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Geochemistry and Petrogenesis of Felsic Meta-volcanic Rocks of Baghmara Formation, Sonakhan Greenstone Belt, Central India

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Abstract

The Neo-Archean Sonakhan Greenstone Belt (SGB) is located in the north-eastern fringes of the Bastar craton in Central India and is composed of greenschist to amphibolite facies meta-volcanic rocks and meta-sedimentary sequences. The felsic meta-volcanic rocks from SGB exhibit steep REE pattern (La/Yb = 66.86). The trace element geochemistry indicates negative Nb and Ti anomalies in the multi-element spider diagrams suggesting subduction related origin for this volcanic suite. It has been inferred that the felsic and mafic volcanic rocks are characterised by bimodal volcanism. The felsic magmatism in SGB might have been generated by the partial melting of the crustal portion, either due to the heat generated by the diapirism of mafic magma or by the heat generated during the subduction process.

Keywords: Archean Sonakhan Greenstone Belt, Bagmara formation, Suprasubduction zone, Bastar Craton, Central India.

Introduction

Convergent plate margins are the major sites of crustal growth and accretion. The mixing of subduction-related mafic magma and crust-derived felsic magma in active continental margins accounts one of the principal mechanisms of crustal generation and growth (Foley *et al*., 2002; Rudnick and Gao, 2003, Taylor and McLennan, 1995). The addition of Juvenile crustal materials and the growth of continental crust are controlled by vertical and lateral accretions. The accretion of oceanic and trench materials onto the active continental margins cause the lateral and vertical growth and thickening of arc crust derived from the magmas derived by melting of mantle wedge fluxed with slab-dehydrated fluids (Santosh, 2013). The Neo-Archean greenstone terrains are characterized by tholeiite-komatiite magmas derived from plume magmatism and bimodal tholeiitic to calc-alkaline assemblage of basalt-andesite-dacite-rhyolite (BADR) derived from an island arc setting (Wyman *et al*., 2002; Wang *et al*., 2013, Wang *et al*., 2008). Rhyolites constitute an integral component of BADR association in convergent margin setting. In subduction related environment, active continental margins are the important sites of rhyolitic magma generation (Eyuboglu *et al*., 2013).

The present study primarily focusses on the preliminary geochemical and petrographic aspects of meta-rhyolites, nature of felsic magmatism and crustal evolution in SGB, which is located on the north-eastern fringes of Bastar craton.

Geological Setting

The Peninsular Indian Shield comprises several cratonic nuclei and records a long history of crustal evolution. The entire region is divided into two distinct crustal provinces, namely the southern crustal province and the northern crustal province, which are separated by the Central Indian Tectonic Zone (CITZ) (Radhakrishna and Naqvi, 1986; Yedekar *et al*., 1990; Rogers and Santhosh, 2003; Santhosh *et al*., 2009). The southern crustal province consists of Archean cratonic nuclei namely Dharwar, Bastar and Singhbhum cratons, whereas the northern crustal province consists of the Bundelkhand craton.

The Bastar craton of central India is bounded by the Central Indian Tectonic Zone (CITZ) to the north and the Eastern Ghats Mobile Belt to the south. The eastern and western boundaries are defined by two Phanerozoic rift systems, the Mahanadi rift, and Godavari rift respectively. The volcano-sedimentary sequence in the northeastern part of the

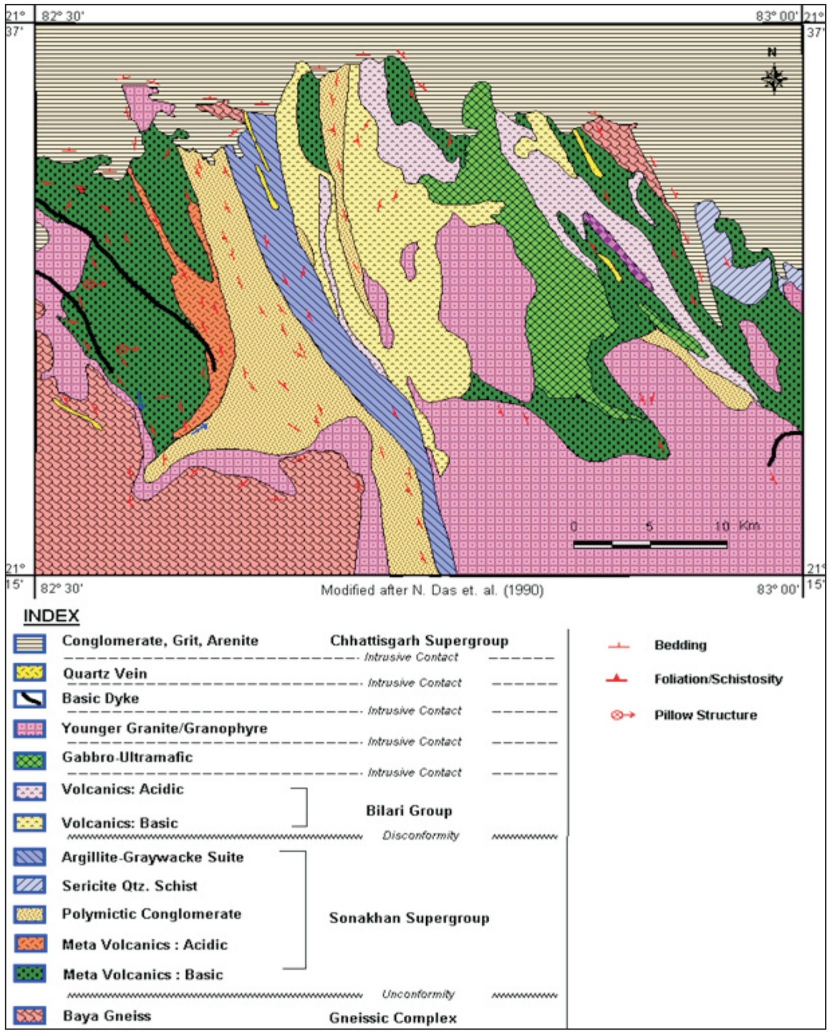

Fig.1. Geological map of Sonakhan Green Stone Belt (*after* Das *et al*., 1990).

Bastar craton represents a typical granite-greenstone belt known as SGB (King, 1899; Naqvi and Rogers. 1987; Radhakrishna, 1983).

The late Archaean SGB covering an area of about 1200km^2 comprises of meta-volcanic and meta-sedimentary sequences which have undergone greenschist to amphibolite facies of metamorphism. The supracrustals around Sonakhan and adjoining area are classified into the Sonakhan Group comprising relatively older Baghmara Formation, which is dominated by mafic meta-volcanic and felsic meta-volcanic rocks and the younger Arjuni Formation is dominated by sandstone and polymictic conglomerate (comprising the clasts derived from Baghmara Formation and Baya gneiss) (Saha *et al.,*1998; Ray and Rai, 2004) (Fig. 1). The lithostratigraphic succession of the Sonakhan Greenstone Belt proposed by Das *et al*. (1990) has been given in Table 1.

The volcanic suite of Baghmara Formation forms the most prominent part of the volcano-sedimentary sequence of Sonakhan Group. It is a suite of bimodal (basic and acidic) meta-volcanic rocks associated with minor intercalations of banded iron formation (BIF) and chert (Ashiya and Kumar, 1992; Rajaiya and Ashiya, 1994; Pasayat, 1994; Mishra., 1996; Ray *et al.,* 2000; Venkatesh, 2001). The identification of igneous textures and magmatic mineral phases was generally possible in thin sections in spite of varying degrees of hydrothermal alteration. Felsic volcanic rocks in the SGB are mainly rhyolites and tuffs. The rhyolites are mostly metamorphosed and are porphyritic to schistose in nature. The presence of acidic tuff was noticed as pockets and lenses, within the meta- rhyolites and dacites.

Petrography

In the meta-rhyolite sample quartz and alkali feldspar are present in abundance as porphyroblasts set in a matrix of fine-grained microcrystalline felsic groundmass comprising of quartz, alkali feldspar, amphibole, chlorite, and opaques (Fig. 2a-b). Opaque are identified as magnetite and hematite. Kaolinization and chloritization are noted throughout the meta-rhyolite sample. In most of the cases, boundaries of amphiboles are found to be chloritised. Kaolinisation of minerals is also noticed in the meta-dacite sample (Fig. 2c).

Table 1: Generalised Geological Succession of Sonakhan Greenstone Belt (*after* Das *et al*., 1990).

Chhattisgarh Supergroup		Conglomerate, Grit, Arenite, limestone
~~ Unconformity ~~~~~~		
Basic Dykes		Quartz vein, Dolerite, Gabbro
______ Intrusive Contact ______		
Granitoids		Pegmatite, Aplite, Granophyre, Biotite and Porphyritic granite
______ Intrusive Contact ______		
Ultramafic Intrusive		
______ Intrusive Contact ______		
Bilari Group	Lakhdabri Acid Igneous suite Arangi Basic Igneous suite	
~~ Unconformity ~~~~~~		
Sonakhan Group	Arjuni Formation	Metamorphosed polymictic Conglomerate Graywacke, argillite, B.H.J., Arenite with thin band of basic volcanics.
	~~ Unconformity ~~~~~~	
	Baghmara Formation	Metaultramafics, Tremolite Actinolite schist, Amphibolite Metabasalt, Pillowed metabasalt, Pyroclastics, Acid volcanics and Tuffs BIF, Chert etc.
~~ Unconformity ~~~~~~		
Baya Gneiss Complex Gneisses		Tonalitic and granodioritic gneiss Migmatites and granites with restites of BHQ, Metaultramafite, Mica schist , Quartzite etc.

The feldspars present in the meta-rhyolites and meta-dacites show sericitisation and saussuritisation. In meta-dacites, biotite, chlorite, and opaque minerals are also present in minor proportions. Syntectonic deformation is confirmed by the presence of elongated porphyroblasts of alkali feldspar and quartz in the meta-rhyolite and meta-dacite sections. Despite variable degrees of alteration, the primary felsic flow structure has been retained in most of the samples.

Geochemistry

Major oxide compositions of the felsic meta-volcanic rocks have moderate Al_2O_3 (10.32% to 26.60%), lower MgO (0.16% to 2.14%), FeO^T (1.78% to 4.89 %), and CaO (0.02% to 4.33%) (Table 2). The concentrations of Na_2O (0.5% to 4.58%) and K_2O (1.63% to 3.72%) varied widely. The lower alkali content in some samples may be due to alteration or low-grade metamorphism. Highly mobile nature of Na and K during metamorphism and hydrothermal alteration changes the initial composition of the rock. When plotted in TAS diagram (Le Bas *et al*., 1986) (Fig. 3), the samples fall exclusively in the dacites and rhyolites fields. Scattering of samples in the TAS diagram indicates that the composition of the rocks was affected by metamorphism and hydrothermal alteration.

The chondrite-normalised REE (Fig. 4) patterns are characterised by a similar trend for all the samples, which indicate common genesis for all the felsic meta-volcanic rocks. The meta-rhyolites and meta-dacite exhibit steep REE pattern (La/Yb = 66.856). Highest LREE values are noticeable in sample SK 10/4, whereas highest HREE values are noticeable in sample SK-54. Low REE (both LREE and HREE) values are

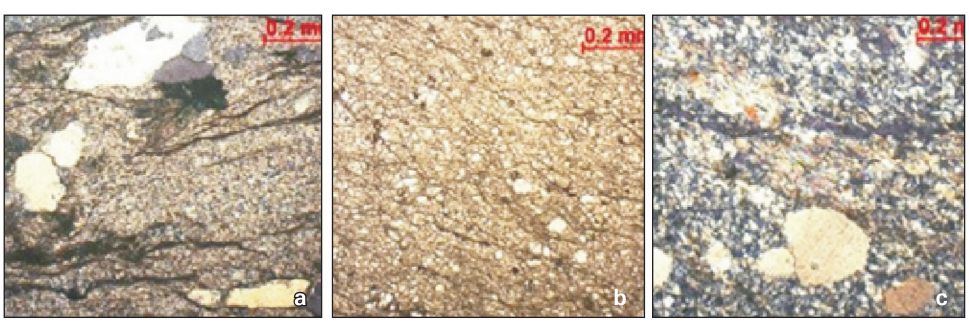

Fig. 2. Photomicrograph showing a) porphyritic texture and primary flow structure in meta-rhyolite; b) meta- rhyolite (PPL) exhibiting the quartz, alkali feldspars and plagioclase feldspar grains; c) meta-dacite from SGB exhibiting serisitisation.

Table 2: Major and trace element data of Sonakhan Greenstone belt felsic meta-volcanics.

Sample No	SK-5/3	SK-6/2	SK-10/4	SK54	SK55	SK56	SK 57
Major Elements							
SiO_2	62.85	70.31	68.58	77.97	77.46	72.87	76.62
TiO_2	0.61	0.78	0.27	0.02	0.31	0.16	0.28
Al_2O_3	26.6	13.62	13.25	14.87	14.52	11.84	10.32
Fe_2O_3	2.63	1.78	4.89	1.87	2.81	2.92	2.64
MnO	0.09	0.13	0.11	0.01	0.02	0.05	0.03
MgO	1.14	1.6	2.48	0.16	0.40	1.52	1.94
CaO	0.83	4.33	2.56	0.11	0.02	2.19	1.87
Na_2O	0.49	2.38	3.72	0.53	0.87	4.58	3.76
K_2O	3.72	2.22	2.15	2.58	2.43	1.82	1.63
P_2O_5	0.56	0.29	0.15	0.02	0.07	0.12	0.34
Sum	99.52	97.44	98.16	98.12	98.91	98.07	99.43
Trace Elements							
Sc	13.335	15.303	8.056	1.613	1.535	5.188	4.478
V	95.589	94.176	51.065	1.411	0.987	4.678	28.523
Cr	239.568	39.201	28.393	6.866	7.259	143.667	114.118
Co	3.325	7.734	12.585	1.131	1.17	11.277	3.028
Ni	7.976	12.419	14.203	1.241	1.396	16.066	102.9
Cu	11.742	37.5	25.138	0.702	0.849	3.127	21.582
Zn	26.65	74.089	115.101	27.723	38.573	92.17	38.293
Ga	33.706	25.395	42.879	26.906	26.79	20.954	35.158
Rb	80.705	68.553	53.764	138.38	138.13	57.801	138.156
Sr	555.355	255.694	692.228	59.791	59.348	450.313	85.733
Y	8.524	29.333	10.925	2.525	2.378	10.694	10.633
Zr	181.224	266.559	133.315	364.684	335.337	386.857	175.248
Nb	1.88	9.415	4.175	26.598	23.422	6.259	6.637
Cs	3.038	1.138	7.523	3.856	2.8	3.695	3.771
Ba	1098.328	593.273	177.334	195.137	192.575	932.44	115.601
Hf	3.536	5.299	2.913	9.788	9.191	8.126	4.472
Ta	0.433	1.928	0.862	3.051	2.809	0.472	0.524
Pb	10.041	11.079	10.48	6.458	5.771	15.447	6.814
Th	29.469	11.595	23.94	15.834	16.309	21.851	25.92
U	1.9	2.361	4.034	11.249	11.337	5.589	2.091
Rare Earth Elements							
La	122.828	63.036	91.672	18.811	11.993	43.093	29.916
Ce	252.089	119.221	162.954	26.503	26.913	81.062	53.03
Pr	24.38	10.936	13.799	4.17	3.216	8.124	5.177
Nd	115.174	50.964	58.709	13.115	13.55	29.306	20.476
Sm	14.284	7.878	7.944	4.175	4.41	5.8	4.318
Eu	3.454	2.132	2.556	1.0786	0.822	1.929	1.29
Gd	14.485	9.698	8.481	3.121	2.131	3.827	3.04
Tb	1.168	1.166	0.727	0.202	0.196	0.438	0.31
Dy	3.022	5.046	2.295	0.514	0.495	1.766	1.655
Ho	0.352	0.916	0.336	0.063	0.059	0.292	0.296
Er	1.454	2.973	1.21	0.234	0.191	1.015	0.834
Tm	0.13	0.443	0.146	0.033	0.029	0.146	0.09
Yb	0.721	2.205	0.814	0.229	0.197	0.938	0.6
Lu	0.098	0.333	0.122	0.04	0.038	0.159	0.127

noticeable in samples SK 6/2 and SK 5/3. None of the samples exhibit prominent Eu anomaly indicating plagioclase fractionation. The primitive mantle normalised diagram show high concentration of Cs, Th, U, K, Pb and Zr and negative anomalies at Ba, Nb, P and Ti (Fig. 5).

Discussion and Conclusions

The occurrence of rhyolite and dacites is widely considered to be a prominent feature in intra-oceanic arc systems (Devine, 1995; Leat *et al.*, 2003). The geochemical signature of the felsic meta-volcanic rocks of SGB generally owe their origin to any one of the following processes (a) Fractional crystallization from a basaltic parent magma with assimilation of middle and upper continental crustal material (b) Partial melting of a subducted oceanic crust infiltrated by slab melts and slab-dehydrated fluid influx (c) Intracrustal melting of the continental crust induced by the crust-mantle

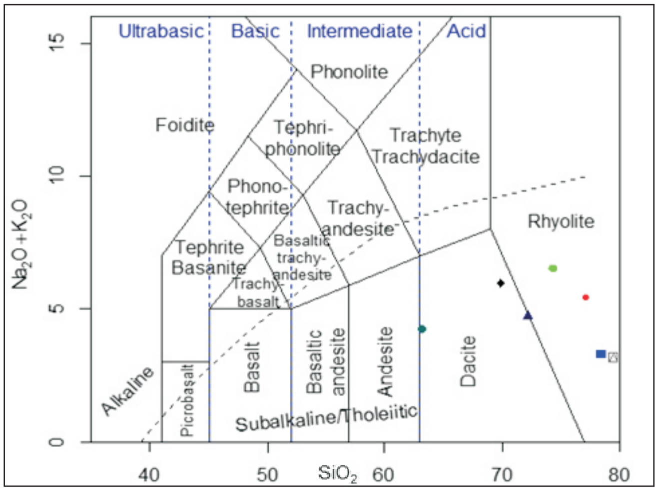

Fig. 3. Na_2O+K_2O/SiO_2 classification diagram for the felsic meta-volcanics from the Sonakhan Greenstone Belt (*fields after* Le Bas *et al*., 1986).

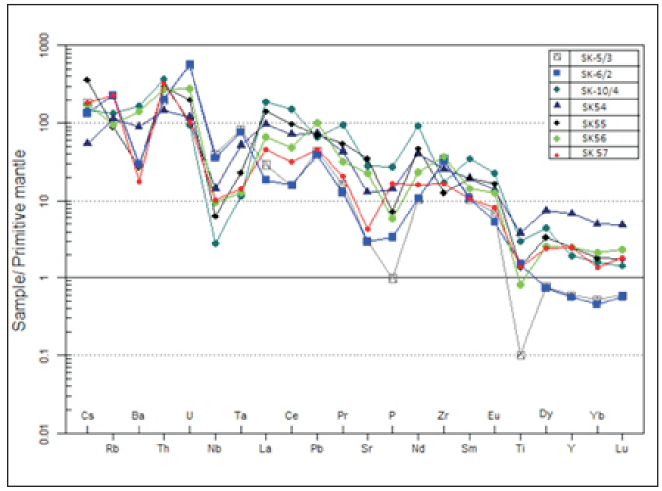

Fig.5. Primitive mantle normalized diagram for the samples from Sonakhan Green Stone belt. Normalizing values are from Mcdonough and Sun (1995), Sun and McDonough (1989).

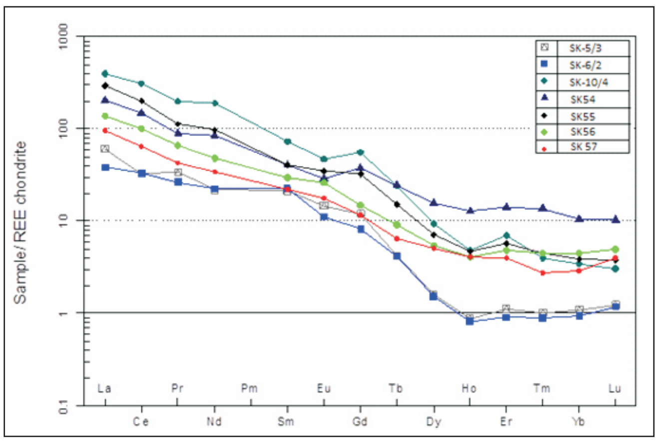

Fig.4. Chondrite normalized REE diagram for the felsic meta volcanics from Sonakhan Green Stone belt. Normalizing values are from Boynton (1984).

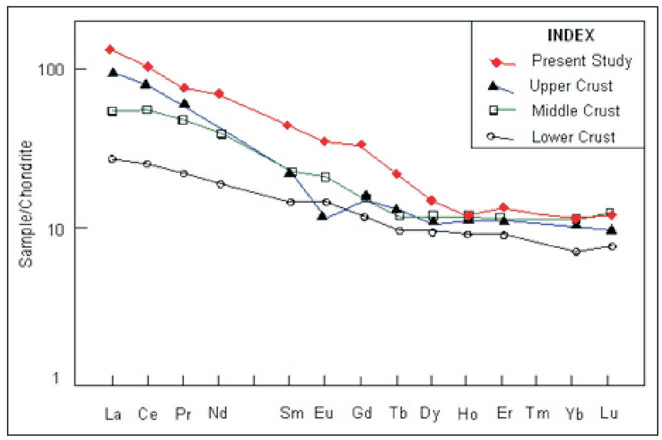

Fig. 6. Comparison of REE pattern of felsic meta-volcanics of Baghmara Formation with those of lower, middle and upper crust (REE values of lower, middle upper crust *after* Taylor and Mc Lennan, 1985)

interactions and the ascent of subduction-related melts. If the felsic volcanic rocks of Baghmara Formation would have derived from magmatic differentiation of parent magma for mafic volcanic rocks, these should have a continuous gradational variation mirrored by various major element oxides and trace elements in the variation diagrams. The lack of consanguinity of the mafic and felsic units which was depicted in the various variation diagrams (not shown here) negate the possibility of co-magmatic nature of mafic and felsic meta-volcanic rocks.

The presence of negative Nb, Ti, Ta and Zr anomaly indicates subduction-related gneisses for the felsic volcanic rocks of Sonakhan Greenstone Belt. In order to get a clear picture of the petrogenesis of the felsic volcanic rocks of Sonakhan area, we have carried out a geochemical modeling with the REE data of the upper, middle and lower crustal rocks. The average values of the of felsic meta-volcanic rocks of Sonakhan area are calculated and has been compared with the upper, middle and lower crust (REE values after Taylor and McLennan, 1985) (Fig. 6.) In the chondrite-normalised diagram, it is observed that the pattern of average REE values of felsic meta-volcanic rocks are similar to that of the middle crust depicting that the felsic rocks are genetically related to the crust.

The felsic magma in Sonakhan area might have been generated either (1) by the melting of the middle crust by the heat generated during the diapirism of mafic magmatism in Sonakhan area or (2) the heat generated during subduction process in the area (as evident from the multi-element diagram) might have melted the middle crust.

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