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CORRESPONDENCE

Remnants of Early Continental Crust in the Amgaon Gneisses, Central India: Geochemical Evidence

Nishchal Wanjari[1,3], Deepanker Asthana[1,*] and V. Divakara Rao[2]

[1] *Department of Applied Geology, Indian School of Mines, Dhanbad - 826 004, India*
[2] *Geology Department, Osmania University, Hyderabad, Andhra Pradesh - 500 007, India.*
[3] *Present address: Department of Geology, University of Delhi, Delhi - 110 007, India*
* *Corresponding author: E-mail: dasthana@hotmail.com*

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Abstract

The Central Indian continental crust is postulated to have formed around the Archean nuclei of the Bastar Craton (Radhakrishna, 1993). Around 3.5 Ga. Old, high-Al_2O_3 trondhjemite gneisses have been reported from the southern part of the Bastar Craton (Sarkar et al., 1993). However, neither isotopic nor geochemical evidence exists in the literature for the presence of rocks older than ~2.5 Ga from the northern part of the Bastar Craton (Sarkar et al., 1990). The absence of tonalite-trondhjemite-granodiorite (TTG) suites from the Amgaon Gneisses (Rao et al., 2000), were considered to indicate substantial geochemical differences between the Amgaon gneisses and the TTG basement gneisses of the Dharwar Craton (i.e., the peninsular gneisses). Accordingly the mode of the tectonomagmatic evolutionary patterns of the Bastar Craton was considered to be different, both in time in space from the bordering Dharwar and Bundelkhand Cratons, respectively. In this communication we report the presence of high-Al_2O_3 trondhjemite from the Amgaon gneisses, along with calc-alkaline and peraluminous granites that are geochemically similar to the late granitoids (~2.5 to 2.6 Ga old) of the Dharwar Craton, suggesting that the two cratons were nearest neighbours at least during the late Archean.

Key words: Amgaon Gneisses, TTG suites, high-Al_2O_3 trondhjemites, Bastar Craton, late Archean.

Introduction

Granite gneiss basements, supracrustal belts, and late stage granitoids characterize the Archean terrains worldwide. The later granitoids represent recycling of the former and/or melting products of cratonic sediments. The Archean granite basements are medium- to fine-grained grey gneisses and are invariably metamorphosed from middle amphibolite to upper granulite facies. Compositionally, the basement grey gneisses correspond to the high-Al_2O_3 trondhjemites of the TTG suites, and represent the earliest mode of continental crust generation (Martin, 1994). In the northern part of the Bastar Craton, the Amgaon gneissic complexes represent the basement gneisses (Fig. 1). The foliated grey gneisses of the Amgaon consist of fine- to medium-grained plagioclase (saussuritised albite/oligoclase), quartz, biotite and minor K-feldspar and amphiboles. Other minor minerals present include epidote, chlorite, sericite, sphene, apatite, zircon and iron oxide. At places the Amgaon Gneisses are characteristically pink due to their high K-felspar content and show granoblastic equigrannular texture.

The origin and evolution of the Amgaon gneissic complex is the least studied and understood component of the Bastar Craton. In order to develop a better understanding of the Bastar Craton during the late Archean, it is necessary to identify the various phases of granite activity (including the TTGs, if any), in the Amgaon Gneissic Complex and compare them with granitoids of the Dharwar Craton. The reasons for doing so are: (1) the Bastar and Dharwar Cratons are separated from each other by Meso- to Neo-Proterozoic rift; (2) the Dharwar Craton is the best-studied craton of the Indian Shield and shares a common and unique crust-forming event between 2.6 and 2.5 Ga with the Bastar Craton, implying a strong late Archean linkage between the two cratons (Kröner et al., 1998; Zhao et al., 2002, 2003) and (3) in pre-Rodinia

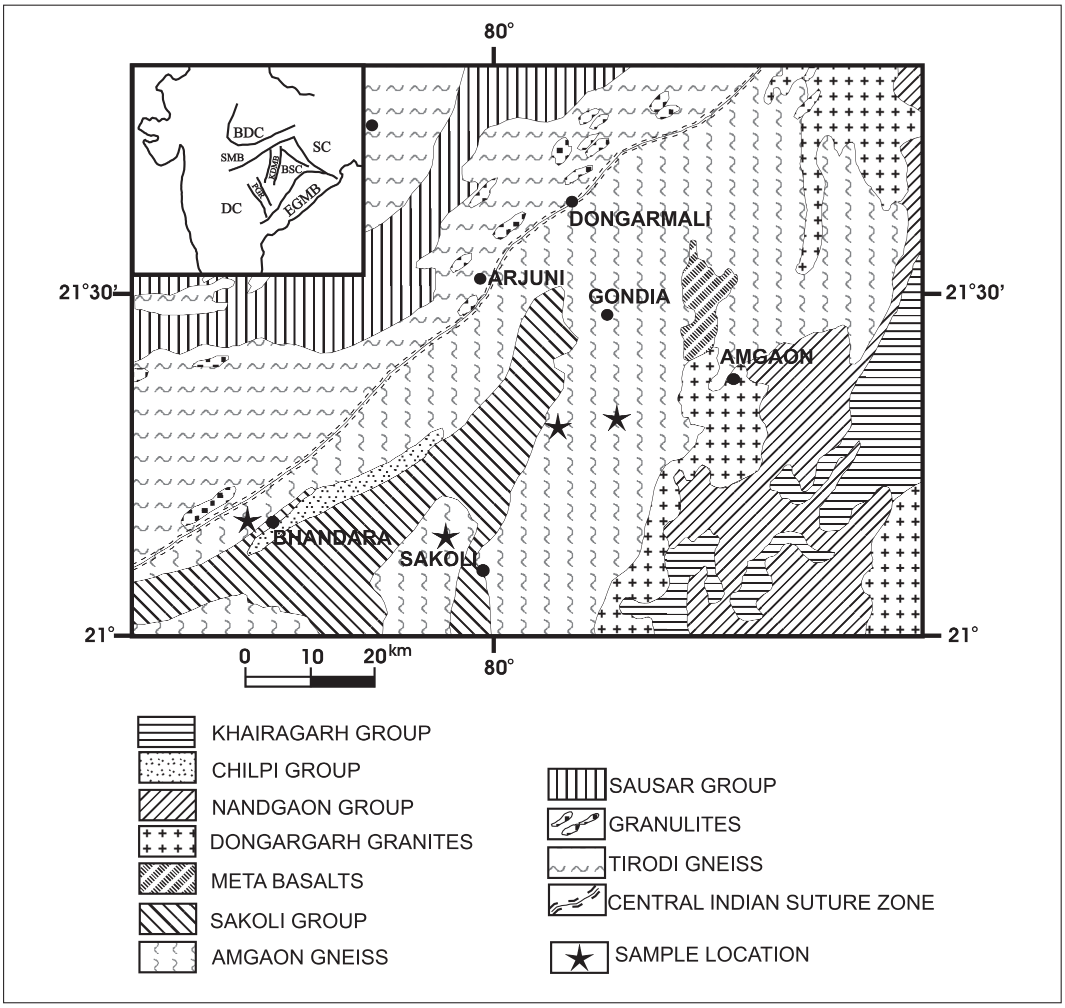

Fig. 1. Regional geological map of the Amgaon Gneissic Complex. BDC–Bundelkhand Craton, BSC–Bastar Craton, DC–Dharwar Craton, SC–Singhbhum Craton, KDMB–Kotri Dongargarh Mobile Belt, EGMB–Eastern Ghat Mobile Belt, SMB–Satpura Mobile Belt, PGR–Pranhita Godavari Rift.

supercontinent assembly, the South Indian Block comprising the Dharwar, Bastar and Singhbhum Cratons are treated as a single supercraton. The purpose of this study is to geochemically identify phases of granite activity in the Amgaon Gneissic Complex and compare and contrast them with granites of the Dharwar Craton in order to constrain the evolution of the Bastar Craton during the late Archean.

Geochemistry

This study is based on the geochemical analyses of the Amgaon Gneisses that were reported by Rao et al. (2000), and the details of the analytical techniques are given in that paper. Harker variation diagrams of the Amgaon gneisses reveal negative correlation for all the major elements, except K_2O that shows an overall positive correlation. The Amgaon Gneisses can be subdivided in four distinct and coherent geochemical groups on the basis of the rare earth element patterns (REE), high field strength elements (HFSE) and interelemental ratios. The REE patterns and the primitive mantle normalized plots of each geochemical group reveal coherent and consistent patterns (Fig. 2). Accordingly, large-scale elemental mobility is considered highly unlikely.

The four geochemical groups of the Amgaon Gneisses are termed trondhjemites, trondhjemite-granites, granites and adamellite granites respectively, on the basis of the Ab-An-Or ternary diagram (Fig. 3). As per the classification scheme of Barker (1979), the Amgaon trondhjemite gneisses are classified as high-Al_2O_3 trondhjemites (>Al_2O_3 15 wt.%, at SiO_2 ~70 wt.%). The average composition of the Amgaon high-Al_2O_3 trondhjemites gneiss approximates the average composition of the Archean grey gneisses (trondhjemites) given by Martin (1994) (Table 1). In common with grey gneisses of the

Table 1. Average major oxides (wt.%) and trace element (ppm) concentrations of the Amgaon Gneisses.

Major Oxide	Granite		Trondhjemite		Adamellite-Granite		Trondhjemite-Granite	
(Wt.%)	Mean	Range	Mean	Range	Mean	Range	Mean	Range
SiO_2	73.51	67.2–75.98	69.66	67.81–73.55	72.39	68.69–75.17	72.72	69.09–75.42
TiO_2	0.34	0.15–0.69	0.30	0.04–0.74	0.33	0.16–0.51	0.26	0.14–0.63
Al_2O_3	12.64	11.81–13.96	15.83	14.39–16.82	14.62	13.79–15.68	14.31	12.66–15.45
Fe_2O_3	2.68	1.5–4.6	2.15	0.98–2.80	2.87	1.97–3.85	1.97	0.98–5.29
MnO	0.04	0.02–0.06	0.03	0.02–0.04	0.03	0.05–0.20	0.03	0.10–0.70
MgO	0.47	0.01–1.43	0.60	0.16–0.86	0.81	0.31–1.17	0.37	0.19–0.59
CaO	1.22	0.34–2.22	3.27	1.79–3.67	1.69	0.68–2.47	2.28	1.26–3.28
Na_2O	3.52	3.02–4.24	5.74	4.95–6.66	3.30	2.02–5.68	4.82	3.67–5.92
K_2O	5.34	4.36–6.5	1.93	1.27–3.99	3.87	1.36–6.27	3.66	1.77–5.18
P_2O_5	0.11	0.02–0.36	0.07	0.04–0.08	0.07	0.60–0.70	0.08	0.04–0.22

Element	Trondhjemite		Trondhjemite-Granite		Granite		Adamellite-Granite	
(ppm)	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Cr	3	0–11	7	3–15	11	5–15	8	0–27
Ni	7	2–20	7	2–24	19	2–27	35	2–59
Sc	4	2–6	7	2–14	16	3–25	12	4–29
V	61	3–181	3	1–5	11	2–22	58	2–194
Rb	40	24–92	94	33–229	139	108–199	136	44–278
Sr	714	368–982	344	54–801	149	14–468	160	19–461
Ba	445	224–1299	830	384–1293	424	208–840	230	81–379
Ta	0.7	0.39–1.4	0.74	0.49–1.32	0.90	0.72–1.32	5.01	0.21–24.97
Nb	3.47	1.91–5.33	5.92	2.18–15.36	10.64	8.82–12.63	12.64	6.56–22.01
Hf	1.72	0.74–3.66	2.94	0.91–6.12	8.68	3.32–12.37	5.99	2.75–15.12
Zr	64	34–125	101	32–183	276	103–437	174	88–411
Y	4	2–8	11	4–24	48	34–61	15	6–25
Th	5.18	1.23–11.13	7.63	2.29–33.82	10.10	7.87–14.75	39.61	5.27–117.23
U	1.58	0.56–4.63	2.34	0.52–6.74	1.66	1.08–2.27	1.83	0.93–3.63
La	15.98	11.54–18.53	24.38	11.52–45.67	54.91	36.38–98.35	76.77	4.72–209.08
Ce	27.94	19.63–33	43.94	22.19–83.82	95.74	69.12–150.96	140.64	18.19–409.99
Pr	2.66	2.09–3.1	4.22	2.18–7.47	13.71	8.56–25.57	24.50	3.22–76.26
Nd	9.39	8.23–11.74	14.74	7.11–29.93	40.10	28.17–56.37	47.69	9.0–132.53
Sm	1.78	1.06–2.39	2.79	1.31–5.87	7.61	4.53–9.04	7.49	2.48–13.92
Eu	0.68	0.09–1.13	1.19	0.73–2.82	0.87	0.4–1.49	1.13	0.23–1.77
Gd	1.25	0.76–2.05	2.37	0.79–5.08	5.94	4.5–7.21	6.06	2.35–9.94
Tb	0.17	0.08–0.24	0.33	0.17–0.64	1.07	0.73–1.21	0.78	0.41–1.23
Dy	0.80	0.32–1.31	2.35	0.85–8.58	6.31	4.43–8.53	3.47	1.92–5.37
Ho	0.14	0.03–0.26	0.32	0.15–0.7	1.18	0.78–1.81	0.40	0.22–0.7
Er	0.51	0.18–0.85	0.89	0.39–1.92	3.48	2.18–5.81	1.17	0.77–2.09
Tm	0.06	0.02–0.12	0.13	0.05–0.27	0.46	0.27–0.74	0.20	0.07–0.29
Yb	0.37	0.14–0.66	0.82	0.28–1.88	3.23	2.1–5.38	1.12	0.51–2.34
Lu	0.07	0.02–0.11	0.12	0.03–0.3	0.48	0.29–0.63	0.19	0.05–0.37

Archean TTG suites, the Amgaon trondhjemite gneisses have low K_2O/Na_2O (0.35) and Rb/Sr (0.064) ratios, and low abundance of the ferromagnesian elements (i.e., $FeO^t + MgO + MnO + TiO_2 < 5$ wt.%). It is rich in Na_2O (Av. 5.74 wt.%), Sr (Av. 713 ppm) and Ba (Av. 445 ppm). REE patterns for the trondhjemite gneisses are steep (Av. $La/Yb_N \sim 31$) with well-developed positive Eu anomalies (Fig. 2). The low abundance of the HREE (Av. $Yb_N \sim 2$) along with fractionated patterns of the REE ($Gd/Yb_N \sim 6$), indicates the presence of garnet, whereas the positive Eu anomalies indicates the absence of plagioclase, in the source (Martin, 1994). The mantle normalized plots reveal enrichment of large ion lithophile elements (LILE) with respect to the neighboring incompatible HFSEs, resulting in well-developed negative Nb and Ti anomalies. All these geochemical features of the Amgaon trondhjemites along with high Sr/Y ratios (Fig. 4) are robust geochemical features and reveal the typical Archean TTG character of these rocks. Numerous experimental data suggest that rocks belonging to the Archean TTG suites, such as the Amgaon high-Al_2O_3 trondhjemites can be generated by ~30% melting of partially hydrated metabasalt at pressures above the garnet-in phase boundary (>10 kbar) and temperatures between 1000 and 1100°C (Martin, 1994; Rapp and Watson, 1995). The overall petrological and geochemical similarity of the Amgaon trondhjemite gneisses and the Archean TTG suites suggests that the majority of these rocks were derived from amphibolite

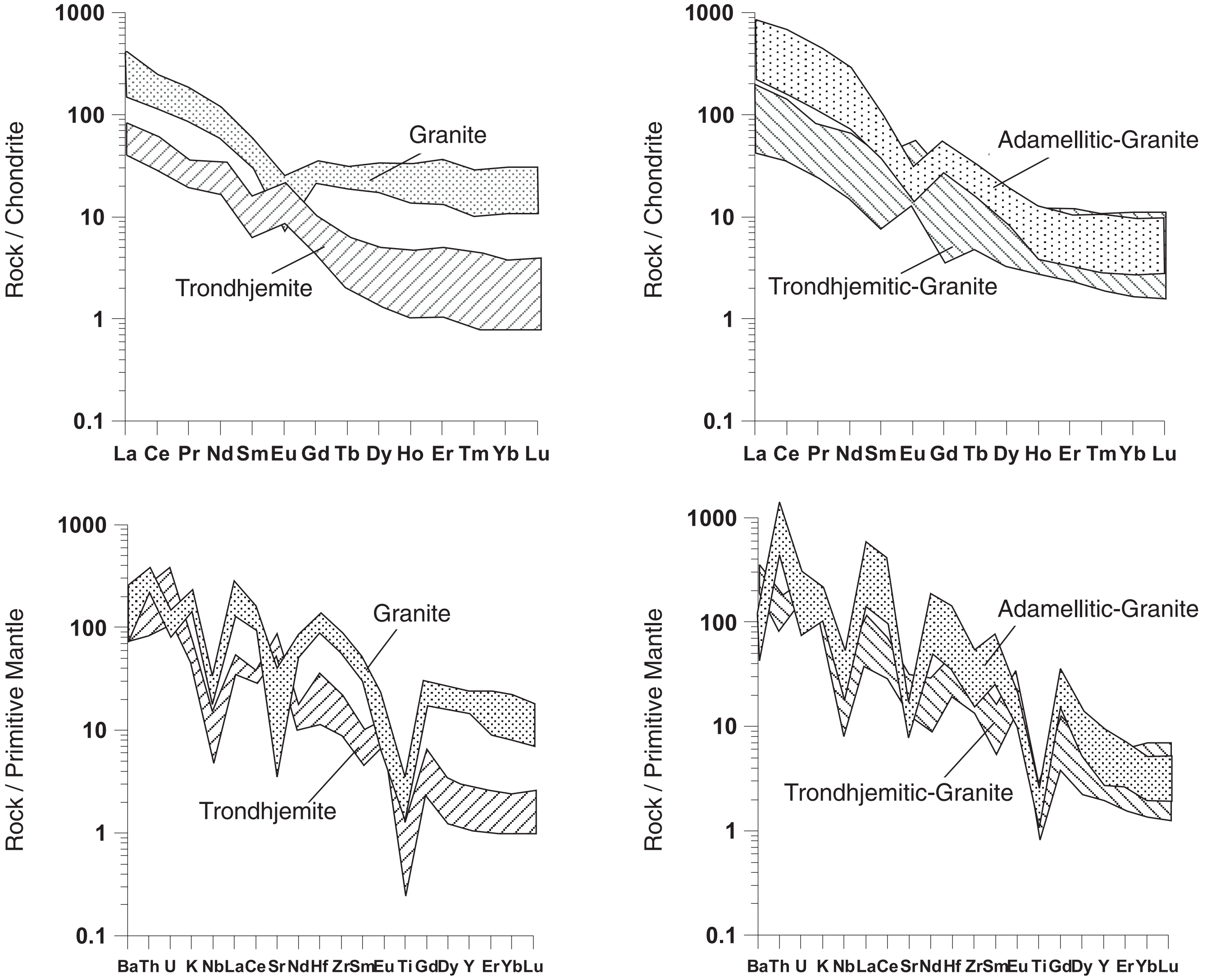

Fig. 2. Chondrite-normalized REE and primitive mantle normalized plots of incompatible elements of the Amgaon trondhjemites, trondhjemitic-granites, granites, and adamellitic-granites. (Normalizing values are from Sun and McDonough, 1989).

melt precursor, a conclusion also supported by the Nb/Ta versus Zr/Sm plot (Fig. 5). However, the tectonic setting(s) where melting of the amphibolites took place is a matter of considerable debate (Martin, 1994; Smithies, 2000).

The Archean TTG suites reveal secular geochemical changes from 4.0 to 2.5 Ga., especially in terms of their MgO, Ni, Cr and Sr contents (Smithies, 2000; Martin and Moyen, 2002). MgO versus SiO_2 plots of the TTG suites are commonly employed to reveal the secular geochemical changes and mantle-melt interaction. The later process would result in an increase in MgO (and Ni and Cr), and a decrease in SiO_2 contents, respectively. These changes have been explained within the framework of two contrasting tectonic models: (1) the Archean TTG suites are the melting products of hydrous met-basalts beneath an over-thickened crust, since they lack geochemical signatures of mantle-melt interaction. The lower MgO and higher SiO_2 contents of the Archean TTG suites in comparison to the Cenozoic adakites does not indicate mantle-melt interaction (Smithies, 2000); and (2) secular changes in the Archaean TTG suites are a function of increased depth of slab melting and resulted in progressively greater mantle-melt interaction. The MgO, Ni, and Cr contents progressively increased in the less differentiated TTGs from 4.0 to 2.5 Ga. (Martin and Moyen, 2002). Significantly the Ni and Cr contents of the Amgaon trondhjemitic gneisses are low (Av. Ni ~7 ppm and Cr ~3 ppm), compared to the average Archean trondhjemites (Table 1). We have plotted high-Al_2O_3 trondhjemites; from the Amgaon and the Makarampara (Sarkar et al., 1993), and the average composition of the peninsular gneisses of the Dharwar Craton (Jayananda et al., 1995) on the

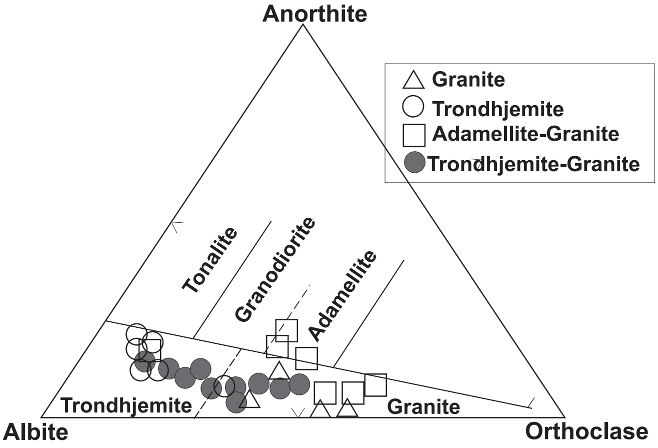

Fig. 3. Normative An-Ab-Or diagram of Amgaon trondhjemites, trondhjemitic-granites, granites, and adamellitic granites. The fields are after Barker (1979).

MgO versus SiO_2 plot (Fig. 6). Also shown in this diagram is the field of liquids produced by experimental melting of basaltic amphibolites (Rapp and Watson, 1995). The high- Al_2O_3 trondhjemites of the Bastar Craton (i.e., Amgaon and Makrampara trondhjemites), in common with the peninsular gneisses of the Dharwar Craton, do not reveal any perceptible evidence for slab melt–mantle interaction. This is so because the TTGs from the Bastar and the Dharwar Cratons plot well within the field of experimental melts of basaltic amphibolites. In the absence of evidence for melt-mantle interaction, generation of the Bastar Craton trondhjemites and Dharwar Craton peninsular gneisses appears more likely to have taken place at the base of an over-thickened continental crust via magmatic under-plating and/or tectonic stacking (Smithies, 2000).

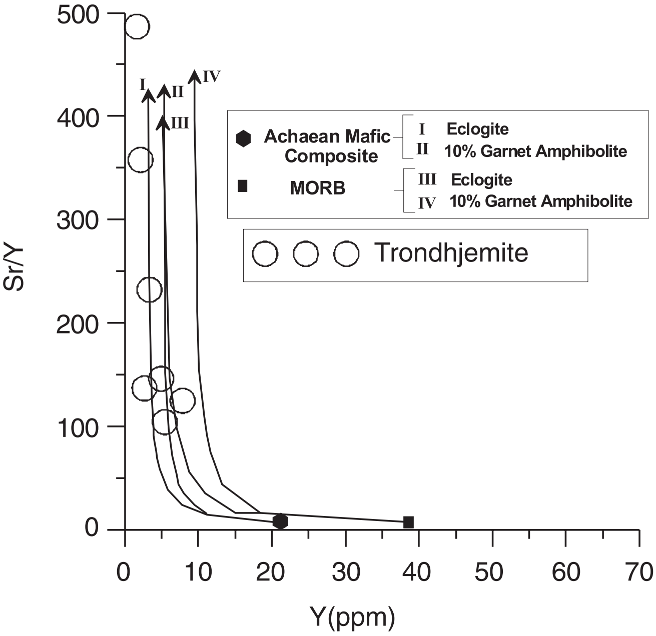

Fig. 4. Sr/Y ratio versus Y (ppm) diagram of the Amgaon trondhjemites showing the typical Archean TTG character of these rocks (Drummond and Defant, 1990).

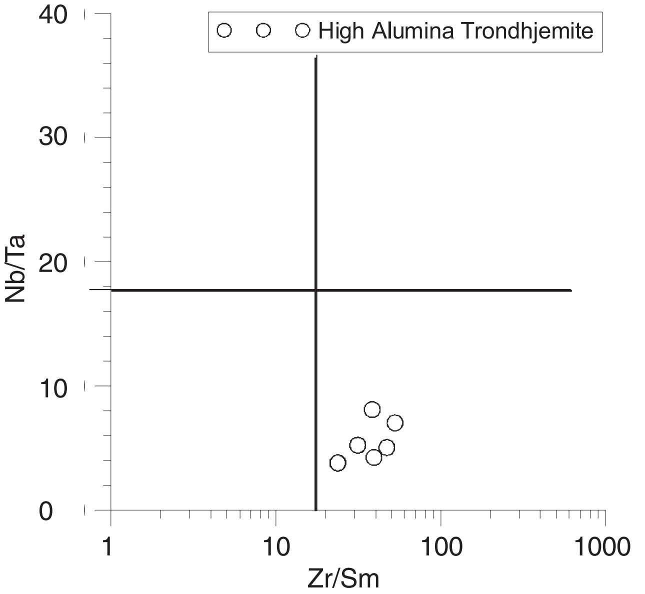

Fig. 5. Nb/Ta ratio versus Zr/Sm ratio plot of the Amgaon trondhjemites. Amgaon trondhjemites plot in the lower right quadrant with low Nb/Ta and high Zr/Sm ratios, as do the Archean TTG suites. Partial melting of amphibolites can only explain the low Nb/Ta and high Zr/Sm ratios in TTGs (Foley et al., 2002).

The trondhjemite-granite gneiss and the granite gneiss group of the Amgaon Gneisses are both calc-alkaline, metaluminous, (ASI<1, Aluminum Saturation Index = molecular Al/[Ca+K+Na-P]), and accordingly belong to the I-type granitoids (Chappell and White, 1974). Overall, the granite gneisses are richer in SiO_2 (Av. 73.5 wt.%), K_2O (Av. 5.34 wt.%), and poorer in Na_2O (Av. 3.5 wt.%), Al_2O_3 (Av. 12.6 wt.%), compared to the trondhjemite granite gneisses (Table 1). The granite gneisses have gentle REE patterns (Av. $La/Yb_N \sim 12.2$) and almost flat HREE patterns (Av. $Gd/Yb_N \sim 1.5$). HREE concentrations are also high (Av. $Yb_N \sim 19$), implying the absence of garnet in the source. The presence of well-developed negative Eu anomalies in their REE patterns, along with negative Sr anomalies in the mantle-normalized plots indicates felspar fractionation. However, the trondhjemite-granite gneisses have fractionated REE patterns (Av. $La/Yb_N \sim 21.4$) as well as low concentration of HREE (Av. $Yb_N \sim 4.8$), indicating the presence of garnet in the source. Sr in the mantle-normalized plot and Eu anomalies in the REE patterns are variable.

Geochemically the granite gneisses and trondhjemite-granite gneiss are nearly identical to the "CA-1 type" and "CA-2 type" Archean pluton of Sylvester (1994).

Experimental melting of biotite-rich and hornblende-poor tonalities, under fluid absent conditions and ~950°C produce melts similar to CA-1 type plutons at 6 kbar, and CA-2 type plutons at 10 kbar, respectively (Sylvester, 1994; Skjerlie et al., 1993). At 6 kbar (i.e., at midcrustal levels), orthopyroxene-bearing, garnet and hornblende free residue forms in equilibrium with the melt, whereas at 10 kbar (i.e., lower crustal levels), garnet along with minor hornblende and orthopyroxene forms in equilibrium with the melt (Skjerlie et al., 1993). Accordingly the Amgaon trondhjemite gneisses and the granite gneisses may have formed due to melting of tonalite gneisses at lower-crustal and mid-crustal levels, respectively.

The adamellite-granite group of the Amgaon Gneisses is peraluminous (ASI>1.0), has high SiO_2 (Av. 72.4 wt.%), moderate K_2O (Av.3.87 wt.%) and Al_2O_3 (Av. 14.62 wt.%), and low Sr (160 ppm), Na_2O (Av. 3.3 wt.%). Steep REE patterns (Av. La/Yb_N ~49), fractionation of the HREEs (Av. Gd/Yb_N ~4.5), and low HREE contents (Av. Yb_N ~6.6), indicate the presence of garnet in the source. However, REE patterns also reveal well-developed negative Eu anomalies. This together with the negative anomalies of Sr, Ba, Ti and Nb in the mantle-normalized plots (Fig. 2) implies feldspar, biotite and iron-titanium oxide fractionation, or their presence in the source (Sylvester, 1994; Patino Douce and Beard, 1995).

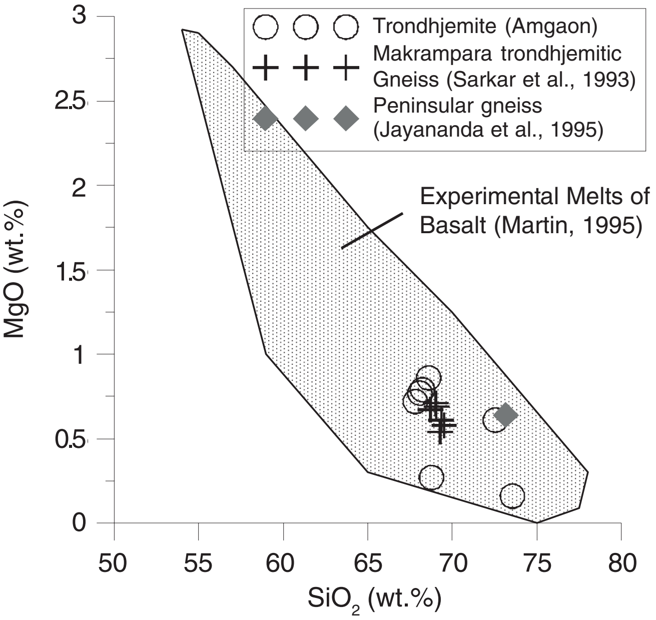

Fig. 6. MgO versus SiO_2 diagram showing Amgaon trondhjemites, Makarampara trondhjemites, and the average composition of the peninsular gneisses of the Dharwar Craton. The field of liquids produced by experimental melting of basaltic amphibolites is after Rapp and Watson (1995). The TTGs from the Bastar and the Dharwar Cratons plot well within the field of experimental melts of basaltic amphibolites indicating the absence of melt-mantle interaction.

The granite-adamellite Amgaon Gneiss is compositionally similar to the "SP-3 type" Archean pluton of Sylvester (1994), which is considered to represent partial melts of greywackes and pellites, with garnet in the residue. The experimental melting of a biotite-gneiss at P of 10 to 12.5 kbar and ~950°C produced melts that are almost similar in composition to the Amgaon granite-adamellite gneisses with plagioclase, quartz, orthopyroxene, biotite and garnet as the residual assemblage (Patino Douce and Beard, 1995). It has been experimentally demonstrated that tonalities interlayered with metasediments produce large volumes of granitic melts (Skjerlie et al., 1993), and a similar situation also seems to have occurred in the Amgaon Gneisses, since large volumes of trondhjemitic granite gneiss and granite gneisses are also present.

Conclusions

The Amgaon Gneissic Complex of the northern Bastar Craton contains at least four phases of granites, that also includes high- Al_2O_3 trondhjemites. In the Dharwar Craton, granites (*sensu lato*) with compositions similar to the trondhjemite-granite gneisses, granite gneisses, and granite adamellitic gneisses formed during deformation, and granulites facies metamorphism at ~2.5 Ga (Jayananda et al., 1995, 2000). These granitoids represent lower-crustal and mid-crustal level anatexis of tonalities interlayered with met sediments along shear zones that supplied both heat and fluids. The Malanjkhand Andean-type Porphyry Cu (Mo) deposit formed at ~2.5 Ga along the Central Indian Tectonic Zone (Stein et al., 2003). This supports the generation of the Amgaon high-Al_2O_3 trondhjemites beneath an over-thickened continental crust and their subsequent remelting and anatexis along with metasediments in close proximity to the CITZ at ~2.5 Ga in response to deformation and metamorphism. This resulted in the formation of trondhjemite-granite gneiss, granite-gneiss and adamellite granite gneisses, respectively. These first order similarities lead us to infer that Dharwar and Bastar Cratons had existed as a single continental block since at least the late Archean.

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