



Geochemistry and tectonic setting of the supracrustal rocks from the central part of the Bundelkhand Craton, India

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Received: Sept 25, 2018; Accepted: Feb 22, 2019.

DOI: 10.25299/jgeet.2019.4.2-2.2175

Abstract

Supracrustal rocks (mafic and ultramafics) occurs along with banded iron formation, and felsic volcanics around Babina, Dhaura, and Mauranipur linear east–west trends in central part of the Bundelkhand Craton represent Archean crust. The mafic and ultramafic rocks geochemically classified into Komatiite and Basaltic Komatiite and have high–Fe Tholeiitic in composition which may relate with the primitive mantle. The major and trace element geochemistry of mafic and ultramafic rocks correspond to hydrated mantle with wedge tectonic sources and ocean ridge geological characteristics.

Keywords: Bundelkhand Craton, Komatiite, island arc, Archean crust, subduction tectonic setting.

1. Introduction

Archean cratons of the world have become the nerve centers for study to decode the earlier crustal history of earth. The formation of supracrustal rocks or first landmass is in fact an irreversible process in the geological history of earth, which led the processes of initiation of stabilization, continental growth, micro-continent, and supracontinental growth (Pearce and Peate, 1995; Fitton et al., 2003; Naqvi, 2005; Condie, 2014, 2015). The Archean–Proterozoic boundary is an important turnover in the Earth's evolution as marking a cardinal change from the island arc and collisional settings of the Archean to the lithospheric extension and global continental rifting in the early Paleoproterozoic (Bogina et al., 2015). The Indian shield comprises two major Northern (Bundelkhand, Aravalli carton) and Southern (Dharwar, Bastar, Singhbhum Craton) Indian crustal blocks separated along the E–W trending Son–Narmada lineament known as Central Indian Tectonic Zone (Naqvi, 2005; Ramakrishnan and Vaidyanadhan, 2010; Slabunov and Singh, 2018). Mostly the central part of each craton consisting of TTG–gneisses and granitoids, commonly associated with sequences of meta-sedimentaries, meta-volcanics and unstratified ultramafic and mafic volcanic rocks (Naqvi, 2005; Mohan et al., 2013; Jayananda et al., 2015).

The Bundelkhand Craton begin with the ca. 3.55 Ga crustal component growth signatures around the Babina and Mauranipur areas, as preserve in the form of TTG–gneissic rocks (Sarkar et al., 1996; Mondal et al., 2002; Kaur et al., 2014; Singh, 2015; Saha et al., 2016; Singh et al., 2019a). The ca. 3.4 Ga ancient basaltic rocks are mostly exposed contemporaneous with TTG in central part of the craton (Singh et al., 2018, 2019b). The mafics and ultramafic rocks are widely exposed around Baragaon, Dhaura, Babina villages. Singh and Slabunov (2015a) suggest two distinct greenstone complex occur in the craton i.e. (i) Central Bundelkhand (Babina; Mauranipur belts) greenstone and (ii) Southern Bundelkhand (Girar) schist belts. Singh (2005, 2015) has carried out detailed study on geology and structure of Babina–Mauranipur areas and in present paper authors using petrological and geochemical data to determine tectonic settings of these Archean basaltic rocks of the central Bundelkhand Craton.

2. Geological setting of Bundelkhand Craton

The Bundelkhand Craton covers 29,000 km², lying between 24°11' to 26°27' N and 78°10' to 81°24' E, represents a semicircular outcrop, which is overlain by low grade metamorphic rocks of the Bijawar Group (Paleoproterozoic) to the south, southeast, and Vindhyan Supergroup (Mesoproterozoic to Neoproterozoic) to the southeast, south, southwest, and west (Basu, 1986; Sarkar et al., 1996; Singh et al., 2007; Ramakrishnan and Vaidyanadhan, 2010; Fig. 1). The major part of the craton comprises the different phases of Archean magmatism, low-grade metamorphism, Paleoproterozoic mafic dykes and quartz veins. Singh (2005, 2015) mapped the older crustal components from the central part of the Bundelkhand Craton which are scattered in the E–W shear zones

of 3–5 km width (Fig. 2). Metabasics, banded iron formation (BIF) and felsic volcanic rocks exposed from 3 km south of the Babina town to Mauranipur in the east consider as a part of the Central Bundelkhand greenstone complex (Singh and Slabunov, 2015a, 2015b; Slabunov and Singh, 2018; Fig. 1). The doleritic dykes are usually dark greyish green in colour and have NNW–SSE to NW–SE trend (Basu, 1986; Sharma and Rahman, 2000; Pradhan et al., 2012). These mafic dykes are subalkaline to tholeiitic in composition and display continental affinity (Pati et al., 2008). A general characteristic of highly jointed quartz veins occur mostly about NE – SW trend.

The supracrustal rock comprises mafic–ultramafic rocks, banded iron formations, felsic volcanics occur along E–W linear trends, generally dipping towards north. Fragments of low-grade metamorphosed mafic–ultramafic rocks are occur nearby boundary between banded iron formation and TTG–gneisses, at the south of Babina area (near Pura village), Mauranipur and Dhaura villages (Figs. 1 and 2). These rocks are intruded by K-rich granitoids (~2500 Ma) at Babina, Dhaura and Rash Pahari near Mauranipur villages. The pegmatite veins are also observed at many places.

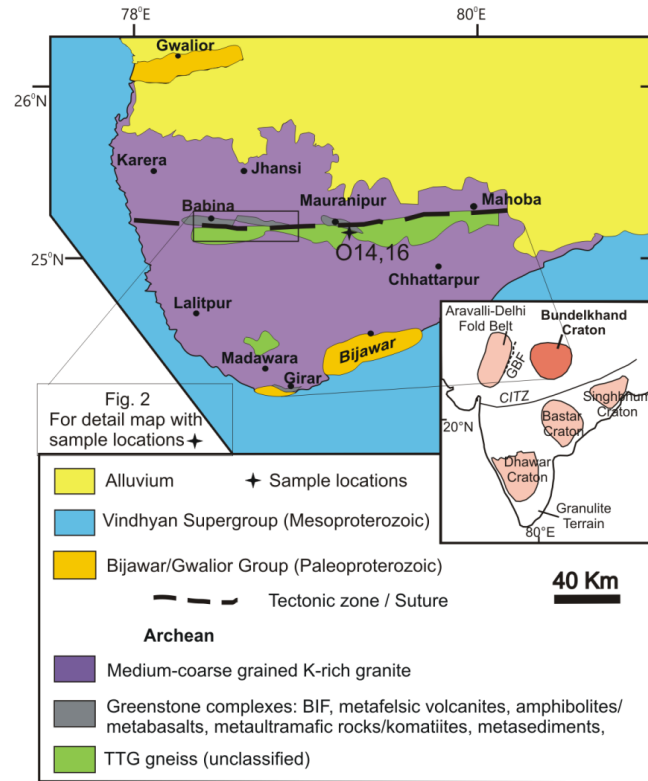
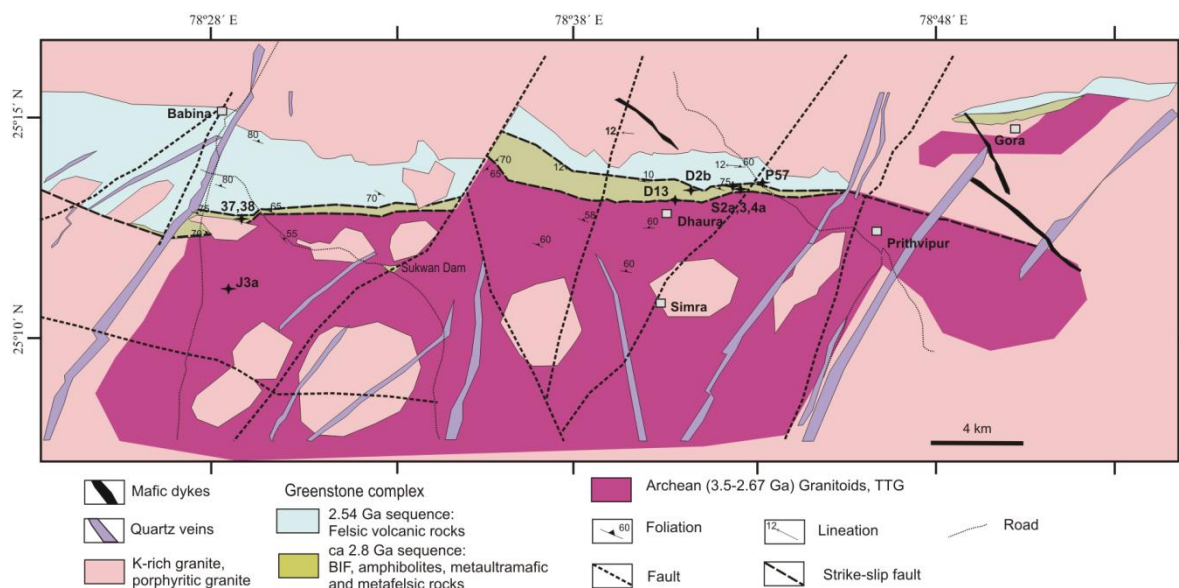


Fig. 1. Geological map of the Bundelkhand Craton (after Ramakrishnan and Vaidyanadhan, 2010 and Slabunov and Singh, 2018), inset map shows the different cratons of Indian shield.



The small body of mafic and ultramafic rocks, exposed along with BIF near village Kuraicha in Mauranipur greenstone belt (Fig. 3a). Basic-ultrabasic rocks also exist in Babina greenstone belt (Fig. 3b) which is resembled with Mauranipur greenstone belt. Exposures of felsic volcanics are observed at north of Babina (Fig. 3c), Paponi, and Dhaura areas. Intrusions of granite are noticed in the felsic volcanics which indicate their younger age. TTG-gneisses are exposed at Babina, Dhaura, Gora and Mauranipur areas. Field relation between basaltic, banded iron formation and TTG-gneisses rocks shows its tectonic colleagues (Fig. 3b; Singh and Slabunov, 2015a). The voluminous pink granites are mostly inhabit of the craton during Neoproterozoic period in multiple phases (Mondal et al., 2002; Verma et al., 2016; Kaur et al., 2016; Joshi et al., 2017; Mishra et al., 2018; Singh et al., 2019c). Slabunov and Singh (2018) noted that Meso-Neoproterozoic felsic rocks formed in a subduction geodynamic setting from the central Bundelkhand greenstone complex.

3. Geochemistry and Tectonic setting

Fresh samples of ultramafics and mafics from central Bundelkhand region have been collected and pulverized in agate ball mill for geochemistry. The samples have analysed at the geochemical lab of NGRI, Hyderabad for major, trace and REE using Inductively coupled Plasma Mass Spectrometry (ICP-MS) while XRF method was used at Wadia Institute of Himalayan Geology, Dehradun. The whole rock major and trace element compositions of the analysed samples are given in Table 1. The different variation diagrams and discrimination diagrams have been obtained using the free access GCDkit 3.00 computer program.

The ultramafic and mafic rocks are classified as subalkaline/tholeiitic picritic, basalt to basaltic andesite with 36.56–55.15 SiO₂ wt. % (Fig. 4a). The rocks display a tholeiitic trend on the AFM diagram (Irvine and Baragar, 1971) (Fig. 4b). In the Jensen (1976) diagram, most rock points are into komatiite, komatiitic basalt, and high-Fe tholeiite fields (Fig. 4c). These rocks vary considerably in MgO (5.66–28.24 wt. %), TiO₂ (0.19–2.52 wt. %), Ni (31–975 ppm) and Cr (67–3121 ppm) concentrations (Table 1). Al₂O₃ concentrations range from 6.58 to 14.25 Wt. %. The Fe₂O₃ in these rocks ranges from 11.89 to 24.3 wt. % which is to some extent high value for tholeiitic magma. Geochemical compositions are plotted on several variation and tectonic diagrams against MgO vs oxides (wt. %; TiO₂ and P₂O₅) and trace elements (ppm; Rb, Sr, Y, and Zr) to examine crystallization behavior, which show decreasing trend with increasing MgO contents (Fig. 5), suggesting that these were more or less incompatible with any fractionating phases.

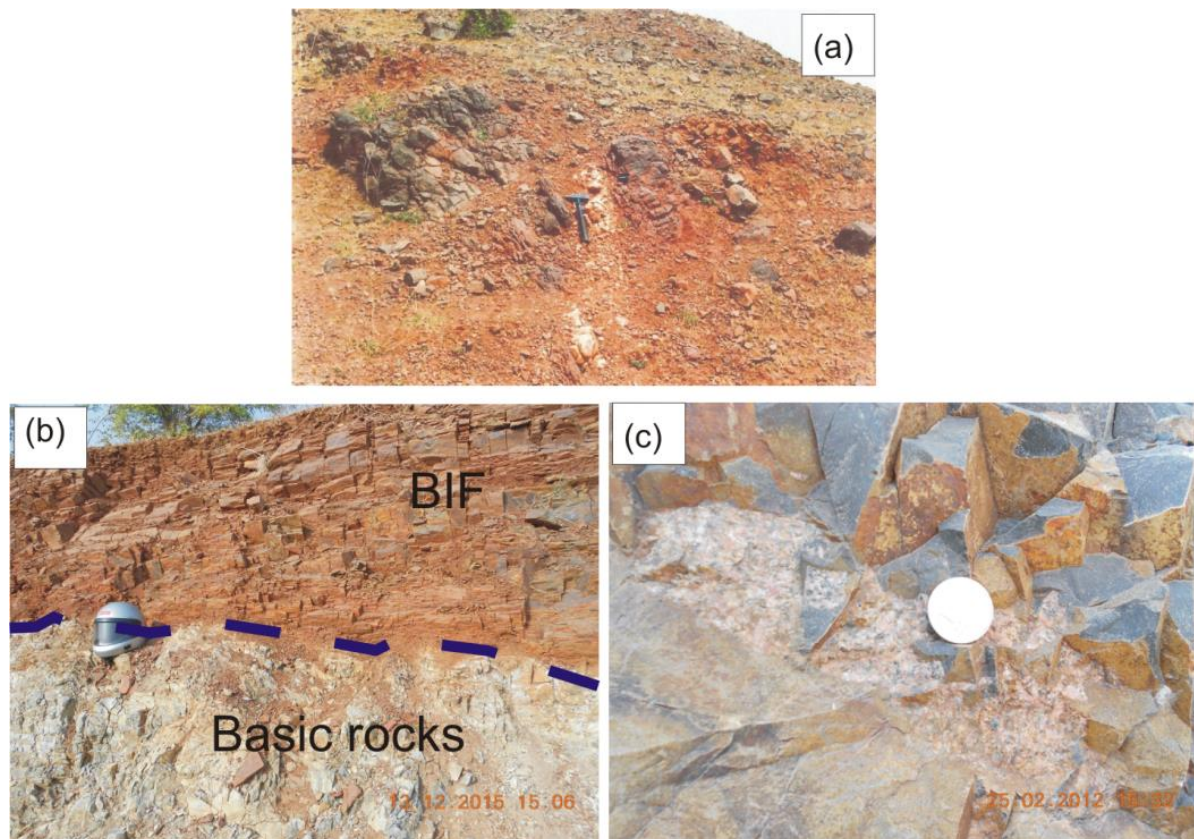


Fig.3. (a) The mafic and ultramafic rocks exposed at the base of BIF near village Kuraicha, Kamla Sagar dam in Mauranipur greenstone belt (size of hammer 15 inch); (b) the underlain basic rocks show tectonic contact with BIF exposed in Babina greenstone belt; (c) Felsic volcanics exposed at 3 km north of Babina with granite intrusion (size of coin 2.5 cm diameter).

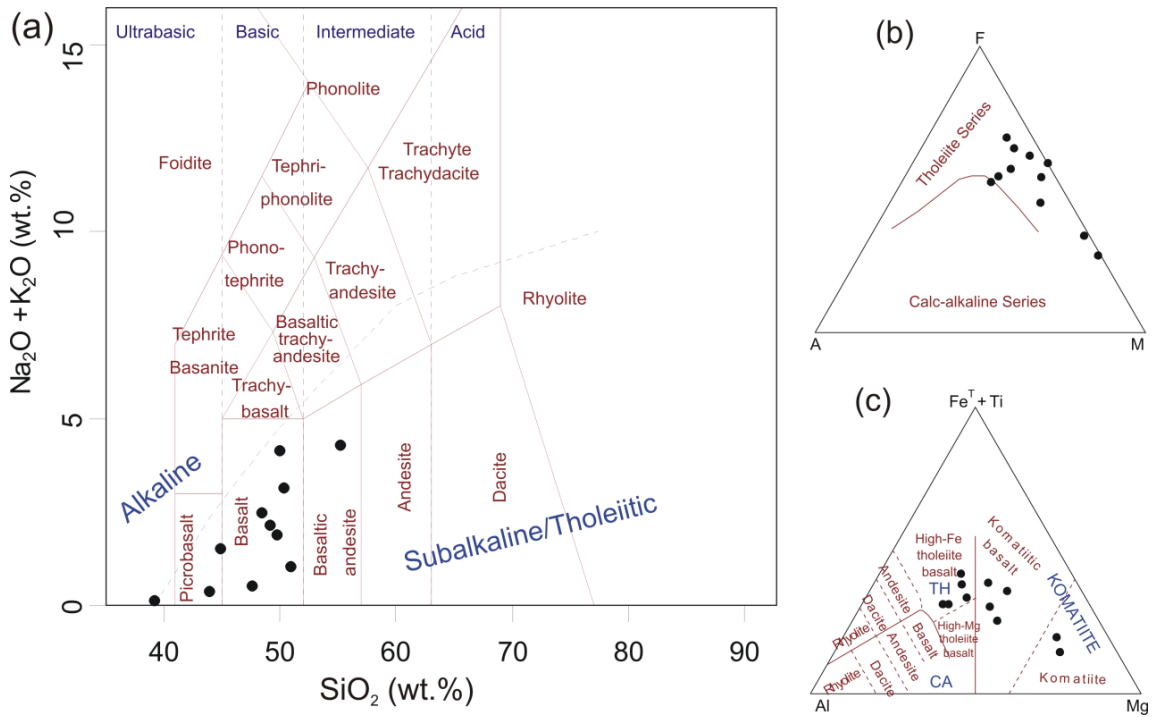


Fig. 4. Classification diagrams of mafic-ultramafic rocks (a) $\text{SiO}_2 \cdot \text{Na}_2\text{O} + \text{K}_2\text{O}$ (Le Bas et al. 1986), (b) AFM (Irvine and Baragar, 1971), (c) cation diagram $\text{FeO}^* + \text{TiO}_2 \cdot \text{Al}_2\text{O}_3 \cdot \text{MgO}$ (Jensen, 1976).

Table 1. Major (wt. %) and trace (ppm) element analytical data of Mafic and Ultramafic rocks from the central Bundelkhand greenstone complex.

Sample	O14	O16	P57	S2a	S3	S4a	D2b	D13	37	38	J3a
Locality	Kuraicha	Kuraicha	Dhaura	Dhaura	Dhaura	Dhaura	Dhaura	Dhaura	Babina	Babina	Babina
SiO ₂	44.23	36.56	42.4	48.06	49.58	55.15	51.31	50.92	49.72	49.18	47.81
TiO ₂	0.19	1.56	2.52	0.51	2.01	2.22	0.79	1.53	1.03	1.36	0.61
Al ₂ O ₃	9.15	10.37	11.56	6.58	11.53	13.07	9.61	14.25	11.72	10.87	10.86
Fe ₂ O ₃	11.89	24.3	23.5	12.51	17.76	12.28	14.22	14.98	16.11	19.98	13.63
MnO	0.22	0.35	0.19	0.27	0.23	0.18	0.17	0.23	0.24	0.28	0.24
MgO	28.24	14.99	11.55	21.29	6.91	5.66	9.62	6.9	7.74	6.26	12.21
CaO	6.35	4.7	1.22	11.11	9.55	6.75	13.95	8.77	9.04	9.85	10.94
Na ₂ O	0.33	0.02	0.95	0.42	1.6	2.82	0.06	2.6	2.48	1.72	1.44
K ₂ O	0.06	0.03	0.47	0.1	0.27	1.48	1	1.61	0.62	0.44	1
P ₂ O ₅	0.04	0.21	0.13	0.09	0.24	0.35	0.11	0.17	0.11	0.14	0.07
Cu	85	31	47		28	175	39	20			99
Zn	120	131	101		83	105	72	130			131
Co	59	75	60		51	59	73	80			78
Ni	900	118	51	975	75	31	69	93	63	34	255
Ga	15.9	16.7	12.1		20.5	17.5	7.4	26.9			8.7
Rb	2.7	3.5	13	5.8	18	81	34.9	48.2	42.5	8.1	61.3
Ba	129	68	44		492	135	45	102			114
Sr	12	299	9	68	140	208	174	163	144	106	82
Y	23.7	30.5	16.1		21.7	25.4	9.7	34.6			14
Zr	7	808	199	30	166	277	77	110	89	102	35
Nb	1	67.3	7	2.7	11	18	4.1	7	4.7	5	2.8
Th	1.9	5.8	2.5		2	0.5	1.6	49.2			3.3
Sc	51	60	45		58	43	40	36			24
Pb	11.7	10	8		9.8	2.8	14.6	27.5			19.1
U	1.4	0.3	1.8		1.1	1.4	0.3	1.9			0.5
Cr	67	105	908		370	170	3121	743			2441
Nb/Th	0.53	11.60	2.8		5.5	36	2.56	0.14			0.85
Zr/Nb	7	12.01	28.43	11.11	15.09	15.39	18.78	15.72	18.94	20.4	12.5
Nb/Y	0.04	2.21	0.44		0.51	0.71	0.42	0.20			0.2
Zr/Y	0.30	26.49	12.36		7.65	10.91	7.94	3.18			2.5

The three fields of mantle domains i.e. enriched mantle (EM), depleted mantle (DM), and hydrated mantle (HM) are define using Nb/Th and Zr/Nb ratio discrimination plot (Condie, 2003, 2005, 2015). The ratios of Nb/Th

is less than 8 and with variable Zr/Nb ratio, show the Archean basalts mostly falls under hydrated mantle domain (Condie, 2015). The Zr/Nb ratio is greater than 10 and Nb/Th less than 10 indicate arc setting (Condie, 2015). The samples from the central Bundelkhand greenstone belt plotted on diagram which show mostly hydrated mantle field and under arc setting conditions (Fig. 6). The sample no O16 which have 11.6 Nb/Th value likely consider an enriched mantle source (Condie, 2015). The sample no S4a have very high Nb/Th value (36) due to less value of Th noticed in specimen may not provide convincing interpretation.

Fitton et al. (2003) describe the Nb/Y versus Zr/Y discrimination diagram which distinguish NMORB and Iceland basalts on Nb incompatible element. The lower limit of Iceland data array as reference line defined a parameter (ΔNb) that expresses excess or deficiency in Nb such that Icelandic basalt has $\Delta Nb > 0$ and NMORB show deficiency in Nb ($\Delta Nb < 0$; Fitton et al., 2003). The mafic and ultramafic rocks from the central Bundelkhand greenstone complex plotted on Fitton et al. (2003) discriminant diagram which falls mostly in the vicinity of Nb/Zr=0.06 line with OIB field and some samples falls in Iceland basaltic type (Fig. 7).

The compositions of mafics and ultramafics rocks are associated to arc type tectonic setting for the magmatism. Singh et al. (2019b) suggest that the mafic-ultramafic rocks from central Bundelkhand greenstone complex have been interpreted to be derived from oceanic crust in a subduction-related setting with depleted mantle composition. Similar rocks are also reported by Malviya et al. (2006) from Mauranipur area and stated that komatiite basalt is nearly constant along the olivine fractional crystallization trend but enriched LREE and LILE as modern boninite formed at a plate convergent margin.

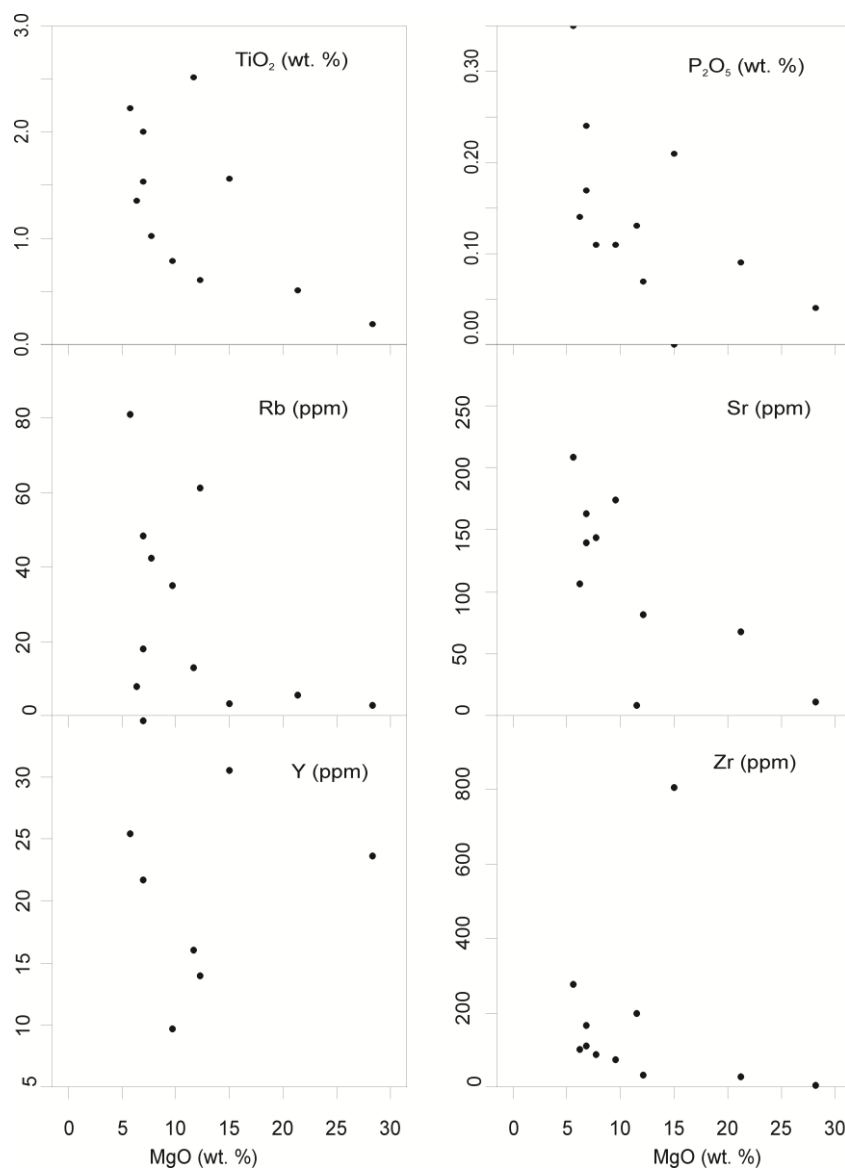


Fig. 5. Geochemical variation diagrams between MgO (wt%) and minor oxides (TiO₂ and P₂O₅; wt%) and trace elements (Rb, Sr, Y, and Zr; in ppm).

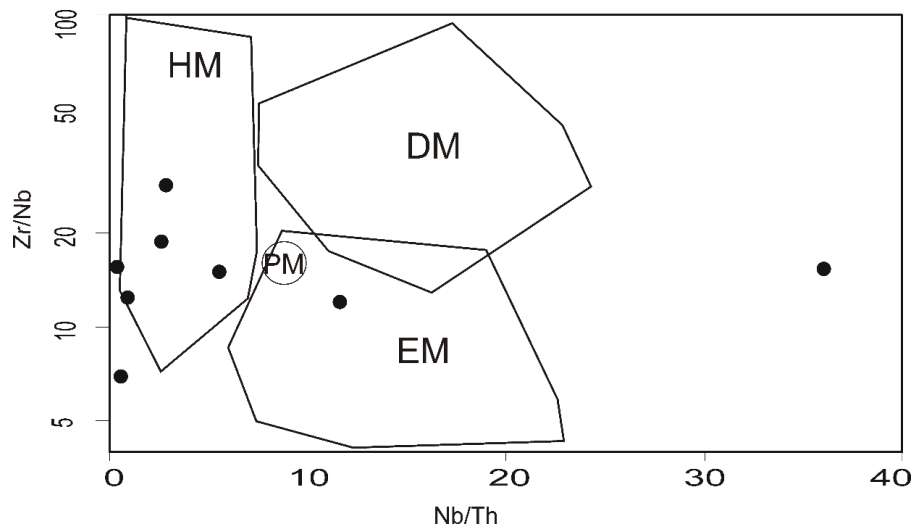


Fig. 6. Discrimination diagrams for distinguishing tectonic setting using Nb/Th and Zr/Nb ratios (Condie, 2015).

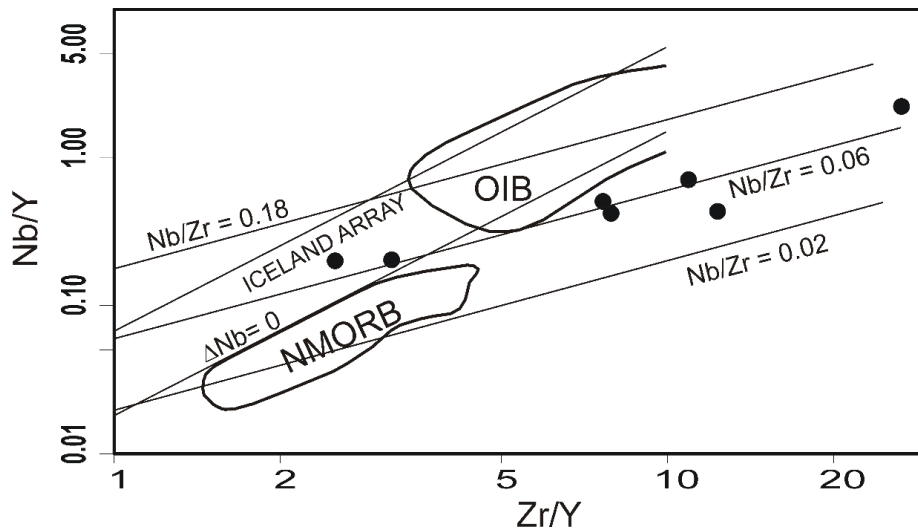


Fig. 7. Zr/Y versus Nb/Y discrimination diagram (after Fitton et al., 2003); NMORB: normal mid-ocean ridge basalt, OIB: ocean-island basalt.

4. Discussion and Conclusions

The supracrustal rocks of Babina and Mauranipur consist of low K–Tholeiitic basalt, basaltic Komatiite, volcanosediment and BIF followed by andesite to rhyodacite volcanics which are similar to those reported from various Archean greenstones (Paris, 1987; Kusky et al., 2001; Polat et al., 2003; Manikyamba et al., 2005). Condie (2015) discussed that Nb/Th and Zr/Nb incompatible element ratios are useful to illustrate their tectonic setting where the ratio of Nb/Th is less than 8 and with variable Zr/Nb ratio, falls under hydrated mantle domain mainly of Archean oceanic basalts. Several hypotheses have been discussed as accretions of oceanic terrain form by plume impact explain the unusual high MgO content of Komatiite (Hertzberg, 1995; Xie et al., 1995; Arndt et al., 1997) causes the large degree of melting and the pyrope-bearing peridotite source material is usually considered for the source of Komatiite magma. The accretion of oceanic volcanic arc may explain a geochemical similarity between Komatiite and modern arc related volcanic for supracrustal rocks of the central Bundelkhand region (Malviya et al. 2006).

The discussions of occurrences of metabasic and ultrabasic rocks and generation of various type of parent (Basaltic/Komatiitic) magma reveal related to different tectonic environment even in smaller tectonic provinces too (Bose, 1997; Barley et al., 2000; Massaki et al., 2001; Svetov et al., 2001; Shimizu et al., 2005; Verma et al., 2015). Fitton et al. (2003) provides a useful discriminant logarithmic plot of Nb/Y versus Zr/Y between Icelandic basalt and NMORB (i.e. plume and nonplume basalt). The Nb/Y versus Zr/Y plotted mafics and ultra-mafics rocks from central part of the Bundelkhand Craton show mostly OIB type plume basalt (Fig. 7). The initial Komatiite composition of magma altered to Komatiitic basalt and Tholeiitic compositions, either due to fractionation or

contamination or metasomatic activities in the area. Geochemically the mafic and ultramafic rocks are very similar to the Komatiitic and Komatiite basalts of greenstone belts.

Singh and Slabunov (2015a) estimated as Paleo–Neoproterozoic time for the formation of supracrustal metabasic rocks from central Bundelkhand greenstone complex. The ultramafic and mafic sequences in Babina and Mauranipur greenstone belt are related to arc type subduction related magmatism (Malviya et al., 2006; Singh, 2015, Condie, 2015). Singh et al. (2018, 2019b) stated that ϵNdt value of +2.0 to +5.6 for the basalts from Babina greenstone belt indicate depleted mantle source at ca.3.4 Ga.

Thus, the geochemical characteristics conclude that the protolith of supracrustal rocks of the central Bundelkhand greenstone complex be produced in hydrated mantle field with arc tectonic setting in Archean time. The Komatiitic–Tholeiitic association of greenstone formed in narrow belt along the Babina–Mauranipur greenstone belt.

Acknowledgements

MMS gratefully acknowledges financial support provided by Ministry of Mines, Government of India, New Delhi vide letter F. No.14/17/2002-Met.IV dated 27th February 2003 to Bundelkhand University Jhansi, UP. VKS is thankful to DST, Gov. of India, for providing the financial support as grants no. [INT/RUS/RFBR/P-279]. Prof. A.I. Slabunov (Petrozavodsk, Russia) and Neeraj Chaudhary thankfully acknowledged for discussions.

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