

The Chemistry and Origin of Amphibolitic Rocks in the Sobaegsan Metamorphic Belt and the Ogbang and Sangdong Tungsten Mine Areas, Korea

So, Chil-Sup* · Kim, Sang-Myeong**

ABSTRACT

19 amphibolite samples from the Precambrian Sobaegsan metamorphic belt including the Ogbang mine amphibolites were analyzed for 24 elements each, by wet chemical and emission spectroscopic methods. All the chemical data were evaluated by the methods outlined by Evans and Leake(1960) and Leake(1964) and by Shaw and Kudo(1965). The chemical similarity of all the studied rocks analyzed to basic igneous rocks is consistently indicated particularly by trace element abundance and variation trends. Petrography and oxidation ratios were also considered in attempting to determine the nature of the parent rocks. 3 analyses of W-bearing mafic metamorphic rocks from Sangdong area of the Ogcheon geosynclinal zone are also presented and discussed. Geochemical data for these latter rocks have been possibly derived from mafic tuffs deposited in an area of carbonate deposition (So, 1968, 1975).

1. INTRODUCTION

The amphibolites of the Sobaegsan metamorphic belt occur in a conformable belt surrounded by Precambrian para-gneisses and granitic gneiss in the Ogbang W-mining area, and as lenses or relicts in the hornblende-biotite gneiss and granitic rocks in Sunsan, Jirye and Dansung area.

Some studies of the petrographic and field characteristics of the amphibolites have been carried out, but the origin of the rocks remains controversial. Especially, granitization of the rocks in the Sobaegsan metamorphic belt make it difficult to distinguish their origin.

The origin of amphibolites, whether metasedimentary or meta-igneous, is commonly very difficult to determine particularly in regions which have undergone high grade metamorphism or metasomatism. In this paper, the writers

have attempted to solve the problem of the origin of the amphibolites in the Sobaegsan metamorphic belt including the Ogbang mining area using the geochemical methods outlined by Evans and Leake(1960), Leake(1964) and Shaw and Kudo (1965).

In addition to the rocks of the Sobaegsan metamorphic belt, three specimens from the Sangdong W-mining district, located in the Cambrian, less metamorphosed zone of the Ogcheon belt, were examined. The location of the samples is shown in Figure 1.

2. METHOD OF STUDY

2.1 Sampling and Treatment

Sampling was designed to obtain material of wide areal distribution and to avoid the effect of metasomatism. Specimens of the amphibolites each weighing 2-3 kg were collected.

All specimens were examined petrographically,

** Department of geology, Korea University

and modal analyses of approximately 1,000 counts each were done with a Swift automatic point counter. Measurements of An content of plagioclase were done by measuring maximum extinction angles. In several thin sections the plagioclase was so poorly twinned and so highly sericitized that no satisfactory measurements of refractive index of hornblende were done by using standard index liquids on cleavage fragments. The index of refraction of the liquid was checked on a Abbe Refractometer immediately after each

match was obtained.

Samples were prepared for chemical and spectroscopic analysis by slicing the rocks across the foliation and breaking the slices 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 (100ml). The powders were ground for 70 sec. until all passed through a 150-mesh sieve.

2.2 Wet Chemical Analysis

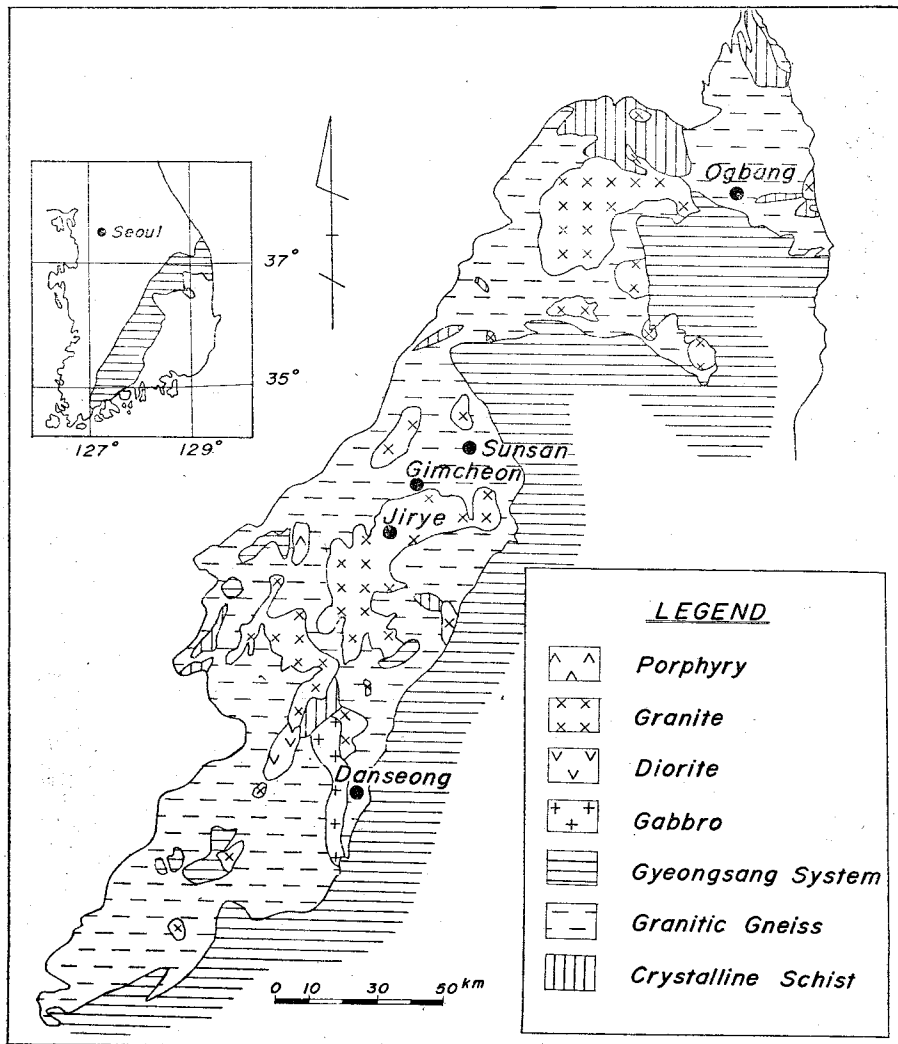


Figure 1. Simplified geologic map showing the sampling localities of amphibolites.

The oxides of silicon, iron(III), calcium, magnesium and aluminum were determined by EDTA titrimetry and gravimetric method. Ferrous oxide was extracted into saturated aqueous solution of boric acid and was titrated with permanganate solution. Determination of manganese was conducted by colorimetry of their permanganate. Potassium and sodium were analyzed by atomic absorption spectrophotometry (Perkin-Elmer, 303). Carbon was determined by elemental analysis. Titrimetry of cerrous sulfate was employed for the determination of titanium.

2.3 Emission Spectroscopic Analysis

2.31 Sample Preparation and Standards

Sample Preparation

Quantitative trace analyses of all the specimens were made for 12 elements by Grating spectrography using the following procedures:

In order to get better burning conditions so called buffer was mixed for 30 minutes in an agate mortar and Wig-L-Bug for each pulverized sample in a weight ratio of 1:1. The buffer was composed of specpure carbon powder SP-3 and specpure NaCl in a weight ratio of 1:1. An internal standard was added to the buffer. For this the compound La_2O_3 was found to be suitable. A test of the samples for the element La was negative. Therefore specpure La_2O_3 (0.2 wt. % La) was added to the buffer as an internal standard.

30 mg of each sample mixed with buffer (+ internal standard) was loaded into sample electrodes and covered with graphite powder SP-2. To avoid spattering during burning each loaded sample electrode was ignited in an electric furnace at 800°C .

Two analyses were made of each sample. If these results varied, a third analysis was done.

Standards

The base substance of the standards consisted of specpure SiO_2 , Al_2O_3 , Fe_2O_3 , CaCO_3 and

MgO in a weight ratio based on the mean content of each sample as determined by wet chemical analysis. This was then mixed with the relevant specpure elements (such as BaCO_3 , Cr_2O_3 , Co_3O_4 , NiO , MoO_3 , ThO_2 , V_2O_5 , Sc_2O_3 , SrCO_3 , Sb_2O_3 , CuO , ZrO_2) in a concentration of 5,000 ppm each. Further addition of the base substance resulted in a lowering of concentration of the interesting elements.

Each standard was also mixed with buffer in a ratio of 1:1 and burned at least 3 times (with a 7 step neutral filter). From the intensity ratios obtained for each standards the mean values were determined and the working curves were drawn up.

This base substance was added to the standard until the analytical elements could just barely be recognized photometrically and supplied "blind values". The detection limit could then be determined.

2.32 Experimental Apparatus and Conditions

Excitation system:

Source unit	Jarrell-Ash Standard Vari-source
Sample electrode	National SPK L-3703 (anode)
Counter electrode	National SPK L-3751
Analytical Gap	$\pm 4\text{mm}$
Input voltage	220 Volt
Arc current	10.8A (DC)
Preburn time	2 sec.
Exposure time	60 sec.
Atmosphere	25 ft ³ /hr of 1:4 O_2 -Ar mixed gas

Optical system:

Spectrograph	Jarrell-Ash 1.5 meter Wadsworth Grating Spectrograph
Grating	15,000 grooves/inch; reciprocal linear dispersion 5.4 Å per mm in second order.

Slit width	25 microns
Filter	Seven step neutral filter
Analysis film	35mm Eastman Kodak SA-1 film

Developing condition:

Development	Eastman Kodak D-19 at ±24°C for 2 min.
Stop	Kodak stop bath for 30 sec.
Fixing	Eastman Kodak Rapid Fixer at ±24°C for 10 min.
Washing	Running water for 10 min. and distilled water for 1 min.
Drying	Warm air for 4 min. Cold air for 5 min.

2.33 Photometry, Calibration and Calculation

The spectral plates were evaluated photometrically with the Jarrell-Ash console microphotometer (slit width 15 μ , slit height 0.5mm, scanning rate 2.5 $\text{\AA}/\text{min.}$, 15 times enlargement of the film plate). In the most favorable blackness area and filter step the densities of the analytical lines and the internal standard lines, as well as the background, were read.

Analytical lines used

Element	Analytical lines (\AA)	Detection limit(ppm)
V II	3118.383	10
Ni I	3003.629	10
Co I	3405.120	5
Sr II	3464.457	10
Cr I	4254.346	5
Ba II	4554.042	5
Zr II	3396.975	5
Sc II	4246.829	5
Th	4019.137	50
Sb I	2877.915	100
Mo	3170.347	5
Cu I	3273.692	1
La II	3245.120	Int. standard

The logarithmic intensity ratios ($I_{\text{elem.}}/I_{\text{La}}$) from the blackness values were computed in the conventional manner (with background correc-

tion) on a Jarrell-Ash calculating board using emulsion calibration curves obtained by 7-step sector method. The concentration could be determined from the working curves drawn up for each element.

Each plate was supplied with a narrow Fe-spectrum. The relative standard deviations(s/\bar{x}) were 0.25 for Zr, Cr, Ba, Sr, Co, Ni, Sc and V, and 0.4 for Th, Sb, Mo, Cu and Ba.

The ppm-values shown in the table are mean values of 2 or 3 analyses each, which were read in the 1st., 2nd., 3rd., 4th., 5th., or 6th. step. The percentages refer to the weight of each sample.

3. PETROGRAPHY AND FIELD RELATIONSHIPS OF THE AMPHIBOLITES.

3.1 Ogbang Mining Area

The rocks associated with the amphibolites are medium to coarse-grained foliated granitic gneisses and interbedded biotite-garnet gneiss and arenaceous gneiss. All the rocks in the area, except hypabyssal rocks, are concordant with each other, and foliation and lineation of the amphibolites are well developed (Fig. 2a). Aluminous schists are scarce or absent, and there are no carbonate rich rocks in the metamorphic sequence containing the amphibolites. The amphibolites form a belt several kilometers in length and about 1 kilometer wide; individual amphibolite bodies within the belt are usually several hundred meters and up to fifty meters thick.

The amphibolites are composed chiefly of hornblende, plagioclase (An 37-45%) and quartz with minor amounts of biotite, apatite, pyrrhotite, ilmenite, pyrite and, rarely chalcopyrite. Hornblende is commonly equigranular and rarely interstitial with plagioclase and quartz grains. Refractive indices of hornblende increase with development of foliation (in order of increasing refractive index: Sunsan-, Jirye-, Ogbang- and Sangdong-area, Fig. 3) as shown by Preto-

Tr. = <0.1%

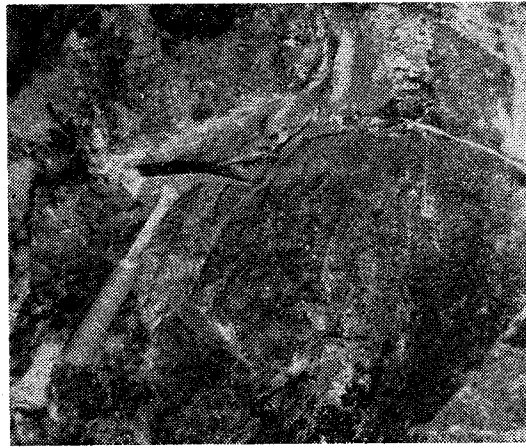
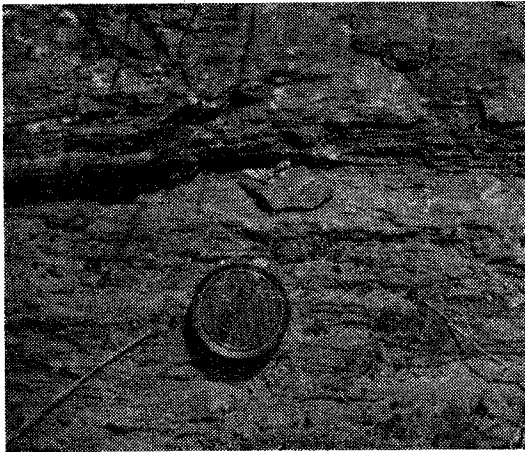
Table 1. Modal Analyses (vol. %)

	Minerals														Ref. index of Hornblende					
	Hornblende class	Quartz	Biotite	Chlorite	Pyroxene	Olivine	Opaques			Apatite	Sphene	Zircon	Calcite	Muscovite	Epidote	Counts Pointed	Traverse Sp. mm	An% of Plagioclase	N _c	N _t
							Ilmenite	Pyrrhotite	Pyrite											
1	49.3	43.5	1.2	4.2	—	—	—	—	—	Tr.	—	—	—	—	—	1031	1/6×1	40	1,656	1,680
2	71.2	17.4	11.2	—	—	—	—	—	—	—	—	—	—	—	—	1056	1/6×1	—	1,654	1,690
3	57.3	23.3	7.3	9.8	—	—	—	0.4	1.2	0.4	Tr.	—	—	—	—	1027	1/6×1	37	1,668	1,701
4	55.3	36.2	5.5	1.2	—	—	—	0.3	0.7	—	Tr.	—	—	—	—	1012	1/6×1	45	1,666	1,705
5	62.3	33.4	0.4	1.9	—	—	—	—	Tr.	—	Tr.	—	—	—	—	1091	1/6×1	45	1,664	1,700
6	59.4	28.1	7.9	1.8	—	—	—	0.5	1.5	0.5	—	—	—	—	—	1076	1/6×1	—	1,666	1,688
7	70.7	10.3	8.5	—	5.7	—	—	—	Tr.	—	1	3	Tr.	Tr.	1006	1/20×1	—	1,656	1,688	
8	67.9	12.1	6.9	4.9	5.2	—	—	—	—	—	—	—	Tr.	—	1021	1/6×1	—	—	1,682	
9	71.8	13.2	2.0	5.8	4.0	—	—	—	Tr.	—	—	—	—	—	1036	1/6×1	—	—	1,696	
10	70.0	11.0	9.8	1.2	2.0	—	—	—	—	—	—	—	—	—	1045	1/6×1	—	—	—	
11	50.4	42.0	Tr.	0.8	Tr.	—	—	3.0	1.5	Tr.	—	—	—	—	1015	1/6×1	—	1,660	1,678	
12	40.2	44.5	—	Tr.	1.2	8.7	—	2.5	1.0	0.5	0.2	Tr.	—	0.2	1016	1/6×1	52	1,658	1,688	
13	Tr.	25.8	—	—	40.8	—	—	0.7	0.3	—	—	—	—	—	1026	1/20×1	16	1,650	1,688	
14	58.4	12.9	0.3	—	Tr.	16.3	—	0.5	0.3	—	Tr.	3	—	8	1088	1/6×1	56	1,634	1,686	
15	50.8	46.2	Tr.	1.2	—	—	—	1.0	0.4	—	Tr.	0.8	—	—	1069	1/5×1	40	1,660	1,692	
16*	59.4	—	—	0.2	9.5	—	24.7	2.0	1.7	0.3	Tr.	—	—	1.2	1051	1/6×1	—	1,630	1,700	
17	40.5	34.2	3.7	10.3	Tr.	—	—	1.0	Tr.	0.2	Tr.	—	—	1.1	1059	1/6×1	—	1,650	1,700	
18	52.3	34.6	3.4	10.5	—	—	—	0.4	—	0.1	Tr.	—	—	—	1047	1/6×1	54	1,654	1,692	
19	45.6	51.2	0.2	1.2	—	—	—	Tr.	—	—	Tr.	1.5	—	—	1006	/201×1	—	1,634	1,684	
20	80.3	7.2	5.5	1.8	—	2	—	0.3	0.5	0.5	—	0.8	Tr.	—	1009	1/20×1	—	1,666	1,701	
21	80.2	3.5	5.5	1.2	—	1.2	—	1.5	1.0	0.5	1.2	—	—	—	1016	1/20×1	—	1,660	1,690	
22	50.6	40.5	3.4	—	2	0.6	—	0.5	—	1.5	Tr.	Tr.	—	—	1028	1/20×1	—	1,680	1,704	

* Mafic intrusives, 1~10 : Ogbang mining area, 11~16 : Samsan, Jirye and Gimcheon areas, 17~19 : Dansung area, 20~22 : Sangdong mining area.

(1970) and So and Kim(1975). Biotite is rich

around the opaques and scheelite concentrations.



a)

b)

Figure 2. Field occurrences of the amphibolites.

- a) Strongly lineated and foliated amphibolite layer concordant with the surrounding para-gneisses.
- b) Massive or poorly lineated and foliated amphibolite lens in the granitic rocks.

3.2 Sunsang, Jirye and Gimcheon Area

The amphibolites are contained as lenses in the Precambrian biotite-hornblende gneiss and as relicts in the hornblende-biotite granitic rocks (Fig. 2b) which formed from the regional metamorphic amphibolites by metasomatic granitization (Chang, 1973). The amphibolite lenses and relicts vary from 15 to 60cm in length and from 5 to 25cm in width. Metacalcareous and rarely metapelitic rocks are also found as relicts in the above surrounding rocks.

Hornblende and plagioclase (An 40-56%) are the main mineral constituents of the amphibolites. Quartz and biotite are scarce or absent. Chlorite, muscovite and epidote are found as retrograde products. Some amphibolites contain appreciable amounts of pyroxene. Opaque minerals are composed mainly of ilmenite and small amounts of pentlandite and pyrrhotite. The ilmenite grains tend to show a fairly directed distribution and are strongly metamorphosed to rutile and titanite.

The coarse-grained, nonfoliated metagabbro

in the Gimcheon area is chiefly composed of

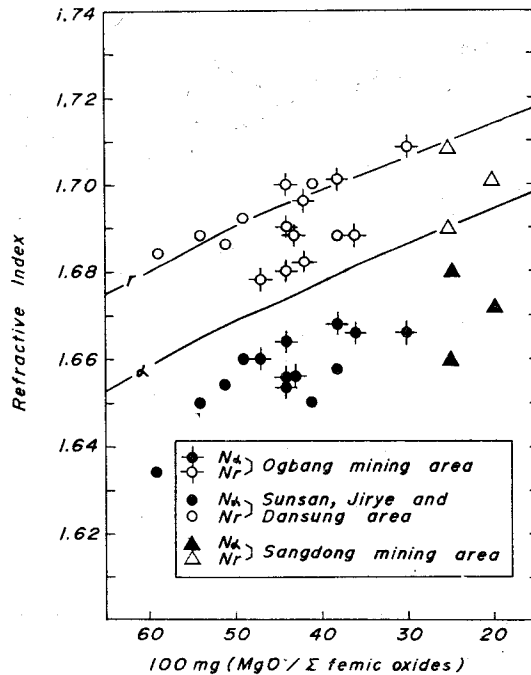


Figure 3. Refractive indices (N_{α} , N_{γ}) of hornblende plotted against 100 Niggli mg.
 N_{α} : Refractive index of common hornblende
 N_{γ} : Refractive index of common hornblende

hornblende and olivine with small ilmenite scales which is developed along the hornblende cleavages. Their contact parts with granitic rocks contain disseminated nickel ore.

3.3 Dansung Area

The amphibolites, which contain in general large amounts of biotite (1.2 - 10.5%), are foliated and conformable to the surrounding Precambrian gneisses. The fine- to medium-grained amphibolites show mostly nematoblastic and rarely granoblastic texture. Well twinned plagioclase has 54% anorthite content and is strongly sericitized. Biotite, reddish brown in color, is distributed randomly. Accessory apatite and zircon are mainly euhedral. The main opaque components are ilmenite, pyrrhotite and pyrite. The ilmenite scales are partly altered to rutile and titanite.

3.4 Sangdong Mining Area

Mafic metamorphic rocks in Sangdong area, which is located near the contact between the Precambrian Sobaegsan massif and the less metamorphosed part of the Ogcheon geosynclinal zone, are productive in tungsten. The ore minerals only occur in six laterally extensive, but relatively thin beds of the lower Paleozoic Myobong Formation: These beds are very stratabound with metapelitic strata of the same age. The ore-bearing layers differ from the normal metapelitic strata of the Myobong Formation in that they contain an abundance of amphibole (its content varies with the abundance of scheelite) and Ti-minerals, and have a high Co-, Ni- and Be-content. The main mineral constituents are hornblende (50%), plagioclase (3.5-40.5%), diopside, biotite, quartz and garnet. The ore-bearing units also contain small amounts of pyrrhotite, pyrite, bismuthinite, bismuth, ilmenite (mostly metamorphosed to titanite and rutile), magnetite, joseite ($\text{Bi}_4\text{Te}_3\text{S}$), chalcopyrite, molybdenite, sphalerite, wolframite, and, more rarely, arsenopyrite, galena, hematite, siderite and hauchecor-

nite. The primary accumulation of tungsten took place earlier than the metamorphism. Any genetic relationship of the tungsten with the post-orogenic granite intrusions in the Sangdong area is excluded (So, 1968).

4. GEOCHEMISTRY AND ORIGIN OF THE AMPHIBOLITES

4.1 General Statement

With increasing metamorphism and metasomatism, amphibolites with originally different characteristics become increasingly similar with respect to such properties as mineralogy, texture, rock magnetism and major element composition. Because of this, much of the previous chemical work has been aimed at discovering differences in abundance levels of certain elements between the para- and ortho-amphibolites, and special attention has been focused on the trace elements.

Although ortho-amphibolites can often be distinguished chemically from para-amphibolites by their higher contents of Cr, Ni and Ti, and lower Niggli k ratios, no criterion based on abundance levels is generally applicable because many basic igneous rocks have low Cr, Ni and Ti contents, and alkali metasomatism in metamorphic terrains often disturbs the k ratio (Leake, 1964).

Leake (*op cit*) emphasized that the most valuable distinction between ortho- and para-amphibolites is likely to be based not so much on the absolute concentrations of certain elements as on the nature of the trends of variation in the amounts of the elements, and their relationship to known igneous and sedimentary trends.

Orville (1969) stated that any rock, whatever its origin, composed chiefly of hornblende with a subordinate amounts of plagioclase will approximate a basaltic composition, and chemical reaction between carbonate-rich rock and carbonate-free pelitic rocks under open-system conditions can produce a hornblende-plagioclase assemblage

Table 2. Chemical and Spectrographic Analyses, Niggli Values and Discriminant Functions

	1	2	3	4	5	6	7	8	9	10	11
SiO ₂	53.4	55.3	63.6	55.3	58.3	59.5	57.8	49.4	50.9	49.1	58.0
Al ₂ O ₃	22.1	20.5	10.9	19.1	17.1	15.2	17.3	18.8	13.9	10.3	24.4
Fe ₂ O ₃	8.30	7.62	7.91	6.76	3.84	6.19	5.63	7.01	5.65	7.72	2.31
CaO	8.33	8.89	5.89	6.45	7.28	7.01	7.98	10.2	12.7	10.6	6.65
MgO	3.43	3.31	2.65	2.86	3.43	3.13	3.43	4.59	4.99	7.00	2.29
FeO	0.22	0.38	4.09	5.74	4.16	4.31	2.87	4.70	6.76	9.41	4.44
TiO ₂	0.91	0.72	0.95	0.83	0.69	0.74	0.81	2.50	3.50	1.42	0.67
MnO	0.21	0.23	0.25	0.28	0.18	0.28	0.30	0.19	0.32	0.32	0.13
K ₂ O	0.58	0.54	1.30	1.05	2.75	0.85	1.65	0.66	0.65	1.56	0.54
Na ₂ O	1.22	1.10	1.37	1.28	0.88	1.31	0.54	3.25	1.62	1.34	1.22
P ₂ O ₅	0.09	0.07	0.11	0.08	0.08	0.12	0.09	0.11	0.20	0.26	0.06
CO ₂	0.57	0.61	0.25	0.34	0.46	0.42	0.53	0.08	0.14	0.15	0.29
Total	99.36	99.27	99.27	100.07	99.15	99.06	98.93	101.49	101.33	98.98	99.00
Ni	230	180	110	210	170	300	300	135	130	150	350
Cr	105	128	<5	<5	290	15	15	50	40	500	240
Co	61	72	63	50	65	88	50	60	55	40	65
Cu	205	27	15	98	48	135	60	20	25	15	42
Sr	62	310	170	170	62	220	220	600	100	100	3400
Ba	24	24	89	96	180	50	220	25	70	30	230
V	430	335	310	460	280	560	280	200	300	250	270
Th	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Zr	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sc	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sb	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Mo	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
<i>al</i>	36.9	35.3	25.2	32.6	31.3	28.5	31.5	26.5	19.8	13.9	47.3
<i>fm</i>	33.3	32.7	41.4	41.8	36.3	41.8	37.2	38.9	42.6	55.9	24.1
<i>c</i>	25.4	27.9	24.8	20.1	24.3	23.9	26.5	26.2	33.0	25.0	23.5
<i>alk</i>	4.4	4.1	8.5	5.5	8.1	5.8	4.9	8.5	4.8	5.2	5.0
<i>si</i>	151.4	161.5	249.9	160.3	181.3	189.2	178.6	118.3	133.0	112.4	191.0
<i>ti</i>	1.9	1.6	2.8	1.8	1.6	1.8	1.9	4.5	6.3	2.4	1.7
<i>p</i>	0.35	0.27	0.18	0.10	0.10	0.16	0.11	0.11	0.20	0.25	0.08
<i>k</i>	0.24	0.44	0.38	0.35	0.67	0.30	0.67	0.12	0.21	0.43	0.23
<i>mg</i>	0.44	0.44	0.38	0.30	0.44	0.36	0.43	0.42	0.42	0.43	0.47
X ₁	-2.64	3.60	4.11	2.09	-4.49	4.33	1.44	6.90	-0.52	-4.03	8.30
X ₂	1.10	1.39	1.16	0.77	1.21	1.72	0.77	1.08	0.93	0.39	1.21
X ₃	-8.65	-6.69	-6.76	0.35	0.58	0.06	0.81	3.87	4.03	2.79	-2.82
Oxid. Ratio	97.1	94.7	94.4	51.4	45.3	56.6	53.8	57.3	42.9	42.5	45.9

Note :

$$X_1 = -2.69 \log \text{Cr} - 3.18 \log \text{V} - 1.25 \log \text{Ni} + 10.57 \log \text{Co} + 7.73 \log \text{Sc} + 7.54 \log \text{Sr} - 1.95 \log \text{Ba} - 1.99 \log \text{Zr} - 19.58$$

$$X_2 = 3.89 \log \text{Co} + 3.99 \log \text{Sc} - 8.63$$

$$X_3 = 7.07 \log \text{TiO}_2 + 1.91 \log \text{Al}_2\text{O}_3 - 3.29 \log \text{Fe}_2\text{O}_3 + 8.48 \log \text{FeO} + 2.97 \log \text{MnO} + 4.81 \log \text{MgO} + 7.80 \log \text{CaO} + 3.92 \log \text{P}_2\text{O}_5 + 0.15 \log \text{CO}_2 - 15.08$$

Table 2. (Continued)

	12	13	14	15	16	17	18	19	20	21	22
SiO ₂	47.3	67.7	51.9	56.9	44.8	45.4	59.9	54.4	51.1	65.9	52.8
Al ₂ O ₃	28.9	12.5	28.2	22.7	34.5	30.0	24.7	23.9	15.9	7.70	15.6
Fe ₂ O ₃	7.42	2.84	5.21	4.78	6.78	6.92	8.60	4.39	11.6	9.10	11.6
CaO	8.12	5.89	6.31	6.65	5.39	7.98	7.28	7.49	10.3	7.14	7.77
MgO	3.23	3.48	2.99	3.08	3.57	3.08	2.51	3.57	2.25	2.29	2.73
FeO	2.58	2.66	0.29	1.22	1.72	1.58	1.44	0.36	4.74	3.45	3.37
TiO ₂	0.75	0.61	0.53	0.59	0.68	0.72	0.83	0.54	0.92	0.90	0.97
MnO	0.14	0.16	0.16	0.14	0.14	0.23	0.18	0.12	0.80	0.50	0.75
K ₂ O	0.58	1.45	2.05	1.50	0.84	1.70	0.58	1.80	1.00	1.20	2.55
Na ₂ O	0.90	1.80	1.05	1.55	0.14	0.77	1.48	1.85	0.44	1.31	0.56
P ₂ O ₅	0.08	0.06	0.07	0.09	0.09	0.10	0.08	0.07	0.13	0.11	0.09
CO ₂	0.53	0.33	0.32	0.37	0.29	0.49	0.39	0.50	0.65	0.34	0.44
Total	100.10	99.48	99.08	99.57	98.94	98.97	107.97	98.99	99.82	99.94	99.23
Ni	145	205	180	200	680	155	380	205	110	73	70
Cr	7	390	15	<5	150	<5	7	290	47	3	13
Co	50	37	52	37	138	34	44	34	20	9	41
Cu	105	29	35	76	33	38	160	18	9	12	13
Sr	5800	480	1050	5000	100	1550	390	2400	12	17	560
Ba	210	100	600	2500	90	420	96	190	25	110	54
V	325	220	325	295	55	71	310	125	21	37	105
Th	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Zr	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sc	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sb	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Mo	<5	<5	<5	<5	<5	<5	<5	<5	84	115	24
<i>al</i>	42.9	28.2	48.2	41.4	52.4	44.8	40.7	41.3	24.5	16.1	25.5
<i>fm</i>	32.0	37.3	25.5	28.9	31.0	28.8	32.4	26.6	43.8	49.5	45.2
<i>c</i>	22.0	24.2	19.6	22.1	14.9	21.7	21.8	23.6	28.9	27.2	23.2
<i>alk</i>	3.1	10.2	6.7	7.6	1.7	4.6	5.1	8.6	2.8	7.2	6.0
<i>si</i>	119.2	259.7	150.5	176.0	115.5	115.2	167.5	159.5	133.7	234.1	146.8
<i>ti</i>	1.4	1.8	1.2	1.4	1.3	1.4	1.7	1.2	1.8	2.4	2.0
<i>p</i>	0.08	0.10	0.09	0.12	0.10	0.11	0.09	0.09	0.14	0.16	0.11
<i>k</i>	0.30	0.35	0.56	0.39	0.80	0.59	0.20	0.39	0.60	0.38	0.75
<i>mg</i>	0.38	0.54	0.51	0.49	0.45	0.41	0.33	0.59	0.20	0.25	0.25
X ₁	13.28	0	5.96	9.66	3.40	9.05	4.05	5.49	-7.66	-8.60	7.08
X ₂	0.77	0.26	0.84	0.26	2.48	0.12	0.55	0.12	-0.78	-2.13	0.43
X ₃	-0.78	-4.04	11.64	-6.14	-7.18	-2.23	-4.33	-9.28	4.62	-1.00	-4.42
Oxid. Ratio	72.1	49.0	94.2	77.9	78.0	79.7	84.3	91.7	68.7	70.3	75.6

Major oxides in weight percent, Trace elements in ppm.

$$\text{Oxidation ratios} = \frac{2\text{Fe}_2\text{O}_3 \times 100}{2\text{Fe}_2\text{O}_3 + \text{FeO}} \quad (\text{oxides in mols})$$

Sample numbers are same as in Table 1.

from a wide range of carbonate-rich pelitic compositions. Orville's metasomatic model for thin-layered amphibolites lists a number of features, of these the presence of muscovite or of aluminosilicate-bearing assemblages within, or in the immediate surroundings of the amphibolite layer are two readily determined characteristics which would strongly indicate that metasomatic processes did not play a significant part in the formation of the amphibolites.

In the present study, most features outlined by Orville as suggestive of metasomatic origin of thin-layered amphibolites are not found, thus his metasomatic model for amphibolite origin is

not considered applicable for this work.

From the methods of multivariate statistical analysis, Shaw and Kudo(1965) have devised a method of distinguishing para- and ortho-amphibolites using empirically defined discriminant functions based on the content and distribution of major (X_3) and minor elements (X_1, X_2). They suggested also that their successful method cannot safely be applied to amphibolites in other areas and of other ages because of the question of the meaning of so called "para-amphibolites", of the existence of regional variations in basalt composition and of the possibility of metasomatic amphibolites. Nevertheless in this study their me-

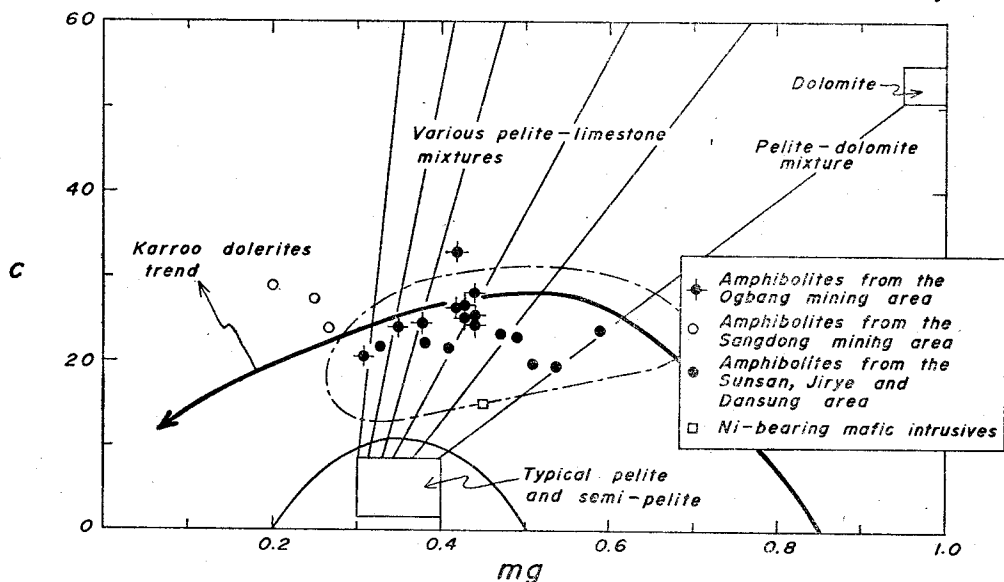


Figure 4. Niggli c versus mg plot.

Area of pelitic rocks: —————

Area of Connemara striped amphibolites and other ortho-amphibolites: - - - - -

thod is compared with the one devised by Evans and Leake.

4.2 Major Elements

The Niggli mg (MgO/Σ femic oxides) which is largely independent of the mode has a very characteristic trend. According to Leake(1964) common amphibolites have compositions which plot around the position of change from increasing c to decreasing c in basic igneous rocks on an mg against c plot, and the trends given by

mixtures of pelite and limestone or dolomite, or both, are approximately at right angles to the trend given by basic igneous rocks, whether or not the latter rocks show an early increase in c with decrease in mg . In Niggli c versus mg plot (Fig. 4), almost all the rocks studied plot within the area of Connemara striped amphibolites and other ortho-amphibolites, and follow fairly well the igneous trend of the Karroo dolerites. The rocks from the Sangdong mining

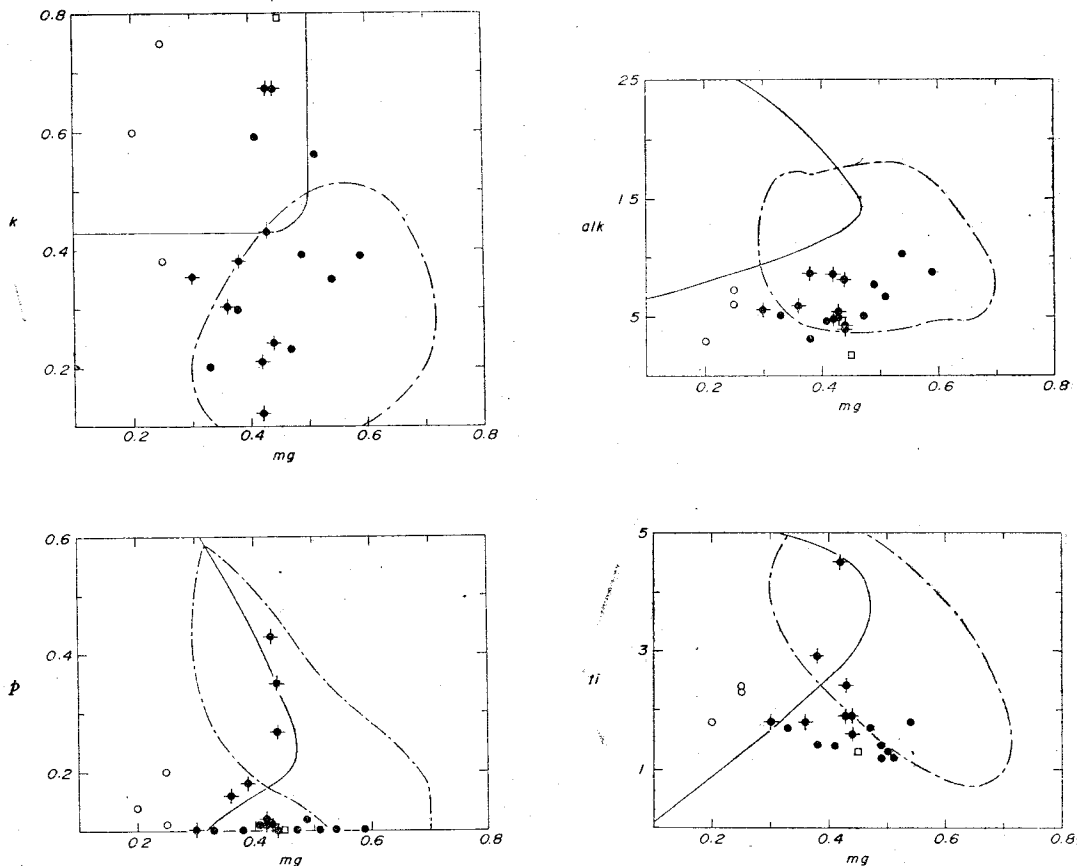


Figure 5. Niggli *k*, *alk*, *p* and *ti* versus *mg* plot.

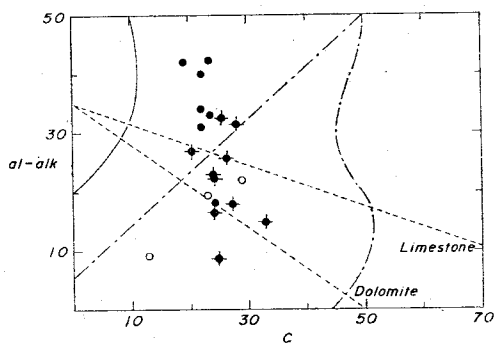


Figure 6. Niggli *al-alk* versus *c* plot.

area with low *mg* values plot out of the igneous region.

The low *k* and moderate *mg* and *c* Niggli values are characteristic of basic igneous rock suites (van de Kamp, 1970). However, *k* and *c* values are dependent of the mineralogical mode,

and it is impossible to distinguish the origin of amphibolites only by *k* or *c* versus *mg*. In particular the rocks which have suffered alkali metasomatism or granitization contain high concentrations of alkali, alumina, halogen and silica (Engel and Engel, 1962). Some amphibolites from the Sobaegsan metamorphic belt have very high *k*, *al* and *si* Niggli values (Table 2), and thus it is impossible to compare the rocks with other studied ortho-amphibolites.

Thus in Niggli *k*, *alk*, *p* and *ti* versus *mg* diagrams (Fig. 5) and *al-alk* versus *c* (Fig. 6), amphibolites from the studied area do not show definite trend.

The diagram of a combination of *mg*, *c*, and *al-alk* (Fig. 7) imply a chemical reconstitution of the rocks. The Sangdong amphibolitic rocks

show low *al* (16.1–25.5) and low *mg* (0.20–0.25) Niggli values, but follow roughly the igneous trend. And the rocks from the Sunsang, Jirye and Dansung area contain higher *al* Niggli values (28.2–52.4) than those of the rocks from the Ogbang and Sangdong mining area. The diagram also shows the same relations to the former plots.

From the above, it is obvious that the major elements of the rocks can be useful in determining their origin only on the presupposition that during metamorphism individual rocks acted essentially as closed systems and also that the rocks do not suffer influx or removal of any materials after the metamorphism of the rocks. Thus the major elements are not useful in determining the origin of the rocks in the present

study as shown by Leake (1964) and Orville (1969).

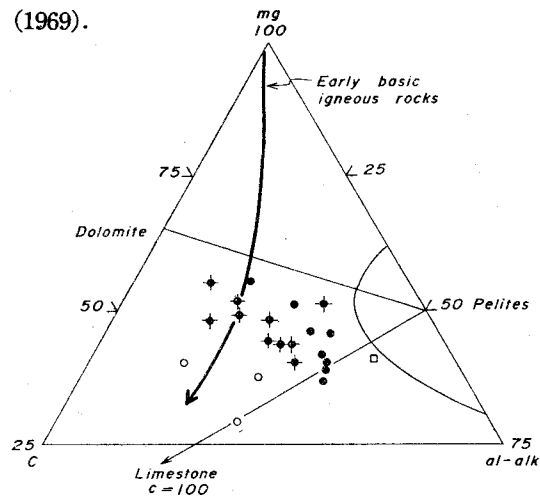


Figure 7. Diagram of a combination of 100mg, c, and al-alk.

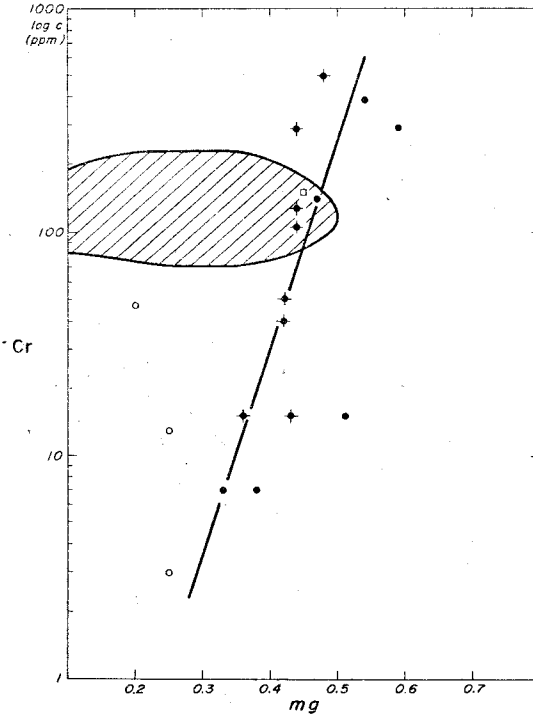
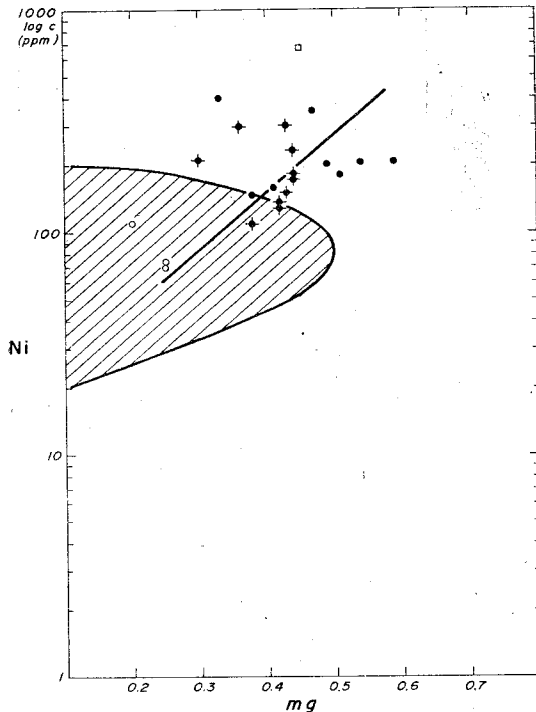


Figure 8. Ni and Cr concentrations plotted against Niggli *mg*.

4.3 Minor Elements

In the differentiation of igneous rocks, a decrease in *mg* is accompanied by a decrease in Cr and Ni, whereas mixtures of pelite and limestone, or dolomite, should show an increase in Cr and Ni with a decrease in the *mg* value and

are poorer in these elements than pelite alone. On this basis Evans and Leake (1960) and Leake (1964) have shown that Cr and Ni are the most useful minor elements in distinguishing sedimentary from igneous trends. Figures 8 a and b show semi-log plots of Cr and Ni versus *mg*.

All the rocks studied show positive correlation.

The mafic metamorphic rocks from the Sangdong area contain lower Cr (3-47 ppm) and Ni (70-110 ppm) contents than the other mafic rocks studied.

As there are systematic trends Ti, Cr and Ni

versus *mg* in the diagrams and in Figure 9 there must be systematic variations between Ti and Cr, Ti and Ni and also Cr and Ni. Both in the differentiated basic igneous rocks and in the pelite-dolomite or pelite-limestone mixtures, Cr and Ni show sympathetic changes (Evans and

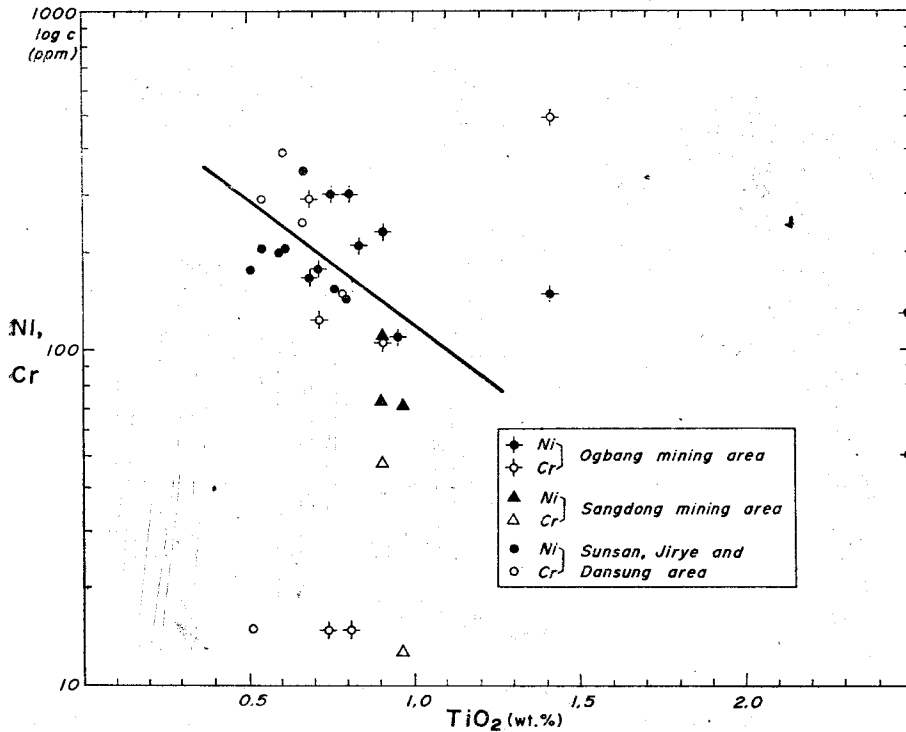


Figure 9. Cr and Ni versus TiO_2 diagram.

Leake, 1960 and Leake, 1964). Therefore, both ortho- and para-amphibolites should show a similar trend. Figure 9 and 10 display this trend; in the Cr, Ni versus TiO_2 plot, all the rocks studied show strong negative correlation. And in the Cr versus Ni plot, there is a steep positive correlation.

The above Ni and Cr versus *mg* and Cr and Ni versus TiO_2 plots unquestionably show that the rocks from the Sobaegsan metamorphic belt are derived from igneous materials. The plots of the Sangdong mining area, however, do not arrange on a definite correlation. These features can also be seen in the Figure 11.

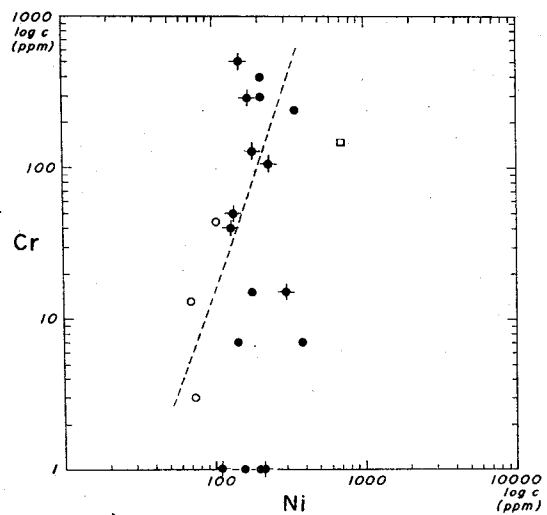


Figure 10. Log-log plot of Cr versus Ni.

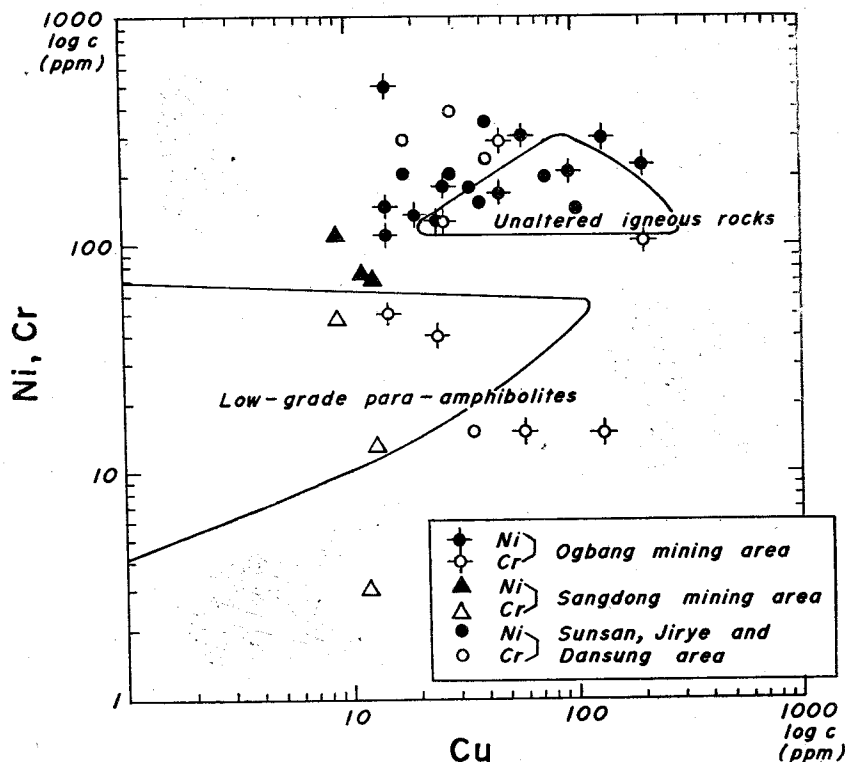


Figure 11. Log-log plot of Cr and Ni versus Cu.

In Ni and Cr versus Cu plots, the rocks from the Sobaegsan metamorphic belt plot well in the area of igneous region and the rocks from the Sangdong mining area plot in the transitional part of the ortho- and para-amphibolite region.

It is interesting to compare the discriminant function described by Shaw and Kudo (1965), in which both the major and trace elements are utilized, with the one devised by Evans and Leake. In accordance with their results amphibolites of negative value can be regarded as of meta-igneous origin and those of positive value as of metasedimentary origin. In the discriminant function analysis (Table 2), more than two negative values of X_1 , X_2 and X_3 are obtained for the two rocks and two positive values of those are obtained for the one specimen from the Sangdong mining area. But all the rocks from the

Sobaegsan metamorphic belt show more than two positive values of X_1 , X_2 and X_3 except in one case ($X_1 = -2.64$, $X_2 = 1.10$, $X_3 = -8.65$ for specimen 1 from Ogbang mining area).

If the trace element abundances vary with increasing grade of granitization, those parameters such as Ni, Cr and Ti can not be useful indicators in determining the origin of amphibolites. But such parameters have been known as independent of the mode and alteration of the rocks, and Leake and Orville suggest that the minor elements are the most useful indicators especially in the regions which have undergone metasomatic metamorphism.

Figure 12 and 13 are the plots of Niggli mg , TiO_2 , Ni, Cr and Co versus Niggli $al+alk+si$. With increasing the $al+alk+si$ values, all the parameters remain almost constant except the

very slight positive correlation of the Ni trend of the rocks from the Sunsan, Jirye and Dansung area. These relations may suggest that the granitization of the amphibolites in the Sobaegsan metamorphic belt did not accompany the removal or influx of Ni, Cr and Co.

Consequently all the trace element features consistently indicate that the amphibolites from the Sobaegsan metamorphic belt including Ogbang mine area are formed from the igneous progenitors but those of the rocks from the Sangdong area do not show a definite correlation: The low Niggli *mg* and low concentrations of V and Sr from the strata-bound Sangdong mining area specimen imply an igneous characteristics. But low Ni, Cr and Ti values and higher *k* values can be either igneous or sedimentary in origin. As

van de Kamp(1968) and Orville(1969) suggested, Sangdong tungsten bearing mafic metamorphic rocks may have been possibly derived from mafic tuffs deposited in an area of carbonate deposition (So, 1968). Geological mapping indicates that the ore horizons grade laterally into calcareous rich sediments.

Having determined that the weight of evidence favored igneous parentage for their amphibolites, Elliott and Cowan(1966) and Preto(1970) used the oxidation ratio, that is, in mols, $2\text{Fe}_2\text{O}_3 \times 100 / 2\text{Fe}_2\text{O}_3 + \text{FeO}$, to determine whether the original rocks were intrusive or extrusive. Applied to the rocks of the present study, this ratio would indicate that all the rocks are probably extrusive (Sobaegsan belt: 45.9-94.2, Ogbang area: 42.5-97.1, Sangdong area: 68.7-75.6).

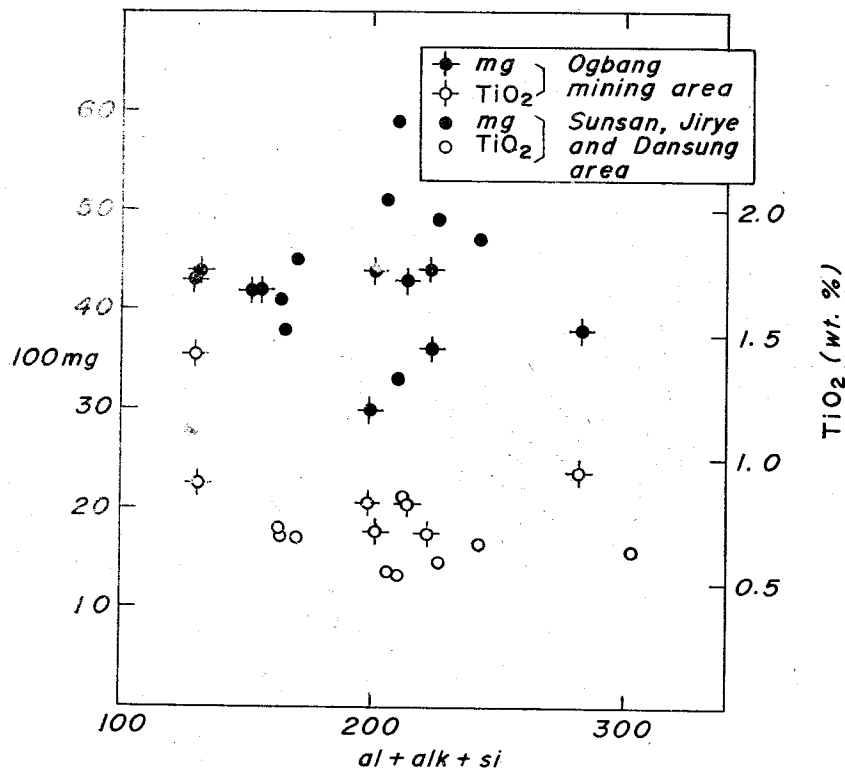


Figure 12. 100 Niggli *mg* and TiO_2 plotted against Niggli *al+alk+si*.

However, as suggested by Chinner, any interpretation based upon the oxidation ratio assumes that during metamorphism each rock behaves as a closed system and that metasomatism has not changed the state of oxidation of the iron in the rocks. The rocks from the Sobaegsan metamorphic belt may not fulfil these conditions because

granitization might have been increased the oxidation of the iron of the rocks. Furthermore the field relationships of some of these rocks in the Sobaegsan Massif (eg. Gimcheon area) are indicative of an intrusive, rather than an extrusive, origin.

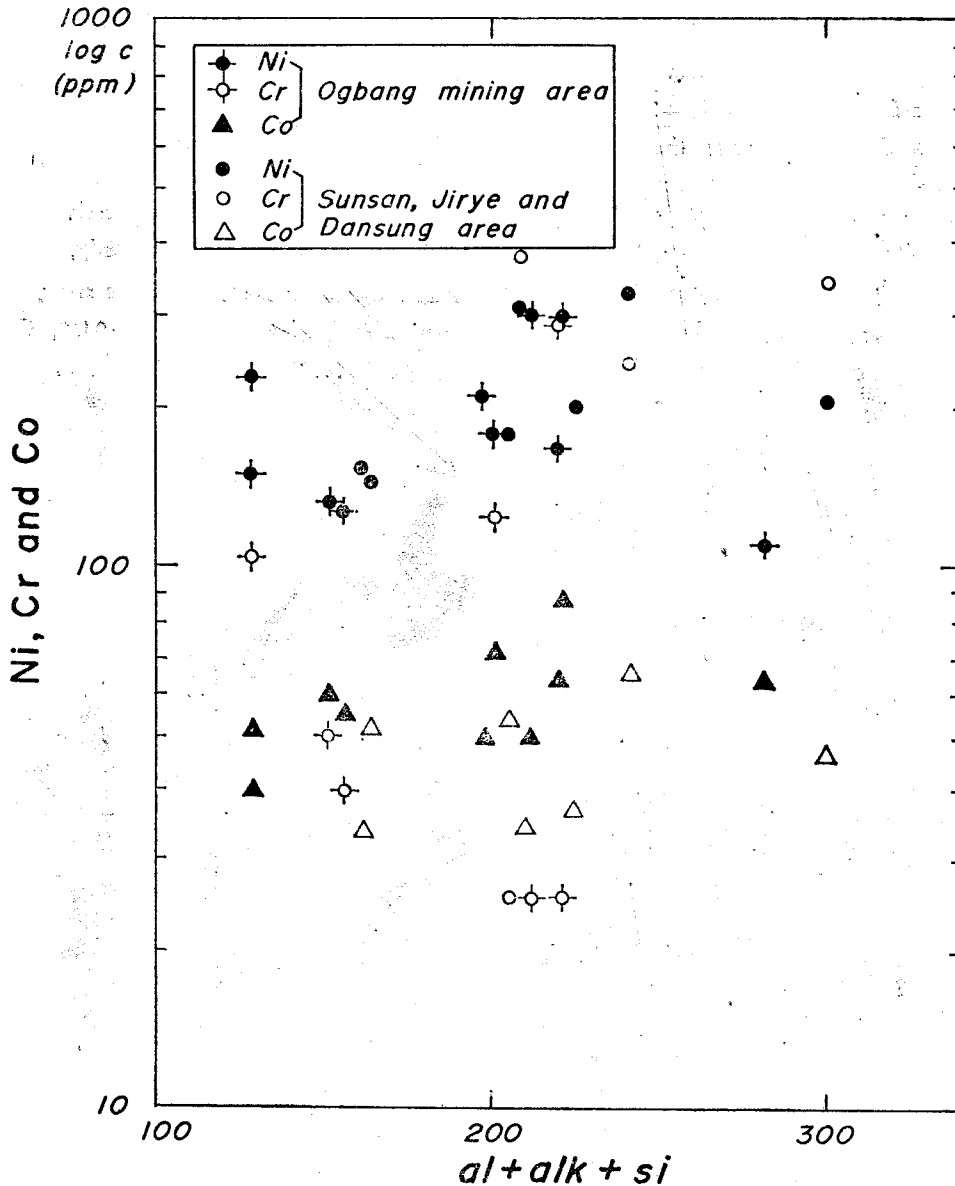


Figure 13. Ni, Cr and Co concentrations versus Niggli $al+alk+si$ plot.

ACKNOWLEDGMENTS: The authors wish to thank Dr. A.J. Reedman, the Anglo-Korean

Mineral Exploration Group for discussions and help with the English manuscript.

小白山變成帶와 玉房 및 上東重石鑛床內의 角閃石質岩의 地化學 및 成因에 關한 研究

蘇 七 變 · 金 尙 明

小白山 變成帶內의 玉房, 善山, 知禮 및 丹城일대에 분포하는 角閃石質岩 중 玉房地域의 것은 주변 變成岩類에 相合的이며 葉理가 잘 발달되어 있고 그의 지역의 것은 심한 花岡岩化作用의 영향을 받아 片磨岩 및 花岡岩質岩內에 lense 狀의 殘留體로 產出된다.

본 연구에서는 주로 小白山 變成帶內의 角閃石質岩(玉房重石鑛床 포함)과 그의 境界부에 위치한 沃川地向斜帶內의 上東鑛床의 鹽基性變成岩의 시료를 대상으로 濕式 및 方出分光分析을 수행하여, 24개 主成分 및 稀有元素의 定性·定量的인 값을 variation trend와 discriminant function analysis 를 통하여 비교 검토함으로써 이들의 成因을 밝혀보려 하였다.

主成分元素의 Niggli value를 사용한 각종 도면에서는 花岡岩化作用으로 인한 alkali, alumina, 및 silica 등의 증가로 인하여 충분한 data를 얻지 못했으나, 研究 대상 試料의 稀有元素들은 alkali, alumina, silica의 增減에 영향을 받지 않아 (도면 12, 13) 成因規明에 만족한 결과를 얻을 수 있었다.

玉房, 善山, 知禮 및 丹城地域의 角閃石質岩은 각 도표에서 높은 비율의 Cr, Ni, Co, Ti, Sr 및 V의 값을 가지며 鹽基性 火成岩의 variation trend를 잘 보여주고, 上東地域의 鹽基性變成岩은 낮은 Cr, Ni, Co, Ti, Sr 및 V의 값과 낮은 Niggli mg 값을 가져서 火成, 堆積의 두 특징을 동시에 나타내고 있으나 화성기원의 특징을 더욱 강조하여 준다. 한편 Discriminant function test (X_1, X_2, X_3)에서도 玉房, 善山, 知禮, 丹城지역의 角閃石質岩은 한 개의 試料를 제외하고는 모두 X_1, X_2, X_3 중 둘이상이 positive 값을 가져 火成起源을 지시해주며 上東鑛床의 것은 하나의 시료는 둘이상의 positive 값 ($X_1=7.08, X_2=0.43, X_3=-4.42$)을 나타내고 두개의 시료는 둘이상의 negative 값 ($X_1=7.66, -8.60, X_2=-0.78, -2.13, X_3=4.62, -1.00$)을 나타낸다.

또한 起源岩의 규명에서 본 연구의 대상이 된 모든 鹽基性 變成岩이 價出岩 및 堆積岩의 특징인 높은 oxidation ratio ($2 Fe_2O_3 \times 100 / 2 Fe_2O_3 + FeO$, in mols)를 가지는 것으로 보아 主成分 및 稀有元素 研究결과와 비교하여 보면 價出岩에서 유래된 것으로 결론 될 수 있으나 小白山 變成帶의 경우는 oxidation ratio의 증가가 심한 花岡岩化作用의 영향 일수도 있으며 야의 산출상태와 현미경기재에서도 價出岩의 잔류증거를 찾지 못하였다.

결론적으로 소백산변성대내의 玉房, 善山, 知禮, 丹城일대의 角閃石質岩은 鹽基性 價入岩으로부터 유래된 것으로 사료되고, 沃川地向斜帶內의 上東鑛床일대의 鹽基性變成岩은 Kamp (1968)와 Orville (1969)가 취급한 연구 결과에서와 같이 炭酸鹽堆積物의 퇴적환경에서 침전한 鹽基性 tuff로부터 유래된 가능성이 많다. (蘇七變, 1968, 1975)

REFERENCES CITED

- Cannon, R. T., 1963, Classification of Amphibolites: Geol. Soc. America Bull., V. 74, p. 1087~1088.
- Chang, T. W., 1973, Petrogenesis of the Hornblende-Biotite Granitic Rocks in Geumneung County Area, Kyungbug Province, Korea: Gyeongbug Univ. Press.
- Choi, Y. K., et al., 1964, Geological Map of Danseong Sheet: Geol. Soc. Korea.
- Engel, A. E. J., and Engel, C. G., 1962, Hornblende Formed During Progressive Metamorphism of Amphibolites, Northwest Adirondack Mountains, New York: Geol. Soc. America Bull., V. 73, p. 1499~1514.
- Evans, B. W., and Leake, B. E., 1960, The Composition and Origin of the Striped Amphibolites of Connemara, Ireland: Jour. Petology, V. 1, p. 337~368.
- Fletcher, C. J. N., 1971, Local Equilibrium in a Two-Pyroxene Amphibolite: Canadian Jour. Earth Sci.

- nces., V. 8, p. 1065~1080.
- Gates, R. M., 1967, Amphibolites: Syntectonic Intrusives?: Am. Jour. Soc., V. 265, p. 118~131.
- Harrison, G. R., 1939, M. I. T. Wavelength 429 S., New York.
- Kamp, van de, P. C., 1970, The Green Beds of the Scottish Dalradian Series: Geochemistry, Origin, and Metamorphism of Mafic Sediments: Geol. Soc. America Bull., V. 80, p. 1127.
- Kamp, van de, P. C., 1969, Origin of Amphibolites in the Beartooth Mountains, Wyoming and Montana: New Data and Interpretation: Geol. Soc. America Bull, V. 80, p. 1127~1136.
- Kamp, van de, P. C., 1971, A Precambrian Conglomerate with an Amphibolite Matrix Near Kaladar, Ontario: Jour. Geol. Soc. V. 127, p. 563~577.
- Kim, O. J., *et al.*, 1963, Geological Map of Sangun Sheet: Geol. Soc. Korea.
- Kim, S. W., *et al.*, 1970, Geological Map of Jirye Sheet: Geol. Soc. Korea.
- Leake, B. E., 1964, Chemical Distinction of Ortho- and Para-Amphibolites: Jour. Petrology, V. 5, p. 237~254.
- Lee, S. M., 1967, Geology and Ore Deposits at the Ogbang Scheelite Mine, North Gyeongsang Province, Korea: Geol. Soc. Korea, V. 3, p. 1~19.
- Niggli, P., 1954, Rocks and Mineral Deposits: W. H. Freeman and Co. p. 7~29.
- Orville, P. M., 1969, A Model for Metamorphic Differentiation Origin of Thin-Layered Amphibolites: Am. Jour. Soc., V. 267, p. 64~86.
- Preto, V. A. G., 1970, Amphibolites from the Grand Forks Quadrangle of British Columbia, Canada: Geol. Soc. America Bull., V. 81, p. 763~782.
- Shaw, D. M., and Kudo, A. M., 1965, A Test of the Discriminant Function in the Amphibolite Problem: Mineralog. Mag., V. 34, p. 423~435.
- So, C. S., 1968, Die Scheelit-Lagerstätte Sangdong: Insug. Diss., 71s., 1Abb., 2Tab., München.
- So, C. S., 1974, Geochemistry and Origin of Amphibolites in Gyeonggi Metamorphic Belt, Korea: Jour. Geol. Soc. Korea, V. 10, No. 4, p. 189~205.
- So, C. S., and Kim, S. M., 1975, Geochemistry, Origin, and Metamorphism of Mafic Metamorphic Rocks in the Ogcheon Geosynclinal Zone, Korea: Geol. Soc. Korea, V. 11, p. 115~137.