.00	77.00
al	14.00	23.00	37.00	37.00	40.00	28.00	24.00	18.00
fm	57.00	41.00	42.00	28.00	49.00	52.00	42.00	57.00
c	24.00	30.00	11.00	18.00	4.00	14.00	29.00	23.00
alk	5.00	6.00	10.00	17.00	7.00	6.00	5.00	2.00
ti	0.52	1.13	2.11	1.34	2.36	1.36	1.25	0.34
p	0.03	0.07	1.54	0.06	0.07	0.03	0.05	0.08
k	0.46	0.40	0.46	0.42	0.38	0.56	0.36	0.50
mg	0.32	0.39	0.33	0.47	0.30	0.50	0.31	0.19
Oxid. Ratio	31	32	55	40	39	41	39	44

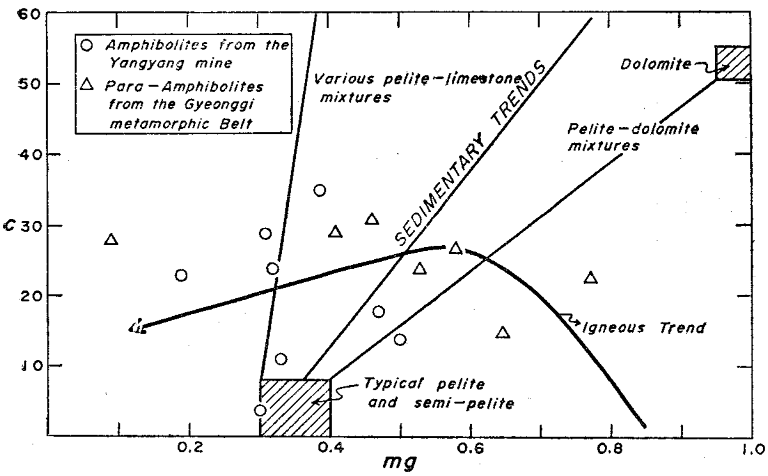

Figure 3. *c versus mg* Niggli plot.

5. RESULTS AND CONCLUSIONS

All the chemical data of the rocks sampled are presented in Table 2 and are recalculated into Niggli values. The *c versus mg* (Fig. 3) and *c*, *al-alk* and 100*mg* Niggli plots (Fig. 4) show all the data points fall in or close to the mixtures of pelite and limestone or dolomite region with a broad scatter. Particularly in Fig. 4 the data points plot along the line joining carbonates and typical pelite which is at right angles to the trend of variation shown by a typical basic igneous series of the Karroo dolerites.

The *k*, *alk* and *p versus mg* Niggli values (Fig. 5) again show mostly similar features, plotting outside the ortho-amphibolite area. Slightly high *k* Niggli values (about 0.4–0.6) show a somewhat erratic variation trend probably due to alkali metasomatism including sericitization.

Trace element data is particularly useful in determining the origin of the amphibolite of the studied area as shown in the Figure 6 and 7. The chromium and cobalt *versus mg* semi-log plot (Fig. 6) show a definite negative correlation together with the Gyeonggi para-amphibolites and their abundance levels of chromium (10–46

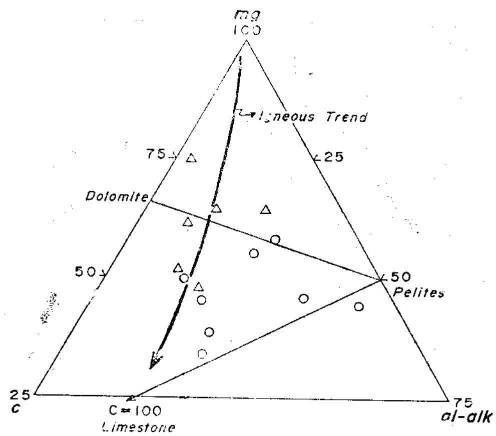

Figure 4. *c*, *al-alk* and 100*mg* plot.

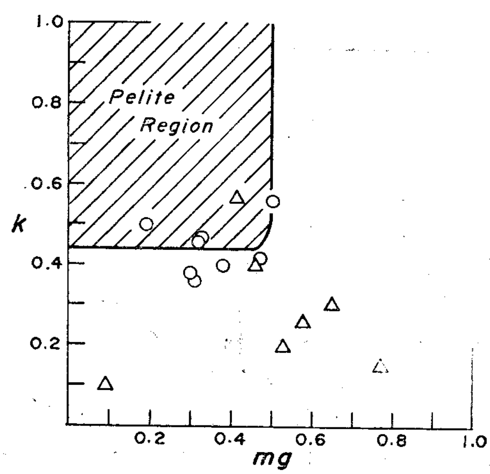

Figure 5a. Niggli *k* is plotted against Niggli *mg*

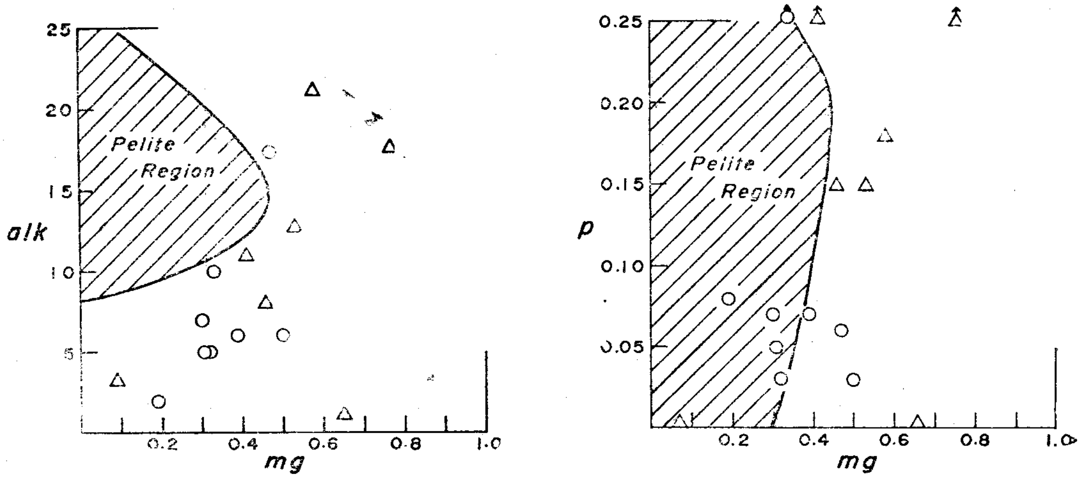

Figure 5b. Niggli *alk* and *p* values are plotted against Niggli *mg*.

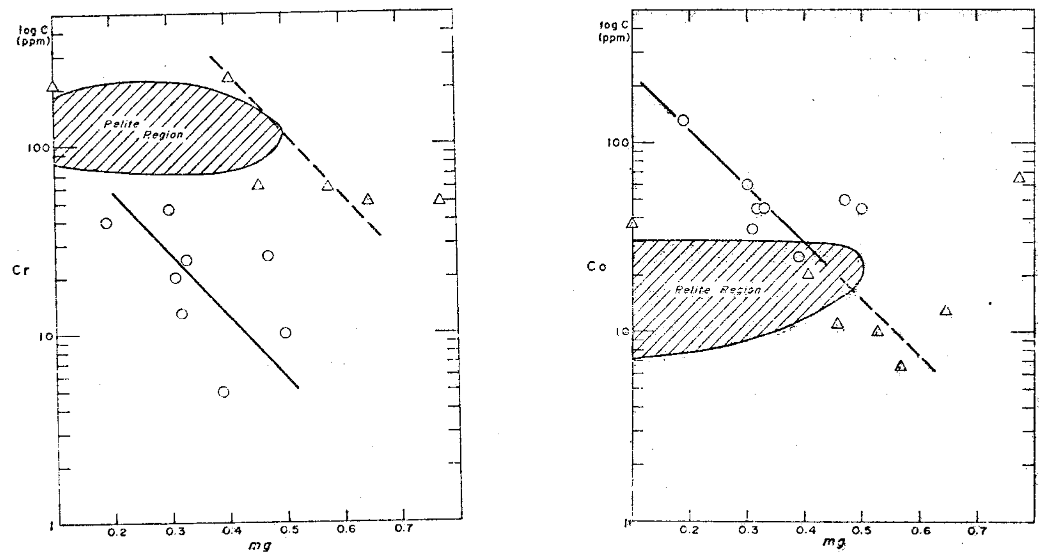

Figure 6. Semi-log plots of Cr and Co *versus* *mg* Niggli plots.

ppm) and cobalt (25–130 ppm) are similar to sediments. Higher abundances or a wide range of trace element contents and positive correlations of those variables were found for basic igneous rock suites, whereas the Connemara and Littleton pelites show little or no systematic change with *mg*, furthermore, if either of these pelites were mixed with dolomite or limestone a distinct negative correlation would result (Leake, 1964).

In log-log plots of copper against chromium and nickel (Fig. 7), the points fall in the area of low-grade para-amphibolites or plot in the region of low Ni (5–85 ppm) and Cr content.

The low abundance levels of strontium (25–165 ppm), vanadium (50–90 ppm) and low molybdenum content (<40) are characteristic of

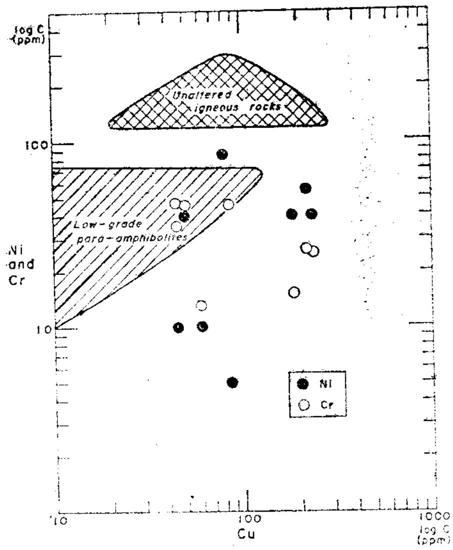

Figure 7. Log-log plots of Ni and Cr *versus* Cu.

both igneous and sedimentary rock suites, and does not appear to be an indicator of origin.

Oxidation ratios, that is, mols, $2Fe_2O_3 \times 100/2Fe_2O_3+FeO$, were used by Elliott and Cowan (1966) and others in determining whether amphibolites were more likely to have an igneous parentage. Applied to the rocks of the present study, all the high oxidation ratios (more than 30) are more typical of extrusive or sedimentary characteristics. The field relationships and petrography of the rocks do not indicate any sign of extrusion.

From all the above major and trace element data, it can be concluded that the magnetite-bearing amphibolites from the Yangyang Iron Mine are derived from mixtures of sedimentary pelites and carbonates.

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襄陽 鐵鑛床의 鐵을 賦存하는 角閃石質岩의 成因

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본 연구는 襄陽 鐵鑛山의 鐵을 賦存하고 있는 角閃石質岩의 成因 규명을 목적으로, 濕式 및 方出分光分析的 방법을 통하여 얻은 18개의 主成分 및 稀有成分의 data를 각종 Niggli 도표에 적용시키고 variaticn trend를 검토한 결과이다. 지금까지의 각 大陸에 분포하는 角閃石質岩의 化學的인 연구결과로는 거의 모든 각섬석질암이 變成堆積岩類의 형태로 產出될지라도 火成起源으로 밝혀져 왔으나 襄陽 鐵鑛山의 含鐵 角閃石質岩은 準一角閃石質岩, 특히 pelite-carbonate mixture의 特性을 뚜렷하게 보여준다.

즉 Niggli 값을 사용한 각 도면에서 본 연구의 대상이 된 시료들은 分散된 分布 및 堆積영역, 특히 pelite-carbonate mixture의 trend를 잘 따르고, Cr, Co 및 Ni의 함량이 매우 낮으며 Cr/*mg*, Co/*mg* 도표에서 堆積起源의 특징인 negative trend를 뚜렷하게 나타낸다. 한편 높은 oxidation ratio의 값(>30)은 上記 결과를 더욱 뒷바침해준다.

이러한 모든 현상은 京畿變成帶에서 堆積起源으로 판명된 準一角閃石質岩(蘇七燮, 1974)이 갖는 특성과 유사하다.

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