Geochemical Characteristics of Precambrian High-Magnesium Mafic Rocks In An Intracratonic Rift-Setting, Bastar Craton, Central India

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Abstract

A wide range of high Mg mafic locks is emplaced in the Bastar craton They show variation from komatiitic basalt to siliceous high Mg basalts (SHMB) Other important high Mg rock reported from this craton is boninite- like rocks. These high- Mg mafic rocks are reported to emplace in an intracratonic rift setting. Existence of intracratonic rift setting since the Archaean time is well supported by field setting exposed rock types including sedimentary rocks and geochemical characteristics .On IUGS recommended geochemical classification diagrams these rocks are classified as boninite, picrite and basaltic andesite. Previously identified SHMB rocks from Dongargarh area are reclassified as basaltic andesite as they do not qualify as high - Mg rocks, High Mg rocks should contain MgO >8% .Trace elements like Ti, Zr ,V, Sc and Yb also corroborates existence of boninite like rocks in the Bastar craton Absence of komatiites in the craton precludes the possibility of high Mg rocks like SHMB produced by AFC process. These high Mg rocks are probably derived from a boninitic magma generated from the refractory mantle source. To develop viable petrogenetic model further geochemical data particularly radioactive isotope data is required but one should be careful while recognising high Mg rocks. IUGS recommendations should be followed to avoid any uncertainty.

Key Words

Precambrian High Mg mafic rock, Boninite ,SHMB, Picrite, Bastar craton.

Introduction

Spatial and temporal distribution of varieties of high Mg mafic rocks is well known and they occur in almost all the tectonic settings .Petrological and geochemical characteristics of high Mg rocks show very wide range although some high Mg rocks show very close similarities .Sometimes it is difficult to classify these rocks on the basis of major elements geochemistry. These include boninite, high-Mg norite, and siliceous high-Mg basalts (Smithies, 2002). IUGS sub-commission on systematic of igneous rocks has modified the existing classification scheme for the high-Mg and picritic rocks and recommended that such rocks should be classified by following these recommendations to avoid any uncertainty. (Le Bas, 2000; Le Maitre, 2002).

In recent years many workers have reported variety of Precambrian high-Mg rocks from the Bastar craton of Central India. This includes siliceous high-Mg basalts (Srivastava and Singh, 1999; Sensarma et al. 2002) and boninite-like rocks (Srivastava and Singh, 2003, Srivastava et al. 2004; Srivastava, 2004). Report of siliceous high-Mg basalts (SHMB) by Sensarma et al. (2002) from the Dongargarh area of Bastar craton is doubtful because its geochemical characteristics reflect basaltic andesite nature rather than SHMB. Few other workers have also studied mafic rocks of Bastar craton showing high-Mg nature but they are not classified properly (Ramachandra et al. 1995; Neogi et al. 1996, Subba Rao et al. 2003). Collectively all these reports of different high-Mg mafic rocks from the Bastar craton create confusion whether these rocks have been classified correctly or not. The aim of this paper is to re-examined all the available geochemical data on the high-Mg rocks from the Bastar craton and provides correct classification for these rocks. This is essential for the future work on these rocks because emplacement of boninite-like rocks or SHMB in an intracratonic rift setting is an important report from any Precambrian terrain. For the present study IUGS recommendations (Le Bas, 2000; Le Maitre, 2002) have been followed and only those samples have been re-examined that come under the classification scheme of high-Mg rocks.

Geological Setting

Figure, 1a shows location of the Archaean Bastar craton, which is rectangular in shape and bounded by NW-SE trending Mahanadi and Godavari rifts, ENE-WSW trending Narmada-Son rift and Eastern Ghats Mobile Belt (Naqvi and Rogers, 1987). This craton comprises vast tract of granitoids and mafic rocks of different petrological characteristics, supracrustal rocks, and unmetamorphosed late Proterozoic sedimentaries (Figs, 1a and 1b; Crookshank, 1963; Ramakrishnan, 1990; Chaudhuri et al. 2002). The Bastar craton evidenced several episodes of Precambrian mafic magmatism that are emplaced in the form of dyke swarms as well as mafic volcanics (Crookshank, 1963; Ramakrishnan, 1990; Srivastava et al. 1996, 2004; Neogi et al. 1996; Sensarma et al. 2002; Srivastava and Singh, 2003; 2004; Subba Rao et al. 2003). These include - (i) Two distinct sub-alkaline mafic dyke swarms, one high-Mg mafic dyke swarm (boninite-like), and mafic volcanic rocks of different compositions (including siliceous high-Mg basalts and boninite) from the southern part (Box 1 in Fig. 1b: Srivastava et al. 1996, 2004; Srivastava and Singh, 1999; 2003; 2004), (ii) High-Mg and high-

Fe tholentic mafic dykes fiom the middle part (Box 2 in Fig lb Ramachnadra et al 1995) (m) High Fe tholente and meta pyroxemte/raeta gabbroic mafic dykes from the south eastern and eastern margins of the Chattisgarh basin (Box 3 in Fig lb Subba Rao et al 2003), and (IV) Two generations of sub alkaline and siliceous high Mg basalts from the northern part (Box 4 in Fig lb Neogi ct al 1996, Sensarma et al 2002)

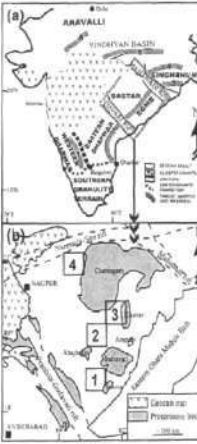

Fig 1 *(a) Major cratons and structural featwes of Mm (after Nap* and Rogers 1987) Mawr structural features we 1 Small thrusts* in *western Dhamar craton 2 Easte^GhatTfront 3 Sukinda 4 Singhbhurn 5 Son Valley and t; GnatBauson fault EGMB Eastern Ghat Mobile Belt (b) Proterozoicbasins of the ^ w w o n (Chaudhun et al 2002) Boxes 1 to 4 ,ep,esent location of study areas for detail see*

Intracratonic Rift Setting

Many evidences support existence of stable continental rift setting in the Bastar craton since the Archaean time. These includes -

1. The lineaments of Narmada-Son, Godavan, and Mahanadi rifts are ancient and supposed to be existed since the Archaean time (Naqvi et al. 1974; Naqvi and Rogers, 1986; Rogers, 1996; Rogers and Santosh, 2002). These ancient lineaments are too deep and probably extended up to the mantle (Naqvi et al. 1974).

2. Rogers (1996) and Rogers and Santosh (2002, 2003) have discussed existence of an Archaean (~ 3 Ga) Supercontinent known as 'Ur'. The configuration of this old Supercontinent includes several Indian cratons (Dharwar, Bastar, and Singhbhum) besides the Kalhari craton of southern Africa, the Pilbara craton of western Australia, and the coastal region of East Antarctica.

3 Several large Meso- and Neoproterozoic intracratonic basins, including basins of the Bastar craton (see Fig. lb), are developed in rift setting (Chaudhuri and Deb, 2004). Although these rifts are not developed into a full-scale, they must be much older than Mesoproterozoic in age (Kale, 1991; Chaudhuri et al. 2002). As rifts are not fully developed, there is a complete absence of oceanic crustal component to these sedimentary basins (Chaudhuri et al. 2002). The Proterozoic supracrustal basins of Bastar craton mainly contain orthoquartzite (quartz-arenite)-carbonate-shale suites (Kale, 1991). This remarkable composition together with structures and absence of metamorphic trace in these basins suggest "Atlantic-type" passive continental margin system that develops under extensional tectonic regimes on the trailing edges of continental blocks (Park, 1988).

4. Neogi et al. (1996) noticed inter-layered sediments vary in composition from immature arkose to the mature orthoquartzites, which indicate a stable continental margin setting. Regional lithology comprising quartz-wacke/lithic-wacke-pelitic-iron formation also supports such tectonic setting.

5. Another important observation is that in spite of estimated burial depths (in the order several thousand meters) of sediments and deformation along basin margins rarely any metamorphic trace is noticed, indicative of its accumulation in an extensional tectonic setting (Robinson, 1987). According to Condie's classification (Condie, 1982) to identify supracrustal succession to establish tectonic settings, Bastar basin shows "Assemblage II" type igneous-sedimentary association. The basal Group (Abujhmar Group) of

Bastar basin comprises dominant type of igneous rocks inter-bedded with the sediments (Kale, 1991). The "Assemblage II" type of supracrustal succession is associated with lithosphere activated continental rifts.

6. Geochemical characteristics, particularly Nb and Eu behaviour, of mafic rocks (Mesoarchaean to Paleoproterozoic in age) of this region also support existence of continental setting for these rocks (Srivastava et al. 1996, 2004; Srivastava and Singh, 2004). Small or no negative Nb anomalies (cf. Saunders et al. 1992; Kent, 1995) and absence or superficial negative Eu anomalies (Cullers and Graf, 1984) are characteristic of most of the continental sub-alkaline mafic rocks.

Geochemistry

Considering importance and problem in classifying high-Mg and picritic rocks, the IUGS sub-committee on the systematic of Igneous Rocks has revised the classification scheme for such rocks (Le Bas, 2000; Le Maitre, 2002). According to these recommendations to qualify for high-Mg rocks the sample should display any one of the following geochemical characteristics:

1. Boninite if MgO >8%, SiO_2 >52%, and TiO_2 <0.5%.
2. Komatiite if MgO >18%, SiO_2 between 30 and 52%, (Na,O+K_2O) <2%, and TiO_2 <1%.
3. Meimechite if MgO >18%, SiO_2 between 30 and 52%, (Na_2O+K,O) <2%, and TiO_2 <1%.
4. Picrite if MgO >12%, SiO, between 30 and 52%, and (Na_2O + 1^0) <3%.

So, according to these recommendations it is clear that if any sample has <8% MgO can not be considered as high-Mg rock but many samples from the Bastar craton are reported as high-Mg rocks even though their MgO content is <8% (e.g. Sensarma et al. 2002). For the present work only those geochemical analyses are considered for geochemical studies that qualify as high-Mg rocks according to IUGS recommendations. Such geochemical data is presented in Table 1. None of the samples reported by Sensarma et al. (2002) as siliceous high-Mg basalts (SHMB) are classified as high-Mg rock. Although SHMB is not included in the IUGS recommendations but it is well defined by many workers that SHMB should have MgO between 10 and 16>% and SiO, between 51 and 55% (Sun and Nesbitt, 1978; Redman and Keays, 1985; Arndt and Jenner, 1986; Sun et al. 1989; Seitz and Keays, 1997). Srivastava and Singh (1999)'have also reported SHMB from the Bastar craton, the very first report of SHMB from any Precambrian terrain of Indian shield and they are well comparable to the other SHMB rocks.

Table 1: Whole rock major (wt%), trace and rare earth elements (in ppm) analyses of high-magnesium mafic rocks from the Bastar Craton, Central India.

Sample	1	2	3	4	5	6	7	8	9
Number	**93/276**	**93/279**	**93/280**	**93/282**	**97/160**	**97/161**	**97/175**	**97/183**	**97/185**
SiO_2	54 52	52 83	53 89	52 88	53 77	52 33	53 65	54 12	53 34
TiO_2	0 44	0 35	0 37	0 41	0 32	0 26	0 49	0 39	0 46
Al_2O_3	9 81	10 35	8 78	9 99	8 97	16 55	12 35	12 87	10 69
Fe_2O	10 53	11 24	11 16	10 22	9 27	7 51	11 08	10 73	10 62
MnO	0 17	0 18	0 18	0 19	0 16	0 12	0 18	0 16	0 17
MgO	16 05	15 57	18 35	16 82	13 10	8 66	10 91	8 31	12 80
CaO	6 16	6 54	5 13	5 76	12 38	13 29	6 83	11 20	6 37
Na_2O	1 20	1 08	0 84	0 98	1 19	1 41	1 65	1 12	1 41
K_2O	0 63	0 71	0 82	0 87	0 21	0 09	1 31	0 05	0 51
P_2O_5	0 06	0 05	0 05	0 04	0 05	0 03	0 06	0 07	0 07
LOI	2 00	2 01	1 98	2 10	0 89	0 51	2 13	0 48	3 48
Total	101 57	100 99	101 55	100 26	100 31	100 76	100 64	99 50	99 92
Mg#	79 32	77 71	80 53	80 55	73 67	74 37	66 10	66 08	70 47
Cr	1668	1625	2070	1724	1810	52)			
Ni	351	363	407	388	319	230			
Sc	30	32	31	32	45	34	31	31	30
V	179	172	173	188	187	146	173	172	173
Rb	28	35	42	40	4	2			
Ba	121	133	140	99	97	85	311	17	138
Sr	62	60	45	46	80	118	96	103	91
Ga					4	)			
Nb	5 0	4 0	4 0	4 0	1 0	1 0			
Zr	53	43	44	46	37	35	66	50	64
Y	12	11	10	13	9	8	13	11	13
Th	7 0	3 0	6 0	7 0	1 6	1 3			
La	9 44	7 47	7 68		6 80	5 10			
Ce	19 19	15 76	15 85		12 00	9 00			
Pr	2 11	1 68	1 68		1 22	0 92			
Nd	7 90	6 10	6 20		5 00	3 90			
Sm	1 70	1 37	1 32		1 20	0 90			
Eu	0 49	0 42	0 38		0 37	0 33			
Gd	1 82	1 56	1 47		1 40	1 10			
Tb					0 30	0 20			
Dy	1 74	1 39	1 41		1 70	1 30			
Ho	0 38	0 32	0 31		0 40	0 30			
Er	1 11	0 92	0 93		1 10	0 90			
Tm					0 17	0 14			
Yb	1 18	0 99	0 98		1 10	0 80			
Lu	0 18	0 17	0 15		0 17	0 13			

Table 1 (Contd) Whole rock major (wt%), trace and rare-earth elements (in ppm) analyses of high magnesium mafic rocks from the Bastar Craton, Central India

Sample	10	11	12	13	14	15	16	17	18
Number	**97/198**	**97/207**	**97/210**	**97/303**	**97/340**	**97/369**	**97/378**	**97/381**	**26G**
SiO_2	53 42	53 81	53 92	54 15	53 19	53 25	53 14	52 91	56 71
TiO_2	0 49	0 41	0 46	0 48	0 39	0 48	0 43	0 39	0 60
Al_2O	11 24	9 60	10 85	11 37	8 90	10 69	10 92	10 25	8 05
Fe_2O_3	11 02	10 90	10 76	11 18	11 13	11 72	10 50	10 31	*9 12
MnO	0 18	0 18	0 17	0 17	0 18	0 19	0 17	0 18	0 14
MgO	11 94	15 36	12 84	12 01	16 19	13 05	13 30	14 59	11 15
CaO	6 25	5 60	6 24	6 72	5 82	5 83	6 11	6 25	6 69
Na_2O	1 44	1 05	0 93	1 68	0 97	1 46	1 12	1 05	0 29
K_2O	1 14	0 79	1 35	0 96	0 48	1 17	0 84	0 65	2 13
P_2O_5	0 07	0 06	0 06	0 07	0 05	0 07	0 12	0 05	0 08
LOI	1 79	2 46	2 62	1 84	1 90	2 18	3 22	1 90	3 91
Total	98 98	100 22	100 20	100 63	99 20	100 09	99 87	98 53	98 47
Mg#	68 21	73 62	70 27	68 02	74 23	68 80	71 50	73 70	71
Cr		1500			1590		927	1080	1307
Ni		361			365		310	278	324
Sc	31	31	30	30	28	32	31	30	
V	179	173	174	168	150	184	170	167	139
Rb		43			27		47	32	53
Ba	236	138	186	267	152	194	205	139	577
Sr	109	67	63	81	85	62	70	65	187
Ga		5			5		7	5	
Nb		3 0			3 0		3 0	3 0	4 0
Zr	70	56	64	71	58	65	58	54	77
Y	13	11	12	15	11	13	11	10	15
Th		4 3			4 3		4 3	4 1	
La		9 40			9 70		9 30	9 40	
Ce		20 00			19 00		21 00	19 00	
Pr		2 16			2 01		2 06	2 09	
Nd		8 30			8 00		8 10	7 90	
Sm		1 70			1 70		1 80	1 80	
Eu		0 47			0 48		0 52	0 47	
Gd		2 00			1 80		2 00	1 90	
Tb		0 30			0 30		0 30	0 30	
Dy		2 00			2 00		2 10	1 80	
Ho		0 40			0 40		0 40	0 40	
Er		1 30			1 20		1 30	1 20	
Tm		0 20			0 18		0 20	0 18	
Yb		1 20			1 30		1 30	1 20	
Lu		0 19			0 18		0 20	0 19	

Table 1 (Contd) **Whole rock major (wt%), trace and rare-earth elements (in ppm) analyses of high magnesium mafic rocks from the Bastar Craton, Central India**

Sample	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Number	**M1**	**M6**	**CG94**	**CG144**	**CG126**	**CG128**	**CG129**	**CG133**	**D 16**
SiO_2	53 09	56 79	46 29	52 07	46 72	47 66	48 16	48 22	51 47
TiO_2	0 57	0 74	0 69	0 64	0 80	0 87	0 77	0 76	0 69
Al_2O_3	13 22	10 59	10 00	12 54	12 71	12 88	12 53	12 38	8 80
Fe_2O_3	*9 88	*10 53	13 24	11 40	13 24	12 77	12 05	11 57	*10 80
MnO	0 15	0 16	0 16	0 16	0 16	0 16	0 16	0 17	0 16
MgO	8 96	8 84	19 59	10 75	13 44	12 57	12 19	12 57	17 00
CaO	6 53	6 74	7 07	8 15	10 83	10 73	11 81	12 41	7 56
Na_2O	1 41	1 36	1 51	1 48	1 05	1 15	1 14	1 22	1 25
K_2O	1 92	2 02	1 19	1 09	0 39	0 41	0 36	0 37	0 48
P_2O_5	0 09	0 10	0 14	0 10	0 10	0 11	0 10	0 10	0 05
LOI	2 94	1 84							
Total	98 76	99 71	99 88	98 38	99 44	99 31	99 27	99 77	98 62
Mg#	63	63	74 6	65 1	66 8	66 1	66 7	68 3	74
Cr	512	751	1463	438	187	202	187	186	1000
Ni	184	214	324	24	84	88	87	77	100
Sc	30 5	27 0	25 6	31 6	35 5	37 5	35 0	35 5	
V	181	192	164	195	226	238	214	216	50
Rb	54	69	93	44	6 6	8 6	6 8	6 0	
Ba	410	260	386	202	52	65	47	53	
Sr	109	112	189	106	71	79	78	86	
Ga			10 4	14 3	14 3	14 3	13 3	13 0	10
Nb	7 0	9 0	6 0	4 5	10 1	10 2	9 5	9 1	
Zr	86	106	79	74	91	85	86	87	10
Y	19	22	15	17 9	21 6	22 7	20 3	22 1	
Th	6 2	10 7	1 7	5 0	0 8	0 2	0 2	0 2	
La	18 00	24 00	11 7	14 4	11 3	11 0	10 3	12 0	
Ce	32 00	45 00	21 8	29 4	22 5	22 4	19 6	22 8	
Pr			2 4	2 7	2 5	2 5	2 2	2 5	
Nd	11 00	15 00	11 4	13 1	12 1	12 4	10 6	12 2	
Sm	2 80	4 00	2 4	2 7	2 7	3 0	2 5	2 8	
Eu	0 70	1 00	0 7	0 7	0 8	1 0	0 7	0 8	
Gd			2 3	3 2	3 0	3 2	2 7	3 1	
Tb	0 50	0 60	0 3	0 5	0 4	0 5	0 4	0 4	
Dy			2 3	2 7	3 3	3 5	3 0	3 3	
Ho			0 4	0 5	0 7	0 7	0 6	0 7	
Er			1 2	1 8	2 0	2 0	1 8	2 0	
Tm			0 1	0 3	0 2	0 2	0 2	0 2	
Yb	1 70	1 90	1 0	1 7	1 4	1 5	1 3	1 4	
Lu	0 25	0 25	0 2	0 2	0 3	0 3	0 3	0 3	

To see geochemical nature of selected samples for present study they have been plotted on total alkalies silica and Jensen s cation plot (Fig 2) All samples clearly show their sub alkaline (Fig .2a Irvin and Baragar 1971) and high Mg nature (Fig 2b Jensen 1976) On Jensen s plot most of the samples plot in the basaltic komatnte field but few samples particularly samples presented by Sensarma et al (2002) show high Mg tholeiitic nature. These classifications do not show actual high- Mg discrimination, so these are plotted on IUGS recommended total alkalies silica (TAS) diagram for high Mg and picritic rocks (Fig. 3a; Le Bas, 2000; Le Maitre, 2002) Results based on high- Mg TAS plot are presented in Table 2. From the Figure 3a and Table 2 it is observed that

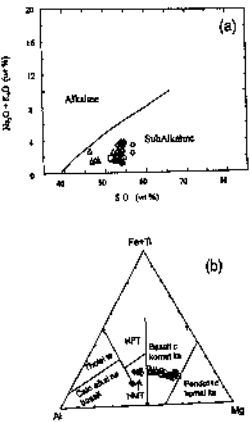

Fig. 2. *(a) Total alkali and silica (TAS) diagram (after Irvin and Baragar, 1971) (b) Cation classification diagram (after Jensen, 1976) Symbols used - Samples from Box 1: open (low-Ca boninites) and filled (high - Ca boninites) circles; Box 2 :open square (pictrite) Box 3: open triangles (picrites and basaltic andesite) Box 4 : open and filled diamonds (basaltic andesite). For reference and other details please see text and Table 2.*

Table 2: Geochemical characteristics reflected on the TAS diagram for selected high-Mg samples from the Bastar craton and recognised rock types.

Location in Fig. 1b and reference	Rock types recognised previously	Present classification based on IUGS-TAS for high-Mg rocks	Geochemical characteristics
Box 1: Srivastava et al . (1996, 2004, Srivastava and Singh, 1999, 2003, 2004)	Siliceous high-Mg basalts and boninites	Boninite	All samples have MgO >8%, SiO, >52%, and TiO_2 <05%.
Box 2 : Ramachnadra et al. (1995)	High- Mg thoeliitic mafic rocks	Picrite	It shows MgO >12%, SiO_2 between 30 and 52%, and (Na_2O + K_2O) <3%
Box 3 : Subba Rao et al .(2003)	Meta-dolerites and meta pyroxenites	Except one sample (1e basaltic and site) others are picnte	They show MgO >12%, SiO_2 between 30 and 52%, and (Na_2 O + K,O) <3% One exceptional sample has SiO_2 >52% and MgO <12% hence basaltic andesite.
Box 4: Neogi et al. (1996)	Basaltic andesite/andesite	Basaltic andesite	All samples have MgO >8% and SiO_2 >52% but TiO, >0 5%
Box 4 :Sensanna et al. (2002)	Siliceous high-Mg basalts	Basaltic sndssitc	All samples have MgO <8%, SiO, >52%, andTiO_2 >0 5%

high-Mg mafic rocks of the Bastar craton may be classified as boninite, picrite, and basaltic andesite but it is also necessary to mention here that IUGS classification for high-Mg rocks does not include SHMB and noritic rocks. Boninites, high-Mg norites, and siliceous high-Mg basalts (SHMB) show considerable compositional overlap. Precisely all the three verities have high-silica, high-Mg, low-Ti, and low-HFSE. It is a difficult task to differentiate boninites from high-Mg nonte on the basis of geochemistry because both the rocks have almost similar geochemical characteristics (see Table .3) but it is believed that boninite (particularly Phanerozoic) occur in convergent margin setting, whereas high-Mg norite is exclusively continental (Cadman et al. 1997; Smithies, 2002). But boninite (mainly Precambrian) can also occur in an intracratonic setting (Piercy et al, 2001; Smithies, 2002). On the other hand, boninite and SHMB have some geochemical differences (Sun et al. 1989; Table 3). Boninite has high ratios of $AI_2 O_3$ / TIO_2 and Sc/Y, low Ti/Zr ratio, and Sr/Nd ratio higher than chondrite than SHMB but these two also have large overlapping values (see Table 3). Another important point is that SHMB may have similar petrogenetic process as observed for high-Mg norite (Sun et al. 1989; Hall and Hughes, 1987; Cadman et al. 1997), this implies that such SHMB is volcanic equivalent of high-Mg norite. Many workers have also suggested that Archaean SHMB is derived from komatiite through assimilation-fractional crystallization (AFC) processes (Arndt and Jenner, 1986; Sun et al. 1989). High-Mg rocks reported by Sensarma et al. (2002) as SHMB needs further check because it neither qualifies as high-Mg rocks (Le Bas, 2000; Le Maitre, 2002) nor SHMB (Sun et al., 1989; see Table 3). In both the cases MgO should be atleast 8% but all the samples reported by Sensarma et al. (2002) contains MgO <8%. Thus, these rocks should be classified as basaltic andesite and not SHMB. Similarly, most of the high-Mg rocks reported by Ramachandra et al. (1995) and Subba Rao et al. (2002) are picrite.

From the available data only high-Mg rocks reported from southern portion of the Bastar craton show boninitic geochemical nature as they contain SiO_2 >52 %, MgO >8%, Mg# >60, and TiO_2 <0.5% (see Fig. 3a; Le Bas, 2000; Le Maitre, 2002). These boninite-like rocks are further classified on the basis of CaO and $A1_2O_3$ compositions (Fig. 3b; Crawford et al. 1989). Most samples fall in low-Ca boninite (Type 3) field but three samples (5, 6, and 8) fall in high-Ca field. It is important to note that later three samples interestingly fall well within the range of boninitic geochemical composition (see Table 3). Geochemical composition of low-Ca boninites overlaps with SHMB composition.

Table 3: Comparison of ranges of some important chemical compositions of Phanerozoic boninite, intracontinental Archaean boninite, Paleoproterozoic high-Mg norite, and Archaean SHMB.

	1	2	3	4
Rock types -> Chemical composition	Phanerozoic boninites	Archaean boninites	Paleoprotcrozic High-Mg noritcs	Archaean SHMB
SiO_2	52.40-61.30	52.00-54.00	47.00-56.00	51.00-57.00
TiO_2	0.07-0.50	0.24-0.28	0.30-1.00	0.40-1.00
Al_2O_3	6.10-15.00	16.60-17.60	6.80-16.10	9.90-13.00
MgO	4.50-21.70	7.80-8.60	5.70-21.60	9.50-16.50
Mg#	42-76	62-67	56-80	69-75
Zr	8-55	33-41	37-128	41-74
Nb	<0.5-2.0	1.1-1.5	1.0-8.0	2.8-3.5
Sc	29-53	35-42	22-40	28-43
V	131-343	157-174	120-312	147-208
Yb	-	1.09-1.67	- -	- -
Al_2O_3/Tio_2	27-133	62-73	13-34	20-30
Ti/Zr	22-153	40-44	26-87	44-85
Ti/V	3-15	9-10	9-23	13-24
Ti/Sc	11-84	34-45	70-211	73-125

Mg# = MgO/(MgO+FeO).

References used 1 (Cameron et al, 1979, Hickey and Fiey, 1982, Crawford et al., 1989, Taylor et al, 1994, Falloon and Crawford, 1999); 2 (Smithies, 2002), 3 (Wcaver and Tarney, 1981; Hall and Hughes, 1987, 1990, Sheraton et al, 1990); 4 (Sun et al., 1989).

Although IUGS has not included SHMB and high-Mg noriteic rocks in its high-Mg classification scheme, few discrimination diagrams, based on geochemical composition, are available to distinguish between many high-Mg rocks that include boninite, high-Mg norite, SHMB, low-Ti tholeiite, and komatiite and komatiitic basalt (Poidevin, 1994; Piercey et al. 2001; Smithies, 2002). These discrimination diagrams are based on incompatible trace elements such as Ti, Zr, V, Sc, and Yb and they successfully discriminate different high-Mg rocks. Figure .4 represents variation of TiO_2 and Zr (Fig. 4a) and Ti/V and Ti/Sc (Fig. 4b). Samples of present study fall in different fields; Most of the boninite-like samples corroborate their boninitic characteristics, although few

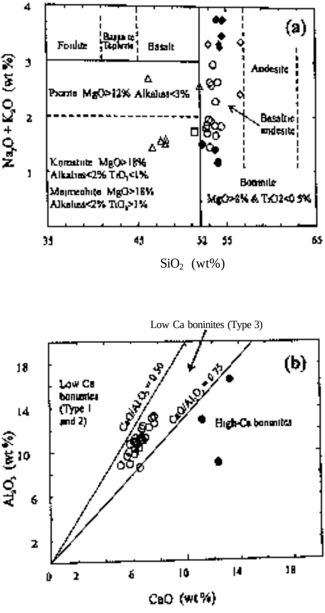

Fig .3. *(a) Total alkali silica (TAS) classification diagram for high- Mg rocks (after Le Bas, 2000 Le Maitre, 2002). (b) Graphic representation of CaO/A* $l_2 0_3$ *classification for boninites (Crawford et al., 1989). Symbols are as Fig. 2.*

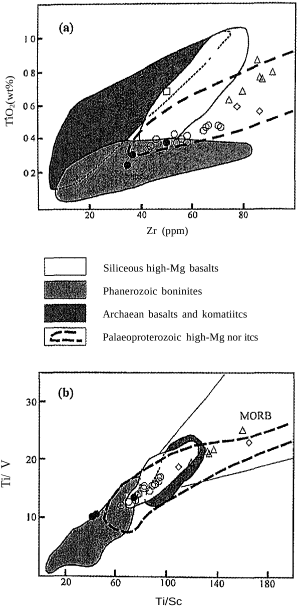

Fig. 4 . *(a) Zr - TiO_2 and (b) Ti/Sc - Ti/V variation diagiam foi high siliceous high magnesium mafic rocks from the Basta? Craton and then comparison with SHMB, Phanerozoic boninites Archaean basalts and komatiites and Paleoproterozoic high Mg norites, and MORB. Different fields are taken from Poidevin (1994), Piercey et al. (2001) and Smithies (2002). Symbols are as Fig. 2.*

samples also fall in SHMB/norite fields Interestingly high- Ca boninites clearly reflect their boninitic composition .Although it is difficult to discriminate SHMB and norite but as most of these rocks are intrusive in nature, hence author prefer to use norite instead of SHMB .On the other hand, most picritic rocks fall in the high Mg norite field. On another discrimination diagram (Fig 5, Yb - Ti plot) most boninite-like samples fall in boninite field and other samples fall in Archaean basalt field. Thus, it may be concluded that the Bastar craton clearly experienced boninitic magmatism during the Precambrian time and other high-Mg derivatives are probably differentiated product of boninite magma. But to conform this conclusion further geochemical data, particularly radioactive isotope data, is essentially required

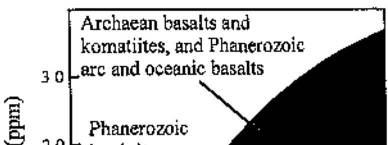

Fig .5 .Ti and Yb variations in high -siliceous high-magnesium mafic rocks from the Bastar craton and their comparison with Phanerozoic boninites, Archaean basalts and komatiites, and Phanerozoic arc and oceanic basalts. Different fields are taken from smithies (2002). symbols are as Fig 2.

Here, it is also necessary to mention petrogenetic processes of SHMB and boninites. Petrogenesis of SHMB type rocks is well explained by Sun et al. (1989). These includes - (i) Derived from a refractory mantle source (Sun and Nesbitt, 1978), (ii) Derived from boninitic magma (Redman and Keays, 1985), and (in). Through assimilation-fractional crystallisation (AFC) process. Many workers favour third model for the genesis of SHMB (Amdt .and Jenner, 1986; Arndt et al, 1987, Sun et al., 1989). According to this hypothesis AFC process in komatiitic magma by contamination of felsic crust may produce composition similar to SHMB (Arndt and Jenner, 1986). Another possible model for genesis of SHMB is through interaction of asthenosphere and lithosphere, in which a high-temperature asthenosphere diapir intrudes refractory harzburgitic continental lithosphere, causing it to melt at low pressure (Jaques and Green, 1980; Fisk, 1986). This model may explain the generation of noritic magma at higher temperature than that involving the melting of a modified lithosphere (Hatton and Sharpe, 1989; Sun et al, 1989). Although Srivastava and Singh (1999) have suggested AFC model assuming assimilation of Bastar granitoids by komatiitic magma, however, these authors noted that it is difficult to identify such contamination geochemically or petrographically. Also, no one has yet reported any komatiite occurrence from the Bastar craton.

On the other hand, the slight interaction between refractory peridotite, hydrous fluids, and the surrounding temperature at the site of partial melting may generate varities of boninite magmas. This model also explains how high-Ca and low-Ca boninites (particularly Type 3) can be genetically associated with each other: best examples are Chichijima of Bonin Islands (Umino, 1986) and Cape Vogel of New Guinea (Crawford et al., 1989). Kuehner (1989) suggested that boninite-like magma can be generated in a continent comprises reasonably thin crust by ~ 30% melting of an anhydrous partial melting of harzburgitic mantle. It is well established that a highly refractory mantle source region is required to form boninitic magma. Such refractory mantle source can be formed by voluminous extraction of basaltic and komatiitic magma during the early history of earth. Voluminous sub-alkaline mafic magmatism is reported from the Bastar craton in the Archaean / early Proterozoic time (Ramachandra et al. 1995; Srivastava et al. 1996; Neogi et al. 1996; Subba Rao et al. 2002; Srivastava and Singh, 2004). Probably this voluminous extraction of sub-alkaline magma would be the cause of the formation of refractory mantle source in the Bastar craton and latter melting of such mantle source may produced high-silica high-Mg magma of boninitic composition. Other high-Mg rocks, including basaltic andesite, reported from the craton are probably derived from such boninitic magma.

Conclusion

Petrological and geochemical characteristics of high siliceous high Mg mafic rocks from the Bastar intracratonic rift setting classified them as boninite norite (picrite and low Ca boninites) and basaltic andesite High Ca boninites have typical boninitic characteristics .There are few high Mg mafic rocks are mistaken to identify as siliceous high Mg basalts rather than basaltic andesite High Mg rocks should be studied only after careful classification particularly as recommended by IUGS. Absence of komatiites in the Bastar craton rules out any possibility of genesis of high Mg rocks (like SHMB) produced by AFC process Reported high Mg rocks (bommtes like) are probably derived from a magma generated from the refractory mantle source and other high Mg rocks may be differentiated product of such magma But to confirm this inference further geochemical data particularly radioactive data is require .Another important point to mention here that boninite-like rocks are supposed to be emplaced in the subduction related tectonic setting but now it is established that such rocks can occur in variety of tectonic settings including intracontinental rift setting (Smithies 2002).

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