MINERAL CHEMISTRY OF BIOTITES FROM JALOR, TOSHAM AND JHUNJHUNU RING COMPLEXES: MALANI IGNEOUS SUITE, INDIA

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This paper describes mineral chemistry of biotites from Jalor, Tosham and Jhunjhunu ring complexes of Malani igneous suite, India. The chemistry reveals iron enrichment trend in all the biotite samples of the three complexes. FeO*/MgO ratio is the highest (6.72) in Jalor samples whereas lower values of (4.08) and (3.72) have been observed in Tosham and Jhunjhunu samples respectively. Higher MgO has not affected the enhanced proportions of FeO* in the biotites of Tosham and Jhunjhunu. Mg⇌ Fe and 2Al⇌ $3Fe^{2+}$ substitution is dominant in Jalor samples whereas, influence of 3M ⇌Al is deciphered in the Tosham and Jhunjhunu samples. Most of the biotites fall in the anorogenic (A-type) suites, representing extensional tectonic environment for their host rocks.

Introduction

The late Proterozoic Malani magmatism (55,000 km^2, 732 Ma) which comprises four distinct igneous complexes *viz.* Siwana, Jalor, Tosham and Jhunjhunu is characterised by ring type intrusions, bimodal suites of granite, rhyolite, gabbro and basalt with an interrelationship between volcanism and plutonism. The detailed petrography and geochemistry (major, trace and REE's) of the A-type, HHP 'within plate' granites and the associated acid volcanics of Jalor, Tosham, Jhunjhunu and Siwana ring complexes have been described in detail by Dhar (1990), Kochhar and Dhar (1993), Dhar et al. (1996), Dhar and Kochhar (1997), Sharma (1992), Kochhar (1983) and Kochhar (2000). The paper reports for the first time the detailed mineral chemistry of the biotites from Jalor, Tosham and Jhunjhunu complexes and its role as tectonic indicator for the rocks which hosts them.

Mineral Chemistry Methodology

The mineral analyses on biotites was carried out on automatic electron microprobe (CAMECA-EMPA) at the Institute of Mineralogy, Hanover University, Germany. The elements Si, Al, Fe, Mg, Ca, Na, K, Ti and Mn were determined using natural silicates and oxides as standards. The calculations were carried out on the basis of 24(O.OH).

Geological Setting and Petrography

The Jalor area comprises two linked ring structures which overlap in east-west position. The dominant lithologic unit in the area is pink biotite-hornblende granite followed by rhyolite. The ring structures are marked by the coeval intrusion of olivine gabbro on the western side. It is inferred that the whole complex is contained inside a ring fault. The biotite-hornblende granite is of subsolvus type containing alkali feldspar (perthite and orthoclase), quartz (subhedral-anhedral high quartz), biotite, plagioclase and hornblende. A few granites have also revealed fayalite, Dhar (1990) and Dhar et al. (1996). Biotites under study have been taken from the dominant biotite-hornblende granite of the area. Tosham area is characterised by ring type structure, radial dykes and cauldron environment. The litho-units in the area are muscovite-biotite granite, granite porphyry, welded tuff, rhyolite, and explosion breccia. The muscovite-biotite granites are of subsolvus type which contain alkali feldspar (perthite and orthoclase), plagioclase, quartz, biotite and muscovite, Kochhar (1983). Jhunjhunu area is characterised by isolated hills comprising lithologic units *viz.* granite porphyry, felsite, rhyolite. The granites vary in colour, grain size and texture. These are two feldspar (subsolvus) as well as one feldspar (hypersolvus) granites, containing alkali feldspars (perthite and orthoclase) and plagioclase. Ferro-magnesian minerals are dominated by biotites which are usually altered to a large extent to chlorite. Shattered quartz phenocrysts and altered sericitised potash feldspars occur in the cryptocrystalline groundmass, Sharma (1992). The granites of Tosham and Jhunjhunu have revealed mineralisation of tin.

Mineral Chemistry

The average major element composition and other parameters of the biotites from the granites of Jalor, Tosham and Jhunjhunu complexes are given in Table 1. In all 16 analyses (11 for J1 and 5 for J4) 24 analyses (7 for D1,

Table 1. Mineral Chemistry of Biotite Samples (EPMA)

Rock	J1	SD	J1	SD	J4	SD	D1	SD	K2	SD	K8	SD	K8	SD	KH17	SD	KH17	NP1	NP1	MK1	SD
SiO_2	34.49	1.07	26.36	0.57	34.34	0.76	35.45	0.35	36.80	0.33	27.65	0.64	26.46	1.02	35.55	0.35	26.27	28.46	34.47	24.08	0.66
TiO_2	3.46	0.39	0.31	0.19	3.09	0.21	2.85	0.38	3.38	0.15	0.03	0.00	0.01	0.01	3.15	0.14	0.14	0.09	0.06	0.07	0.05
Al_2O_3	12.74	0.36	15.91	0.70	12.26	0.13	12.36	0.48	11.58	0.30	17.00	0.79	17.00	1.15	13.32	0.13	17.08	16.10	16.60	18.83	0.51
FeO*	29.33	0.93	37.51	0.38	29.96	0.24	29.32	0.65	23.64	1.15	29.90	0.31	33.59	1.49	26.12	0.33	33.15	24.75	21.79	38.54	0.54
MnO	0.55	0.11	0.63	0.10	0.42	0.07	0.44	0.04	0.24	0.04	0.85	0.12	0.96	0.01	0.42	0.07	0.58	0.54	0.55	1.38	0.11
MgO	3.63	0.36	4.88	0.53	4.73	0.24	4.63	0.56	9.05	0.65	6.86	0.21	6.83	2.04	6.44	0.12	9.33	14.99	10.27	3.96	0.39
CaO	0.05	0.04	0.19	0.08	0.08	0.08	0.05	0.02	0.08	0.05	0.27	0.02	0.18	0.14	0.04	0.03	0.07	0.20	0.16	0.07	0.05
Na_2O	0.09	0.08	0.08	0.02	0.10	0.01	0.15	0.05	0.11	0.02	0.06	0.00	0.04	0.04	0.09	0.04	0.04	0.02	0.27	0.04	0.06
K_2O	8.00	0.85	0.60	0.36	8.27	0.13	8.35	0.78	0.83	0.27	0.77	0.24	0.41	0.35	8.94	0.24	0.08	0.12	0.01	0.11	0.16
Total	**92.34**		**86.47**		**93.25**		**93.59**		**93.71**		**83.40**		**85.48**		**94.02**		**86.74**	**85.27**	**86.18**	**87.81**	
									Number of Cations based on 24(O.OH)												
Si	4.90		3.80		4.96		5.42		5.58		3.91		3.83		5.27		3.71	4.04	4.01	3.49	
Al^{iv}	2.14		2.72		2.22		2.22		1.93		2.69		2.81		2.49		2.84	1.78	1.81	3.20	
Ti	0.35		0.06		0.35		0.32		0.37		0.00		0.00		0.36		0.42	0.00	0.00	0.01	
Al^{vi}	0.96		1.47		0.97		0.32		0.46		1.41		1.39		0.25		1.43	2.18	2.18	1.30	
Fe^{2+}	3.55		4.51		3.85		3.75		2.96		3.35		3.94		3.47		3.92	2.92	2.10	4.05	
Mg	0.77		1.05		1.09		1.06		2.05		1.39		1.57		1.35		1.98	0.31	0.26	0.86	
Y	4.38		5.64		5.00		4.80		5.07		4.85		5.49		4.84		5.96	3.55	3.12	5.66	
Ca	0.006		0.025		0.009		0.006		0.009		0.225		0.025		0.005		0.008	0.005	0.001	0.009	
Na	0.008		0.043		0.024		0.033		0.020		0.005		0.004		0.071		0.010	0.004	0.006	0.005	
K	1.45		0.10		1.90		1.62		1.43		0.10		0.30		1.83		0.01	0.01	0.00	0.01	
X	1.67		0.09		1.93		1.73		1.46		0.33		0.35		1.89		0.03	0.02	0.02	0.03	
OH	7.34		13.04		7.81		6.86		6.56		7.47		6.78		6.28		12.56	13.96	12.76	12.46	
X_{Mg}	0.52		0.20		0.22		0.22		0.46		0.29		0.27		0.28		0.33	0.99	0.05	0.65	
Fe/Mg	4.44		4.33		3.78		3.56		1.48		2.41		3.14		2.72		1.97	9.15	8.04	5.44	
XAl^{vi}	0.82		0.28		0.22		0.12		0.19		0.35		0.33		0.08		0.71	0.47	0.55	0.29	

J1, J4 = Jalor Samples; D1, K2, K8, KH17 = Tosham Samples; NP1, MK1 = Jhunjhunu Samples; SD = Standard Deviation; Other Table details are mentioned in the text.

* Total Fe as FeO

6 for K2, 4 for KH8 and 7 for KH17) and 8 analyses (2 for NP1 and 6 for MK1) were obtained for Jalor, Tosham and Jhunjhunu representative samples of biotites. The compositions of individual samples which do not reveal significant variation are averaged and presented in Table 1. SD values of different compositions are also given. Single compositional analyses of the individual samples which could not be grouped because of variations are also presented for comparison. A few biotite compositions which show low totals reveal enrichment in FeO* (iron total). On the whole higher values of TiO_2 and FeO* are deciphered in most of the composition. This could probably be related to the annite-rich nature of the biotites. The average value of Al_2O_3, FeO* and MgO for the three areas are, Jalor: (12.93, 29.26, 4.35), Tosham (13.69, 27.95, 6.84), Jhunjhunu (17.59, 30.90, 8.29) respectively. The average FeO*/MgO ratios for Jalor, Tosham and Jhunjhunu are 6.72, 4.08 and 3.72 respectively. It is observed that the FeO*/MgO for Jalor sample show highest values followed by Tosham and Jhunjhunu samples. Al_2O_3 and MgO for the two igneous complexes of Tosham and Jhunjhunu are higher than that of Jalor. However, in such case the FeO* for Tosham and Jhunjhunu should have been lower, but this is not the case and in these two complexes the biotite reveals almost comparable proportions with that of Jalor for FeO* values. The data further reveals that in CaO, Na_2O and MnO there is an overall deficiency whereas K_2O shows enhanced trend in all the samples.

The chemical composition of biotite mineral has been used as an indicator of tectonic setting and the nature and the physicochemical conditions of magma from which it is formed, Abdel-Rahman (1994). The biotite minerals (*op. cit.*) on the basis of their composition from various igneous suites exhibit three new compositional fields representing three magmatic rock groups *viz.* anorogenic extensional related alkaline rock, calc-alkaline I-type orogenic suites, and peraluminous including S-type rocks.

The role of FeO*-MgO-Al_2O_3 in the biotite composition of Jalor, Tosham and Jhunjhunu can be visualised in the discrimination triangular plot (Fig. 1). Almost all the samples from Jalor, Tosham and Jhunjhunu fall in the field–A, representing anorogenic extensional related tectonic environment for rock groups containing biotites (Abdel-Rahman, 1994). Biotites in this field are conspicuously

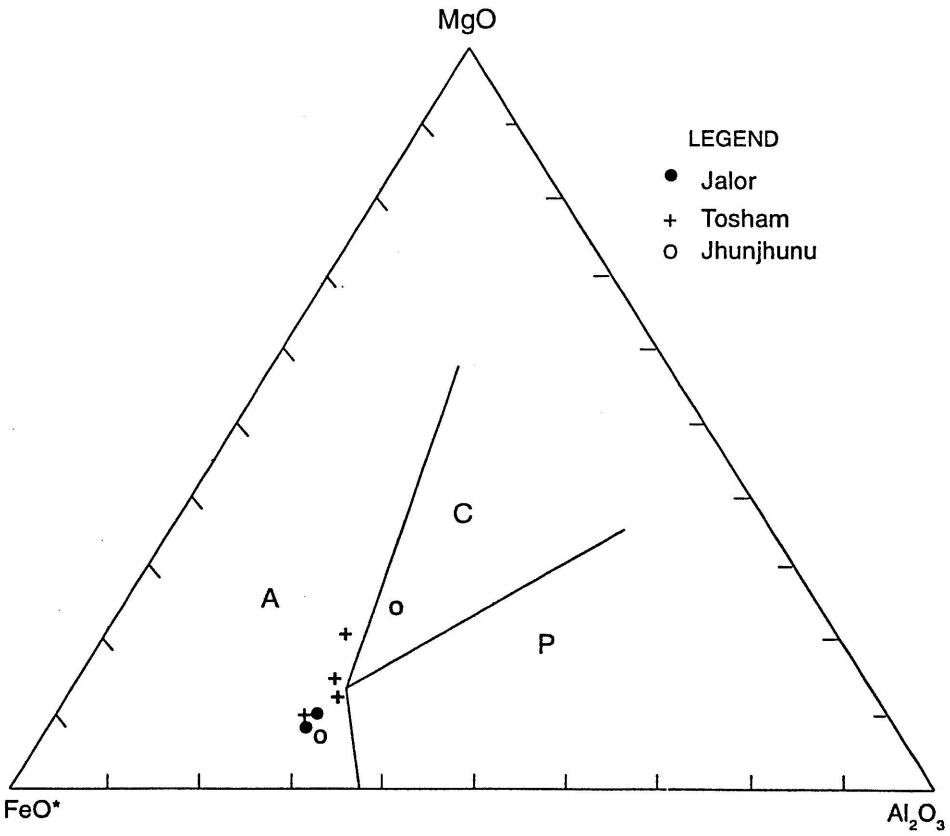

Fig.1. Feo*–MgO–Al_2O_3 diagram for biotite. **Field A**: Anorogenic alkaline suites, A-type; **Field C**: Calc-alkaline suite, I - type; **Field P**: Peraluminous suite, S-type; Fields after Abdel-Rahman (1994).

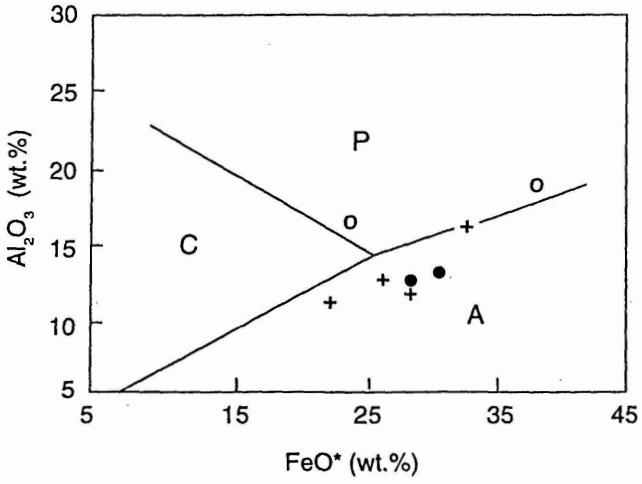

Fig.2. FeO*–Al_2O_3 diagram. Fields and symbols as in Fig.1.

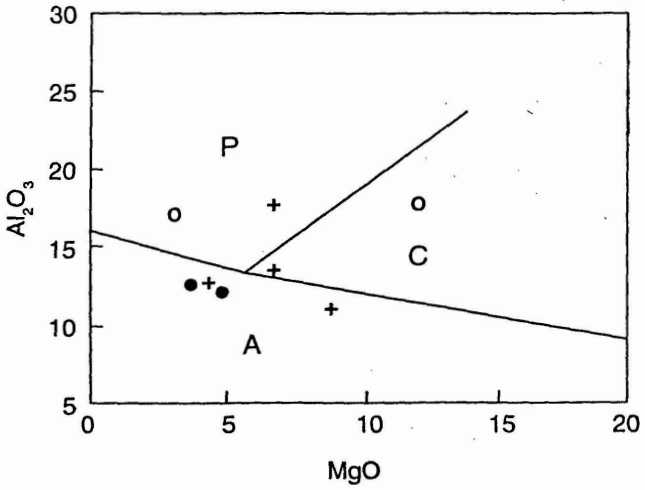

Fig.3. MgO–Al_2O_3 diagram. Fields and symbols as in Fig.1.

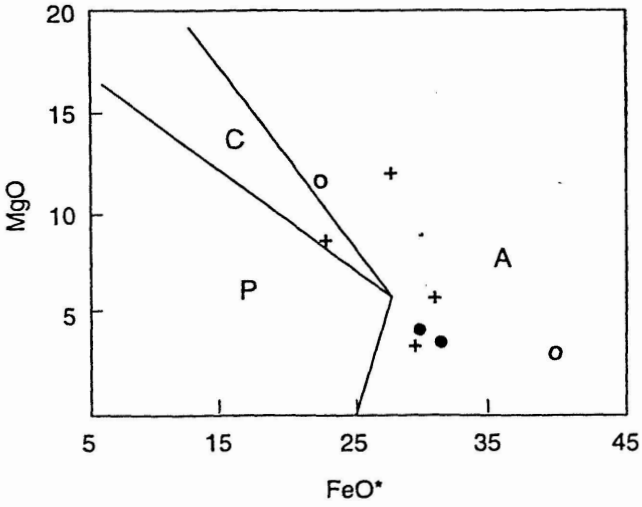

Fig.4. FeO*–MgO diagram. Fields and symbols as in Fig.1.

iron-rich and are typically associated with alkali-amphibole, alkali-pyroxene and/or fayalite. A similar kind of mineralogy is quite common in the Jalor granite in which fayalite has been reported (Dhar 1990, Kochhar and Dhar 1993). Depletion of MgO is evidently seen in all the samples. However those samples having higher FeO*, substantial depletion of MgO is deciphered. Hint of negative correlation between FeO* and MgO is observed in the plot. A similar iron enrichment trend in the amphiboles of Jalor granites have been observed (Dhar and Kochhar, 1997).

In Fig.2, the variation between FeO* and Al_2O_3 is seen and again in this plot almost all the samples plot in the anorogenic-extensional field. The two Jhunjhunu samples which show slightly higher proportions of Al_2O_3 plot outside but close to the A-type field. The variation plot further suggests $2Al \leftrightharpoons 3Fe^{2+}$ substitution to be more significant in the evolution and composition of the biotites. Compared to Jalor and Tosham samples, the Jhunjhunu samples are less depleted in Al_2O_3. In the MgO-Al_2O_3 diagram (Fig.3) most of the samples plot in the A-type anorogenic fields with the exception of Jhunjhunu and one Tosham sample. These are the samples which reveal slightly higher contents of Al_2O_3 compared to the other samples and do not signify any variation between MgO-Al_2O_3. But in the other samples which plot in A-type field, hint of $Mg \leftrightharpoons Al$ substitution is seen evidently. In the FeO*-MgO plot (Fig.4), barring one Tosham sample, all the values plot outside the P and C field of Abdel-Rahman (1994) and show characteristic anorogenic trend. Higher FeO*/MgO ratio (6.72) for Jalor samples are very well deciphered. A general negative correlation trends is observed in all the samples, suggesting FeO* $\leftrightharpoons$ MgO substitution as one of the influencing factor for the evolution of biotite composition.

Conclusions

From the variation diagrams it is evident that the enrichment of iron is the dominant influencing factor which governs the discrimination of the A - P and S fields of Abdel-Rahman (1994). However, the roles of Al_2O_3 and MgO is no less significant. Iron-rich trends are generally produced largely owing to a delay in the crystallisation of iron-oxides and iron titanium oxides, which form only late in the fractionation sequence. It would be pertinent to note that biotites of the study area are annite rich and reveal to have some kind of reaction relationship with the iron-oxides. Further, the scarcity of water affects the availability of free oxygen and in turn causes a delay in the crystallisation of iron-oxides and iron titanium oxides, thus producing iron-enrichment trends. Biotites that crystallise from such melts are iron-rich (Abdel-Rahman, 1994; Dhar, 1990 and Sharma,

1992). For Jalor the iron-enrichment trend (FeO*/MgO ratio = 6.72) is largely as a result of the above phenomena. The lower FeO*/MgO ratios of 4.08 and 3.72 for Tosham and Jhunjhunu respectively are due to slightly higher MgO contents in the biotites. However, this feature does not affect the enhanced proportions of iron in the biotite composition of these two complexes. This also reflects the inherent enrichment of iron in the magmas of the two complexes as well and perhaps a role of 3Mg ⇌ Al substitution rather than Mg ⇌ Fe substitution in the Tosham and Jhunjhunu trends. The iron enrichment in Jalor samples is at the expense of the both Mg and Al and involves substitution scheme Mg ⇌ Fe and 2Al ⇌ $3Fe^{2+}$ in the octahedral sites.

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