Jour. Petrol. Soc. Korea
Vol. 7, No. 1, p. 27~36, 1998

Petrology of the Cretaceous volcanic rocks in northern Yucheon Minor Basin, Korea

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ABSTRACT : The volcanic piles in the northern Yucheon Minor Basin area are the Hagbong basaltic rocks, the Chaeyaksan basaltic rocks, the Jusasan andesitic rocks, the Unmunsa rhyolitic rocks, and the Tertiary volcanics. Stratigraphically, from the lowermost, (1) the Hagbong basaltic rocks are composed mainly of basaltic tuff with two olivine basalt flows intercalated, (2) the Chaeyagsan basaltic rocks are predominantly in tuffs and agglomerate with 3 basaltic flow interlayers, (3) the Jusasan andesitic rocks consist of thick piles of alternated sequences of 4 andesite flows and 5 andesitic tuffs and tuffaceous sediments and (4) the Unmunsa rhyolitic rocks which embed some rhyolite and obsidian are dominant in tuffs such as ash flow and crystal welded tuff. These volcanics reveal distinguishable characteristics in petrochemistry. In discriminating by major elements, the Hagbong and the Chaeyagsan basaltic rocks are alkaline, whereas the latter is also spilitic. In comparison, the volcanic rocks of the Jusasan andesitic rocks and the Tertiary sequences are characteristically calc-alkaline although their distribution is spatially separated. On the other hand, the variations in immobile trace elements indicate that the Hagbong basaltic rocks range from alkaline to calc-alkaline and from WPB/VAB transition to VAB, whereas the Chaeyagsan basaltic rocks are calc-alkaline WPB/VAB transition type and the two others calc-alkaline VAB. In order to show such a variety in their rock series of the volcanic rocks, the environment during their magma generation, magma rising, and post-eruption alteration could be positively considered.

Key word : Yucheon minor basin, volcanic activity, contamination, fractional crystallization

INTRODUCTION

In the northern part of the Yucheon Minor Basin, three Cretaceous and one Tertiary volcanic piles are wildly distributed with both temporal and spatial differences. Tateiwa(1929) coined the lowermost (HKB; Hagbong basaltic rocks) as Hagbong porphyrite, the intermediate (CYB; Chaeyagsan basaltic rocks) as Chaeyagsan porphyrite, and the uppermost (JSA; Jusasan andesitic rocks) as Jusasan porphyrite. Between HKB and CYB, thick (about 3,300 m) sedimentary rocks of the Haman, the Banyawol, and the Songnaedong Formations are occupied, and about 200-m-thick black shale of the Geonchonri Formation is distributed between CYB and JSA. The Tertiary basaltic and andesitic rocks (PYB/PYA) overlie unconformably the others.

Both of HKB and CYB are alkaline, but CYB has a petrochemical characteristic of spilitic rocks (Yang, 1991; Kim, 1993). On the other hand, JSA is calc-alkalic such as most of the Cretaceous and the Tertiary volcanics in the study area and southwestern Japan (Cha, 1976; Hwang, 1979; Kim, 1982; Kim and Lee, 1981; Kim and Park, 1988; Kim, *et al.*, 1991, 1993; Lee, *et al.*, 1987).

In the petrochemical study of JSA in the Jain area, Kim, *et al.*(1993) proposed that the andesitic rocks were derived from protomagma formed by partial melting of mantle wedge and their spatially different evolution trends are probably due to their different degree of contamination by lower crust or inhomogeneity of crustal rocks affected to contamination of the protomagma. Both JSA and PYB/PYA are calc-alkaline (Kim and Park, 1988), reflecting that the volcanisms from Cretaceous to Miocene in the area could be characterized by a magmatism in similar tectonic environment.

GEOLOGY

In Taegu-Gyeongju area of the Gyeongsang Basin, three volcanic piles are distributed in ascending order; HKB is intercalated between the Paldal Conglomerate and the Haman Formation, CYB is between the Songnaedong and the Konchonri Formation, and JSA overlies Konchonri Formation and covered by Unmunsa rhyolitic rocks (Fig. 1). The volume of the volcanics increases upward stratigraphically; HKB is made of small lenticular body of 120 m in the thickness and about 15 km in the extension, and CYB about 250 m and 43 km. In comparison with those, JSA entirely occupies the Yuchon Minor Basin area (70×100 km^2) with a thickness of about 1600 m. Between HKB and CYB, about 2400-m-thick sandstones and mudstones are interlayered, and about 300-m-thick black shale is interposed between CYB and JSA. HKB is dominant in basaltic tuff and intercalated with two layers of olivine basalt. CYB consists predominantly of basaltic tuffs with three interlayered hornblende-pyroxene basalts. JSA is composed mostly of alternated sequences of 4 andesite flow layers and 5 andesitic tuffs and tuffaceous sediments.

TECTONIC SETTING

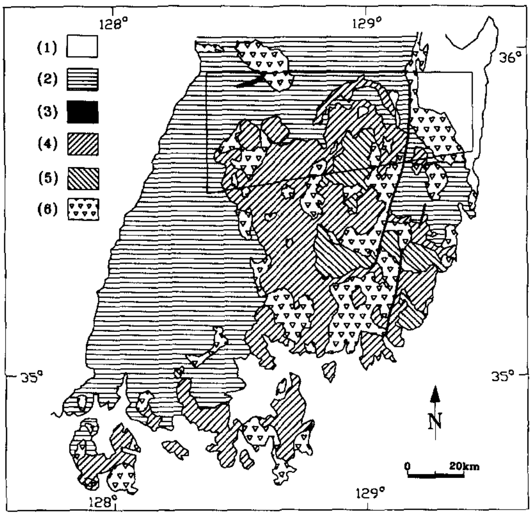

Fig. 1. Generalized geologic map of the study area (insetted) and the vicinity. 1; undivided, 2; Cretaceous sedimentary rocks, 3; Hagbong basaltic rocks, 4; Chaeyagsan basaltic rocks, 4; Jusasan andesitic rocks, 5; Unmunsa rhylitic rocks, 6; granite

The study area is located in northern part of the Yuchon Minor Basin known as the center of the Cretaceous volcanisms in Gyeongsang Basin. JSA is volcanic rocks originated from the magmatism related genetically to subduction of Kula-Pacific plate similar to the Cretaceous volcanic rocks in southwestern Japan (Miyashiro, 1974; Kim, 1982). Judging from the fact that all of the volcanic suites in the study area were erupted during evolution of the Gyeongsang Basin, they might be derived from the magmatisms of similar tectonic environment. Indeed, the significant changes in tectonic development possibly exist in the area through long geologic time from HKB eruption stage to PYB/PYA eruption stage. It is difficult to imagine that there could be distinguishable temporal changes in tectonic setting of the areas between CYB and JSA eruption stages in spite of their petrochemical differences. No geologic criteria indicating any changes in tectonic setting is evidently found in the area. Thus, in a consequence, CYB and JSA volcanisms were activated in tectonic environments similar to each other.

MINERALOGY

Predominant texture of the volcanic suites in the study area is porphyritic and the amount and kind of phenocrysts vary with each suite and sequential level of each flow unit in the suite. As the characteristics of the phenocryst constituents show early crystallization and fractionation of the magma in subsurface before eruption, it is important to compare with those of the suites, each other.

Modal phenocryst constituents of the volcanic suites in the area are 8-11% of olivine and 10-23% of pyroxene in HKB (Kim, 1993), 10-40% of plagioclase, 1-6% of olivine, 2-14% of pyroxene and 0-14% of hornblende in CYB (Yang, 1991), 10-35% of plagioclase, 1-4% of pyroxene, and 0-1% of hornblende in JSA (Kim, 1982), and 11-35% of plagioclase, 2-14% of olivine, and 0-15% of pyroxene in PYB (Park, 1993).

Basalts of HKB containing phenocrysts of pyroxene and olivine formed before the original magma reached at the stability field of plagioclase, and the magma seems to be evolved through relatively short crystallization stage without plagioclase fractionation. PYB is probably affected by fractionation of olivine, pyroxene, and plagioclase during magma rising up to relatively shallow depth. CYB and the lower part of JSA with phenocrysts of plagioclase, pyroxrene, and hornblende on the other hand, may reflect that the phenocrysts were crystallized in relatively deep crust (more than 5 Kb) and the fractionation by pyroxene and hornblende dominated in high degree of water saturation. The mineralogy of the phenocryst might reveal the rough crystallization courses of the volcanic associations in accordance with the experimental data on the crystallization of basaltic magma (Green, 1982).

PETROCHEMISTRY

Petrochemical studies of the Cretaceous to the the Tertiary volcanics in the study area with a comparison each other were made for understanding the characteristics of the evolution of magmatisms in each volcanic stage. As JSA, a product of the Cretaceous intermediate volcanism in the area, is conceived by volcanic rocks related to the subduction of the Pacific plate, the other suites formed during the evolution period of the Gyeongsang Basin in the area could also be derived from magmatism in a similar tectonic environment. Therefore, the volcanic suites in the area reveal significant diversity in their petrochemical properties in spite of high possibility of similar mechanism in their protomagma genesis. The chemical analysis data used in this study were taken from Kim (1993) for HKB, Yang (1991) for CYB, Kim (1982) and Kim *et al.* (1993) for JSA, and Park (1993) for the Tertiary volcanic rocks. The data are carefully reviewed and the selected for the rocks with similar SiO_2 contents as possible to compare easily each other without considering the extrapolation of the discrimination trend.

Major elements

The characteristic volcanic rocks in ocean-continent and ocean-ocean convergent zones are calc-alkaline associations dominant in andesite with K enriched trends although a considerable diversity of volcanic rock suites have been recognized. Some progressive compositional changes in either a lateral or vertical sense were observed (Baker, 1982). For the study of major elements, the basalt and basaltic andesite samples were selected among JSA to compare with basalts of HKB and CYB. Therefore, the comparison of fractionation trends of each volcanics in the area at similar SiO_2-content ranges of basaltic to mafic andesite could be available.

The variation trends in alkali contents of the volcanics indicate that HKB and CYB are alkaline and JSA and PYB/PYA calc-alkaline. As shown in the relationship between alkalies and SiO_2 contents of the volcanics (Fig. 2), CYB shows a differentiation trend of higher alkali contents than those of HKB although both have characteristics of alkaline suite, whereas both of JSA and the Tertiary volcanic rocks are calc-alkaline. Such temporal differences in their rock suites are also recognized

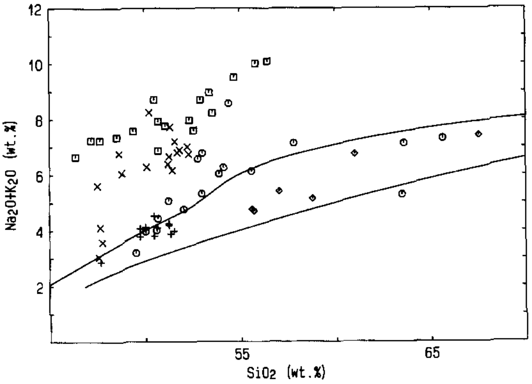

Fig. 2. Total alkali-SiO_2 diagram for the volcanic suites. Symbols are cross; HKB, quad; CYB, circle; JSA, diamond; PYB and plus; PYA (after Kuno, 1966).

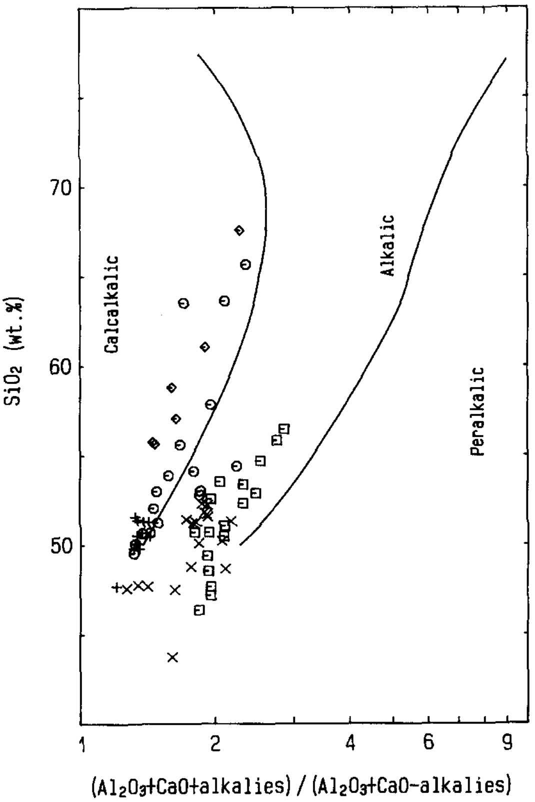

Fig. 3. Distribution of alkalinity for the volcanic suites. Symbols are same as shown in Fig. 2 (after Wright, 1969).

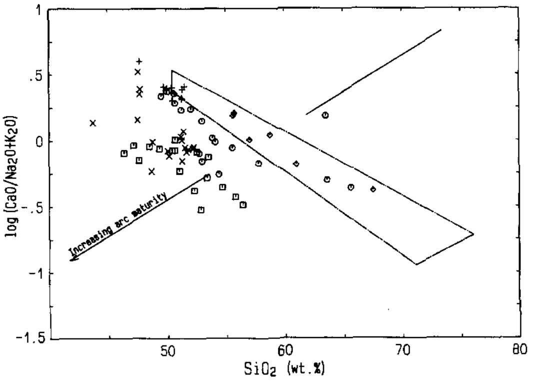

Fig. 4. Calc alkali ratio-silica trends for the volcanic suites compared with the range for normal calc alkaline suite(insetted by broken line. Symbols are same as shown in Fig. 2 (after Brown, 1982).

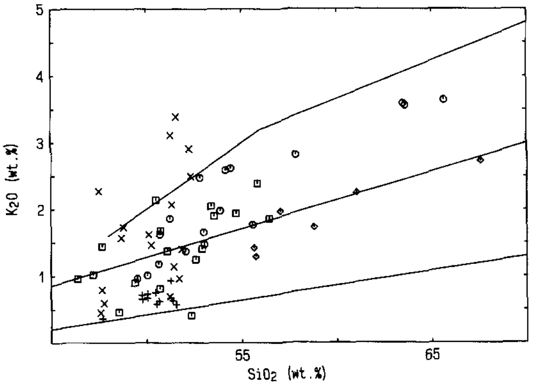

Fig. 5. Diagram of K_2O versus SiO_2 for the suites in the study area. Symbols are same as shown in Fig. 2.

in Fig. 3 and 4. The variation diagram of calc-alkali ratio indicates that the alkali-lime index of HKB and CYB is about 50 and JSA and the Tertiary volcanic rocks belong to the normal calc-alkaline suite with Peacock's index of about 58.

Brown(1982) insisted that the alkalinity and K_2O/Na_2O ratio of the arc magma increases with increasing in maturity of continental crust and degree of crustal thickening in continental margin. His illustration seems not to be enough to explain the petrochemical diversity of the volcanic suites in the study area. In Fig. 5 plotting K_2O versus SiO_2 contents, the diversity of the volcanic rocks in the area is revealed. HKB shows an abrupt change ranging from calc-alkaline to shoshonitic series and CYB varies with a steep gradient from low-K to high-K calc-alkaline series. JSA and PYB/PYA show,

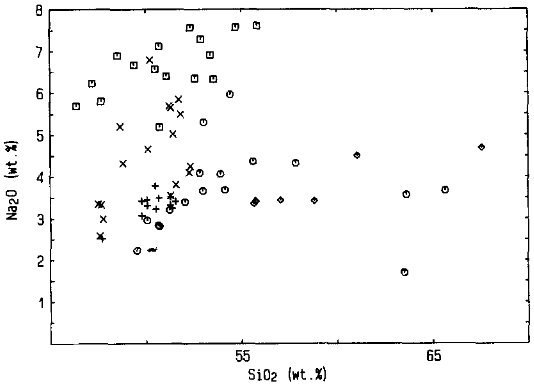

Fig. 6. Diagram of Na_2O versus SiO_2 for the volcanic suites. Symbols are same as shown in Fig. 2.

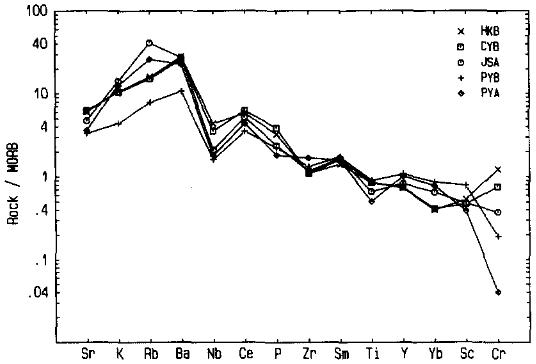

Fig. 7. Distribution of MORB normalized incompatible element abundances for the suites. Symbols are same as shown in Fig. 2.

however, normal calc-alkaline differentiation trends, even though JSA spreads wide from calc-alkaline to high-K calc-alkaline series. On the other hand, variation trends of Na_2O with increasing SiO_2 content show more systematic changes than those for K_2O, but CYB has the highest Na_2O content and JSA and the PYB/PYA show normal calc-alkaline variation trend. The increasing rate in HKB is so steep that any fractionation tendency for Na_2O of the volcanics could not explain this steep increasing rate (Fig. 6). The ratios of HKB seem not to be any relation to magmatic differentiation and those of CYB show also changes with abnormally high gradient with increasing in SiO_2 content. This suggests that the magmatic evolution of the suites could considerably be affected not only by the crystal fractionation but also by the different kind and degree of crustal contamination or magma mixing. In addition to these, a possible explanation is that the primary magmas are originally different from each other.

Trace elements

The volcanic rocks in the area reveal significant differences in relationships between major elements although similarity of the tectonic environment of their original magma generation in destructive plate continental margin could be acceptable. Hence, it is worthwhile to consider the tendency of the trace elements variation with those of the conventional major elements, because the magma could be affected by aqueous fluids from subducting oceanic crust into mantle source region (Pearce, 1982, Saunders and Tarney, 1979) or crustal contaminations (Hildreth and Moorbath, 1988). Pearce (1982) compared incompatible element distribution patterns of MORB, within plate basalt, volcanic arc basalt, and transitional volcanic arc basalt to each other. A degree of enrichment in incompatible elements of the volcanic rocks in the area shows significantly higher pattern than those in normal volcanic arcs and is similar to the pattern of the volcanics in transitional volcanic arcs (Fig. 7). The contents of the compatible element Cr is highly diversified in comparison with both of other intermediate ionic potential and incompatible elements such as Nb, Zr, Y, etc., and such a tendency of Cr distribution also appears in the discrimination diagram of Cr vs. MgO contents (Fig. 8). The decreasing rate of Cr toward proceeding of fractionation of mafic minerals in HKB is lower than the others, and an appearance similar to this is also shown in the relationship between Ni and MgO contents. This might reflect that each volcanic suite has a peculiar course of crystal fractionation and crustal contamination.

Immobile elements, such as incompatible elements Ti and Y, and compatible elements Cr

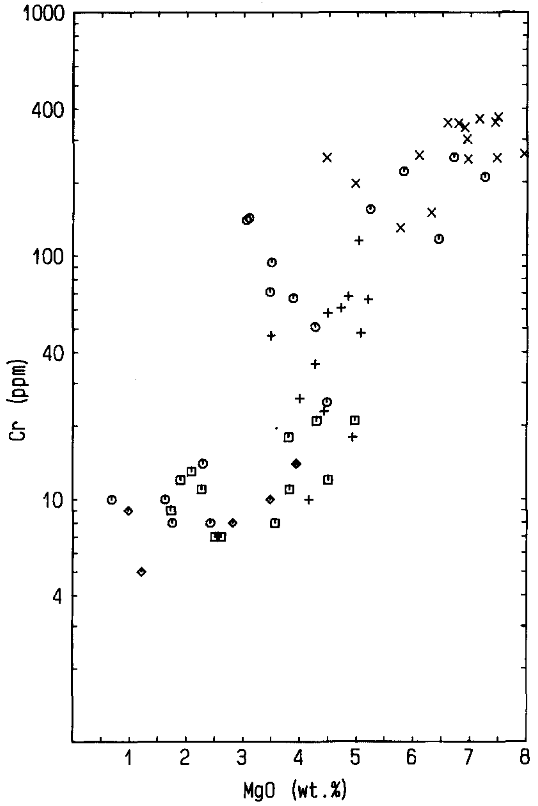

Fig. 8. Cr-MgO relationship showing fractionation trend of the volcanic suites. Symbols are same as shown in Fig. 2.

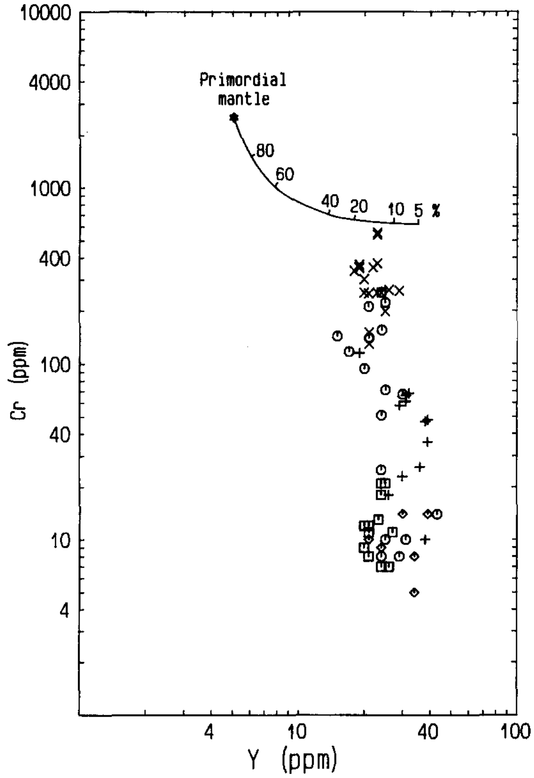

Fig. 9. Plots of Cr and MgO showing the petrogenetic trends compared with primordial mantle composition (after Pearce, 1982). Symbols are same as shown in Fig. 2.

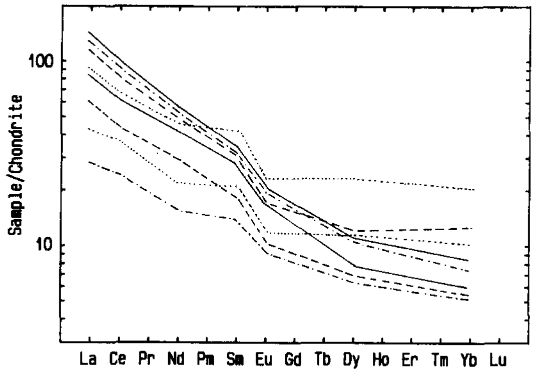

Fig. 10. Chondrite normalized REE distribution pattern for the volcanic suites. Dot and dash; HKB, full line; CYB, broken line; JSA, dotted line; PYB.

and Ni are often used to determine the origin of the magma and degree of fractionation. In the discriminant diagram (Fig. 9) showing the relationship between Y and Cr contents, the variation trends of the volcanic suites are subparallel to Cr axis, suggesting that the mafic mineral fractionation prevails over fractional crystallization of feldspar. All of the trends extrapolated back to the area of 15 to 25% partial melting of plagioclase lherzolite (Ol$_{0.6}$Opx$_{0.2}$ Cpx$_{0.1}$Pl$_{0.1}$) and a degree of partial melting in PYB looks lower than that of other suites if other factors affecting in discrimination of the elements except for crystal fractionation are ignored. The distribution of Cr content of each suite is peculiar as shown in Fig. 9; HKB is significantly enriched in and CYB depleted in Cr with very restrict range, and the distribution of the other suites seems to be implicated in a wide range of mafic mineral fractionation.

REE distribution patterns of the suites (Fig.

10) range in continental margin andesites and basalts associated with subduction zone, and CYB and PYB are in a marked contrast to each other; LREE is predominantly enriched most in CYB and HREE distinctively in PYB. Each REE pattern of the volcanic suites implies a peculiar fractional crystallization dominantly affected by a certain crystal; PYB looks to be differentiated by plagioclase, JSA by pyroxene and plagioclase and CYB by hornblende and pyroxene. In case of HKB, the lower limit of REE content is the most low among in the suites, and the degree of enrichment in LREE varies in very wide range. This is probably due to metasomatism in contact aureole around the Palgongsan granite.

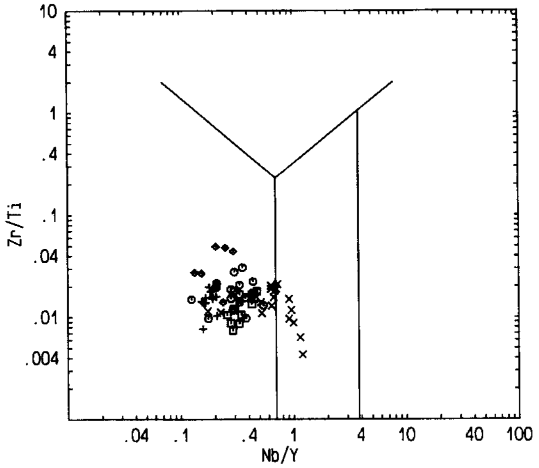

Fig. 11. Zr/Ti vs Nb/Y discrimination diagram (after Winchester and Floyd, 1977). Symbols are same as shown in Fig. 2.

Some immobile elements show partly different discrimination features from mobile major element variations. In Zr/Ti-Nb/Y diagram (Fig. 11), HKB is plotted in alkaline field and extends to calc-alkaline, whereas the others are in normal calc-alkaline. Such a variation trend of HKB probably indicates that HKB is originated from magma formed by the fractional melting of lherzolite and its eruption and replenishment. Nb/Y ratios of HKB and CYB are higher than those of PYB/PYA, indicating that the original magmas of the formers yield a lower degree of melting than the latter. Magma types of the volcanic rocks are shown in Ti-Zr-Y diagram (Fig. 12). Most of HKB and CYB are plotted in transition zone between within-plate basalt (WPB) and volcanic arc basalt (VAB) and JSA and PYB/PYA show typical calc-alkaline VAB trends. The basalts in this transitional WPB/VAB setting of HKB and CYB have been interpreted as originated from a magma formed by 1) low fraction melting of mantle, 2) partial melting of enriched mantle, or 3) partial melting of upper mantle beneath an attenuated continental lithosphere (Morrison, 1978). It is supposed that attenuation of continental lithosphere would be more or less promoted during the active evolution period of the

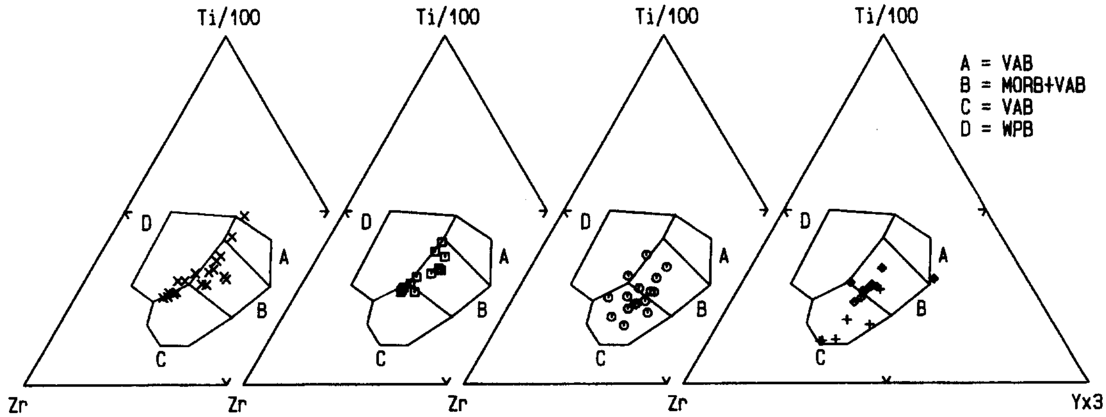

Fig. 12. Ti-Zr-Y diagrams for petrogenetic classification (after Morrison, 1978). Symbols are same as shown in Fig. 2.

Gyeongsang Basin. Thus, HKB and CYB erupted in this stage come from the magmas formed by partial melting of upper mantle beneath the attenuated continental lithosphere.

DISCUSSION AND CONCLUSIONS

As mentioned above, a diversity in rock series of the volcanic suites in the study area is distinctive although the volcanic suites are assumed to be derived from magmas generated by partial melting of peridotite in mantle wedge, as a mechanism of parental magma genesis of most volcanic rocks in the circum-Pacific volcanic belt is used to be explained. Compositional characteristics of magma can be determined by 1) degree and depth of partial melting of mantle, 2) role of fluid derived from subducting oceanic crust, 3) crustal contamination and 4) magma mixing (Kay, 1980; Coulon and Thorpe, 1981; Brown, 1982; Green, 1982; pearce, 1982; Watson, 1982; Hildreth and Moorbath, 1988; Esperanca *et al.*, 1992). Jake and Gill (1970) insisted that primitive basaltic magma derived from mantle partial melting could be island arc tholeiite type, and Pearce (1982) explained the differences in the variation trend of Y content of the volcanic associations as depending on partial melting degree of wedge peridotite.

Although most of volcanic rocks in continental margin are characterized by calc-alkaline, the volcanic suites in the area show a wide variety in their major element petrochemistry ranging from calc-alkaline to alkaline (Fig. 2, 3 and 4) and in alkaline suites, HKB varies up to shoshonitic and CYB is characterized by spilitic natures(Fig. 5 and 6). Immobile elements such as Ti, Zr, Nb and Y have been recognized as they have a behaviour to conserve themselves (Morrison, 1978; Winchester and Floyd, 1977). HKB lies in alkaline-calc-alkaline field and the others including CYB are plotted in calc-alkaline field in Zr/Ti-Nb/Y diagram (Fig. 11), HKB and CYB are plotted in WPB/VAB transition zone, and JSA and PYB/PYA show typical calc-alkaline VAB trends in Ti-Zr-Y discrimination diagram (Fig. 12). In comparison with major/trace element discrimination trends, CYB derived from calc-alkaline parental magma might become to alkaline (spilitic) rocks during evolution of the magma or after its eruption.

Considering about role of the crustal contamination of the primitive magma, the melting, assimilation, storage, and homogenization (MASH) hypothesis of Hildreth an Moorbath (1988) could be a fundamental guiding principle. For understanding the characteristics in MASH processes of each suite, it is necessary to consider about 1) size of the magma body, 2) depth and duration of magma storage, 3) ascending speed of the magma and 4) contents of fluid component in the magma. Tuffs and tuffaceous sedimentary rocks are dominant in CYB, suggesting that the water content of the magmas was high enough to explode.

In the mineralogical aspects, the phenocryst minerals in the rocks implicate the approximate depth of crystallization of the phenocryst through the composite P-T phase diagram compiled by Green (1982). Phenocrysts of CYB are hornblende, pyroxene, and plagioclase. The hornblende phenocrysts are rimmed by dark Fe-hornblende or Fe-oxides, further to be resorbed. This suggests the followings; 1) the phenocrysts were crystallized at deep depth of about 10 kb (lower continental crust) beyond the stability field of olivine and below that of garnet, considering on the basis of no olivine/garnet phenocrysts found in the rocks and 2) the original magma of the suite might already have a plenty amount of water and Na_2O content enough to yield hornblende at the stage of hornblende phenocryst growing. Therefore, MASH occurs mainly in around this stage, and can make the original magma to be enriched in Na_2O by selective partial melting of plagioclase of metagabbro or amphibolite of the lower crust in depth of the magma storage. It is supposed that there was not enough time to be contaminated by upper crustal materials during magma ascending and eruption after growth of phenocrysts, because an average width of the hornblende reaction rim formed by degassing during eruption and magma ascent, is narrow (about 50 um). This width represents a short magma ascending duration, estimating by the basis of experimental data of Rutherford (1993). On the other hand, the possibility of spilitization of CYB in its post-eruption could be considered. Plagioclase of CYB is commonly albitized and saussuritized. This may indicate that the possibility of spilitization of the rocks is not negligible. The mechanism that causes the alkaline CYB is still ambiguous.

ACKNOWLEDGEMENT

This study was supported by academic research fund of Ministry of Education, Republic of Korea (BSRI-96-5421).

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(책임편집 : 윤성효)
(1997년 12월 18일 접수, 1998년 4월 23일 수리)

북부 유천소분지에 분포하는 백악기 화산암류에 대한 암석학적 연구

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요 약 : 대구-경주지역에 분포하는 백악기 화산암류는 하부로부터 학봉현무암질암류, 채약산현무암질암류 및 유천층군의 주사산안산암질암류와 운문사유문암질암류 등으로 구성된다. 학봉현무암질암류는 신라역암층을 덮고 있으며 이와 그 상위에 놓이는 채약산현무암질암류 사이에는 두께 약 2400 m에 달하는 함안층, 반야월층 및 송내동층의 두터운 퇴적암층이 놓여 있고 채약산현무암질암류와 주사산안산암질암류 사이에는 두께 300 m 가량의 건천리층이 개재되어 있어 이들 화산암류는 상당한 시간적, 위치적 공간을 사이에 두고 일어난 화산활동의 산물인 만큼 이들은 각기 상이한 암석학적 특성을 지니고 있음이 들어난다. 주성분 지화학적 특성에 있어서 학봉현무암질암류와 채약산현무암질암류는 알카리계열의 특성을 보이며 주사산안산암질암류는 포항지역의 제 3기 현무암/안산암류와 흡사하게 칼크알카리계열에 속한다. 반면 Nb, Y, Zr, Ti 등 저변성작용에서도 이동성이 매우 적은 원소에 의하면 학봉현무암질암류는 알카리에서 칼크알카리계열에 속하는 모마그마형을 보이나 스필라이트질인 채약산현무암질암류는 주사산안산암질암류와 유사한 칼크알카리계열의 모마그마로 부터 유래했음을 보여준다. 이러한 모마그마와 그 산물의 상이성은 마그마의 상승과정을 통한 지각물질에 의한 혼염작용 혹은 분출한 다음에 있었던 변질작용등에 의한 것으로 해석될 수도 있을 것이다.

주요어 : 유천 소분지, 화산활동, 혼염작용, 결정분별작용