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Proterozoic Charnockites at 1.6 & 1.0 Ga in the Eastern Ghats Belt, India, Mirror Secular Evolution of Continental Crust

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Abstract

As the Earth continued to cool down, the chemistry of granitic rocks reflect the changing conditions &/or processes of continental crust formation. Compared to the 1.6 Ga charnockites, the 1.0 Ga charnockites in the Eastern Ghats Belt, are more potassium and Rubidium rich, with more negative Eu anomalies and show much less HREE fractionation. Thus the 1.0 Ga charnockites are more evolved in composition and this is consistent with secular evolution of the continental crust throughout the Proterozoic era.

Key words: Proterozoic charnockites; Secular evolution; Continental crust

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INTRODUCTION

The byouant quartzofeldspathic materials, the dominant component of the continental crust, are difficult to destroy by subduction and hence can be considered as the principal record of crustal evolution through the geological time. The continental crust of andesitic composition can not be extracted directly from peridotitic mantle. A second event of either fractional crystallization (Soesoo, 2000), or remelting of basaltic magma (Kemp & Hawkesworth, 2004), is required. Significant differences in key geochemical features have been documented between Archaean and later granitic rocks (Taylor & McLennan, 1985; Rudnick & Gao, 2004). TTG suites of Archaean greenstone belts are taken as the Archaean continental crust, while varieties of Proterozoic grantic plutons represent the Proterozoic continental crust (Kemp & Hawkesworth, 2004).

Eastern Ghats Granulite Belt, India, comprises several charnockite massifs of different ages, namely, Archaean (Bhattacharya et al., 2001) and Proterozoic (Bhattacharya, Basei, & Kar, 2014). Although, some workers have described magmatic charnockites from the Eastern Ghats, presumably as mantle derived (SubbaRao & DivakaraRao, 1988), it is most unlikely that charnockites of silicic composition could be directly extracted from melting of mantle-peridotite. Some others described enderbitic charnockites as metamorphosed igneous precursors, but have not clarified on the nature and composition of the "igneous precursors"(Bhui, Sengupta, & Sengupta, 2007). On the other hand, we have documented ample evidence of hornblende-dehydration melting in mafic precursors for several charnockite massifs, both Archaean (Kar et al., 2003) and Proterozoic (Bhattacharya, 2003; Bhattacharya et al., 2010). Hence, a deep crustal anatexis and granulite facies metamorphism could be considered as coeval. It is also consistent with dehydration melting experiments (Wolf & Wyllie, 1994; PatinoDouce & Beard, 1995).

Considering charnockite massifs as product of partial melting in the deep crust under granulite facies conditions, this deep crustal anatexis could be dated by U-Pb isotopes in zircons; and this was reported by us for several charnockite massifs (Bhattacharya, Basei, & Kar, 2014). We have also recorded secular evolution of continental crust between Archaean and Proterozoic times (Bhattacharya & Chaudhary, 2010).

In the present communiquét, we describe the petrological/geochemical features of the Sunki charnockite massif, dated as ca. 1.0 Ga and compare key geochemical features with those of early Mesoproterozoic (ca. 1.6 Ga) charnockite massifs of the Eastern Ghats Belt. These distinctive features may provide useful constraints indicating further secular changes of the continental crust throughout the Proterozoic era.

1. GEOLOGICAL SETTING

Several charnockite massifs occur as large-scale bodies of variable composition in the Eastern Ghats Belt (Figure 1). The petrogenetic model of deep crustal anatexis have been described for one Archaean (Kar et al., 2003) and some Proterozoic massifs (Bhattacharya, 2003; Bhattacharya et al., 2010). The Sunki charnockite massif occurs in the central part of the Proterozoic Eastern Ghats Province (Dobmeier & Raith, 2003). This massif is characterized by a gneissic foliation, designated S_1, often as an axial planar foliation to rootless folds, represented by mafic granulite enclaves (Figure 2).

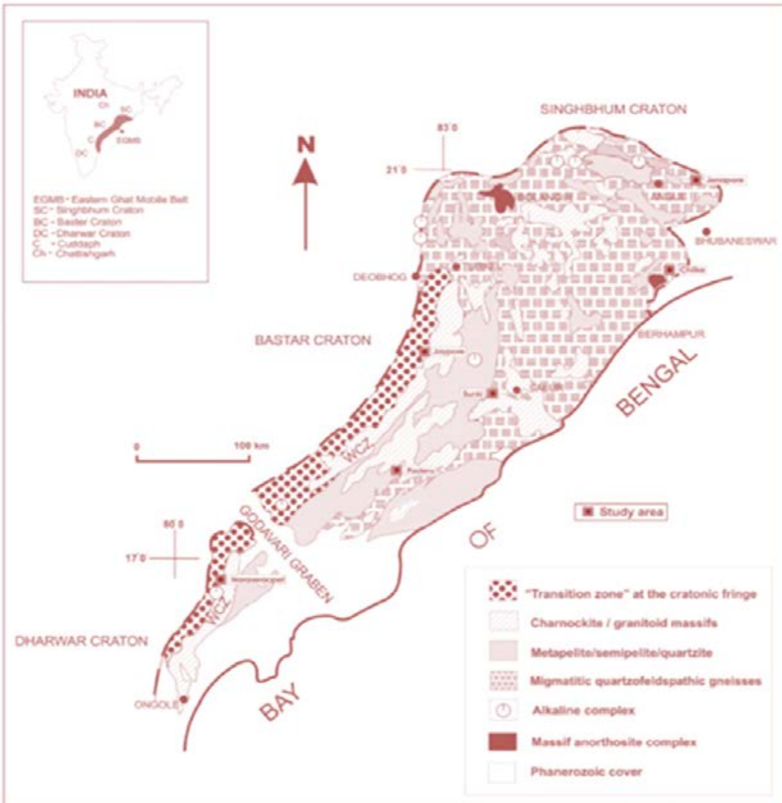


Figure 1
Simplified Geological Map of the Eastern Ghats Belt, India, With Important Locations of Charnockite Massifs

Figure 2
Folded Mafic Granulite Enclave Within Host Charnockitic Gneiss at Sunki, Eastern Ghats Belt

2. PETROGRAPHY AND MINERALOGY

The typical assemblage in the charnockites is quartz-plagioclase feldspar-alkali-feldspar-orthopyroxene-Fe-Ti oxides ± garnet ± hornblende. The mafic granulite enclaves, some times folded, have the assemblage: quartz-plagioclase-hornblende-orthopyroxene-clinopyroxene-Fe-Ti oxides ± garnet. Notably these enclaves, or inclusions do not contain alkali-feldspar. A characteristic reaction texture observed in these enclaves is the growth of orthopyroxene and plagioclase at the embayed margins of hornblende, indicating prograde hornblende breakdown reaction (Figure 3a). Also these enclaves occasionally show quartzofeldspathic films at hornblende margin, indicating in situ melting (Figure 3b). Selected mineral compositional data are presented in Tables 3 & 4. The mineral compositional data were obtained by electron probe micro-analysis at the Geological Survey of India, Kolkata, using CAMECA Sx 100. Operating conditions were 15 kV accelerating voltage, 0.2- nA sample current and 3 µm beam diameter. One notable feature in the mafic granulite enclaves is subtle Mg-enrichment in the hornblende margins (Table 3), indicating prograde nature of the hornblendes in these rocks. Also, plagioclase in the mafic granulite enclaves are more anorthitic compared to those in the host charnockites (Table 4), consistent with the restitic nature of the hornblende-mafic granulites.

Table 1
Bulk Composition of Charnockites, Sunki Suite. EGP

Sample no.	SK6/5	SK7/1	L6/1	B4/1	S3/1	N4/1	L4/1	F1/3
SiO_2	73.01	65.72	61.75	60.48	65.28	57.25	66.21	73.61
TiO_2	0.19	1.12	1.84	1.51	0.02	1.88	1.34	0.08
Al_2O_3	12.59	14.58	12.98	14.28	15.14	16.2	14.1	13.91
Fe_2O_3	2.8	5.49	8.35	7.89	2.75	8.56	6.81	0.94
MnO	0.04	0.1	0.14	0.15	0.05	0.16	0.12	0.01
MgO	0.94	1.34	2.69	2.21	1.3	2.11	0.37	0.81
CaO	1.07	4.52	4.94	7.3	3.83	6.4	2.92	1.4
Na_2O	1.38	1.82	1.87	1.73	2.2	1.92	1.82	1.97
K_2O	6.16	3.59	2.79	2.55	5.75	3.78	5.75	7.37
P_2O_5	0.16	0.7	0.78	0.61	1.72	0.48	0.45	0.04
Total	98.34	98.98	98.13	98.71	98.04	98.74	99.89	100.14
A/CNK	1.16	0.97	0.86	0.76	0.9	0.86	0.97	1.01
Mg. No.	37	30	36	33	45	30	9	60
Trace element in ppm								
Rb	293	115.6	104	59.9	404.8	174	175	174
Ba	1945	847	1055	456.2	1323.7	1282	1352	1340
Th	3.4	3.5	6.2	4.1	34.7	0.4	2.7	0.4
Nb	19.2	35.9	40.7	28	5.8	2	35	2
Sr	111.2	78.4	90.4	83.3	94.3	435	115	435
Zr	19.6	21.7	13.2	18.5	122.1	64	388	64
Y	17.2	48.5	71.1	57.4	179.7	2	31	2
Zn	35.4	54.8	92.7	68	26.7	12	70	12
Cu	1.3	1.8	3.7	1.9	2.8	3	12	3
Cr	81.3	6.9	4.5	12	3.5	49	3	2
Ni	8.3	11.7	16.6	12.4	10	3	15	3
Sm	8	15.1	18.2	10.7	49.1			
Nd	41.8	8.3	98.8	48.8	221.2			
Eu	2.5	1.5	1.9	1.3	2.8			
Gd	5.6	11.8	15.1	9.2	40.4			
Yb	1.3	3.3	5.5	4.9	8.9			

Table 2
Bulk Composition of Hornblende-Mafic Granulite, Sunki Suite, EGB

Sample	SK 1	SK 2	SK 3	SK 5	SK 6
SiO_2	45.57	42.8	46.66	48.41	45.18
Al_2O_3	15.25	17.58	15.05	14.13	15.21
TiO_2	1.34	1.64	1.37	1.46	1.05
Fe_2O_3	13.61	15.95	15.63	15.82	13.62
MnO	0.19	0.27	0.24	0.25	0.25
MgO	8.64	6.24	6.36	6.77	7.96
CaO	11.73	11.42	11.73	12.53	12.14
Na_2O	0.81	0.71	0.63	0.61	0.69
K_2O	0.53	0.11	0.44	0.22	0.13
P_2O_5	0.15	0.33	0.16	0.15	0.08
Total	97.83	97.04	98.27	100.34	96.31
Trace element in ppm					
Cr	318.7	122.7	127.8	119.8	206.8
Ni	60.0	62.9	39.1	40.0	54.3
Co	72.1	62.7	48.2	70.9	53.3
Sc	6.3	4.7	10.5	8.8	9.6
V	253.6	257.4	441.1	403.4	320.3
Cu	75.7	45.1	42.0	36.4	6.1
Zn	83.9	120.0	90.6	79.7	75.2
K	4399.8	913.2	3652.7	1826.3	1079.2
Rb	11.0	0.9	6.6	3.0	1.8
Ba	307.7	368.3	163.8	148.9	238.2
Sr	229.4	168.3	96.1	102.5	131.6
Ta	1.0	0.7	1.8	1.4	0.2
Nb	7.9	11.0	13.1	7.5	4.1
Zr	25.2	12.0	29.9	32.4	22.2
Ti	8031.9	9830.1	8211.8	8751.2	6293.7
P	654.6	1440.1	698.2	654.6	349.1
Y	26.6	22.5	31.7	22.9	26.3
Th	1.5	0.5	0.9	0.8	2.3
U	0.5	0.2	0.4	0.4	0.3
La	19.4	18.8	11.3	10.1	12.3
Ce	36.0	34.6	21.5	19.2	22.8
Pr	5.1	4.8	3.1	2.8	3.1
Nd	19.6	17.7	12.6	11.1	12.3
Sm	5.1	4.2	3.6	3.1	3.2
Eu	1.3	1.2	0.4	0.8	0.9
Gd	4.2	3.8	3.0	2.5	2.9
Tb	0.8	0.7	0.7	0.6	0.6
Dy	4.8	4.3	5.3	4.0	4.3
Ho	1.0	0.9	1.2	0.9	1.0
Er	2.5	2.4	3.3	2.4	2.7
Tm	0.4	0.4	1.9	0.4	0.4
Yb	1.3	1.5	1.3	1.7	1.7
Lu	0.3	0.3	0.4	0.3	0.3

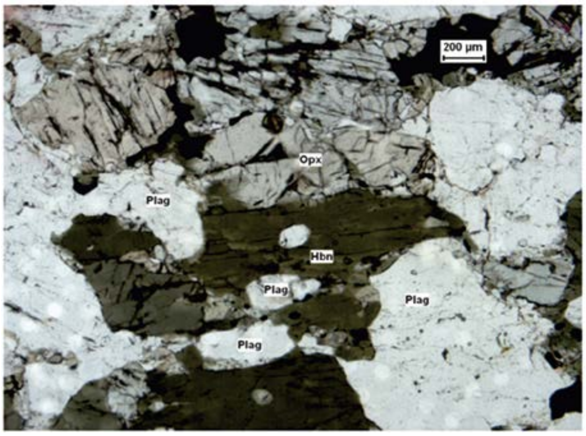
Table 3
Mineral Chemical Analysis of Hornblende Grains From Hbl-Granulite

	Hbl-granulite (D2/2/S2)							
Oxides	**15 (Margin)**	**16 (Core)**	**22 (Margin)**	**23 (Core)**	**19 (Margin)**	**24 (Core)**	**30 (Margin)**	**31 (Core)**
SiO_2	41.21	40.7	41	41.5	41.1	41.11	40.96	40.86
TiO_2	1.5	1.58	1.59	1.71	1.52	1.66	1.72	1.64
Al_2O_3	10.98	11.5	11.29	11.87	11.45	11.38	11.81	11.98
FeO	13.5	13.88	13.2	13.61	13.09	13.76	13.39	13.97
MnO	0.1	0.13	0.16	0.19	0.07	0.11	0.12	0.17
MgO	12.45	12.32	12.64	12.15	12.85	12.38	12.37	12.01
CaO	11.69	11.81	11.33	11.44	11.73	11.62	11.65	11.65
NaO	1.44	1.44	1.43	1.42	1.49	1.53	1.36	1.42
K_2O	1.93	1.98	1.81	1.93	1.94	1.91	1.97	0.11
Cations at 23 oxygen basis								
Si	6.346	6.256	6.323	6.315	6.29	6.295	6.268	6.252
Al	1.993	2.084	2.053	2.13	2.066	2.054	2.131	2.161
Fe	1.739	1.784	1.702	1.732	1.675	1.762	1.714	1.788
Mn	0.013	0.017	0.021	0.024	0.009	0.014	0.016	0.022
Mg	2.857	2.822	2.905	2.756	2.931	2.825	2.821	2.739
Ca	1.929	1.945	1.872	1.865	1.924	1.907	1.91	1.91
Na	0.43	0.429	0.428	0.419	0.442	0.454	0.404	0.421
K	0.379	0.388	0.356	0.375	0.379	0.373	0.385	0.377
Ti	0.174	0.183	0.184	0.196	0.175	0.191	0.198	0.189
Cr	0.018	0.013	0.01	0.006	0.015	0.016	0.012	0.012
X_{Mg}	0.62	0.61	0.63	0.61	0.64	0.61	0.62	0.61

Table 4
Representative Plagioclase Composition in the Charnockiteand Mafic Granulite of Sunki Suite

Rock	**Charnockite (F1/5 S2)**					**Hbl-granulite (D2/2S2)**					
Point no.	**10**	**11**	**12**	**13**	**14**	**17/1**	**18/1**	**20/1**	**21/1**	**26/1**	**27/1**
SiO_2	57.28	56.91	58.41	58.01	58.97	44.06	43.81	44.48	43.96	44.45	44.50
Al_2O_3	26.74	26.68	26.63	26.53	26.85	33.98	34.29	33.75	33.93	34.72	34.24
FeO	0.50	0.11	0.06	0.08	0.05	0.21	0.30	0.19	0.21	0.18	0.20
CaO	8.96	9.02	8.82	8.71	8.78	17.67	18.11	17.25	17.64	18.05	18.16
Na2O	6.36	6.19	6.38	6.34	6.07	1.15	1.10	1.20	1.10	1.02	1.31
K_2O	0.21	0.34	0.30	0.27	0.30	0.05	0.00	0.08	0.03	0.02	0.00
Total	100.04	99.26	100.58	99.94	101.02	97.12	97.61	96.95	96.87	98.44	98.41
Cation at 8 oxygen basis											
Si	2.57	2.57	2.60	2.60	2.61	2.09	2.07	2.11	2.09	2.08	2.09
Al	1.42	1.42	1.40	1.40	1.40	1.90	1.91	1.89	1.90	1.92	1.89
Fe	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Ca	0.43	0.44	0.42	0.42	0.42	0.90	0.92	0.88	0.90	0.91	0.91
Na	0.55	0.54	0.55	0.55	0.52	0.11	0.10	0.11	0.10	0.09	0.12
K	0.01	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Total	5.00	5.00	4.99	4.98	4.96	5.01	5.02	5.00	5.01	5.01	5.02
X_{Ca}	0.43	0.44	0.43	0.42	0.44	0.89	0.90	0.88	0.90	0.91	0.88

(a)



(b)

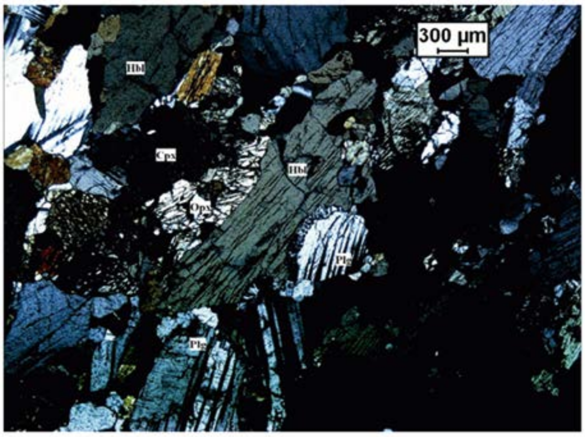


Figure 3
(a)Orthopyroxene & Plagioclase at Embayed (Hornblende Margin in Hornblende-Mafic Granulite Enclave. (b) Quartzofeldspathic Film at Embayed Hornblende Margin: In Situ Melt?

These petrographic and mineralogical features, along with the field relations, suggest a mode of origin of the charnockite by hornblende-dehydration melting in the deep crust, the hornblende-mafic granulites being the restites. In this respect, Sunki charnockite massif is similar to some other such massifs in the Eastern Ghats Belt (Kar et al., 2003; Sen, Bhattacharya, & Acharyaa, 1995; Bhattacharya & Kar, 2002).

3. GEOCHEMICAL FEATURES

Bulk chemical analysis was carried out by X-ray fluorescence (XRF) spectrometry at the National Geophysical Research Institute, Hydreabad. Operating conditions were 20/40 kV for major oxides and 50/60 kV for trace elements. Nominal analysis time was 300 s for all major oxides and 100 s for each trace element. The overall error in accuracy (% relative standard deviation) for major and minor oxides was less than 5% and that for trace elements were less than 12%. The average precision was better than 1.5%.

Bulk compositions of the Sunki charnockites and hornblende-mafic granulites are given in Tables 1 & 2, while bulk composition, including selected trace element data of the Chilka and Naraseraopet charnockites are presented in Table 5.

Table 5
Bulk Composition, Including Selected Trace Elements, of Charnockites in the Chilka and Naraseraopet Suites

	Chilka		Naraseraopet		
Sample	CK 2/4	D4/01	D7/01	A5/2	C1/2
SiO_2	68.03	64.94	72.31	73.7	64.8
Al_2O_3	15.19	14.59	14.3	13.6	15.7
TiO_2	0.36	0.4	0.05	0.5	0.7
Fe_2O_3	3.95	4.69	1.24	3.2	5
MnO	0.05	0.06	0.02	0.1	0.1
MgO	1.2	1.75	0.56	0.7	1.4
CaO	3.87	4.42	2.64	2.3	4.1
Na_2O	3.61	3	3.08	4	3.2
K_2O	3.17	2.35	4.54	3.6	3.4
P_2O_5	0.22	0.11	0.02	0.2	0.4
Total	99.65	96.32	98.74	101.8	98.8
Mg. No.	34.91	39.71	44.36	34	39
Trace element in ppm					
Rb	78.9	56.9	90.3	43.2	109
Sr	182.1	156.1	182.8	185.4	356.3
Gd	4.4	3.7	2	4.3	11.1
Yb	0.4	0.9	0.1	0.6	2.1
Sm	3.5	2.6	0.8	2.8	11.6
Nd	17.6	11.9	4.9	15.6	58.8
Eu	1.3	0.8	0.4	0.8	2.9

Compared to the hornblende-mafic granulites the charnockites are highly enriched in K and Rb, while much depleted in Ti and base metals, relative to the hornblende-mafic granulites. These complementary trace element distribution between the charnockites and mafic granulites is consistent with the dehydration melting model (Figure 4).

4. SECULAR EVOLUTION OF CONTINENTAL CRUST DURING PROTEROZOIC ERA

Previously we have documented secular evolution of continental crust from Archaean to Proterozoic, as represented by charnockite massifs in the Eastern Ghats Belt, India (Bhattacharya & Chaudhary, 2010). Here we demonstrate further compositional changes throughout the Proterozoic era.

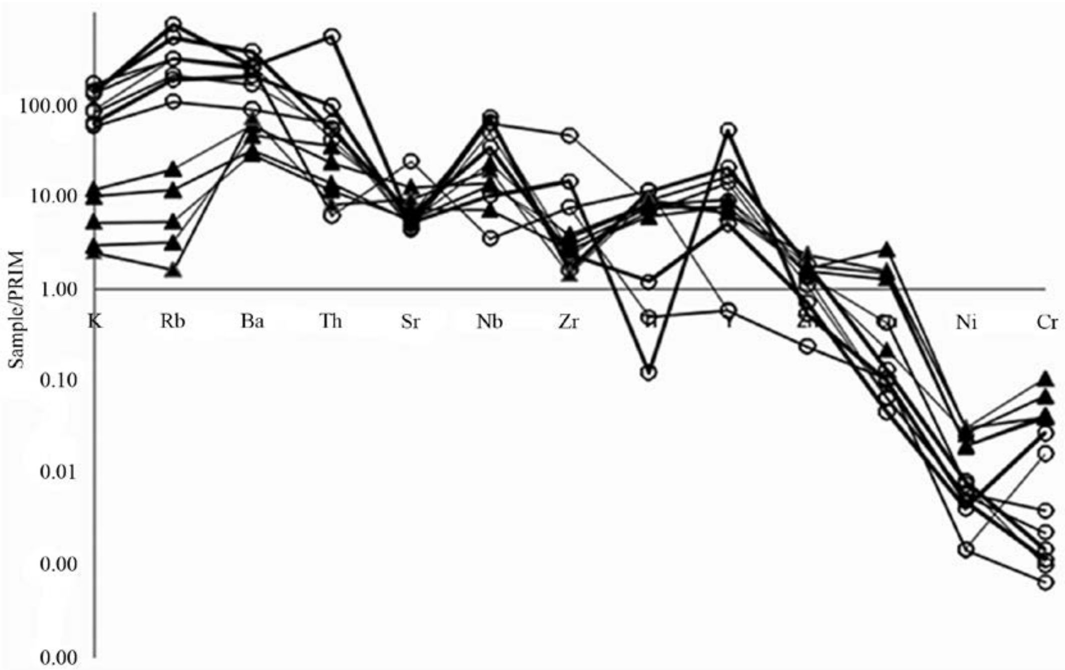


Figure 4
Complementary Trace Element Distribution Between Mafic Granulite Enclaves and Host Charnockites of the Sunki Suite, Eastern Ghats Belt

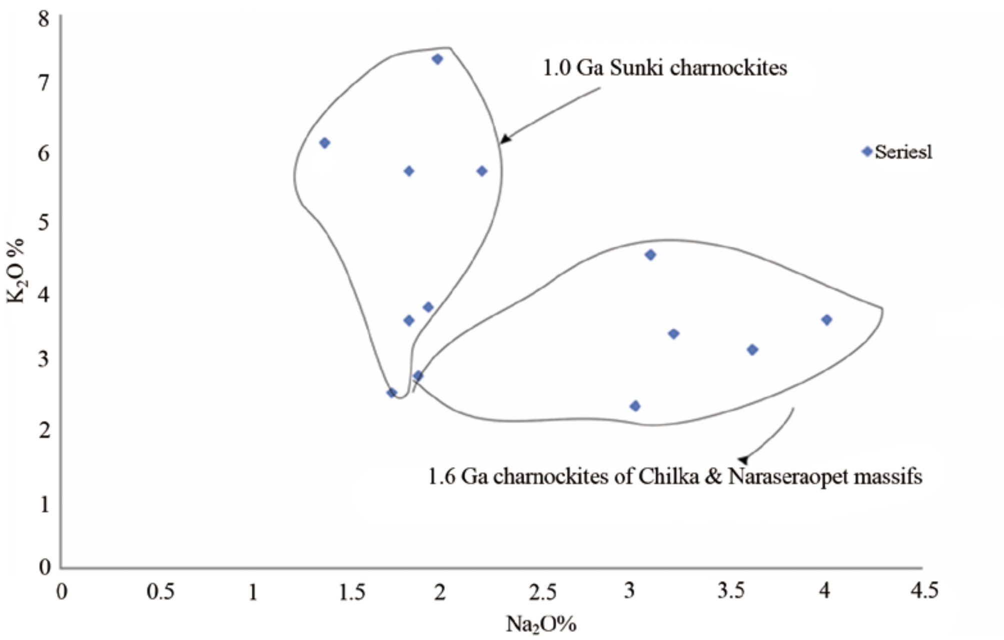


Figure 5
Na_2O/K_2O Ratios Coparision Between 1.0 & 1.6 Ga Charnockites in Eastern Ghats

The ca. 1.0 Ga charnockites of the Sunki suite are of much more evolved composition, relative to the ca. 1.6 Ga charnockites of Chilka and Naraseraopet suites and this is evident in the more potassic composition of the Sunki charnockites (Figure 5). Also the Sunki charnockites are more Rb-rich (Figure 6). Additionally, much more negative Eu anomalies and less HREE fractionation in the Sunki charnockites (Figure 7) are consistent with melting at shallow depths, in the stability field of plagioclase. While peak metamorphic pressure of ~9-10 Kbar were recorded from Chilka and Paderu (Sen, Bhattacharya, & Acharyaa, 1995; Bhattacharya & Kar, 2002), it was recoded as ~8 Kbar in the Sunki area (Korhonen et al., 2013).

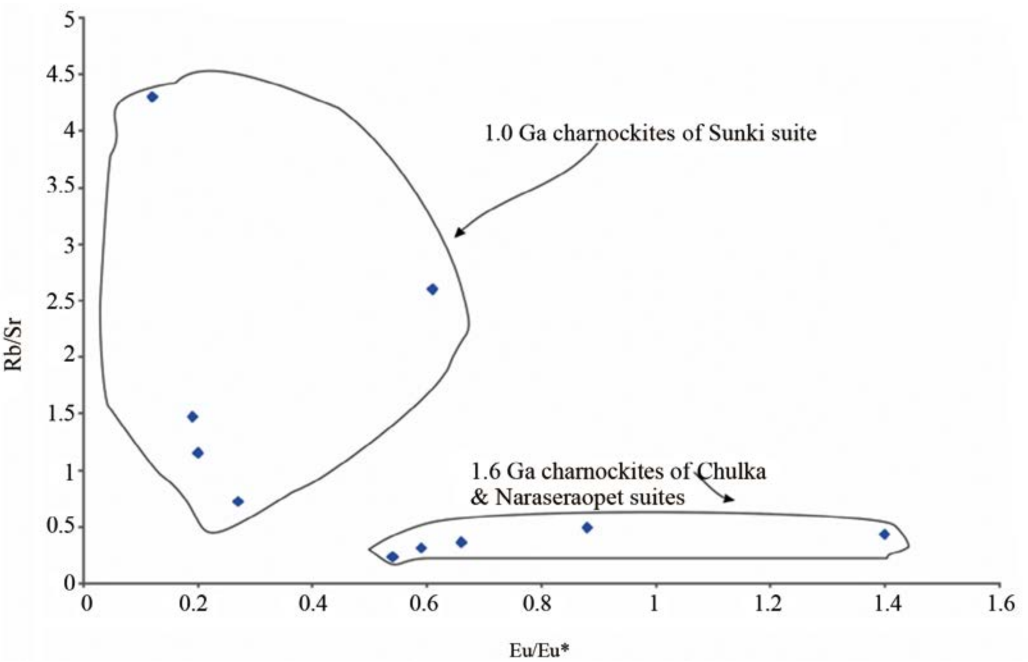


Figure 6
Rb/Sr vs Eu/Eu* Plots for the Charnockites in the Eastern Ghats Belt

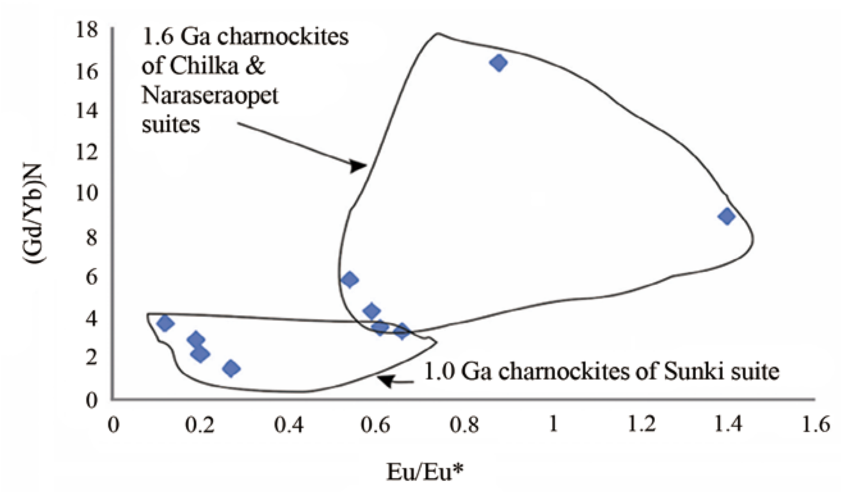


Figure 7
(Gd/Yb)N vs Eu/Eu* Plots for Charnockites in the Eastern Ghats Belt

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