Mechanisms and processes leading to reverse zoning in the Andong granitoid pluton, Andong batholith, Korea

Sang Koo Hwang

Dept. of Earth and Environmental Science, Andong Nat'l Univ. (hwangsk@andong.ac.kr)

1. INTRODUCTION

The Andong batholith is a Jurassic plutonic complex intruding metamorphic rocks of the RRyeongnam massif that extends from NE to SW in the southern Korean Peninsula. Detailed mapping and petrographic studies show that the batholith exhibits five sparate plutons: Andong, Dosan, Pungsan, Imha, and Nokjeon. The oldest Andong pluton among them exhibits reverse zoning. This feature contrasts with typical modal and chemical zoning trends in calc-alkaline plutons in which higher color index and more mafic rocks in the outer rim surround lower color index felsic rocks in the interior.

This report presents the results of detailed mapping, petrographic, and bulk chemistry studies of the Andong pluton. A brief summary of the results obtained from K-Ar geochronologic, and major, trace and rare earth element geochemical studies is also included because it supplements the field observations. Such observations place strong constrains on the sequence of emplacement, and magmatic evolution accounting for the reverse zoning within the pluton.

2. GEOLOGICAL SETTING

The Andong batholith outcrops in the northwestern Ryeongnam massif that is stratigraphically characterized by a thick pile of Precambrian metamorphic rocks. The metamorphic rocks consist mainly of pelite metasedimentary rocks of the Wonnam Group. The metasedimentary rocks are consistently moderate as greenschist to epidote amphibolite facies in metamorphic grade and show great differences in lithology.

Five granitoid plutons, which make Andong batholith, are intruded in the Wonnam group in the Ryeongnam massif. These intrusives are mainly composed of calc-alkaline, I-type granitoids, which are exposed in the core between NE trending Yecheon shear zone and NWW trending Andong fault. Another Yeongju granitoid batholith is exposed north of the Andong batholith. Petrographic contrast (abundance of mafic minerals, ratio of magnetite to ilmenite, rock type variation) between the Andong and the Yeongju batholith has argued against correlation of the two granitoids.

3. The ANDONG PLUTON

The Andong pluton is an elliptical allochtonous intrusion that covers an area of 305㎢ within the Andong batholith. The pluton shows considerable lithological variation consisting characteristically of tonalite in central lithofacies, granodiorite in marginal lithofacies, and porphyritic granite in the topside lithofacies (Fig. 1). Three main lithofacies can be mapped on the basis of varying mineralogy, textures and internal structures. These lithofacies are closely related by very gradual contacts. Distribution of these lithofacies define both horizontal and vertical zonation.

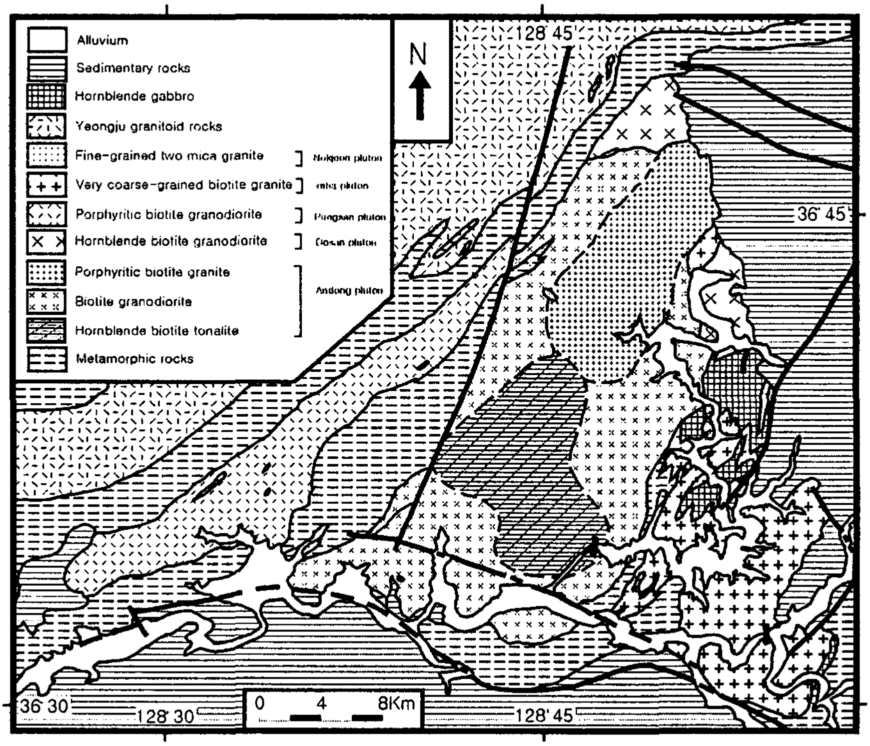

Fig. 1. Geological map showing three lithofacies of the Andong pluton in the Andong granitoid batholith.

4. PETROCHEMISTRY

The preceding sections demonstrated that the Andong pluton was zoned mineralogically and texturally. This zoning is also evident in the bulk chemistry of the granitoids from central via marginal to topside lithofacies. A summary of the petrochemical variations follows in these figures.

Major elements

The petrochemical data show that three lithofacies are within the diagnostic range for calc-alkaline series, and that spatial compositional variations change progressively from tonalite through granodiorite to granite in the pluton.

The most important observation derived from the bulk chemical change in the pluton is that with the exception of the Na_2O content, there is remarkable compositional colinearity from the interior via the margins to topside.

The chemical data show downward concave or upward convex curve along the traverse OC-AD (Ongcheon-Andong) and NJ-WR (Nokjeon-Waryong) lines. Along the traverse OC-AD lines, SiO_2 and K_2O trends make wavy curves that the tonalite is downwards concave, whereas MnO, CaO, TiO_2, $Fe_2O_3^t$, MgO and P_2O_5 trends make upward convex curves of the tonalite. Along the traverse NJ-WR lines, SiO_2 and K_2O trends make wavy curves that the porphyritic granite is upwards convex, whereas MnO, CaO, TiO_2, $Fe_2O_3^t$, MgO and P_2O_5 trends make downward concave curves of the porphyritic granite.

Trace rare earth elements

Preliminary trace element determinations show irregular gradients within the pluton, except for the strong and consistent variations in V, Co, Cr, Sc, Sr, Rb, Y and Zn. These elements support the distinction between each lithofacies and the reverse zoning from core to topside.

REE represent a marked variation in content from tonalite via granodiorite to porphyritic granite. The total content of REE diminishes with differentiation, being this tendency more pronounced in HREE than in LREE.

5. DISCUSSION

The pluton evolved as an independent geochemical system, in which the initial state of the evolutionary path after the individual magma chambers were established was the development of chemical gradient, with hotter, more mafic magma at the base and more felsic one at the top of the chamber (Fig. 2A). Crystal-liquid equilibria were of secondary importance to explain the reverse zoning and were superimposed on the original chemical zoning of the magma chamber. The gradient and division of the chamber into three domains assured that the fractionating assemblage precipitated in these individual domains maintained equilibrium with only part of the chamber. Fractional crystallization by accretion and settling may have resulted, for example, in some accumulation of more calcic plagioclase and mafic minerals (Fig. 2B). Influxes of more mafic magma at the base of the chamber would probably result in disruption of the convective cells, and partly mingling of magmas at different stages of differentiation in the magma root zone of the chamber.

Surges of hotter mafic magma into the base of the chamber resulted in remobilization and resurgence of the lower, more mafic crystal mush into the upper, more felsic layers. Alternatively, Bailey (1976) suggested that resurgent doming might occur from partially removing the top of the chamber as a result of volcanism. He suggested that isostatic equilibrium is restored by inward flow in the magma root zone leading to a rise in the subcaldera crustal column and magma chamber. In either case, field observations suggest that the central lithofacies for the pluton was emplaced at this level of exposure subsequent to the marginal lithofacies (Fig. 2C).

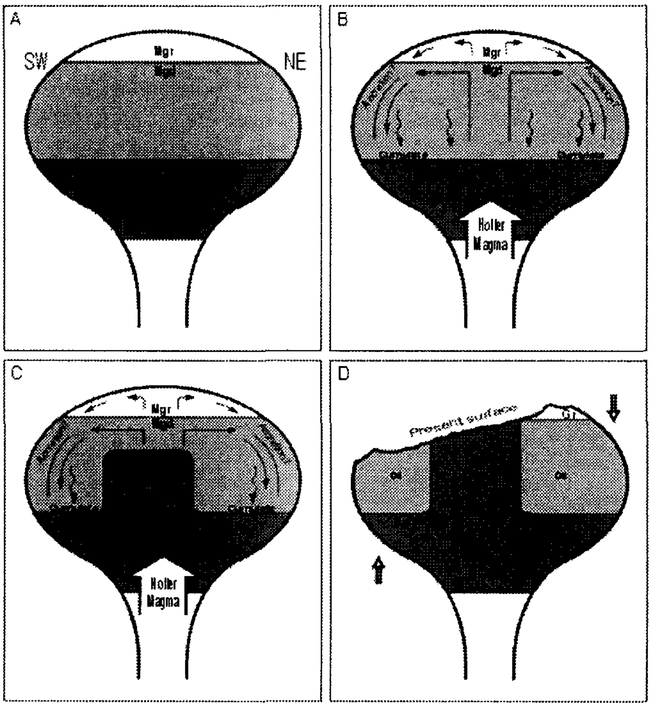

Fig. 2. Generalized diagram showing a model for the reversely zoned Andong pluton.

The pluton was intruded high in the crust, and this location may explain the preservation of their reversely zoned features. This shallow level of emplacement together with decreased replenishment of hotter mafic magma at the base of the chamber might have resulted in a faster rate of cooling, less efficient convection, and an increase in viscosity. As elemental diffusion became more sluggish and less systematic, the solidus temperature was reached. The granitoids consolidated and preserved the reversely zoned features that have typically destroyed in plutons that have longer evolutionary paths. The pluton tilted upward in the SW part and downward in the NE, and thus exposed three lithofacies (Fig. 2D).

6. CONCLUSIONS

The Andong pluton constitutes outstanding examples of reversely zoned granitoids. The pluton have three lithofacies: hornblende biotite tonalite, biotite granodiorite, and porphyritic biotite granite. The zoned pattern forms by locating a tonalite core containing high-temperature mafic assemblages in central part, granodiorite rims in marginal part, and a porphyritic granite cap containing more felsic assemblages in topside.

Modal and chemical data from the pluton show quantitative compositional variations from the interior via the margin to the topside of the pluton. Quartz and K-feldspar decrease toward the interior of the pluton, whereas hornblende, biotite and color index increase. Abundances of SiO_2 and K_2O decrease toward the interior according to the variation in quartz and K-feldspar, whereas those of MnO, CaO, TiO_2, $Fe_2O_3^t$, MgO and P_2O_5 increase corresponding to the variation in mafics. The regular compositional variations within the pluton support the argument that the pluton behaved as an individual geochemical system. Modal abundances are in agreement with the bulk compositions gradients, suggesting that no significant interaction with country rocks occurred.

Remobilization (resurgence) of deeper parts of the system into the more felsic magmas of the chamber explains the reverse zoning. Fractional crystallization was of importance and probably accounts for the selective removal of the settling phases. The Andong pluton is an example of reversely zoned plutons related by remobilization of more mafic but consanguineous magmas. Large-scale upwelling occurred in the pluton leading to the present arrangement of three lithofacies. It is conceivable that remnants of the reverse zoning become more difficult to discern as the plutonic rocks reach the latest stages of their evolution. In this case, the Andong pluton represents an earlier stage in the evolution of a felsic system that is usually represented by the final stages in normally zoned plutons.