

III. GEOLOGY

Petrology

BIOTITES FROM THE OLDER METAMORPHIC TONALITE-GNEISS AND THE SINGHBHUM GRANITE, EASTERN INDIA

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Biotites from the older metamorphic group tonalite-gneiss and the Singhbhum granite (phase II and phase III) were studied by optical, chemical and X-ray diffraction methods. Oxygen fugacities of the biotites of the OMG tonalites followed an approximate 'buffer' curve during crystallisation in between those of Ni-NiO and $\text{Fe}_3\text{O}_4\text{-Fe}_2\text{O}_3$ buffers, while those of Singhbhum granite crystallised under variable f_{O_2} conditions, sometimes at f_{O_2} exceeding that for $\text{Fe}_3\text{O}_4\text{-Fe}_2\text{O}_3$ buffer. The biotites from OMG tonalite and Singhbhum granite have distinctive oxidation state, degree of R^{2+} atomic substitution and $\text{Fe}/(\text{Fe} + \text{Mg})$ ratio. They can be efficiently discriminated quantitatively by using the Linear Discriminate Function, $Z = 4.044A + 5.000B - 3.425$, where A is $\text{Fe}/(\text{Fe} + \text{Mg})$, B is $\text{Fe}^{3+}/(\text{Fe}^{2+} + \text{Fe}^{3+})$ and Z is negative for OMG biotites and Z is positive for biotites of Singhbhum granite.

Key words: Biotite; Linear discriminant function; Oxygen fugacity; OMG tonalite-gneiss; Singhbhum granite.

INTRODUCTION

SAHA (1966, 1972) showed that the large Precambrian batholithic mass of Singhbhum Granitic Complex consists in the main of (a) an old (3200 Ma) tonalitic granodioritic gneiss (called Older Metamorphic Group Gneiss), (b) three phases of magmatic intrusions (2900-3000 Ma), which were emplaced in at least twelve late- to post-tectonic, epizonal-mesozonal intrusions and (c) several isolated patches of granitised metabasics associated with these intrusive phases. The last two groups of granitic rocks are designated as Singhbhum Granite. Distinctive modal, major-element and trace-element characteristics for the above-noted members of this granitic complex have been described elsewhere (Saha, 1972; Saha & Rao, 1971; and Sarkar & Saha, 1977).

In this paper, an attempt has been made to (a) study the compositional variations of biotite in the OMG tonalite-gneiss and in phase II and phase III units of the Singhbhum granite, and (b) to obtain generalised idea regarding the P-T conditions of the crystallisation of the granites belonging to the Older Metamorphic and the Iron Ore orogenic cycles (cf. Sarkar & Saha, 1977). Since biotite is the

chief ferromagnesian mineral in both OMG tonalite-gneiss and Singhbhum granite, the petrogenesis of biotite has been utilised as a tool for determining the P-T conditions of formation of granitoids. Biotites from the phase I units of Singhbhum granite could not be included for this study as biotite in this unit is largely chloritised and such biotites have not yet been analysed in the absence of electron probe micro-analysis facilities. For phase II and phase III, Besoi-Asana-Manda (unit XII) and Gamaria-Khorband-Maluka (unit VIII) respectively were considered as representative units for the purpose of this study (Fig. 1).

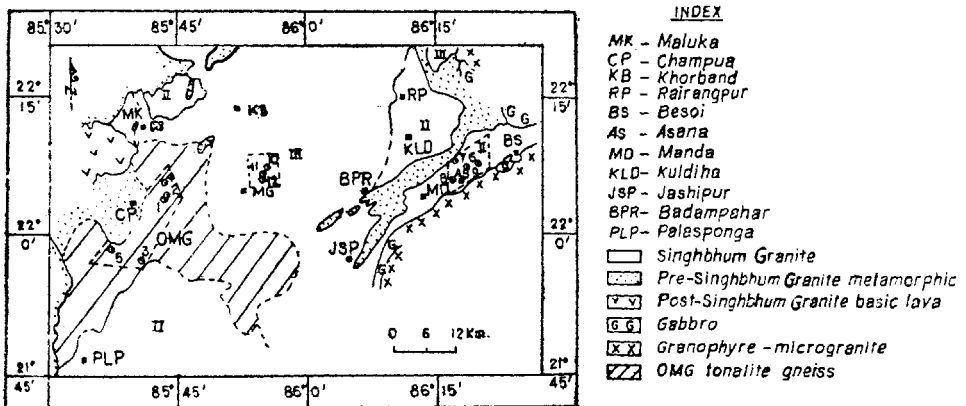


FIG. 1. Geological map of Singhbhum-Keonjhar-Mayurbhanj districts showing the location of the studied areas and the samples. (after Sarkar & Saha, 1977).

OCCURRENCE OF BIOTITES

Out of twelve samples, five biotites are from OMG tonalite-gneiss of Champua area, four from Singhbhum granite (phase II) of Asana area and three from Singhbhum granite (phase III) of Majhgaon area (Fig. 1). The mode of occurrence, association alteration, pleochroism and R.I. are shown in Table I.

METHOD OF SEPARATION AND ANALYSIS

Selected rock samples were crushed, sieved to +120 -80 mesh, and made magnetite-free with a hand magnet and then the biotites were separated by means of Franz isodynamic separator. Finally the sample was hand picked to obtain biotite with 99 per cent purity.

Major elements and a few minor elements (in % level) were determined by 'Rapid Methods' (Shapiro & Brannock, 1962); EDTA titration for CaO and MgO, KMnO_4 titration for FeO and Flame photometry for K_2O and Na_2O were employed. Four times dilution of sample solution was made during total iron estimation by spectrophotometry in order to eliminate the effect of excess iron present in biotite.

COMPOSITION OF BIOTITES

The results of the twelve biotite analyses are shown in Table II in order of increasing

TABLE I
Optical and other characters of the biotites
 (Figures in parentheses indicate number of samples studied)

	OMG tonalite-gneiss (50)	Singhbhum granite Phase II (30)	Singhbhum granite Phase III (10)
Rock type	Biotite-tonalite gneiss, medium grained	Coarse biotite granodi- orite, granite and augen gneiss	Coarse to medium bio- tite granite
Biotite content in rock (volume%)	3.5-18.3	3.4-7.7	2.4-4.7
Pleochroism	Light yellowish brown to dark brown $X < Y = Z$	Straw yellow to deep brown and green $X < Y = Z$	Light brown to reddish brown $X < Y = Z$
R.I. (N_g)	1.624-1.655	1.620-1.634	1.637-1.642
Mode of occurrence	As discrete flaky grains	As recrystallised mosaic- like aggregate and in- dividual flakes	As discrete flaky grains
Mode of association	Mainly with plagioc- lase; other mafics are epidote chlorite and rare hornblende	With quartz and plagioc- lase; other mafics are epidote, magnetite, apa- tite and rarely horn- blende	With both alkali felds- par and plagioclase; other mafics are epi- dote, muscovite and chlorite
Alteration	Slightly altered to chlo- rite	Inter-laminated biotite- chlorite and along mar- gins	Alteration along cleav- age and margin

100 Mg/(Mg + Fe²⁺ + Fe³⁺ + Mn). The data have been discussed with the help of the following variation diagrams and parameters:—

1. The ternary diagram, (FeO + MnO) — (Fe₂O₃ + TiO₂) — MgO (Heinrich, 1946) shows that all the plots lie in the field restricted between diorite and granite. This suggests that the major element composition of the biotites is not of any unusual character (Fig. 2).
2. The Al₂O₃-FeO-MgO diagram (Nockolds & Mitchell, 1948) indicates only minor differentiation during the crystallization in all the three individual units and the general trend of differentiation appears to be from MgO-rich to relatively FeO-rich (Fig. 3).
3. While biotite is the only ferromagnesian mineral in calc-alkaline suite of rocks, the average contents of (Fe as FeO)/MgO, Fe₂O₃/FeO and Na₂O/K₂O parameters (Nockolds, 1947) should be 3.05, 0.14 and 0.07 respectively. In the context of these data, biotites of the tonalite suite and the phase II unit have less than normal Fe as FeO/MgO while this ratio for phase III unit is higher than normal; Fe₂O₃/FeO ratio and Na₂O/K₂O ratio are generally higher than normal in all the three units.

TABLE II
Analysis of biotites

	1	2	3	4	5	6	7	8	9	10	11	12
SiO ₂	36.23	34.67	37.78	36.08	36.74	33.87	34.95	35.20	37.12	37.71	38.80	36.71
Al ₂ O ₃	16.05	16.55	15.58	15.74	15.74	15.59	16.35	14.75	15.25	16.92	16.00	16.00
TiO ₂	2.44	2.44	3.58	2.59	2.49	1.99	2.38	3.10	1.98	2.21	1.64	2.19
Fe ₂ O ₃	4.50	5.35	4.05	5.05	4.65	8.68	11.38	8.07	6.32	6.08	6.01	5.11
FeO	19.93	18.95	18.16	18.55	17.02	19.26	14.50	15.52	15.37	18.92	18.66	21.63
MgO	8.82	9.06	8.50	9.62	11.40	8.58	10.22	10.38	11.40	5.22	6.12	6.38
CaO	0.68	0.73	1.12	1.13	0.34	0.91	0.58	0.36	0.77	1.07	1.72	1.37
Na ₂ O	0.54	1.02	0.44	0.66	0.52	0.55	0.53	0.62	1.44	0.40	1.14	0.51
K ₂ O	7.70	8.10	8.07	7.78	7.63	7.57	7.95	7.65	8.67	7.51	6.89	7.31
MnO	0.36	0.48	0.21	0.36	0.26	0.29	0.13	0.13	0.30	0.29	0.50	0.65
H ₂ O ⁺	3.13	3.23	2.32	2.12	3.01	2.15	1.35	2.75	1.80	2.55	2.54	2.10
H ₂ O ⁻	n.d.	n.d.	n.d.	n.d.	n.d.	0.62	0.54	0.53	0.40	n.d.	n.d.	n.d.
Total	100.38	100.58	99.81	99.68	99.80	99.55	99.86	99.06	100.82	98.87	100.02	100.03
Fe/Fe + Mg	0.604	0.596	0.591	0.573	0.510	0.638	0.577	0.552	0.509	0.724	0.698	0.688

1. Sp. No. SR/14 of OMG tonalite gneiss, northeast of Champua

2. Sp. No. SR/7A of OMG tonalite gneiss, east of Champua

3. Sp. No. SR/211 of OMG tonalite gneiss, SSW of Champua

4. Sp. No. SR/103 of OMG tonalite gneiss, northeast of Champua

5. Sp. No. SR/160 of OMG tonalite gneiss, northeast of 3

6. Sp. No. 279 of coarse biotite granite, east of Asana

7. Sp. No. 99 of Augen gneiss, near Chaspani, NNW of Asana

8. Sp. No. 93 of coarse biotite granodiorite, north of Asana

9. Sp. No. 172 of coarse biotite granodiorite, West of Asana

10. Sp. No. KS/70 of medium grained biotite granite, northeast of Majhgaon

11. Sp. No. KS/132 of medium grained biotite granite, northeast of Majhgaon

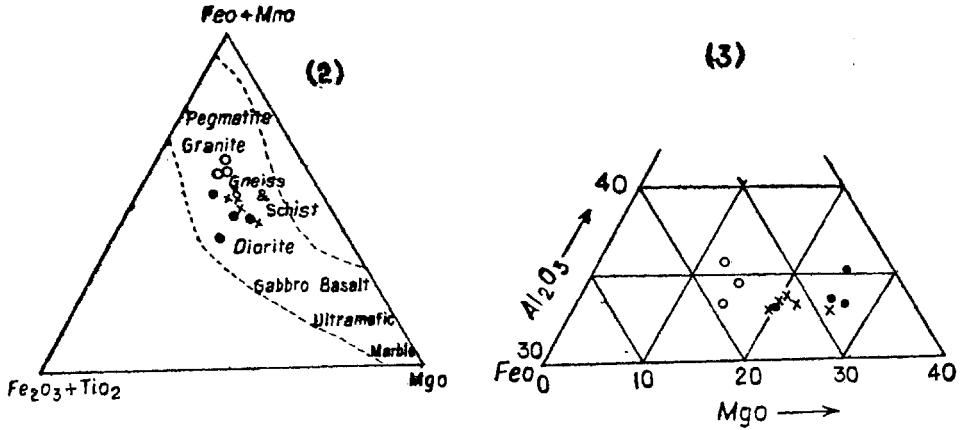
12. Sp. No. KS/128 of medium grained biotite granite, northeast of Majhgaon

n.d.—no data

Analyst : S.L. Ray

Analyst : S. Ghosh

Analyst : S. L. Ray



Figs. 2-3. 2. (FeO + MnO)-(Fe₂O₃ + TiO₂)-MgO variation diagram (after Heinrich, 1946). Crosses, dots and circles stand for biotites of OMG, Singhbhum Granite phase II and phase III respectively for all the diagrams. 3. Al₂O₃-MgO-FeO variation diagram (after Nockolds *et al.*, 1948).

STRUCTURAL FORMULA

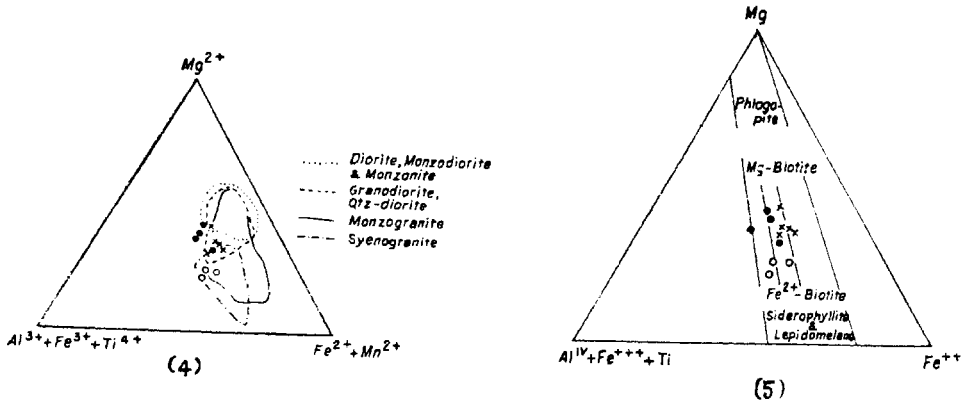
The general formula of micas to which biotite belongs is $X_2 Y_{4-6} Z_8 O_{20} (OH, F)_4$ and structural formulae calculated here on the basis of 24(O, OH) are given in Table III. Three types of coordination-tetrahedral (4-fold), octahedral (6-fold) and dodecahedral (12-fold) are present in biotite structure. The tetrahedrally co-ordinated Z-cations consist of Si and Al^{IV} and the greater part of Al which varies between 2.04 and 2.66 in the present case, is in tetrahedral co-ordination. The octahedrally co-ordinated Y-cations range between 5.60 and 6.25 in comparison to 6.00 in idealised trioctahedral mica. Twelve co-ordinated large cations of the X group range between 1.70 and 2.27 and only in two cases do they exceed the ideal condition of 2.00 atoms. However, in no case, Na exceeds 0.5 atoms per formula unit while K-ion constitutes a maximum up to 87 per cent of X group of cations.

Since Y group of cations largely consists of Mg, Fe²⁺ and Fe³⁺ with lesser amounts of Al^{VI}, Ti and Mn, the variation between members of the Y group of cations and amongst different granitoid units are summarised with the help of the several variation diagrams and parameters as follows:—

1. The Mg²⁺-(Fe²⁺ + Mn)-(Al^{VI} + Fe³⁺ + Ti) diagram (Neilsen *et al.*, 1973) shows that the plots for the OMG tonalites lie in Granodiorite-Quartzdiorite field while these for phase II units show a close affinity to the above (Fig. 4). But biotites in phase III unit fall in the field of Syenogranite. From the view point of structural order, biotites from phase II and OMG units are relatively Mg²⁺-rich with respect to those in phase III while the phase II and phase III biotites are relatively (Al^{VI} + Fe³⁺ + Ti)-rich in comparison with the biotites from OMG tonalites.
2. In the Mg-Fe²⁺-(Al^{VI} + Fe³⁺ + Ti) diagram (Dodge *et al.*, 1969), all plots except one fall within the field of biotite and show trends from Mg-rich biotite

TABLE III
Structural formulae on the basis of 24(O, OH) and some parameters of biotites

	1	2	3	4	5	6	7	8	9	10	11	12
Si	5.56	5.34	5.83	5.64	5.60	5.40	5.47	5.49	5.74	5.87	5.77	5.96
Al ^{IV}	2.44	2.66	2.17	2.36	2.40	2.60	2.53	2.51	2.26	2.13	2.23	2.04
Z	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al ^{IV}	0.46	0.35	0.66	0.54	0.43	0.33	0.49	0.20	0.52	0.97	0.75	0.86
Fe ⁺⁺⁺	0.52	0.62	0.47	0.52	0.53	1.04	1.34	0.95	0.74	0.71	0.60	0.69
Ti	0.28	0.28	0.42	0.30	0.29	0.24	0.28	0.36	0.23	0.26	0.26	0.19
Mg	2.02	2.08	1.95	2.24	2.59	2.04	2.38	2.41	2.63	1.21	1.49	1.40
Fe ⁺⁺	2.56	2.44	2.34	2.42	2.17	2.56	1.90	2.02	1.99	2.46	2.84	2.40
Mn	0.05	0.06	0.03	0.05	0.03	0.04	0.02	0.02	0.04	0.04	0.09	0.06
Y	5.89	5.83	5.87	6.14	6.04	6.25	6.41	5.76	6.15	5.69	6.03	5.60
Ca	0.11	0.12	0.19	0.19	0.06	0.16	0.10	0.06	0.13	0.09	0.23	0.28
Na	0.16	0.31	0.13	0.20	0.15	0.17	0.16	0.19	0.43	0.12	0.19	0.34
K	1.51	1.59	1.59	1.55	1.48	1.54	1.59	1.52	1.71	1.49	1.47	1.35
X	1.78	2.02	1.91	1.94	1.69	1.87	1.85	1.77	2.27	1.70	1.85	1.97
OH	3.21	3.32	2.39	2.21	3.06	2.28	1.41	2.86	1.85	2.65	2.20	2.60
Fe ³⁺ /(Fe ²⁺ + Fe ³⁺)	0.17	0.20	0.17	0.20	0.20	0.29	0.41	0.32	0.27	0.22	0.17	0.22
R ²⁺ /Total octahedral ions	0.79	0.79	0.74	0.77	0.79	0.74	0.67	0.77	0.76	0.66	0.73	0.69
100 Mg/(Mg + Fe ²⁺ + Fe ³⁺ + Mn)	39.22	40.00	40.80	42.26	48.68	23.31	28.21	30.44	34.14	27.38	29.68	30.77



FIGS. 4-5. 4. Mg^{2+} -($Fe^{2+} + Mn^{2+}$)-(Al^{VI} + Fe^{3+} + Ti) variation diagram (after Neilson *et al.*, 1973). 5. Mg- Fe^{2+} -(Al^{VI} + Fe^{3+} + Ti) variation diagram (after Dodge *et al.*, 1969).

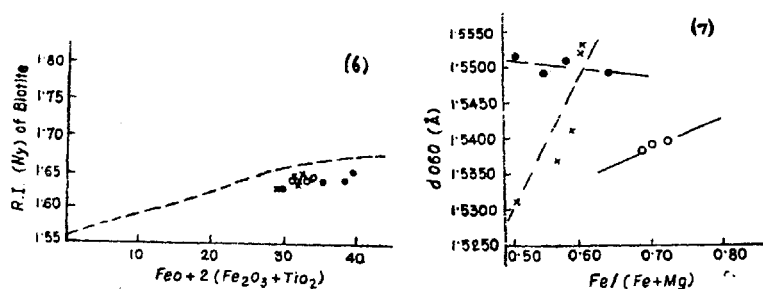
to Fe-rich biotite (Fig. 5). The trend of OMG tonalite is comparable with that of Sierran biotites while the biotites from both phases of Singhbhum Granite show a single common trend in which phase II members are relatively Mg-rich and phase III members are relatively Fe-rich. The biotite sample which plots just outside the biotite field of Dodge *et al.* (1969) belongs to an augen-gneiss member of phase II and this abnormality could be an effect of recrystallisation.

3. Deer (1937) found in Carsphairn Igneous Complex that biotites from more and more acid parent rocks have higher Fe^{2+}/Mg and R^{3+}/R^{2+} ratios. The average of Fe^{2+}/Mg and R^{3+}/R^{2+} for biotites of granitic rocks are 0.91 and 0.40 respectively. The mean values of the above ratios in the biotites of the three units of granitic rocks here indicate an increasing trend from OMG tonalites (1.11, 0.29) to phase III (1.88, 0.44) through phase II (0.91, 0.40).
4. Atomic substitution takes place more in the octahedral site and in biotites generally Mg^{2+} is replaced by Fe^{2+} and also by trivalent (Fe^{3+} , Al^{3+}) atoms; hence the parameter (octahedral R^{2+} ions)/(total octahedral ions per formula unit) ratio is a useful index to quantify the degree of displaced R^{2+} cations and the proxying R^{3+} cations in octahedral site. It is interesting to note (Table III) that the degree of atomic substitution (octahedral R^{2+})/(total octahedral ions per formula unit) is low (0.78) in OMG tonalite, relatively high (0.73) in phase II and highest (0.69) in phase III units of Singhbhum granite.
5. The $Fe^{3+}/(Fe^{2+} + Fe^{3+})$ ratio of biotites is low in OMG tonalites (0.17-0.22) while it is relatively high in phase II unit (0.27-0.41). The mean oxidation ratio of host rocks (after Chinner, 1960) from available analyses are 0.313, 0.469 and 0.490 respectively for OMG tonalite, phase II and phase III units. This fact suggests that the state of oxidation in biotites is comparable to that

in host rocks oxidation ratio and that the state of oxidation increases with younger intrusive phases.

OPTICAL PROPERTIES

The pleochroism, R.I. (N_v) of biotites are shown in Table I. The relationship between R.I. and chemical composition of biotite has been studied by various workers. Heinrich (1946) suggests that the effect of ferric iron in raising R.I. of biotite is approximately twice that of ferrous iron and about the same as that of titanium, although replacement of all (OH) by *F* lowers N_v by 0.22. In $\text{FeO} + 2(\text{Fe}_2\text{O}_3 + \text{TiO}_2)$ vs. R.I. diagram (Fig. 6) after Heinrich (1946), all the plots closely follow the above relationship and support Heinrich's conclusion.



FIGS. 6-7. 6. Relationship between R.I. (N_v) of biotite and $\text{FeO} + 2(\text{Fe}_2\text{O}_3 + \text{TiO}_2)$ in biotite (after Heinrich, 1946). 7. Relationship between $\text{Fe}/(\text{Fe} + \text{Mg})$ and d_{060} (Å) in biotites (after Wones, 1963).

X-RAY PROPERTIES

The biotite samples were studied by powder X-ray diffraction technique using Co-radiation and Fe-filter. From d_{060} spacings between 1.53 Å and 1.55 Å and weak basal reflection, all the biotites under study are presumed to belong to 1M polymorph of trioctahedral micas (Deer *et al.*, 1962).

Since almost all the non-basal reflections are doublets, in the present study (004), (005), (201) and (060) lines are used for calculating the cell parameters a , b , c , and β , considering $b/a = \sqrt{3}$ as constant Dodge *et al.* (1969, p. 263). The cell volume and other cell-parameters are given in Table IV. The relationship between X-ray parameters and chemical-structural parameters is discussed below :—

1. Gower (1957) suggested that the Fe/Mg ratio in biotite may be determined with ± 5 per cent accuracy measuring the intensity ratio of (004) to (005) and this ratio is highly sensitive to Fe/Mg substitution and is virtually unaffected by other substitutions. Accordingly, Fe per cent in octahedral sites was determined from I_{004}/I_{005} ratios and compared with the Fe per cent in octahedral sites determined from chemical analysis. Gower (1957) observes that $c \sin \beta$ is inversely proportional to Fe per cent in octahedral sites while the cell edges ' a ' and ' b ' are independent of iron content. The

TABLE IV
X-ray properties and some parameters of the biotites

Sam- ple Nos.	d_{004}	d_{101}	d_{005}	d_{040}	I_{010}^{004}	Fe% in octa- hedral sites		a (\AA)	b (\AA)	c (\AA)	β	Cell Volume (\AA^3)	$c \sin \beta$	Fe Fe + Mg (chemical)
	(\AA)	(\AA)	(\AA)	(\AA)	I_{005}^{005}	X-ray	Chemical							
1.	2.544	2.465	2.023	1.553	0.87	50.0	52.3	5.380	9.318	10.263	99.72	507.11	10.1160	0.604
2.	2.550	2.473	2.039	1.552	0.91	53.5	52.8	5.377	9.313	10.331	99.24	510.56	10.1965	0.596
3.	2.510	2.462	2.004	1.541	0.83	47.0	47.9	5.341	9.251	10.140	98.74	495.20	10.0220	0.591
4.	2.503	2.443	2.000	1.537	0.87	50.0	49.0	5.323	9.220	10.139	99.43	490.87	10.0020	0.573
5.	2.509	2.445	2.002	1.531	0.81	45.0	44.7	5.304	9.186	10.129	98.76	487.71	10.0105	0.510
6.	2.535	2.454	2.010	1.549	0.90	52.0	57.6	5.367	0.295	10.153	100.02	503.76	10.0985	0.638
7.	2.541	2.467	2.027	1.550	0.73	53.0	50.5	5.370	9.301	10.269	99.32	506.15	10.0133	0.577
8.	2.530	2.454	2.002	1.549	0.83	47.0	51.5	5.367	9.295	10.163	99.89	499.42	10.0105	0.552
9.	2.537	2.459	2.028	1.551	0.68	39.0	44.3	5.375	9.309	10.298	99.98	507.46	10.1425	0.509
10.	2.509	2.451	2.010	1.531	0.94	56.0	56.1	5.333	9.236	10.271	100.51	497.44	10.0990	0.724
11.	2.518	2.440	2.013	1.539	0.91	53.0	57.0	5.331	9.234	10.216	99.91	495.45	10.0640	0.698
12.	2.523	2.467	2.007	1.538	0.92	54.0	55.2	5.328	9.228	10.165	99.15	499.82	10.0365	0.688

present data show overall non-dependence among the I(004)/I(005) ratio, Fe/Mg ratio and $c \sin \beta$.

- Wones (1963) has shown the increase of d_{060} with increase in Fe/(Fe + Mg) ratio and this fact is supported by the biotites in both OMG tonalites and the phase III unit (Fig. 7). But for phase II unit d_{060} spacings are almost constant regardless of compositional variations and supports the conclusions drawn by Dodge *et al.* (1969) for Sierran biotites and Dhana Raju (1975) for Srikakulam biotites. It is also interesting to note that the increment rate of d_{060} with Fe/(Fe + Mg) is higher in OMG tonalites in comparison with that in phase III granites.
- Müller (1966) and Dodge *et al.* (1969) found a general decrease of d_{005} with increase in octahedral Al^{VI}. The present data shows the reverse relationship for phase II and near constancy of octahedral Al with increase of d_{005} spacings for the other units (Fig. 8).
- Considerable variations were noted in c and β parameters with a consequent variation in cell volume. The increase of volume with increase of Fe/(Fe + Mg) is expected theoretically. In the present case there is in general no such relationship—this observation tallies with those of Dodge *et al.* (1969) and Dhana Raju (1975). However in the case of OMG tonalites an increasing trend of cell volume with increasing Fe/(Fe + Mg) is evident (Fig. 9).

PETROGENESIS OF BIOTITES

Biotites on the join phlogopite-annite are formed by reaction among a number of phases and the reactions are governed by the independent intensive parameters viz. temperature (T), H_2O -fugacity (f_{H_2O}) and oxygen fugacity (f_{O_2}). The compositions of biotites in the ternary system, $K Fe_2^{3+} Al Si_3 O_{10} (OH)_2$ (annite)- $K Mg_2^{3+} Al Si_3 O_{10} (OH)_2$ (phlogopite)- $K Fe_3^{3+} Al Si_3 O_{12} (H_{-1})$ (oxybiotite) in co-existence with sandine-magnetite assemblage were experimentally determined for varying f_{H_2O} , f_{O_2} and T (Wones & Eugster, 1965). The Fe^{3+} - Fe^{2+} -Mg diagram (Wones & Eugster, 1965, Fig. 1) depicts the composition of biotite at different f_{O_2} as controlled by individual buffer equilibria viz. Fe_3O_4 - Fe_2O_3 ,

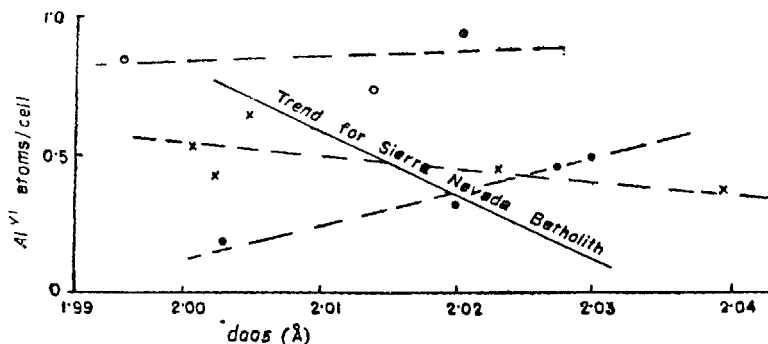


FIG. 8. Relationship between d_{005} (Å) and Al^{VI} atoms per cell in biotites (after Dodge *et al.*, 1969).

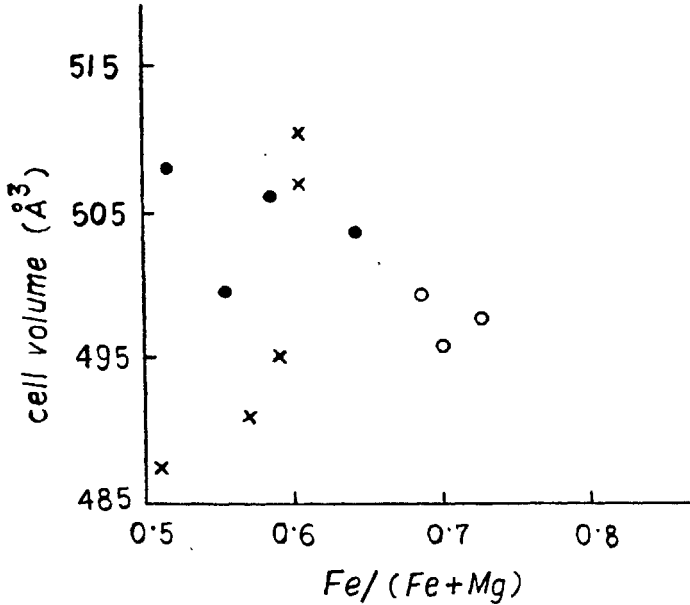


FIG. 9. Relationship between $Fe/(Fe + Mg)$ ratio and cell volume of biotites.

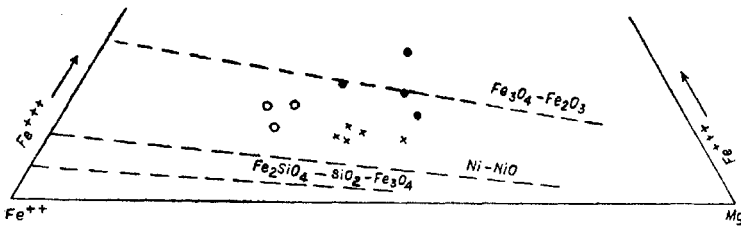


FIG. 10. Fe^{3+} - Fe^{2+} -Mg variation diagram (after Wones *et al.*, 1965) showing trend lines of different buffers and biotite compositions.

$Ni-NiO$ and $Fe_2SiO_4-SiO_2-Fe_3O_4$. The plots of the OMG biotites define the compositions with f_{O_2} slightly lower than that for $Fe_3O_4-Fe_2O_3$ buffer while the biotite compositions of Singhbhum Granite (phase II in particular) suggest f_{O_2} closely following that for the $Fe_3O_4-Fe_2O_3$ buffer (Fig. 10).

In general, this diagram implies that OMG tonalites crystallised under relatively lower f_{O_2} with respect to both the phases of the Singhbhum Granite. It is also interesting to note that the plots for the OMG biotites follow a linear trend which is parallel to those for the buffer equilibria—this suggests that crystallisation of biotites in the OMG tonalites occurred at approximately constant f_{O_2} . For the biotites of Singhbhum Granite there is no such regular trend.

Considering the mean $Fe/(Fe + Mg)$ values of biotites in the three suites of granitic rocks, comparison with experimental data indicates that biotites in the OMG

tonalites formed at $\log f_{O_2}$ ranging from -14.0 to -15.0 with temperature varying from 590°C to 770°C while biotites in the phase II of the Singhbhum Granite formed at $\log f_{O_2}$ and temperature around -15.0 and 590°C respectively and formation of biotites in the Singhbhum Granite phase III took place under $\log f_{O_2}$ ranging from -15.5 to -16.7 and temperature varying from 530°C to 730°C (approximate f_{O_2} and temperature ranges determined from Wones & Eugster, 1965, p. 1244, Fig. 4).

CONCLUSIONS

The biotites of the three suites can be distinguished qualitatively on the basis of three parameters viz., $\text{Fe}/(\text{Fe} + \text{Mg})$, $\text{Fe}^{3+}/(\text{Fe}^{2+} + \text{Fe}^{3+})$ and $(\text{octahedral } R^{2+})/(\text{total octahedral ions per formula unit})$.

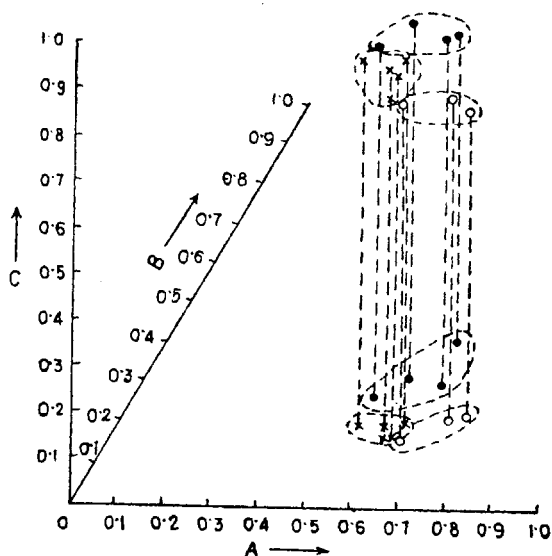


FIG. 11. Orthogonal ternary diagram showing relationships amongst $\text{Fe}/(\text{Fe} + \text{Mg})$, $\text{Fe}^{3+}/(\text{Fe}^{2+} + \text{Fe}^{3+})$ and Octahedral $R^{2+}/(\text{total octahedral ions per formula unit})$ ratios.

An orthogonal ternary diagram of the above parameters (Fig. 11) shows three distinct clusters and each suite is distinguishable from each other from this diagram. A Linear Discriminant Function (L.D.F.) has been computed (cf. Krumbein & Graybill, 1965) to discriminate between the biotites from OMG suite and Singhbhum suite, using the two major parameters,

$$A = \text{Fe}/(\text{Fe} + \text{Mg}) \text{ and } B = \text{Fe}^{3+}/(\text{Fe}^{2+} + \text{Fe}^{3+}).$$

The L.D.F. between OMG biotite and Singhbhum Granite biotite is $Z = 4.044A + 5.000B - 3.425$.

Using the above equation, there is one misfit out of the twelve data i.e. the efficiency of the function is 91.7 per cent. From the relative absolute magnitude of coefficients of variables in L.D.F. the relative contribution of each variable to

the discriminant function can be estimated, and it appears that the discriminant function between OMG tonalite gneiss and the Singhbhum granite is primarily controlled by $Fe^{3+}/(Fe^{2+} + Fe^{3+})$.

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