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New experimental constraints: implications for petrogenesis of charnockite of dioritic composition

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ABSTRACT

Hornblende-dehydration melting experiments at high temperatures (> 950°C) indicate change of melt composition from tonalite/granodiorite to quartz-diorite; clinopyroxene instead of hornblende as the residual phase and change in melting reaction from peritectic hornblende-dehydration to eutectic clinopyroxene-orthopyroxene-plagioclase. In the light of these experimental results, petrogenesis of a charnockite pluton of homogeneous dioritic composition in the Eastern Ghats Belt, India, can be explained as melting at high-temperatures (> 950°C). Negative Sr and Eu anomalies further indicate plagioclase as a major residual phase, consistent with melting at high-temperatures (> 950°C).

Keywords: Dioritic charnockite; Residual clinopyroxene; Residual plagioclase; Eutectic melting

1. INTRODUCTION

It is quite common that large-scale charnockitic bodies are of variable composition from tonalite to granodiorite, and sometimes even dioritic composition is reported [1]. On the other hand, petrogenesis of massif-type charnockites have been variously described: a) mantle-derived and differentiated melt [2]; b) high-temperature melting of dry granulite facies rocks [3]; c) more mafic varieties as mantle-derived melts [4]; d) product of hornblende-dehydration melting in the deep crust [5]. New melting experiments provide constraints on the petrogenesis of charnockitic rocks of dioritic composition. From the Jenapore area in the Eastern Ghats Belt, India, charnockite-massif was described as the product of hornblende-dehydration melting under granulite facies conditions, and with residual hornblende. There the two-pyroxene granulites occur as minor patches and bands and were explained as peritectic segregates [5]. A stock-like body of charnockite (pluton) occurs in the same locale, a few kilometer to the south (Lat: 20°46' N; Long: 86°05' E). In contrast to the charnockite-massif, it is of more mafic and homogeneous composition at the outcrop-scale and commonly has both orthopyroxene and clinopyroxene.

In the present communication we present geochemical data from the charnockite pluton and in the light of new experimental constraints explain its origin by melting at high-temperatures (≥ 950°C).

2. EXPERIMENTAL CONSTRAINTS

The selected results of the hornblende-dehydration melting experiments is presented in **Figure 1**. The melts of 900°C and 925°C are tonalitic (normative Qtz / Plag > 0.25) and those above 950°C are quartz dioritic (normative Qtz / Plag < 0.25) in composition. The melt composition changes from corundum normative to diopside normative when temperature increases from 925°C to 950°C. Also there is gradual decrease of plagioclase proportion with temperature rise. Moreover, the orthopyroxene and clinopyroxene are subequal in proportion at 900°C, and orthopyroxene gradually decreases in proportion to a trace amount at 1100°C. These results suggest that the nature of melting reaction changes from hornblende breakdown reaction at 925°C to eutectic clinopyroxene-orthopyroxene-plagioclase melting reaction at 950°C [6].

3. CHARNOCKITE PLUTON

The charnockite pluton at Jenapore is a relatively homogeneous body of two-pyroxene granulite, unlike those occurring as minor bands and patches within the massif-type charnockite described from the area to the north [5]. Also as distinct from those within massif-type charnockite garnet is absent, while clinopyroxene is much more abundant than orthopyroxene (**Table 1**).

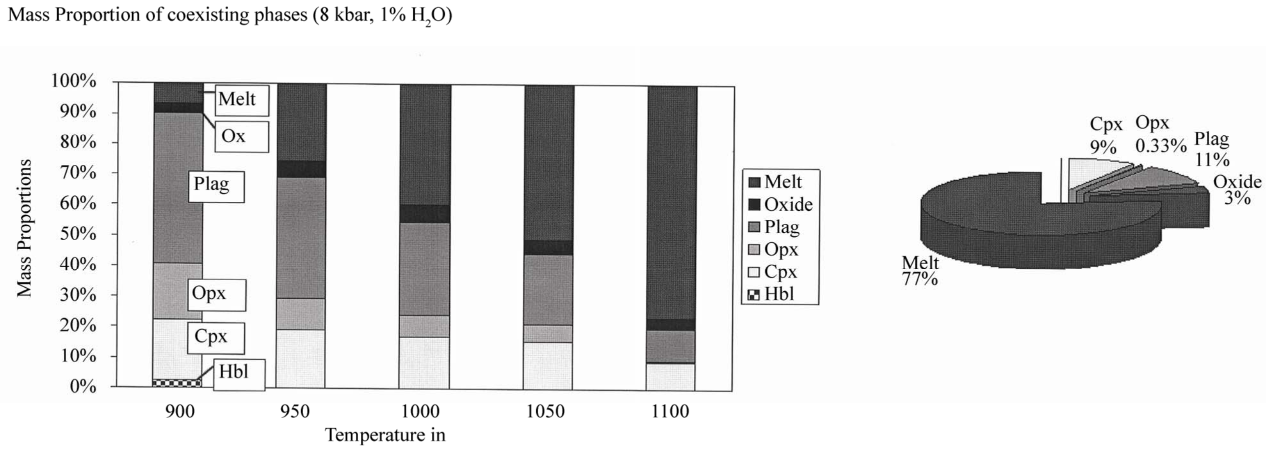

Figure 1. Mass proportions in melting experiments at 8 kbar.

Table 1. Modal mineralogy of the Charnockite pluton at Jenapore, Eastern Ghats Belt.

Sample	JN35A	2.J.95	2.J.82	2.J.90A	JN 194A	2.J.50A	JN 35F
Quartz	4.3	6.2	10.4	6.3	5.7	8.1	8.5
K-feldspar	4.2	3.1	2.5	3.2	2.7	1.8	2.1
Plagioclase	25	24.3	22.4	22.6	23.4	21.5	23
Orthopyroxene	13.3	14.5	16.4	18.3	17.4	14.6	15.3
Clinopyroxene	41.2	42	38.5	38.6	39.2	41	39.3
Hornblende	2.5	3.1	1.5	1.7	3.4	4.2	3.8
Biotite	5.4	3.7	5.2	4.6	3.9	4.5	5.3
Opaque	2.2	3.1	1.5	3.4	2.7	3.2	2.5
Accessory	1.2	Trace	1.1	0.7	1.4	0.4	0.3

3.1. Geochemistry

3.1.1. Analytical Procedure

Both major and minor oxides as well as trace elements were analyzed by ICP-MS at the Australian Geological Survey Organization, Canberra. At AGSO the sample preparation for ICP-MS has been based on a method outlined in Jenner *et al.*, 1990 [7]. However, some refractory elements like Zr have been problematic and to overcome this problem, a new method has been introduced. The new method involves digesting pieces of the lithium tetraborate/lithium metaborate fusions that have been prepared and run for XRF major element analysis. Approximately 100 micrograms of chips from the smashed discs are weighed accurately into Savillex Teflon vessels. Five milliliters of internal standard, one milliliter of HF and five milliliters of HNO_3 are then added. The vessels are sealed and heated for twelve hours at 120°C on a timed hotplate, such that cooled samples are ready the following morning. The digests are then transferred to volumetric flasks and made up to volume ready for the ICP-MS. The precision can be assessed from the Zr analysis (**Table 2**).

3.1.2. Results

The analytical data for the seven samples from the charnockite-pluton is presented in **Table 3**. In the Qz-Or-Pl diagram six (6) of the seven (7) analyzed samples plot in the field of Qz-diorite, while one sample plots in the field of Qz-monzodiorite (**Figure 2**). Normative quartz: plagioclase ratios vary between 0.02 and 0.15 and all the samples are diopside normative, varying between 6.4 and 11.7. All these features are compatible with the new experimental constraints indicating high temperature melting (≥ 950°C) in mafic rocks. Moreover, these compositional characteristics (homogeneous) suggest a change of melting reaction from peritectic to eutectic, as in the recent melting experiment [6].

The incompatible elements like K, Rb & Ba are enriched, while Ti and base metals like Cr & Ni are depleted

Table 2. Comparative Zr analysis in ppm.

Standards	ICP-MS old	ICP-MS new	AGSO XRF	Recommended [8]
W-2	78	95	93	94
BIR-1	15	15	15	15.5
DNC-1	36	37	36	41
QLO-1	171	189	188	185
BHVO-1	151	176	175	179
AGV-1	205	235	235	227

Table 3. Composition of the charnockite pluton of Jenapore, Eastern Ghats, India.

Area	Jenapore						
Sample	JN35A	2.J.95	2.J.82	2.J.90A	JN 194A	2.J.50A	JN 35F
SiO_2	49.69	52.03	54.42	52.19	52.74	52.87	53.05
TiO_2	2.9	1.72	1.53	1.34	0.97	1.11	1.71
Al_2O_3	13.85	15.53	15.09	15.74	16.58	16.63	15.29
Fe_2O_3	2.38	1.36	1.75	1.08	1.46	0.75	1.71
FeO	13.64	9.44	9.18	8.85	8.01	7.78	8.8
MnO	0.22	0.16	0.16	0.15	0.14	0.13	0.15
MgO	3.75	5.5	4.75	6.46	6.94	6.07	5.16
CaO	7.9	8.19	7.28	8.48	8.51	8.68	8.05
Na_2O	1.14	2.78	2.96	2.73	2.3	2.26	2.97
K_2O	2.07	1.51	1.56	1.26	1.06	1.87	1.79
P_2O_5	0.75	0.42	0.37	0.28	0.21	0.3	0.41
LOI	1.54	1.28	0.86	1.37	0.98	1.47	0.81
Total	99.83	99.92	99.91	99.93	99.9	99.92	99.9
			Trace elements in ppm				
Cr	9	119	105	185	98	205	78
Ni	8	50.5	33.5	37.5	20	49	24
Ni	8	50.5	33.5	37.5	20	49	24
Sc	45	31.5	31.5	33.5	32	31	34
V	263	193	162	170	167	160	184
Cu	36	26	26	20	22	22	19
Zn	176	120	127	104	97	89	114
Zn	176	120	127	104	97	89	114
Ti	17400	10320	9180	8040	5820	1660	10260
K	8588	6265	6472	5228	4338	7759	7427
Rb	48	54	54.5	34	40	56	49
Ba	1527	727	734	736	376	1066	1076
Sr	341	327	296	325	314	376	324
Zr	329	255	226	177	117	197	257
Nb	35.3	25.3	24.8	15.5	11.6	17	24.1
Th	2.46	1.98	1.51	2.83	8.84	1.49	3.72
U	0.41	0.3	0.48	0.32	0.56	0.27	0.5
La	92.7	55.3	44.9	47.5	56	56.2	64.2
Ce	234	120	97.2	97	115	115	135
Pr	22.7	13.1	11	10.4	11.8	12.2	14.8
Nd	87.7	50.3	43	39.4	42.8	45.2	55.7
Sm	15.5	9.45	8.23	7.06	7.55	7.29	9.85
Eu	3.87	2.26	2.13	1.99	1.6	2.21	2.58
Gd	15	8.92	8.33	7.05	6.96	7.14	9.2
Tb	2.28	1.37	1.32	1.11	1.06	1.07	1.43
Dy	12.9	7.83	7.5	6.32	5.98	5.96	8.01
Ho	2.8	1.69	1.64	1.4	1.29	1.28	1.76
Er	8.11	4.74	4.74	4.09	3.63	3.64	5.07
Yb	6.88	4.07	3.99	3.57	3.2	3.22	4.33
Lu	1.01	0.59	0.59	0.52	0.47	0.46	0.65
$\sum$ REE	505.45	279.62	234.57	227.41	257.34	260.87	312.58
$(La/Sm)_N$	3.76	3.68	3.43	4.23	4.67	4.85	4.10
$(Gd/Lu)_N$	1.85	1.88	1.76	1.69	1.84	1.93	1.76
Eu/Eu*	0.19	0.19	0.19	0.21	0.17	0.23	0.20

(**Figure 3**). These features suggest a melt character for these dioritic charnockites. However, Zn is significantly enriched and could be related to clinopyroxene as a major phase, which commonly contains trace amounts of Zn. Similar degrees of enrichment in Rb & Sr relative to primitive mantle is consistent with partial melting in ma-

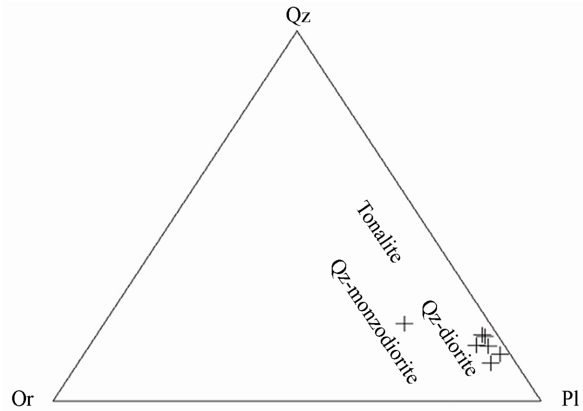

Figure 2. Normative Qz-Or-Pl diagram for the charnockites.

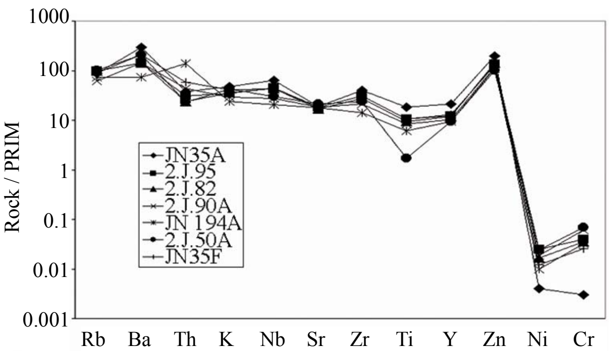

Figure 3. Multi-element spider diagram for the charnockites. Normalizing values from Taylor and McLennan, 1985 [23].

fic rocks involved in the break down of hornblende and plagioclase. However, unlike the tonalitic charnockites (cf. Figure 9 in [5]), negative Sr anomaly in the dioritic charnockites here implies plagioclase as a major residual phase [9]. Zr contents between 117 & 329 are variable, but most of the samples have near saturation concentration. This and relatively high Th (between 1.49 & 8.84 ppm) and U (between 0.27 & 0.56 ppm) suggest interaction between melt and restitic zircon. Also unlike the tonalitic charnockites, total REE contents are high, between 227 & 505 ppm, suggests near saturation concentration. Relatively less HREE fractionation $(Gd / Yb)_N$, between 1.69 & 1.88 than LREE fractionation $(La / Sm)_N$, between 3.43 & 4.85, suggests melt-pyroxene coexistence. Significant negative Eu anomaly is characteristic of these charnockites of quartz-dioritic composition unlike those in the tonalitic charnockites and Archaean tonalites [5,10] suggests major residual plagioclase (**Figure 4**). This is also consistent with the signature of negative Sr anomaly.

4. DISCUSSIONS

The Eastern Ghats Mobile Belt, along the east coast of peninsular India, is commonly described as a collisional orogen [11]. Extremely high temperatures (> 900°C) have been recorded from different granulite lithologies and from different parts of this regional granulite terrain [12-16]. On the other hand, dehydration melting experiments provided important constraints on the petrogenesis of massif-type charnockitic rocks of tonalitic and granodioritic compositions [17-20]. The latest experiments of hornblende-dehydration melting at high-temperatures (≥ 950°C), indicate changing melt composition from tonalite /granodiorite to quartz-diorite, along with residual clinopyroxene instead of hornblende [6]. In this context it is important to note that this is the first report of charnockite pluton of dioritic composition in the Eastern Ghats Belt. Erstwhile magmatic charnockite or their protoliths are described as enderbite, of tonalitic composition [21-22]. The tonalitic to granodioritic charnockite-massif of Jenapore was described as the product of hornblende-dehydration melting with residual hornblende & or garnet by Kar *et al*. [5]. In the same locale a stock-like body of charnockite, its quartz-dioritic composition with residual clinopyroxene and plagioclase provide evidence of high-temperatures (> 950°C). This is also consistent with the proposed change in the melting reaction from peritectic hornblende-dehydration melting to eutectic clinopyroxene-orthopyroxene-plagioclase melting.

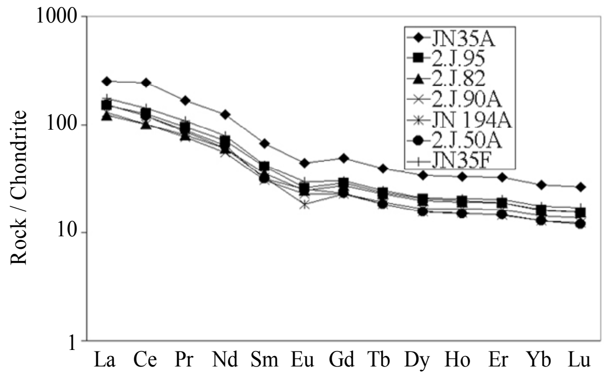

Figure 4. Chondrite normalized REE diagram for the charnockites. Normalizing values from Taylor and McLennan, 1985 [23].

5. CONCLUSIONS

1) This is the first report of dioritic charnockite pluton in the Eastern Ghats Belt.
2) Yet another evidence of Ultra-high temperature crustal metamorphism in the Eastern Ghats Belt.
3) Negative Sr and Eu anomalies, unlike those of tonalitic charnockites and Archaean tonalites, imply plagioclase as a major residual phase.

6. ACKNOWLEDGEMENTS

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