

## Chemical composition of biotite as a guide to petrological characteristics in the Jebal-e-Barez plutonic complex, SE Iran

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### Introduction

Biotites from Jebal-e-Barez plutonic complex (JBPC) are selected for this study. Biotite, a ubiquitous ferromagnesian mineral of granitoids, proved to be a valuable guide to their petrogenesis (Ague & Brimhall, 1988). Its composition is classically used to estimate the physico-chemical conditions of crystallization of the parental magma such as chemical composition, oxygen and halogen fugacities (Speer, 1984) and even to evaluate the tectono-magmatic environment of its host-rock (Wones & Eugster, 1965; Nachit *et al.*, 1985; Patino-Douce, 1993). At the early stages of mica studies, evaluations were mainly focused on the chemical composition of different types of host rocks. For example, Heinrich (1946) used the mica composition to investigate the variation with rock types from granites to diorites. Later, Foster (1960) observed that there were important overlaps from different rock types when octahedral mica composition plotted on ternary  $Al^{VI}+Fe^{3+}+Ti^{4+}$ - $Fe^{2+}+Mn^{2+}-Mg^{2+}$  diagram. In those studies, there was no emphasis on the rock names for mica composition. For that reason, Neilson and Haynes (1973) proposed a plot comparable to Foster's (1960) biotite composition. In recent years, Nachit *et al.*, (1985) used mica composition in granitoids to relate magma types in which biotite crystallized. In Al<sup>VI</sup> vs. Mg classification diagram, the nature of granitoid magmas grouped into four types such as peraluminous (P), calcalkaline (C), subalkaline (SA), and alkaline-peralkaline (A-PA). Abdel- Rahman (1994) gave discrimination diagrams between alkaline (A), calc-alkaline (C), and peraluminous (P) granite suites based on the biotite chemistry. Rieder *et al.*, (1998) has written an article regarding the nomenclature of the micas. Yavuz (2001) wrote a program for estimating Li from electronmicroprobe mica analyses and classifying trioctahedral micas in terms of composition and octahedral site occupancy. Yavuz (2001) has written a program for evaluating and plotting microprobe analyses of biotite from barren and mineralized magmatic suites. In this study, we focused on chemical composition of biotite to specify petrological characteristics in Jebal-e-Barez plutonic complex, SE Iran.

### Analytical Techniques

In this study, for determination the chemical composition of biotite in 68 points on biotites from 7 rock samples taken from different units of JBPC were carried out by electron probe micro-analyzer (EPMA) technique on polished thin sections. Analyses were done using a XGT-7200 micro-XRF analyzer-HORIBA with voltage of 20 kv, current of 15 nA and counting time 40 s for peak at the Kansaran Binaloud Laboratory, Tehran, Iran. The accuracy of the reported values for the analyses is 1%–5% in 1s. Depending on the abundance of the element. A microprobe analysis is defined as the arithmetic mean of five spot analyses of a biotite grain. The OH values are calculated on the basis of 11 oxygen formula units. The X and X values Mg Fe are determined from cation fractions and are defined as  $Mg/Fe + Mg$  and  $(Fe + Al^{VI})/(Mg + Fe + Al^{VI})$ . The X, X, and X are the mole fractions of F, Cl, F, Cl. OH and OH in the hydroxyl.

### Geological setting

Figure 1 shows a simplified geological map of the Jebale Barez Plutonic complex (JBPC). The Oligocene–Eocene intrusive rocks in JBPC were emplaced into the volcanic rocks. These rocks consist of granodiorite, quartzdiorite, granite and monzogranite and also these rocks includes abundant of

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rounded and ellipsoid Magmatic enclaves composed of quartz diorite, monzodiorite and quartz monzodiorite. It is noteworthy that biotite is the most abundant mafic mineral in most rocks at JBPC. The geochemical variation diagrams of major oxides, the continuous spectrum of rock compositions has been carried out which indicates the crystallization of magmatic differentiation and extensive appendices (Rasouli et al, 2015). The magma nature of these rocks is sub-alkaline-calc-alkaline, which in  $\text{SiO}_2\text{-K}_2\text{O}$  plot they fall into calc-alkaline series with high potassium (Rasouli et al, 2015). Field observations, petrographic and geochemical studies suggest that the rocks in this area have granitoides I type (Rasouli et al, 2015). Studying the geochemical diagrams of the rocks in the studied area indicates that these rocks have been formed in active continental margin tectonic setting. Most of the volcanic arc granites (VAG) are of "pre-collision" and "syn-collision" types (Rasouli et al, 2015). Based on The location of JBPC seems the rocks of this region there came to subducted oceanic crust Neotethyan beneath continental crust of central Iran (Rasouli et al, 2015). This area tectonically has been active since Cretaceous to Pleistocene (Ghorbani, 2014). Its evidence could be seen as volcanic activities and intrusions which all happened in continuation of subduction of oceanic slab below continental crust (Ghorbani, 2013). Outpouring of such thick volume of lavas and pyroclastics during Eocene, and subsequent frequent foldings, uplifting and weathering/erosion are all signs of early Alpine orogeny. The formation of marine shallow sediments in Oligocene indicates the lowest activities during this time (Rasouli et al, 2014).

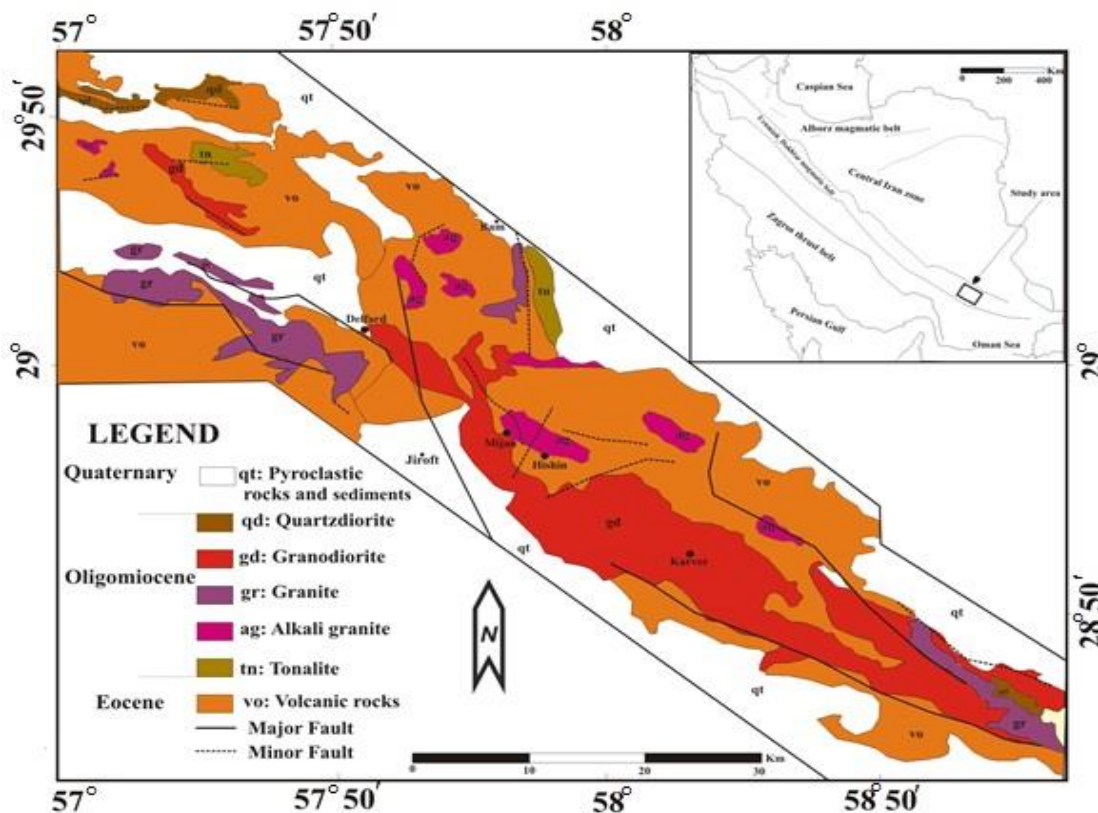


Figure 1: The distribution of Cenozoic volcanic and plutonic rocks of UDMA in relation to the Sanandaj-Sirjan arc and Central Iran. Modified after Alavi, 1994, simplified geological map of the studied area.

### Mineral chemistry

The 68 points from 7 samples, analyzed from rocks of the JBPC, are all trioctahedral common micas ( $5 < M \text{ site} < 6$  atoms per formula unit, apfu) and, for the different units fall within biotite field. Average biotite compositions and their calculated structural formulae based on  $24(\text{O,OH,F,Cl})$ . The major element chemistry of the micas shows average  $\text{TiO}_2$  contents in all samples from 1.98 to 3.36 wt%. It changes from 2.19 to 3.24 wt% in quartzdiorite, 1.8 to 3.4 in granodiorite and 2.3 to 2.9 for monzogranite unit.

Consequently Ti cations vary between (0.24 - 0.71), (0.5 – 0.38) and (0.32 – 0.53) apfu in these units respectively. As shown by Lalonde and Bernard (1993) biotite is perhaps the most common mineralogical sink for excess aluminum in granitic rocks. The peraluminosity index (A/CNK) of whole-rock samples ranging from 0.8 to 1.3 whereas of biotites varies approximately between 1.5 and 1.9, indicating clearly biotite higher A/CNK values relative to those of its host rock.

Total Al and Fe/(Fe+Mg) variables are commonly used to illustrate compositional relationships of trioctahedral micas from igneous rock suites (Speer 1984). Figure 2A shows the composition of biotite from different units plotted in the annite – siderophyllite – phlogopite – eastonite quadrilateral (ASPE). They show variation in composition in a way that biotites from granodiorite and monzogranite units are fairly Fe rich whereas those from quartzdiorites are relatively Mg rich (Fig. 2A). Biotite from granodioritic rocks of JBPC exhibits a fairly wide range of Al values reaching up to 3.42 apfu, at very narrow Fe/(Fe + Mg) ratios (0.76 to 0.85). The biotite samples from the monzogranite like granodiorite define a field with a relatively narrow range but slightly higher Fe/(Fe+Mg) with total Al values range from 3.36 to 3.63 apfu. Biotite from the quartzdiorite shows approximately a fixed range of Fe/(Fe+Mg) and a large variation of moderate Al contents (2.44 to 3.14 apfu) in the ASPE quadrilateral. Their lower Fe/(Fe+Mg) ratios indicate that biotite from quartzdiorite is enriched in Mg and contains less Al with respect to the other units.

### **Crystallization conditions of biotite**

The composition of biotites depends on a number of interdependent variables e.g. P, T,  $fO_2$ ,  $fH_2O$ , and element activities, one of which must be defined either empirically or indirectly so as to determine the others.

### **Estimation of oxygen fugacity and redox condition**

In the Fe<sup>2+</sup>-Fe<sup>3+</sup>-Mg ternary diagram (Wones & Eugster, 1965), the comparison of biotite compositions with common oxygen buffers (quartz—fayalite—magnetite QFM, nickel—nickel oxide, NNO and hematite—magnetite, HM) shows all biotite samples from different units of JBPC plotted above the NNO buffer (Fig. 2B). Our results indicate relatively more oxidizing conditions for quartzdiorite and granodiorite and slightly reducing conditions for monzogranite but still above NNO buffer. The oxidizing conditions of the quartzdiorite magma are also supported by the presence of titanomagnetite and euhedral titanite (Ishihara, 1977; Wones, 1989). Imposed on the Figure 2B is the discrimination boundary of Buda et al., (2004), the boundary between magnetite and ilmenite granitoids. As it can be seen, biotite compositions from monzogranite fall below this line, in the field of ilmenite granitoids, while those from granodiorite and quartzdiorite plot in the field of magnetite granitoids. This is consistent with the presence of magnetite, allanite and euhedral titanite in the latter rocks.

### **Quantitative determination of Oxygen and water fugacity**

Granitoid biotites react to form a number of assemblages, among them biotite-K- feldsparmagnetite act as a buffer of oxygen and water fugacities in the magma (Wones & Eugster 1965). Estimating the  $fO_2$  in the magma and activities of magnetite and K-feldspar and the activity of annite in biotite with some certainty result in deriving the water fugacity through the reaction (Czamanske and Wones 1973):  $\log f_{H_2O} = 7409/T + 4.25 + 0.5 \log f_{O_2} + \log a_{ann} - \log a_{Kf} - \log a_{mag}$  Where  $T$  is in °K, and activities are shown rather than molar fractions. The ideal activity model of Mueller (1972), Wones (1972) and Czamanske and Wones (1973) are used here for annite in biotite.  $a_{ann} = (X_{Fe^{2+}})^3$  The activity of K-feldspar is 0.6 for magmatic temperatures (Czamanske & Wones 1973) and activity of most re-equilibrated magnetites is close to 1 (ideal). Oxygen fugacity (Log  $f_{O_2}$ ) of -17.66 bars and water fugacity ( $f_{H_2O}$ ) of 400 and 700 bars were calculated for granodiorite and monzogranites respectively, whereas the Log  $f_{O_2}$  of -15.4 to -17.5 bars and water fugacity ( $f_{H_2O}$ ) of 200 to 560 bars were calculated for quartzdiorite.

### **Tectonomagmatic implication**

Abdel-Rahman (1994) collected a large number of biotite analyses from literature and made-up different diagrams discriminating biotites from anorogenic extension-related peralkaline granites, calc-alkaline I-

type orogenic suites and peraluminous rocks including S-type granites. These diagrams are capable to discriminate the composition of biotite from different tectonic settings in terms of its FeO, MgO, and Al<sub>2</sub>O<sub>3</sub> contents. Among those, ternary FeO\*–MgO–Al<sub>2</sub>O<sub>3</sub> plot is employed (Fig. 2C), which reflects variations in redox state and peraluminosity much like the ASPE quadrilateral. In the FeO\*–MgO–Al<sub>2</sub>O<sub>3</sub> diagram of Abdel- Rahman (1994), biotite compositions from the JBPC are distributed between the calc-alkaline and peraluminous fields (Fig. 2C); compositions of biotite from the quartzdiioritic rocks fall principally in the C (calc-alkaline) field, whereas those from the peraluminous granites e.g. granodioritic and monzogranitic unit, plot almost exclusively in the P (peraluminous) field. The composition of biotite from quartzdiioritic unit principally falls in the calc-alkaline subduction related I-type field (Fig. 2C) which is consistent with their tectonomagmatic characteristics investigated by Rasouli et al., (2015) on the basis of whole rock geochemistry. However, granodioritic and monzogranitic units including metaluminous to slightly peraluminous I-type, and some peraluminous S-type granites whose major- and trace-element compositions are comparable to those of granite suites from classical volcanic arc granites, convergent and collisional environments, respectively.

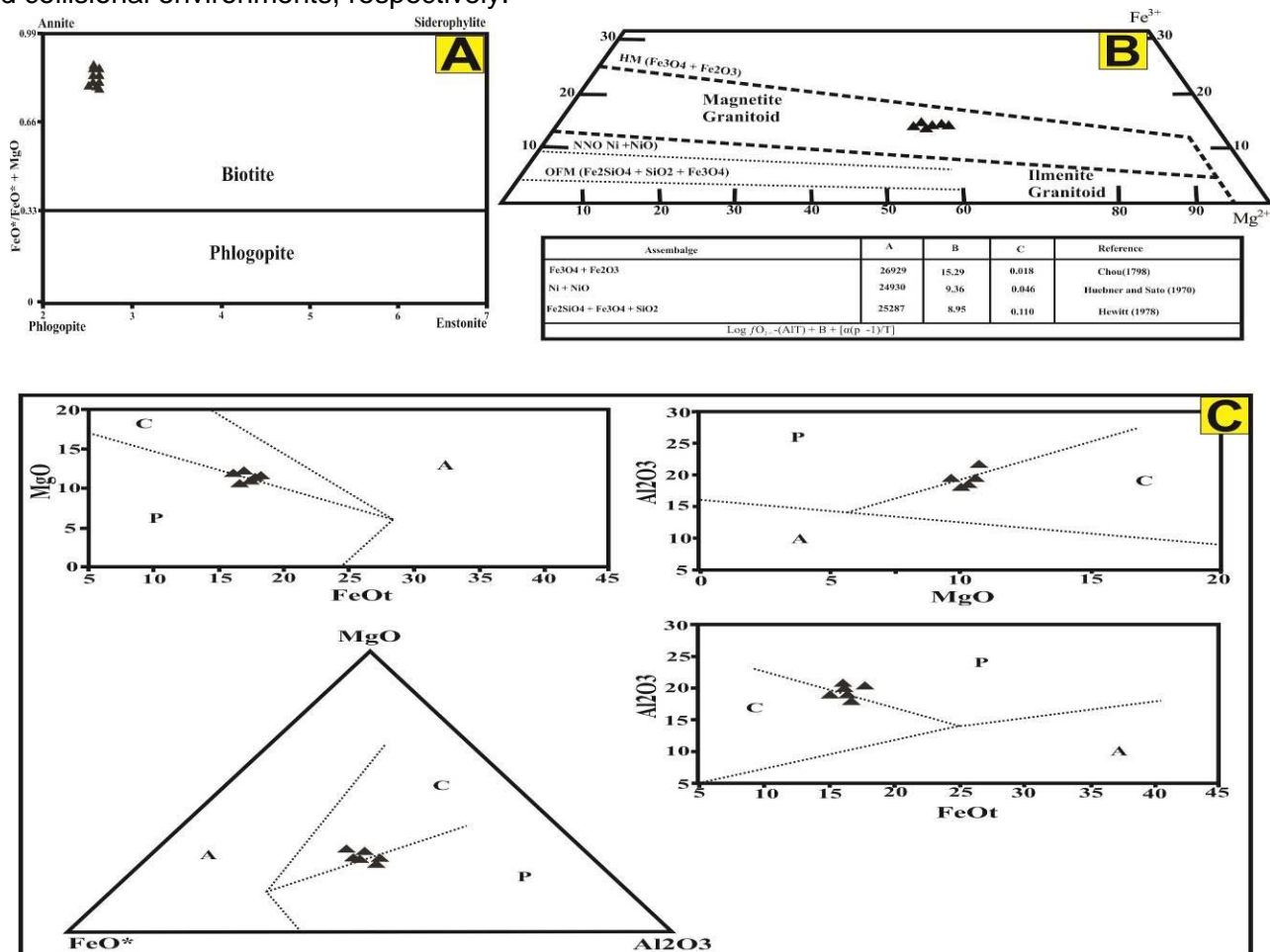


Figure 2: A) Composition of biotite from different units of JBPC plotted in the anorthite – siderophyllite – phlogopite – eastonite Quadrilateral (ASPE). B) Composition of biotite from JBPC plotted in the Fe<sup>2+</sup>- Fe<sup>3+</sup>-Mg ternary diagram along with the three common oxygen fugacity buffers: quartz – fayalite – magnetite (QFM), nickel–nickel oxide (NNO), and hematite– magnetite (HM). The solid line separates magnetite granites realm from ilmenite granites one. C) Composition of biotite from JBPC plotted in the discrimination diagrams of Abdel Rahman, (1994). A: alkaline, C: calc-alkaline, and P: peraluminous granite fields.

## Conclusions

Granites from different units of JBPC are interpreted as having formed within a subduction-related environment. They contain biotite that is compositionally possessing moderate to relatively high Al contents, suggestive of significant contributions from either aluminous metasedimentary material or magmas originated from aluminous supracrustal material. biotite compositions from metaluminous I-type

quartzdioritic units have slightly lower content of  $\text{Al}_2\text{O}_3$  in contrast to the other two units, but being moderately enriched in Mg, they plot in the calcalkaline I-type field in the tectonic discrimination diagram. These compositional features of biotite are consistent with the nature of their host rocks. The granodiorite and monzogranite plutons are peraluminous and belong to the I-type granites of Chappell and White (1974). biotite compositions from these units considered to be derived entirely from crustal material, showing a remarkable increase in both total Al and Fe.

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