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Secular evolution of continental crust: recorded from massif-type charnockites of Eastern Ghats belt, India

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ABSTRACT

It is reasonably well established that the Earth has substantially cooled from the Archean to the present and hence the sites, rates and processes of crust formation must have changed through geologic time. Archean and Proterozoic granitic rocks are the principal record of such changes. Massif-type charnockites in the Eastern Ghats granulite belt, India, of Archean and Proterozoic ages mirror the changing conditions and/or processes of continental crust formation. Though both can be explained by dehydration melting of mafic rocks, the conditions differ. Potasium and rubidium rich Proterozoic charnockites have significant negative Eu anomaly indicating melting at shallow depths in the stability field of plagioclase. In contrast, sodium and strontium rich Archean charnockites with less LREE enrichment and less depletion in Eu indicate melting at greater depths in the stability field of garnet or amphibole.

Keywords: Secular changes; Continental crust; Massif-charnockites; Eastern Ghats

1. INTRODUCTION

The continental crust comprising byouant quartzo-feldspathic materials are difficult to destroy by subduction and hence can be considered as the principal record of crustal evolution through geologic time. New continental crust may form magmatically from underlying mantle. However, mantle melting products are predominantly basaltic, whereas continental crust is andesitic which can not be extracted directly from melting of mantle-peridotite. Continental crust formation therefore requires a second stage/or event of fractional crystallization [1] or remelting of basaltic magma [2]. Although there remains considerable debate on the processes of crust formation in the Archean compared to those operating in the later period (post-Archean), significant differences in key geochemical features have been documented between Archean and later granitic rocks [3-5]. Moreover, tectonic setting for Archean magmatism as exemplified by TTG remains unresolved. Partial melting may have taken place in subducted slabs [6,7] or in underplated basalt beneath thickened crust or oceanic plateau [8]. TTG suites of Archean greenstone belts are taken as the Archean continental crust, while large varieties of Proterozoic granitic plutons represent the Proterozoic continental crust (cf. Table 3 in [2]). These authors have presented extensive discussion on these differences from a Granitic perspective and their possible implications on the changing processes and or conditions of crust formation from Archean to Proterozoic times.

Eastern Ghats granulite belt, India, comprises massif-type charnockite as a major component in the regional granulite terrane, and there is unambiguous evidence of different generation of such charnockites. Archaean charnockites have been described from northern margin against Singhbhum craton and western margin against Bastar craton [9-11]. Some of the massif-type charnockite suites in the central part of the granulite belt record only Proterozoic ages [12,13]. Although, some workers have described magmatic charnockites from the Eastern Ghats, presumably as mantle-derived melt [14], it is difficult to postulate silicic melts directly from mantle-melting. On the other hand, some workers consider enderbitic charnockites of the Eastern Ghats belt as metamorphosed igneous precursors and commonly describe them as "now enderbite" [15]. Here again, the question of felsic igneous rocks directly derived from mantle remains unresolved. Dehydration melting experiments have demonstrated that silicic melts of tonalitic, granodioritic and granitic compositions are produced at 8-10 Kbar, and ≥ 850℃ from mafic rocks [16-18]. The massif-type charnockites in the Eastern Ghats belt are of variable composition and P-T conditions of granulite facies metamorphism are comparable to the experimental constraints as mentioned above [19,20]. Thus a remelting of mantle-derived melt or hydrated amphibolite under granulite facies conditions could be the favored model for the massif-type charnockites of the Eastern Ghats belt [20-22].

Considering charnockite-massifs as products of partial melting in the deep crust under granulite facies conditions, U-Pb ages of zircons in them can be taken as representing this deep crustal anatexis, while the Nd-model ages could provide the mantle-derivation ages of their protoliths.

In this communiqué, we present selected geochemical and isotopic data for two sets of massif-type charnockites of the Eastern Ghats belt, of Archean and Proterozoic ages respectively. These data could mirror the differences in some key geochemical features of the continental crust. These distinctive features may also provide some useful constraints on changing processes of crust formation from Archean to Proterozoic.

2. GEOLOGICAL SETTING

The Eastern Ghats granulite belt skirting the eastern coast of India is bounded by granite-greenstone belts of Singhbhum and Bastar cratons to the north and west respectively (**Figure 1**). The granulite lithologies record polyphase deformation and possible multiple granulite facies imprints [23-26]. Massif-type charnockite is a

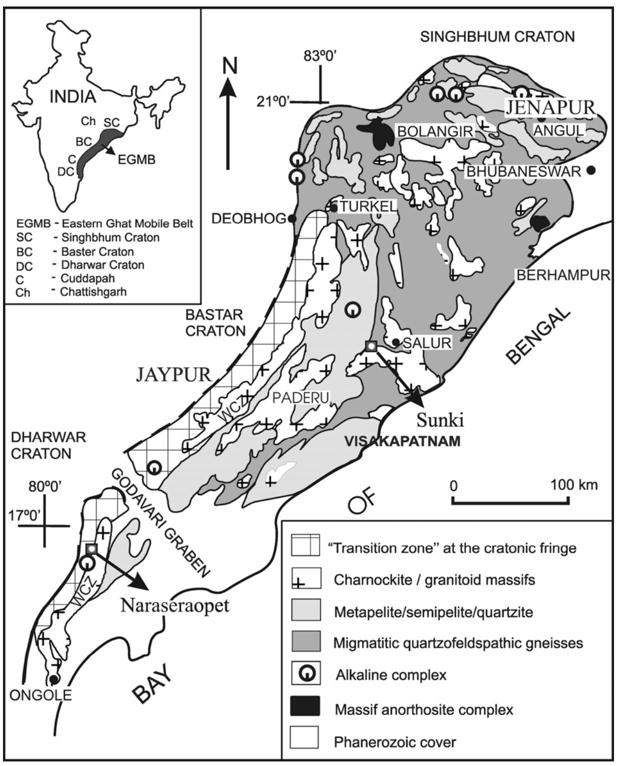

Figure 1. Generalized geological map of the Eastern Ghats Granulite belt, India.

major component in this regional granulite terrane and occurs in different crustal domains [10]. The charnockite-massifs considered here occur in the Archean domains around Jenapore & Jaypur and Proterozoic domains around Sunki, Paderu and Naraseraopet (see locations in **Figure 1**).

3. GEOCHEMICAL SIGNATURES

Bulk composition was determined by XRF spectrometry at National Geophysical Research Institute, Hyderabad and Operating condition for XRF machine was 20/40 KV for Major oxides, nominal analysis time was 300 seconds for all major oxides. For the XRF analysis the overall accuracy (% relative standard deviation) for major and minor oxides are given as less than 5%. The average precision is reported as better than 1.5%. For ICP–MS analysis at Institute Instrumentation Centre, Indian Institute of Technology, Roorkee, the average precision were 4.1% RSD.

The analytical data are given in **Table 1**. Compared to the Archean charnockites the Proterozoic charnockites are potash-rich, with high K_2O / Na_2O ratios (**Figure 2**) and this is consistent with the compositions of granitic rocks of the two periods, as described in Kemp and Hawkesworth, 2004 [2]. Compared with the Archean charnockites the Proterozoic charnockites are rubidium-rich with high Rb / Sr ratios (average 1.01, n = 11: Proterozoic and average 0.18, n = 7: Archean). The lower Rb / Sr ratios in the Archean charnockites reflect elevated Sr in the Archean than in the Proterozoic charnockites (**Figure 3**). However, Sr / Nd and Nb / La ratios are variable in both sets (**Figure 4**); though lower Nb / La ratios in many samples from Archean could reflect different processes in the Archean [2]. Greater fractionation of HREE, extending to higher $(Gd / Yb)_N$ ratios in the Archean charnockites is consistent with those in Archean greenstone belts (**Figure 5**). REE patterns are distinctive, primarily in the significant Eu depletion in the Proterozoic charnockites and much less Eu depletion in the Archean charnockites. Significant Eu-depletion coupled with Sr-depletion is characteristic of the Proterozoic charnockites compared with those of the Archean charnockites (**Figure 6**). Archean charnockites show relatively less enrichment in LREE, much less Eu-depletion and greater fractionation of HREE, compared to those in the Proterozoic charnockites.

4. ISOTOPIC SIGNATURES

Mantle-derivation ages for the charnockite suites were determined by Sm-Nd isotopic analysis of whole rocks by Thermal Ionisation Mass Spectrometry at Indian Institute of Technology, Roorkee. Detail analytical proce-

Table 1. Selected oxides, trace element and isotopic data of massif-type charnockites in EGB.

	Naraseraopet			Paderu				Sunki				Jenapore			Jaypur			
Sample	A 5/2	D 5/2	F 4/2	PD 4/4	PD 5/2	PD A1/2	PD A2/3	B4/1/S3	SK 6/5/05	SK 7/1/05	S3/1/S3	JN 2/3	JN 3/3	JN 5/3	JP 10/1	JP 5/1	JP 3/1	JP 2/1
Na2O	3.98	1.98		1.85	1.98	2.41	2.53	1.92	1.38	1.82	2.2	5.36	4.08	3.36	4.6	3.24	4.19	3.89
K2O	3.56	4.34		4.91	4.34	4.41	5.8	2.07	6.16	3.59	5.75	1.03	0.86	3.79	2.2	3.6	3.07	1.78
Rb	43.2	8.2	14.9	327.8	278.8	228.6	323.7	59.9	293	115.6	404.8	5.56	3.63	60.55	12.14	82.07	59.23	11.54
Sr	185.4	388.8	521.1	137.3	131.1	138.1	207.7	145.3	111.2	78.4	94.3	265.23	250.76	121.1	367.05	204.5	234.17	171.2
Y	6.4	36.6	20.4	35	34.6	45.8	35.4	52.1	17.209	48.5	179.7	38.65	7.19	39.12	11.64	3.5	3.38	2.69
Nb	7.6	17.6	10.2	8.3	13.8	15.9	33	35.6	19.2	35.9	5.8	13.02	13.49	10.35	11.49	1.86	5.68	0.84
La	22.2	73.4	36.5	137.2	87.1	120.8	173.8	59.3	65.5	79.4	155.9	28.24	13.27	54.26	71.81	35.1	24.77	26.93
Ce	40.3	133.2	65.8	253.6	153.8	225.9	686.8	108.9	108.8	175	387.3	51.51	24.62	99.27	108.28	47.96	39.36	33.54
Sm	2.8	13.2	6.5	15.4	10.9	15.1	16.8	11.1	8	15.1	49.1	6.49	2.11	9.66	5.24	1.57	1.88	0.78
Nd	15.6	62.6	30.6	97.8	62.3	91.9	119.6	49.7	41.8	83	221.2	25.64	10.14	43.12	32.79	11.95	12.27	7.04
Eu	0.8	4	2	3	2.8	3.1	4	3.7	2.5	1.5	2.8	2.28	0.76	3.2	1.49	0.98	0.93	0.85
Gd	4.3	13.2	6.5	16.3	11.8	16.2	18.6	12.3	5.6	11.8	40.4	6.3	3.01	11.85	6.38	2.2	2.28	1.34
Dy	1.3	7.8	4	8.2	7.6	9.6	7.9	9.5	3.7	9.6	36.7	6.93	1.34	7.33	2.3	0.6	0.65	0.42
Er	0.6	3.6	6.5	2.9	2.7	4.1	3.4	5.5	1.2	3.2	10.7	3.91	0.65	3.66	0.91	0.34	0.29	0.24
Yd	0.6	3.1	2.2	2	2.1	4.4	3.7	6.2	1.3	3.3	8.9	5.4	0.86	4.56	0.87	0.46	0.28	0.34
Lu	0.1	0.4	0.3	0.3	0.3	0.6	0.5	0.7	0.2	0.5	1.3	0.57	0.08	0.42	0.12	0.08	0.05	0.05
Isotopic	data																	
	A 5/2	C 6/9				PD A1/2	PD A2/3			SK 7/1/05	S3/1/S3		JN 3/3	JN 5/3		JP 5/1	JP 3/1	
Sm	5.11	6.3				16.94	19.34			14.44	42.32		2.64	12.1		1.78	2.22	
Nd	33.32	38.46				95.93	123.97			77.12	181.56		15.01	61.98		14.96	15.55	
$^{147}Sm/^{143}Nd$	0.0926	0.099				0.1068	0.0943			0.1132	0.1409		0.1063	0.118		0.0721	0.0863	
$^{144}Nd/^{143}Nd$	0.51078	0.5113				0.51136	0.51123			0.511672	0.511566		0.51072	0.51091		0.50986	0.51027	
$T_{DM\ Ga}$	2.8	2.3				2.4	2.3			2.8	3.1		3.3	3.5		3.5	3.4	
U-Pb Zircon	1.6 Ga [27]			0.9 to 1.1 Ga [29]				0.9 Ga [27]				3.0 Ga [9]			2.8 Ga [11]			

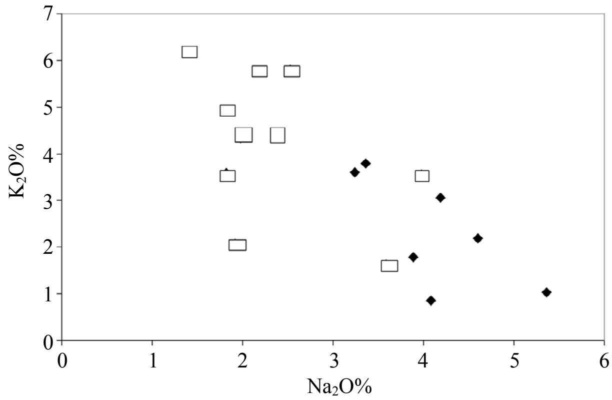

Figure 2. K_2O versus Na_2O plot of the charnockites in the Eastern Ghats Granulite belt. Archean charnockites: solid symbols; Proterozoic charnockites: open symbols.

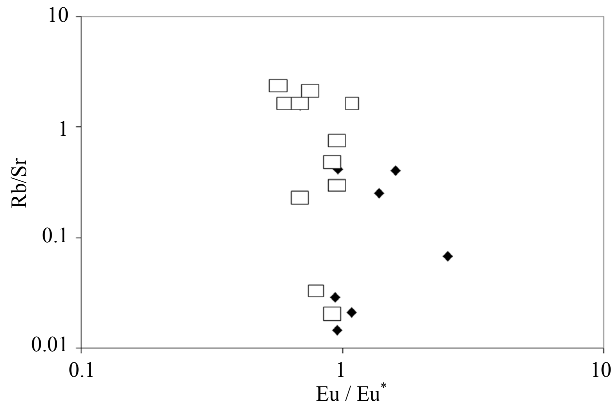

Figure 3. Rb / Sr versus Eu / Eu* plot of the charnockites in the Eastern Ghats Granulite belt. Symbols as in **Figure 2**.

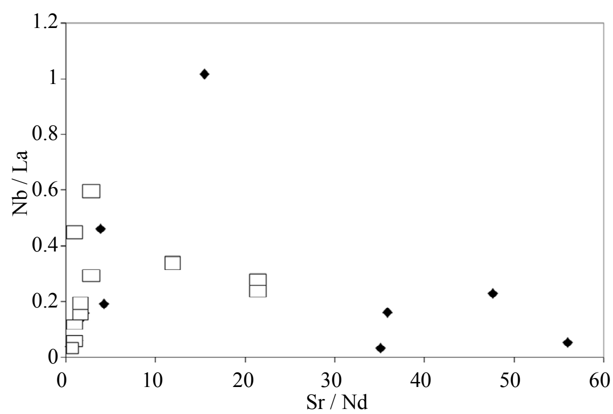

Figure 4. Nb / La versus Sr / Nd plot of the charnockites in the Eastern Ghats Granulite belt. Symbols as in **Figure 2**.

dure is given in Bhattacharya *et al.*, 2010 [27]. Measured ratios for isotopic composition are normalized to ^{146}Nd / ^{144}Nd = 0.7219 for Nd. The measured ratio of ^{143}Nd / ^{144}Nd for Ames Nd Standard was 0.512138 ± 4 (quoted

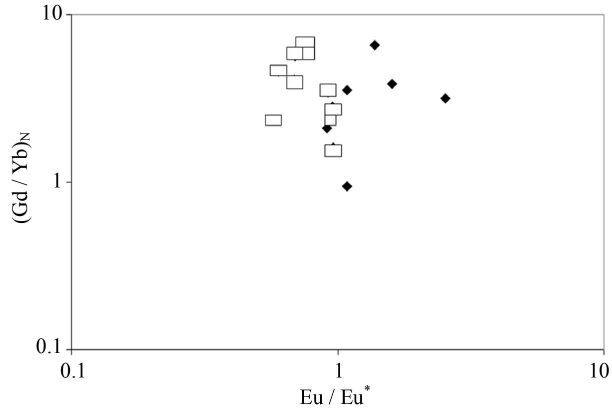

Figure 5. $(Gd / Yb)_N$ versus Eu / Eu* plot of the charnockites in the Eastern Ghats Granulite belt. Symbols as in **Figure 2**.

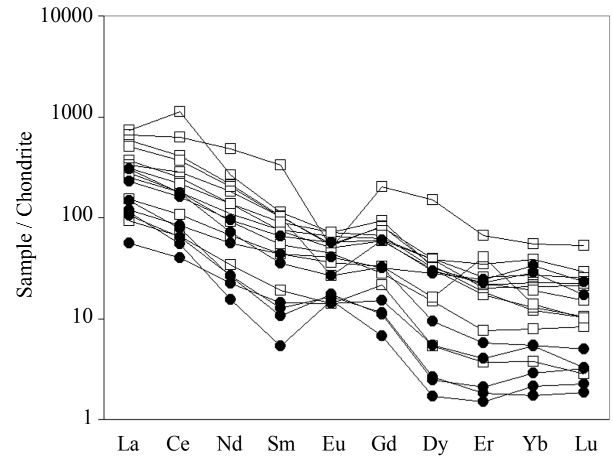

Figure 6. Chondrite normalized REE plot of the charnockites in the Eastern Ghats Granulite belt.

value 0.512138).

Mantle-derivation ages (T_{DM}) for the Proterozoic charnockites vary between 2.3 and 2.8 Ga (Naraseraopet), between 2.3 and 2.4 Ga (Paderu) and between 2.8 and 3.1 Ga (Sunki) and those for the Archean charnockites vary between 3.3 and 3.5 Ga (Jenapore) and between 3.4 and 3.5 Ga (Jaypur) respectively (**Table 1**).

5. DISCUSSIONS

High Rb / Sr ratios and significant negative Eu-anomalies in the Proterozoic charnockites indicate residual plagioclase. The implication is that intracrustal melting occurred at shallow depths, in the stability field of plagioclase. In contrast, low Rb / Sr ratios, indicating elevated Sr, and lack of significant negative Eu-anomalies in the Archean charnockites are indicative of intracrustal melting at greater depths in the stability field of garnet or amphibole [2].

Large discrepancies between crystallization ages (of anatectic charnockitic melt), given by U-Pb zircon ages reported in the literature (**Table 1**) and mantle derivation ages given by T_{DM} for the Proterozoic charnockites confirm that older crustal material was present within the source regions of the charnockitic magma [28]. This is in contrast to the relatively little time gap between crystallization ages and Nd-model ages for the Archean charnockites, similar to those observed in Archean TTGs.

6. CONCLUSIONS

These differences in the geochemical and isotopic signatures between Archean and Proterozoic charnockites reflect different conditions of crust formation rather than different processes: both can be explained by dehydration melting of hydrated basalt or amphibolite under granulite facies conditions; but Proterozoic charnockites at shallower depths (in plagioclase-stability field) than Archean charnockites (in garnet or amphibole-stability field).

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