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ON THE HIGH-MAGNESIAN LAVAS OF THE DALMA METAVOLCANIC SEQUENCE OF SINGHBHUM DISTRICT, BIHAR

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Petrographic and chemical variation within the Dalma metavolcanic belt is manifested through development of Mg-rich lavas particularly constituting the basal part of the volcanic sequence. The rock types have been grouped with FM $\leqslant$ 65. The ultrabasic type includes tremolite-actinolite rock, the metabasalts are represented by amphibolites and pyroclastics embrace meta-tuffs and agglomerates. The chemical character of the ultrabasic members suggests a close resemblance with that of picrite. The metabasic members suggest tholeiitic parent magma while a komatiitic affinity is indicated by the volcanic clasts in agglomerates, developed between metabasalts and ultrabasic flow. An increase in normative feldspar and differentiation index (D.I.) is observed from base towards the upper part of the sequence.

Development of ultrabasic member at the initiation of Dalma Volcanism is in harmony with evolutionary history of ancient greenstone belts in general. Chemical data on the investigated Dalma metavolcanics strongly suggest an oceanic environment in a marginal basin tectonic setting.

Key Words : Dalma Volcanism; Dalma Trap; Ultrabasics; Magnesium Lavas

INTRODUCTION

A century ago, Ball[1] unravelled the Precambrian geology of Singhbhum. Subsequent regional work by Dunn and Dey[2] forms the basis of local as well as detailed investigations in this terrain.[3,4,5,6]

The volcanic sequence presently under study was named as 'Dalma Trap' by Ball.[1] It is an arcuate body (Fig. 1) extending for 192km from Singhbhum district in eastern Bihar to Ranchi district in western Bihar, confined between the Singhbhum granitic complex to the south and Chotanagpur granitic and granulitic terrain to the north. Though extensive field and laboratory studies have been carried out on the granitic rocks of Singhbhum, detailed studies on the petrology and geochemistry of the Dalma metavolcanic belt lying to the north of the granitic terrain (Fig. 1) have only recently been undertaken by different workers.[7,8]

Archaean greenstone belts are characterised by ultramafic lavas[9] compared to Phanerozoic volcanism. The tectonic setting for the Precambrian greenstone belts is considered equivalent to that in the marginal basins situated in the back arc region.[10,11] The Singhbhum metamorphic belt with associated metavolcanics has a

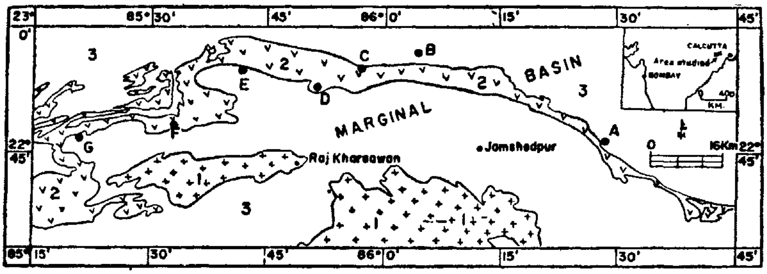

FIG. 1. Key map showing the extension of the Dalma volcanic belt, Singhbhum district, Bihar (after Dunn and Dey, 1942). Locations : A Kunchia, B Chandil, C Khunti, D Kunderkuti, E Sonapet Valley, F Hesadih, G Bano. 1 = Salic platform, 2 = Dalma volcanic belt. 3 = Marginal basin filled with volcaniclastics, clastics and volcanics. Inset shows location of area investigated

similar tectonic setting.[12] Primitive basalt viz. basaltic komatiite was reported earlier from Singhbhum[13] and subsequently by other workers.[14,8]

Field and laboratory investigations across different sections in different parts of the volcanic belt reveal a large dominance of high magnesian members in the volcanic sequence though in a low grade metamorphic assemblage. The bulk of this volcanic belt is constituted of mafic, ultrabasic lavas and pyroclastic members.[8,15]

PETROGRAPHY

Different volcanic members of the suite reveal that high magnesian types[14] are distributed over three petrography groups : Ultrabasics (tremolite-actinolite rock, hornblendite and talc chlorite schists), Basics (amphibolites and pillow lavas) and Pyroclastics (igneous clasts in volcanic agglomerates).

The tremolite-actinolite rock type is more or less well developed in all sections studied. The rock is fine to medium grained with a crude to well-marked foliation often defined by the alignment of large actinolite plates. This rock is closely associated with talc-chlorite schist, which is well exposed particularly in Hassadih area. Small bodies of hornblendites, which are dark coloured, coarser grained and very tough, occur as isolated exposures.

Under the microscope the rocks are composed of tremolite and actinolite, chlorite, granular altered plagioclase, epidote and opaque minerals in varying proportions. Chlorites and carbonates occur as accessory minerals in tremolite rocks and in significant amount in the talc-chlorite schists. Occasionally carbonates occur as coarse patches simulating deformed vesicle fillings. Hornblendites show granular texture with elongated to acicular hornblende crystals. Epidote comes next to hornblende in abundance. The rock is very poor in plagioclase. Zoisite present, may be the alteration product of plagioclase.

The amphibolites represent the metamorphosed basic flows and the coarser homophanous type developed in large volume overlying the pyroclastics in the volcanic sequence.[17] Relic vesicular surfaces and pillow structure attest to their effusive character. The best developed exposures of pillow lava are restricted to the Kareranga, Gunti, Khunti and neighbouring areas. Some basaltic flows in the upper part of the lava sequence show ultrabasic lithic fragments embedded in basalts. These ultrabasic fragments are likely to have been derived from lower pyroclastic horizon during the ascent of basaltic magma. Such inhomogeneous rocks resembling lava breccia are excluded from the present study.

Under the microscope the schistose type is fine grained and consists chiefly of amphibole, plagioclase, epidote and opaques. The amphibole is actinolitic with long slender prisms defining the schistosity (Fig. 2). Rarely flattened pyroxene crystals are arranged parallel to the schistosity. In the coarser homophanous type dominant mineral constituent is amphibole, mostly hornblendic with tabular prisms arranged haphazardly, in the interspaces of which occurs granular opaques and plagioclase. Randomely oriented plagioclase laths and altered glassy materials (Fig. 3) are suggestive of primary basaltic texture.

Volcanic agglomerates are best developed near Subarnarekha river section to the south of Chandil and near Mahulkocha to the south of Khunti. Coarse fragments constituting more than 80 per cent of the total rock volume and finer matrix constituting the rest, is composed of altered feldspar, carbonates, amphibole, chlorite and fine rock fragments with opaques. The dark coarse fragments show an aphanitic character and are composed of felty mass of amphipoles, granular plagioclase and epidote.[15]

Preservation of vesicular surfaces, agglomerates and pillow structures indicate that the rocks have not always suffered intensive recrystallisation and regional development of penetrative fabric. Complete alteration of pyroxene to amphibole without large affecting the primary nature of plagioclase and absence of penetrative fabric suggest that the volcanic pile suffered at least in part burial metamorphism or ocean floor metamorphism.[18] Most of the metabasalts are in greenschist facies or transitional to the amphibolite facies. In some cases, however, the metamorphic planar fabric (viz. schistosity defined by hornblende plates) cut across the flattened vesicles indicating imprint of deformation subsequent to burial metamorphism. The primary calcic plagioclase in the rocks has broken down to epidote and less calcic plagioclase (An_{30}) but there has not been extensive removal of Ca from the system. However, the members towards the base of the volcanic pile are primarily depleted in Ca and enriched in chlorite and talc rather than in calciferous phases.

CHEMICAL PETROLOGY

Chemical analyses of the metavolcanics have been carried out following the methods suggested by Shapiro and Brannock.[19] Various United States Geological Survey rock standards,[20] viz., G-2, BCR-1 and AGV-1 were used as a check on the precision and accuracy.

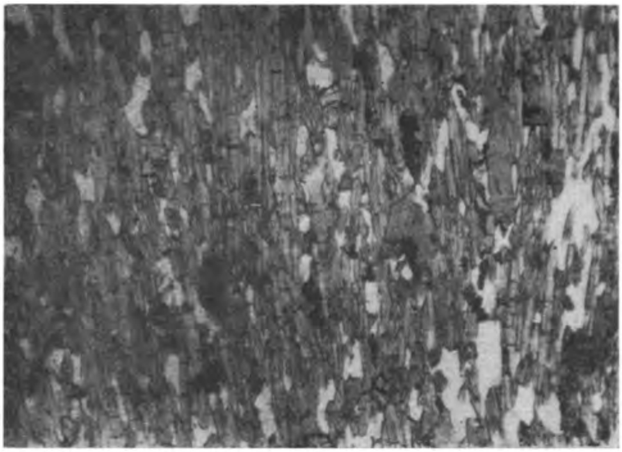

FIG. 2. Slender actinolite prisms defining the schistosity in the schistose amphibolite (Polarised light, 25 X)

FIG. 3. Randomely oriented plagioclase crystals showing primary basaltic texture (Cross polars, 36 X)

The chemical composition (Table I) of the tremolite-actinolite-chlorite rock suggests that it is poor in silica and alumina and high in magnesia indicating their picritic character. In the amphibolites, MgO content varies between 6.70 per cent and 9.03 per cent with an average value of 7.87 per cent which is greater than that (6.60 per cent) of all 'basalt'[21] and closer to that (7.62 per cent) of 'marginal basin basalt.'[32] These high magnesian basic members show a compositional range within narrow limits. However, variation is apparent from occasional development of normative nepheline, spread of An/Ab ratio and differentiation index (Table I). The pillow lava is quartz normative. Miyashiro[18] pointed out that many abyssal tholeiites present in greenschist facies show marked decrease in CaO and variation in SiO_2 contents; some may even be spilitic. Such compositional variation may becaused by flow of hot aqueous fluid through the crust. Such compositional changes may even produce chlorite-rich rocks as encountered in the basal units of the Dalma volcanic pile. It is observed that only in a few cases Fe_2O_3 dominates over FeO (Table I) which indicates that the extent of post-eruptive oxidation of the lavas is small. The normative diopside, hypersthene and olivine constitute 40 to 60per cent of the rocks. All these certainly qualify in designating the rocks as high magnesian basalts, sometimes even grading to picrite.

TABLE I

Chemical analyses and normative composition of high magnesian lavas within the Dalmas

Sl. No.	1	2	3	4	5	6
Sp. No.	G/57	G/181A	DK/82	R/83	MH/67	DK/113
SiO_2	48.36	47.83	43.15	40.74	37.48	43.49
TiO_2	1.49	2.64	0.63	0.28	1.80	0.18
Al_2O_3	10.59	11.05	12.41	7.77	15.33	16.41
Fe_2O_3	1.00	3.16	1.36	7.36	2.74	3.38
FeO	8.76	7.47	8.61	3.46	15.65	7.18
MnO	0.35	0.44	0.25	0.04	0.21	0.33
MgO	14.66	11.36	17.61	24.76	15.64	14.83
CaO	10.45	10.64	10.71	8.82	9.81	9.17
Na_2O	2.13	2.40	2.60	0.17	0.70	2.40
K_2O	0.15	0.38	0.59	0.10	0.08	0.24
P_2O_5	tr.	0.02	0.19	0.01	0.43	tr.
H_2O	2.45	3.00	2.12	6.24	1.33	2.19
CO_2	—	—	—	—	—	—
Total	100.39	100.39	100.23	99.75	99.50	99.80
QZ	—	—	—	—	—	—
Or	0.56	2.22	3.34	0.55	0.56	1.67
Ab	17.82	20.44	0.26	1.57	2.86	12.68
An	19.18	18.07	20.57	20.10	38.36	33.08
Ne	—	—	11.79	—	1.52	4.20
C	—	—	—	—	—	—
Di	26.32	27.67	26.01	17.71	8.37	9.98

(Continued)

TABLE I (*Continued*)

	1	2	3	4	5	6
Hy	10.04	10.74	—	15.70	—	—
Ol	19.71	8.59	32.79	26.60	35.25	30.93
Mt	1.39	4.64	1.86	10.44	3.94	4.87
Hm	—	—	—	0.16	—	—
Il	2.89	5.02	1.22	0.45	2.13	0.30
Ap	—	—	0.34	0.23	1.01	—
Ct	—	—	—	—	—	—
An/Ab	1.07	0.88	79.11	12.74	13.41	2.60
CaO/Al_2O_3	0.99	0.96	0.86	1.14	0.64	0.56
D. I.	18.38	22.68	3.60	2.12	3.42	14.35

Sl. No.	7	8	9	10	11	12
Sp. No.	R/80	R/65	G/102	G/5	DS/59	MH/4
SiO_2	38.74	47.20	47.37	45.84	46.38	51.32
TiO_2	0.40	1.05	1.60	1.18	0.80	0.64
Al_2O_3	6.22	14.55	13.78	15.76	13.50	15.33
Fe_2O_3	7.36	6.10	2.16	3.90	7.36	2.41
FeO	4.61	7.57	9.62	9.19	7.20	8.52
MnO	0.03	0.04	0.52	0.03	0.03	0.20
MgO	29.90	9.03	8.36	7.29	7.76	6.70
CaO	3.41	7.92	10.32	10.03	11.51	8.50
Na_2O_2	0.20	3.33	3.20	3.04	1.88	4.80
K_2O	0.04	0.57	0.20	0.75	0.22	0.56
P_2O_5	0.04	0.02	0.01	0.06	0.07	0.10
H_2O	8.56	1.60	3.10	2.60	2.52	1.04
CO_2	—	0.71	—	—	0.78	—
Total	99.51	99.70	100.23	99.67	100.01	100.12
CIPW NORM						
Qz	—	—	—	—	3.30	—
Or	1.57	3.33	1.11	4.45	1.11	3.34
Ab	14.17	28.30	25.94	21.75	15.72	35.47
An	—	22.80	22.52	26.97	27.80	18.63
Ne	—	—	0.71	2.13	—	2.64
C	0.61	—	—	—	—	—
Di	0.66	9.33	23.37	18.57	19.52	19.35
Hy	29.82	12.63	—	—	15.90	—
Ol	31.55	8.96	17.32	15.14	—	14.74
Mt	10.67	8.61	3.02	5.57	10.67	3.48
Hm	—	—	—	—	—	—
Il	0.75	1.98	3.04	2.28	1.52	1.22
Ap	0.67	1.60	—	—	—	0.34
Ct	—	—	—	—	1.80	—
An/Ab	—	0.80	0.86	1.24	1.76	0.52
CaO/Al_2O_3	0.55	0.54	0.75	0.64	0.85	0.55
D. I.	15.74	31.65	27.05	26.20	20.13	38.81

TABLE I (*Continued*)

Sl. NO.	13	14	15	16	17	18
SiO_2	45.84	40.66	44.91	53.06	42.87	48.44
TiO_2	0.07	1.00	0.57	1.05	0.40	0.66
Al_2O_3	15.87	10.42	12.39	6.01	9.60	10.05
Fe_2O_3	4.47	4.87	1.39	4.35	0.54	3.32
FeO	8.89	7.99	9.33	9.22	8.62	9.68
MnO	0.05	0.06	0.18	0.02	0.21	0.05
MgO	8.08	18.82	17.59	9.82	20.72	11.12
CaO	8.25	8.18	8.73	10.44	9.42	12.82
Na_2O	4.40	1.40	0.80	2.58	1.10	1.88
K_2O	0.71	0.16	0.16	0.48	0.52	0.64
P_2O_5	0.30	0.04	0.38	0.14	0.35	0.01
N_2O	2.90	6.24	2.79	0.94	2.40	0.76
CO_2	—	—	—	1.51	—	0.80
Total	99.83	99.84	99.22	99.59	99.75	100.23
C.I.P.W. NORM						
Qz	—	—	—	6.36	—	—
Or	3.89	0.44	1.11	2.78	2.78	3.34
Ab	23.84	11.79	6.81	22.01	9.43	15.72
An	22.24	21.68	29.61	3.34	19.74	17.24
Ne	7.24	—	—	—	—	—
C	—	—	—	—	—	—
Di	13.57	14.72	8.79	30.74	21.96	33.73
Hy	—	1.86	23.10	21.26	3.63	11.85
Ol	18.95	83.02	22.99	—	37.60	9.48
Mt	6.50	7.88	2.09	6.26	0.70	4.64
Hm	—	—	—	—	—	—
Il	0.15	1.97	1.06	1.98	0.76	1.22
Ap	0.67	0.06	1.01	0.34	0.67	1.80
Ct	—	—	—	3.40	—	—
An/Ab	0.93	1.83	4.34	0.15	2.09	1.09
CaO/Al_2O_3	0.52	0.79	0.70	1.74	0.98	1.28
D. I.	27.73	12.23	7.92	31.15	12.21	19.06

Serial Nos.	1–7	Tremolite-actinolite rocks
	8–13	Amphibolites (No. 11 is piilow lava)
	14–18	Igneous clasts of volcanic agglomerate (Analyst : Manas K Chakraborti)

The high magnesian rocks are further evaluted on the basis of $FM = \frac{\text{FeO (total)} + \text{MnO}}{\text{FeO (total)} + \text{MnO} + \text{MgO}} \times 100$ values[16]. The investigated rocks having FM values $\leqslant 65$ when plotted in the variation diagram MgO vs. FeO_t (Fig. 4) fall within high magnesia basalt field. The amphibolite though showing a high magnesian character, in comparison with the tremolite-actinolite rocks, have much lower ratios and are concentrated in a small area in the diagram while the plots for tremolite-actinolite rocks show some scater. The igneous clasts of volcanic agglo-

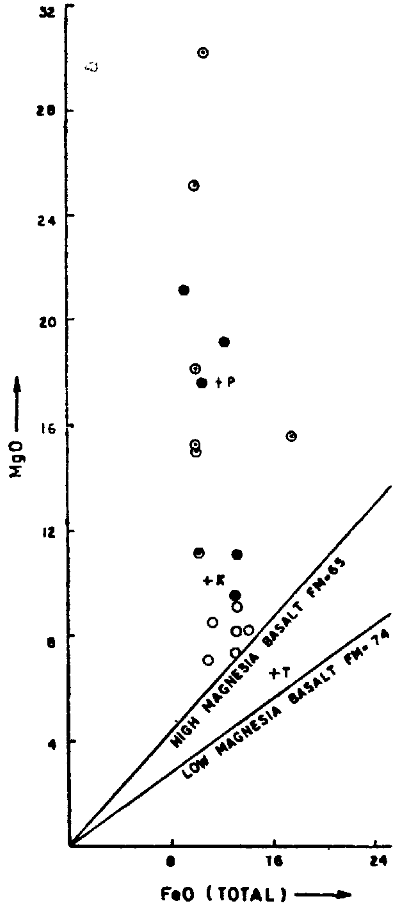

FIG. 4. MgO versus FeO_t in wt. per cent (after Wood, 1978) of 18 lava samples of Dalma volcanics Singhbhum.

Centered cricles—tremolite—actinolite rocks; Open circles—amphibolites; solid circles—igneous clasts of volcanic agglomerates; and the average values of Picrite (+ P), tholeiite (+ T) (after Gunn, 1976) and komatiite (+ K) after Viljoen and Viljoen, 1969) are also given for comparison.

merates[15] are also characterised by high magnesia (Fig. 4). Fig. 4 also shows plots for average picrite, tholeiite[23] and komatiite[24], which are taken for comparison. This figure also depicts a variation trend from a very high magnesian magma to a low magnesian type, with limited variation in FeO (total), represented by the tremolite-actinolite rock and the amphibolites, respectively, whereas the igneous clasts of volcanic agglomerates lie between the two. The average Archaean tholeiite[23] plots below the line of FM = 65 which suggests that the investigated rocks are more magnesian than the ancient tholeiitic basalt. Rather they are much closer in character to picrite and komatiite implying their primitive (unfractionated) character.

The igneous clasts of volcanic agglomerates have higher MgO values than that of normal basalts, CaO/Al_2O_3 is greater than unity (Table I) in some rocks suggesting a komatiitic nature. This is again supported by their locations on CaO-MgO-Al_2O_3 diagram (Fig. 5) where the plots are closer to the komatiite fields, namely of the Barberton and Geluk type.

In the MgO/Al_2O_3 *vs.* $(Na_2O + K_2O)/(\text{Total FeO} + TiO_2)$ diagram (Fig. 6) the plots for the investigated rocks are found to be sub-parallel to the oceanic tholeiite trend.[25]

In the Al_2O_3 *vs*. K_2O/MgO diagram (Fig. 7) the plots are located in and around the field of high magnesia basalts and extend also within the field of low potash tholeiite (LKT). So it is evident that the rocks are characterised by high magnesia and low potash contents in the said discrimination diagram.

CONCLUSION

The Dalma volcanic belt is developed along the median zone of a metasedimentary belt situated between Singhbhum granite and older metamorphic granite gneissic platform to the south and high grade granulite belt and Chotanagpur gneiss to the north. It is significant to observe that in all Archaean greenstone belts of the world ultramafic members occur at the base, followed upwards by the basic differentiates.[9] Anhaeusser *et al.*[26] suggested that Archaean greenstone belts comprise three units from top to bottom viz. sedimentary group, greenschist group and ultramafic group. The Dalma volcanic belt closely resembles this model in which ultramafic rocks at the base are overlain by tuffs and tholeiitic basalts and sedimentation possibly continued on two domains of the large basin separated by volcanic ridge. So the whole metamorphic belt with abundant volcaniclastic and basic magmatic rocks simulate a marginal basin developed on the flank of a sialic platform and the volcanic belt represents back arc spreading along the median zone of this marginal basin.[13]

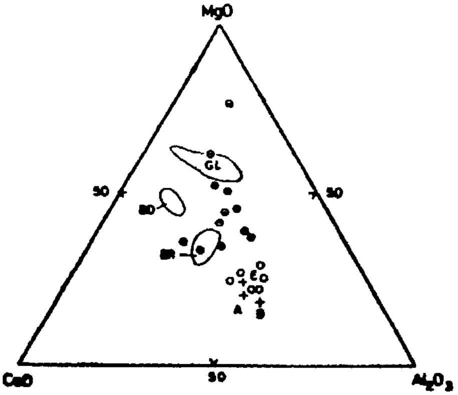

FIG. 5. CaO—MgO—Al_2O_3 diagram (after Viljoen and Viljoen, 1969) of 18 lava samples of Dalma volcanics, Singhbhum. Centered circles—tremolite-actinolite rock; Open circles—amphibolites and solid circles—igneous clasts of volcanic agglomerate. A. For average oceanic tholeiite; B. For average continental tholeiite and E. For average Archaean tholeiite

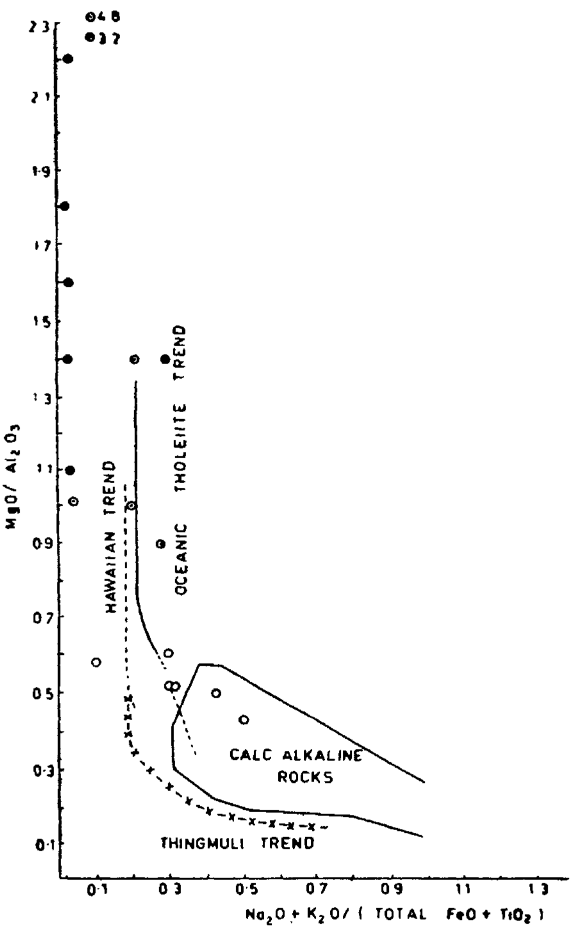

FIG. 6 MgO/Al_2O_3 *vs.* $(Na_2O + K_2O)/(FeO_t + TiO_2)$ diagram (after Green, 1973) of 18 lava samples of Dalma volcanics, Singhbhum. Centered circles—tremolite-actinolite rock; open circles—amphibolites and solid circles—igneous clasts of volcanic agglomerates.

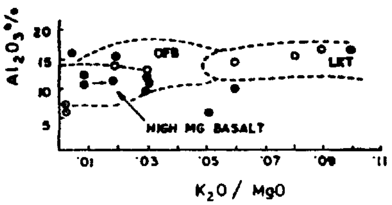

FIG. 7. K_2O/MgO versus Al_2O_3 diagram (after Pearce, 1976) of 18 lava samples of Dalma volcanics, Singhbhum. Centered circles—tremolite-actinolite rock; Open circles—amphibolites and solid circles—igneous clasts of volcanic agglomerates. OFB = Ocean Floor Basalt Field. LKT = Low K Tholeiite Field.

The basal high magnesian facies often approaching picrite, is possibly not a product of differentiation *in situ* i.e., they are not crystal cumulate from overlying tholeiite flows, because between the ultramafics and tholeiites above them, occurs a zone of pyroclastics and reworked tuffs representing a time gap of undeterminable extent. On the other hand, the basal member represents manifestation of high MgO primary magma during earlier phase of magmatism (representing high degree of mantle melting) and the overlying tholeiites are possibly derived from the depleted mantle.

Mineral assemblage characterised by tremolite, actinolite, epidote clearly suggests that the area had experienced only low grade metamorphism in the lower part of greenschist facies. Such low grade metabasalts with low K_2O content contrasted by high MgO values, strongly suggest an affinity towards ocean floor type. Also the differentiation trend in Dalma closely corresponds to the oceanic tholeiite trend of MgO/Al_2O_3 vs. $(Na_2O + K_2O)/(\text{Total FeO} + TiO_2)$ diagram (Fig. 6).

Unequivocal evidence of submarine magmatism and contemporaneous sedimentation is offered by pillow structures and tuffaceous sediments which are well represented in this volcanogenic belt. Considering all the evidences given above it is concluded that the Dalmas were erupted in a dominantly oceanic environment. Highly magnesia rich fraction coming from a shallow mantle source and having a close resemblance to basaltic komatite (viz., fragments in volcanic agglomerates), were ultimately followed by Mg rich basalts.

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