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Research Article

Neoarchean Granitoids of Bundelkhand Craton, India: Geochemistry and Geodynamic Settings

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Abstract

The potash-rich granite and granodiorite-granite series rocks are extensively exposed in the Bundelkhand granite–greenstone belt around Jhansi, Babina and Mauranipur in the central part of the craton, which are mostly calc-alkaline in nature, relatively high Sr (12–436ppm), low Y (9.1–67) and low Sr/Y (0.24–21.37) ratio characteristics. These rocks have high Rb (77.7–539), moderate Nb (7.2–42.2) and Nd (21.92–115), and geochemically vary from mostly I- to A-type granites generally formed during syn–to post–collision. The chondrite normalized rare earth element distribution pattern is poorly fractionated La_N/Lu_N=(3.4–31.79) with a negative Europium (Eu) anomaly (Eu/Eu*=0.2-0.82) showing subduction environment. The granodiorite-granite series rocks show mostly volcanic arc setting while potash-rich–granites plots within the syn-collosion to post-collisional granite fields on the Yb+Ta versus Rb and Nb versus Y discrimination diagram. Geochemical characteristics indicate that anhydrous partial melting of the Paleo-Mesoarchean Tonalite-trondhjemite-granodiorite or mafic crust through subduction setting responsible for formation of these rocks.

Keywords: Neoarchean granitoids; Subduction tectonics; Geodynamics settings; Bundelkhand Craton

Introduction

The early earth crust formation still remains immense wide scope for in depth research on the Precambrian crustal growth which evolved a wide range of geological processes including plate tectonics and magmatism [1-4]. Understanding the early earth evolution and its geodynamics is one of most fundamental scientific issues in geology, because the evolutionary trends of the planet earth cannot be resolved without adequate knowledge of Archean period. To understand the tectonic growth of continental crusts in Archean cratons, the granites are playing most important role in this context. The Bundelkhand Craton is nestled in the northern margins of Peninsular India. The Bundelkhand Craton begin with the ~3.5Ga crustal component growth signatures, as preserve in the form of TTG gneisses [5-7]. The Craton mainly constitutes older basement of TTG and mafic gneisses and is associated with migmatites, amphibolites, schist, and supra-crustal belt of meta-sedimentary and meta-volcanics. The ample potash-rich granites and granodiorite-granite series rocks mostly inhabit of the craton and crustal growth takes place during Neoarchean period in multiple phases [7-9]. Recently, Singh & Slabunov [10-13] depict the Greenstone Belts and establish tectonic evolution of the craton, based on SHRIMP-dating of zircon and geochemistry from the felsic volcanic rocks from the Babina belt. The present paper deal with the geochemistry of granitiods (granodiorite-granite series and potash-rich granite) rocks from mostly central part of the Bundelkhand Craton to establish tectonic settings and the continental growth of the craton during Neoarchean period.

Geological Setting

The Bundelkhand Craton covers 29,000 km^2, lying between 24°11' to 26°27' N and 78°10' to 81°24' E, represents a semicircular outcrop. The low grade metamorphic rocks of the Bijawar Group (Paleoproterozoic) to the south, southeast, and Vindhyan Supergroup (Meso-to Neoproterozoic) to the southeast, south, southwest, and west are resting over on Bundelkhand Craton [7,14,15]. The major part of the craton comprises the different phases of magmatism, low-grade metamorphism and deformation of Archean TTG-gneissic rocks, mafic dykes and undeformed quartz veins [8,9,16-18]. The doleritic dykes are usually dark grayish green in color and have NNW-SSE to NW-SE trend [14,19]. A general characteristic of highly jointed quartz veins occur mostly about NE- SW to NNE-SSW trend. Slabunov & Singh [20] illustrate the greenstone belts from the central part of Bundelkhand Craton which are scattered in the E-W shear zones of 3-5kms width. The potash-rich granites

(~2.5 Ga) occurring around the Babina, Dhaura, and 3km south of the Mauranipur regions. The pegmatites veins are also observed at many places. TTG-gneisses are exposed at the Babina, Dhaura, Gora and Mauranipur areas (Figure 1).

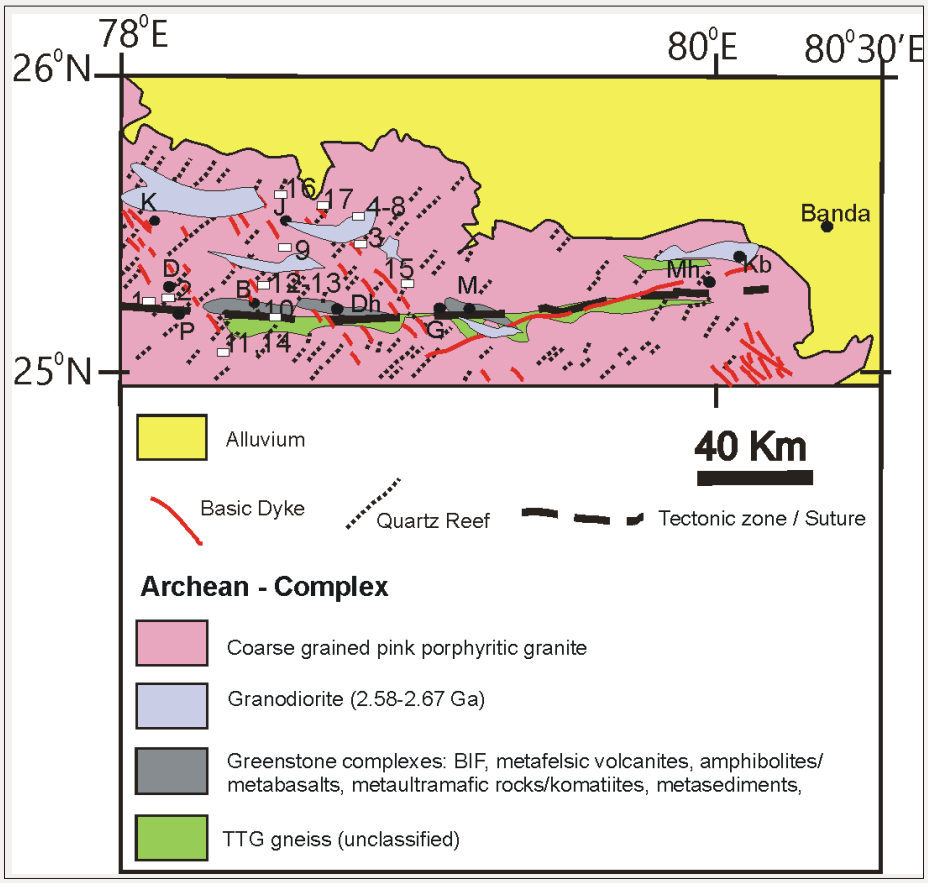

Figure 1: General geological map of central Bundelkhand Craton showing sample locations.
Abbreviations: B: Babina; D: Dhala; Dh: Dhaura; G: Gora; J: Jhansi; K: Karera; Kb: Kabrai; M: Mauranipur; Mh: Mahoba; P: Pichhore

Methodology

Fresh samples of granodiorite-granite series rocks and potash-rich granite, from central Bundelkhand Craton have been collected , and pulverized in agate ball mill for geochemical analysis. For major element analysis, 1.2g sample powder was weighed and mixed with 6g lithium borate flux (consisting of 35.3% tetraborate and 64.7% metaborate). Further, the fusion bead method was used to prepare the glass bead at 1000 °C for ≈8 min in Pt-Au crucible for only major elements analysis. For selected trace element analysis, 9g of sample powder was pressed into a pellet using 1.2g Wax binding agent. Both, glass bead and pressed pellet analysis were carried out at Institute of Geosciences, University of Campinas (UNICAMP), Brazil for seven samples. Major oxides concentrations were determined by X-ray Fluorescence Spectrometer (XRF), utilizing fusion beads whereas trace elements were obtained by inductively coupled plasma-mass spectrometry (ICP-MS) in press pellets. The loss of ignition (LOI) determined by TGA furnace. The base metals were analyzed using four acid digestions method by ICP- atomic emission spectroscopy (ICP-AES). Whereas total carbon and sulfur obtained by Leco combustion techniques. Five samples (SCB-1,SCB-2,SCB-3,SCB-4 and SCB-5) for whole rock geochemical analyses were conducted at Australian Laboratory services Pty. Ltd., Malaga, Western Australia, Australia. Five potash-rich granite samples (BL-5,BL-6,BL-29,BL-30,SB-31) for whole rock geochemistry are analyzed at Petrozavodsk, Russia and detail methodology is given in Singh & Slabunov [12].

Geochemistry and Tectonic Settings

Geochemical compositions of Neoarchean granitoid samples from the Bundelkhand Craton are summarized in Table 1 and Table 2. In TAS (Total alkali vs Silica) diagram, the samples are classified volcanic equivalent [21] as dacite (SCB-04,BH-8,BM-6), trachyte (SCB-01,SCB-05), rhyolite (SCB-02,SCB-03,BH-11,UM-4,BJ-1;PL-1). The majority of potash-rich granite rocks are classified as rhyolite, whereas granodiorite-granite series rocks plotted in dacite and trachydacite field (Figure 2a). The granodiorite-granite series rocks are mostly high-K calc-alkaline and potash-rich granites are varies from high-K calc-alkaline to shoshonite series in nature (Figure 2b) [22]. In granodiorite-granite series rocks Na_2O varies from 3.29 to 3.83wt% and K_2O content varies from 2.44 to 4.04wt.%. The Al_2O_3 content varies from 12.61 to 15.79wt. % (av. Al_2O_3: 14.79wt. %) and SiO2 having range from 61.63 to 74.2wt %. The titanium (TiO_2) content is low ranging from 0.25 to 1.32 wt.%.

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Table 1: Major (wt.%) and trace (ppm) element analytical data of granodiorite (1-6) and granite (7-17) rocks from the central part of the Bundelkhand Craton.

Sample	1	2	3	4	5	6	7	8	9
	BM-6	UM-4	BH-8	SCB-1	SCB-4	SCB-5	SCB-2	SCB-3	BJ-1
SiO_2	61.63	74.2	62.13	63.21	63.23	62.93	71.81	73.72	68.36
TiO_2	0.535	0.252	0.554	0.55	0.56	1.32	0.37	0.16	0.294
Al_2O_3	14.92	12.61	15.39	15.46	15.79	14.57	13.92	13.9	15.18
Fe_2O_3	5.98	1.95	5.96	5.84	5.6	6.82	2.83	1.41	2.81
MnO	0.092	0.038	0.095	0.12	0.1	0.09	0.05	0.03	0.051
MgO	3.24	0.72	3.77	2.26	2.66	1.58	0.64	0.25	0.79
CaO	4.66	2.98	4.13	3.49	4.92	3.75	1.03	1.32	2.86
Na_2O	3.47	3.71	3.69	3.83	3.68	3.29	3.19	3.19	3.9
K_2O	2.87	2.55	3.03	3.65	2.44	4.04	5.4	5.42	3.86
P_2O_5	0.153	0.07	0.158	0.16	0.16	0.66	0.09	0.04	0.079
LOI	1.63	0.86	0.99	1.42	0.92	0.82	0.89	0.42	0.97
Cr	86	11.4	83	100	90	40	10	10	13.6
Ni	21.6	6.8	21.3	18	21	22	4	7	6.4
Co	0	0	0	19	19	14	11	14	
Sc	11	4	12	12	13	8	4	1	5
V	93	29	96	106	115	87	29	8	30
Cu	15.1	42	25	1	39	25	3	6	2.5
Pb	28.1	18	33.8	22	22	32	32	55	27
Zn	80	23.7	90	80	76	104	34	35	46
Bi	0	0	0	0.12	0.23	0.11	0.05	0.21	
In				0.026	0.014	0.037	0.018	0.007	
Sn				3	3	5	3	2	
Mo				<1	2	4	1	1	
S				0.01	0.05	0.05	0.01	0.01	
Sb				0.06	0.16	0.05	<0.05	<0.05	
Te				0.01	0.01	0.02	0.01	0.01	
Rb	91	87	101	150.5	77.7	167	216	242	154
Cs				1.29	6.24	3.43	1.05	5.19	
Ba	624	510	662	895	704	1000	787	492	757
Sr	337	251	308	285	436	334	154	164.5	247
Tl				0.1	0.32	0.65	0.06	0.25	
Ga	15.7	14.9	18.8	19	20.4	24.2	19.3	17.1	20.7
Li				30	120	30	10	30	
Ta				1	2.4	2.5	2.3	1.3	
Nb	9.6	10.4	9.4	9.5	9.6	42.2	20.3	7.2	11.9
Hf				3.8	4.5	16.2	10	3.9	
Zr	149	162	151	139	170	703	378	116	165
Y	19.1	15.8	21	18.9	20.4	41.3	38.9	9.1	22.4
Th	13.7	26.8	16	13.15	13.6	35.3	47.6	31.2	23
U				4.84	4.4	5.47	12.95	9.92	
La	26	34	29	33.9	33.6	145	112	35.2	40
Ce	70	58	66	63.4	68.6	298	211	64.6	72
Pr	0	0	0	7.75	7.78	34.1	24.3	7.16	

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Nd	32	25	25	27.2	27.5	115	78	22.9	32
Sm				4.96	5.17	18.5	11.9	3.68	
Eu				1.19	1.1	2.47	1.31	0.71	
Gd				4.02	4.08	12.4	8.56	2.35	0
Tb				0.65	0.65	1.7	1.37	0.32	0
Dy				3.47	3.65	8.65	7.23	1.53	0
Ho				0.67	0.74	1.51	1.39	0.29	0
Er				1.98	2.03	3.79	3.84	0.88	0
Tm				0.28	0.32	0.54	0.56	0.14	0
Yb				1.85	1.96	3.09	3.42	1.13	0
Lu				0.27	0.31	0.47	0.47	0.2	0
Sr/Y	17.644	15.8861	14.6667	15.0794	21.3725	8.08717	3.95887	18.0769	11.0268
K_2O/Na_2O	0.82709	0.68733	0.82114	0.953	0.66304	1.22796	1.69279	1.69906	0.98974
Na_2O+K_2O	6.34	6.26	6.72	7.48	6.12	7.33	8.59	8.61	7.76

Table 2:

Sample	10	11	12	13	14	15	16	17
	SB-31	BL-30	BL-6	BL-5	BL-29	BH-11	KR-12	PL-1
SiO_2	72.7	74.02	75.28	71.84	74.86	72.35	64.62	70.45
TiO_2	0.34	0.13	0.11	0.23	0.1	0.196	1.83	0.328
Al_2O_3	12.35	13.4	12.24	13.47	13.03	14.16	10.18	15.29
Fe_2O_3	0.97	0.6	0.79	1.14	0.53	2.4	13.33	4.76
FeO	1.36	0.86	0.79	1.22	0.65			
MnO	0.04	0.02	0.03	0.05	0.01	0.034	0.023	0.08
MgO	0.71	0.29	0.14	0.71	0.47	0.42	1.01	1.4
CaO	1.46	1.02	0.51	1.24	0.44	0.82	0.52	0.34
Na_2O	3.36	3.47	3.68	3.56	3.68	4.06	0.07	0.12
K_2O	5	5.33	5.26	5.11	5.26	4.42	4.97	3.45
P_2O_5	0.08	0.03	0.02	0.08	0.05	0.043	0.307	0.126
LOI	1.48	0.69	0.67	1.07	0.68	0.98	2.34	3.57
Cr	9	6		9		7.7	11	22.9
Ni	2.2	2	0.5	3.2	0.7	3.7	10.8	18.6
Co	45	33	46	28	33			
Sc			3			3	22	3
V	21	5		21		15.3	188	49
Cu	4	4	1	11	7	2.9	12.3	4
Pb	33	54	24	35	49	23	26.2	14.5
Zn	47	22	50	50	16	30	38	132
Bi	0.18	0.14	0.38	0.29	0.17			
Cd	3.38	2.21	3.03	2.05	1.74			
In	0.02		0.08	0.03				
Sn	4.8	5.15	2.99	8	1.99			
Mo	2.64	2.94	2.55	0.38	1.12			
Sb	0.09	0.18	0.11	0.44	0.12			
Te		0.07	0.04					
Ag	0.1				0.1			
Rb	271	539	230	208	436	142	196	148

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Cs	1.42	4.92	1.46	1.16	2.6			
Ba	596	222	78	975	215	1041	384	601
Sr	162	85	12	222	43	135	16.3	30
Tl	1.06	2.32	1.25	1.02	1.7			
Ga	17	25	22	25	23	18.3	11.9	18.2
Li	11.54	11.63	2.18	6.83	10.46			
Ta	2.38	7.84	2.03	2.24	4.73			
Nb	20.2	40.3	20.5	13.8	31.3	9.9	8.9	13.4
Hf	10.29	8.66	11.45	7.34	7.14			
Zr	306	193	293	193	147	218	188	163
Ti	2185	877	647	1604	571			
Y	35	56	35	24	34	15.7	67	26.8
Th	43.32	80.24	31.76	25.73	61.64	30.9	8.2	63
U	8.62	33.85	6.18	4.86	50.4			
La	110.59	82.59	88.27	58.19	24.89	63	<13	107
Ce	191.34	161.66	165.9	105.94	50.9	124	288	104
Pr	17.1	15.35	16.33	10.24	5.63			
Nd	62.91	54.55	61.11	37.34	21.92	43	82	36
Sm	10.49	9.9	10.4	6	4.81			
Eu	1.38	0.63	0.27	1.23	0.52			
Gd	9.64	9.63	9.71	5.68	5.01			
Tb	1.23	1.39	1.25	0.73	0.85			
Dy	6.61	8.31	6.73	3.99	5.4			
Ho	1.27	1.7	1.32	0.8	1.17			
Er	3.9	5.53	3.82	2.48	3.87			
Tm	0.56	0.9	0.54	0.37	0.64			
Yb	3.76	6.54	3.66	2.6	4.74			
Lu	0.54	0.97	0.52	0.39	0.75			
Be	4.39	7.92	3.02	2.74	5.92			
Sr/Y	4.62857	1.51786	0.34286	9.25	1.26471	8.59873	0.24328	1.1194
K_2O/Na_2O	1.4881	1.53602	1.42935	1.43539	1.42935	1.08867	71	28.75
Na_2O+K_2O	8.36	8.8	8.94	8.67	8.94	8.48	5.04	3.57

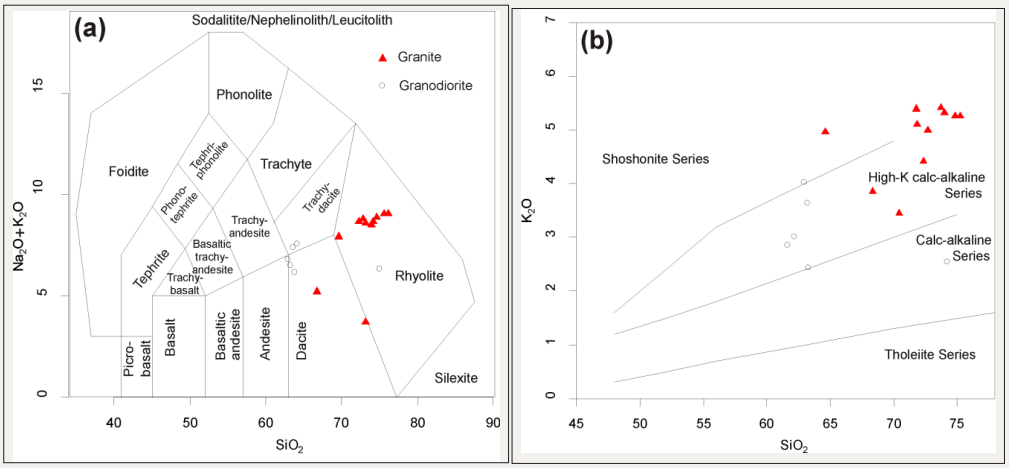

Figure 2: Classification diagram SiO_2 vs. Na_2O+K_2O [21].
Figure 2b: SiO_2 vs. K_2O diagram [22].

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The potash-rich granite rocks having Na_2O varies from 3.19 to 4.06wt. % and K_2O content varies from 3.45 to 5.42wt %. The Al_2O_3 content varies 10.18 to 15.18wt. % and SiO_2 having range from 64.62 to 75.28wt %. The Titania (TiO_2) content are low ranging from 0.1 to 1.83wt. %. Most of the samples from granodiorite-granite series rocks are poor in potash (K_2O/ Na_2O varies from 0.66 to 1.22) while K_2O/ Na_2O > 1 for potash-rich granite.

The granodiorite-granite series belongs to high-K calc alkaline magma series, with metaluminous character while potash-rich granite shows metaluminous to peraluminous character [23] (Figure 3). These granodiorite-granite series and potash-rich granite rocks mostly occur in I-type to A-type granitoids field of Whalen et al. [24] diagram (Figure 4). On Harker diagram (Figure 5), the abundances of TiO_2, Al_2O_3, MgO, CaO, P_2O_5, Fe_2O_3T and MnO decrease with linear or near-linear trends increasing SiO_2 on variation diagrams indicate a typical feature of I-type granites [25]. In the Yb+Ta versus Rb and Nb versus Y discrimination diagram of Pearce et al. [26], the granodiorite-granite series rocks plot within volcanic arc granite field whereas potash-rich granitic rocks plot within the syn-collosion to post-collisional granite fields (Figure 6). This is also supported by the R1-R2[R1=4Si^{4+}-11(Na^{+}+K^{+})2(Fe^{3+}+Ti^{4+}), molar; R2=6Ca^{2+}+2Mg^{2+}+Al^{3+}, molar] tectonic discrimination diagram (Figure 7) [27].

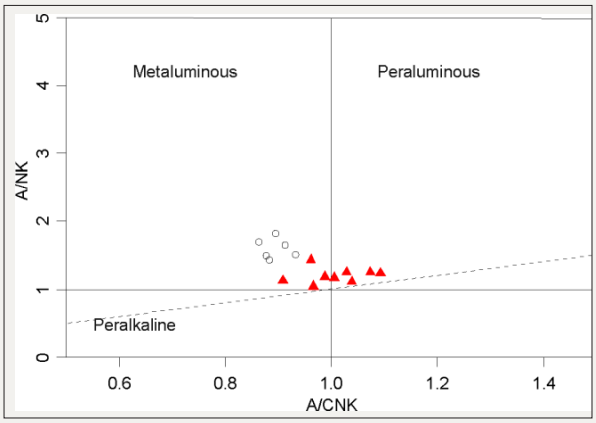

Figure 3: A/NK versus A/CNK diagram [23].

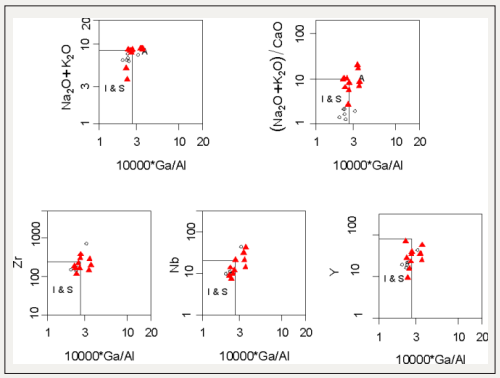

Figure 4: Classification of granitoids after Whalen et al. [24].

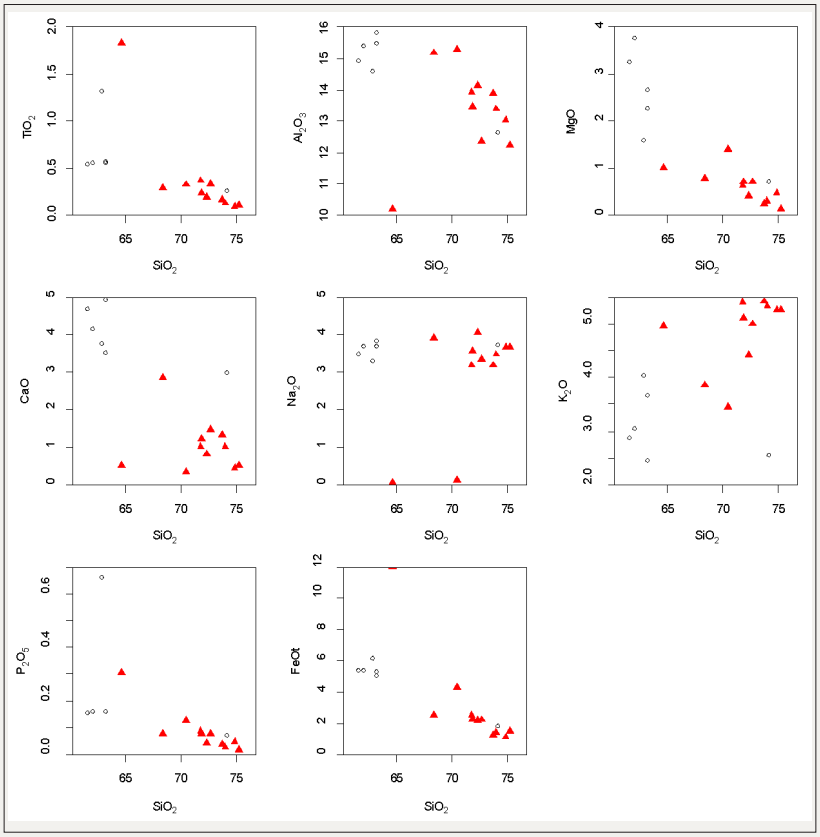

Figure 5: Harker diagrams for granitoid rocks from Bundelkhand Craton. Symbols are the same as in Figure 2.

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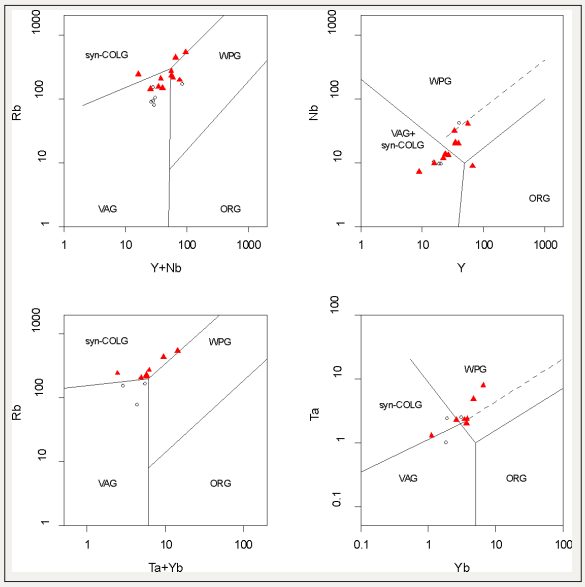

Figure 6: Discrimination diagrams Rb:Y+Nb, Nb:Y [26] for the TTG:gneiss and granite of the central Bundelkhand craton. Symbols are the same as in Figure 2.
ORG: Ocean Ridge Granites; syn: COLG: Syn: Collision Granites; VAG: Volcanic Arc Granites; WPG: Within Plate Granites

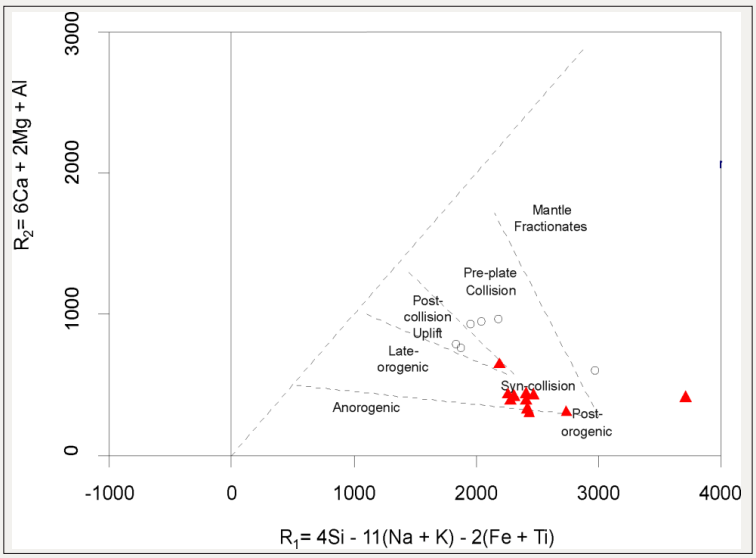

Figure 7: R1:R2 multicationic variation diagram [R1 = $4Si^{4+}$:$11(Na^{+}+K+)$: $(Fe^{3+}+Ti^{4+})$, molar; R2 = $6Ca^{2+}$+ $2Mg^{2+}$ +Al^{3+}, molar], [27].

Discussion and Conclusion

The granodiorite-granite series samples are classified as dacite to rhyolite composition occur in subduction environment and potash-rich granites formed during syn-collision at shallow depth. The silica percentage ranging from 61–75wt% suggests acidic, calc-alkaline nature. It is characterized by relatively high Sr (12–436ppm), low Y (9.1–56) and low ratio of Sr/Y (0.34–21.37). Most of the potash-rich granite samples are rich in potash (K_2O/ Na_2O>1), with high Rb (77.7–539), moderate Nb (7.2–42.2) and Nd (21.92–115). The chondrite normalized rare earth element distribution pattern is poorly fractionated La_N/Lu_N=(3.4–31.79) with a negative Europium (Eu) anomaly (Eu/Eu*=0.2–0.82) showing subduction environment (Figure 8a; [10,12,28]). A primitive mantle normalized [29] multi-element diagram (Figure 8b) showed a wide range in the concentration of the trace elements. Most of the samples show enrichment of large-ion lithophile elements (LILE) but depletion of Nb, Ta and Ti [30]. The depletion of Nb and Ta in the rocks is most significant with Nb/La ratios (Figure 8b). It is noteworthy that the granodiorite-granite series and potash-rich granitic rocks are characterized by the Ba-poor, Sr, P, Nb-Ta and Ti anomalies. The negative Nb-Ta anomalies and a positive Pb anomaly are generally interpreted as subduction-related magma generation. Similarly, High-Field-Strength Elements (HFSE) depletions are common in rocks formed in arc environments, those that have interacted with continental crust, or those, which crystallized Ti-rich phases [31].

The Harker diagram of granitoids show positive correlation of K_2O vs. SiO_2 suggest that K-feldspar fractionation is an important differentiation process during the late stages of crystallization for the potash-rich granite in the Bundelkhand Craton [15]. Most of the samples are occur in I- to A-type granitic field of the Whalen

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et al. [24] diagram which indicates that the granitoids are formed during syn-collision to post-collision tectonic environment. Singh & Singh [15] have established similar observation for the granites and TTG from central part of the Bundelkhand craton. The geochemical analysis suggests a subduction tectonic setting for granodiorite-granite series formed in active continental edge where oceanic crust subducted under continental block in Neoarchean time by accretion-collision system. Chauhan et al. [16] also indicate that anhydrous partial melting of the Paleo-Mesoarchean TTG or mafic crustal materials in an extensional regime produce K-rich granites. The plagioclase-orthoclase granite advanced in post-accretionary processes after granodiorite-granite series formed in the craton. The Bundelkhand Craton stabilized at around 2.5Ga.

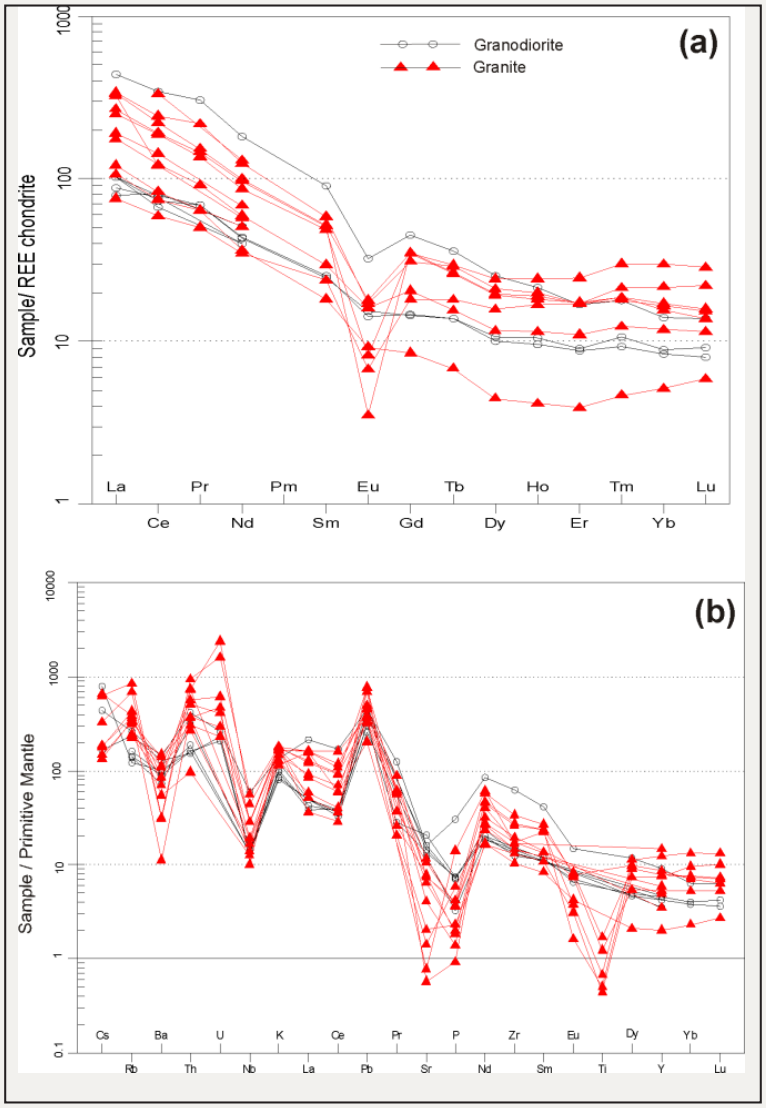

Figure 8: REE Chondrite spider plot after Nakamura [28].
Figure 8b: Primitive mantle:normalized elements [29] for the Neoarchean granitoids.

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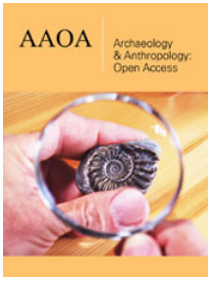

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