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Geochemical Appraisal of Granite and Charnockite of Muhlig Hofmannfjella, East Antarctica

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ABSTRACT

Muhlig Hofmannfjella, cDML, East Antarctica, exposes post collisional granite and charnockite, representing late orogenic episode of emplacements. Different petrochemical plots, suggest that both lithounits have evolved from the same source, which later got differentiated and fractionated to form these bodies. This is further supported by their field disposition and petrographic studies. Physical properties of these granite and charnockite are almost the same. Both of them differ only in their colours. Presence of enclaves of different shapes and sizes, characterize the area as the marginal region and/or roof area of the emplacement. Two generations of melanocratic discordant intrusives, represent latest events of emplacement.

INTRODUCTION

Geological mapping was carried out in the western part of Muhlig Hofmannfjella, between 71.86º S and 72.13º S latitudes and 4.43º E and 4.97º E longitudes **(Fig. 1)**. The area lies on the western side of central Dronning Maud Land, East Antarctica. This area is mainly covered by plutonic granite and charnockite, along with gneisses and some basic intrusive and enclaves. The geochemical analysis of these rocks tells about their involvement in continent-continent collision. Both granite and charnockite have many similarities in their chemical trends, suggesting the same source of origin.

The igneous rocks associated with Pan-African orogeny form a very important part of the lithological entity in central Dronning Maud Land. These magmatic rocks have been dated to represent an early Pan African phase and a post collision late phase of origin. In the neighboring area such as the Petermannketten, the Conradgebirge and the Filchnerfjella, the granitoids represent post-collisional A-type granitoids (Mikhalsky et al.,

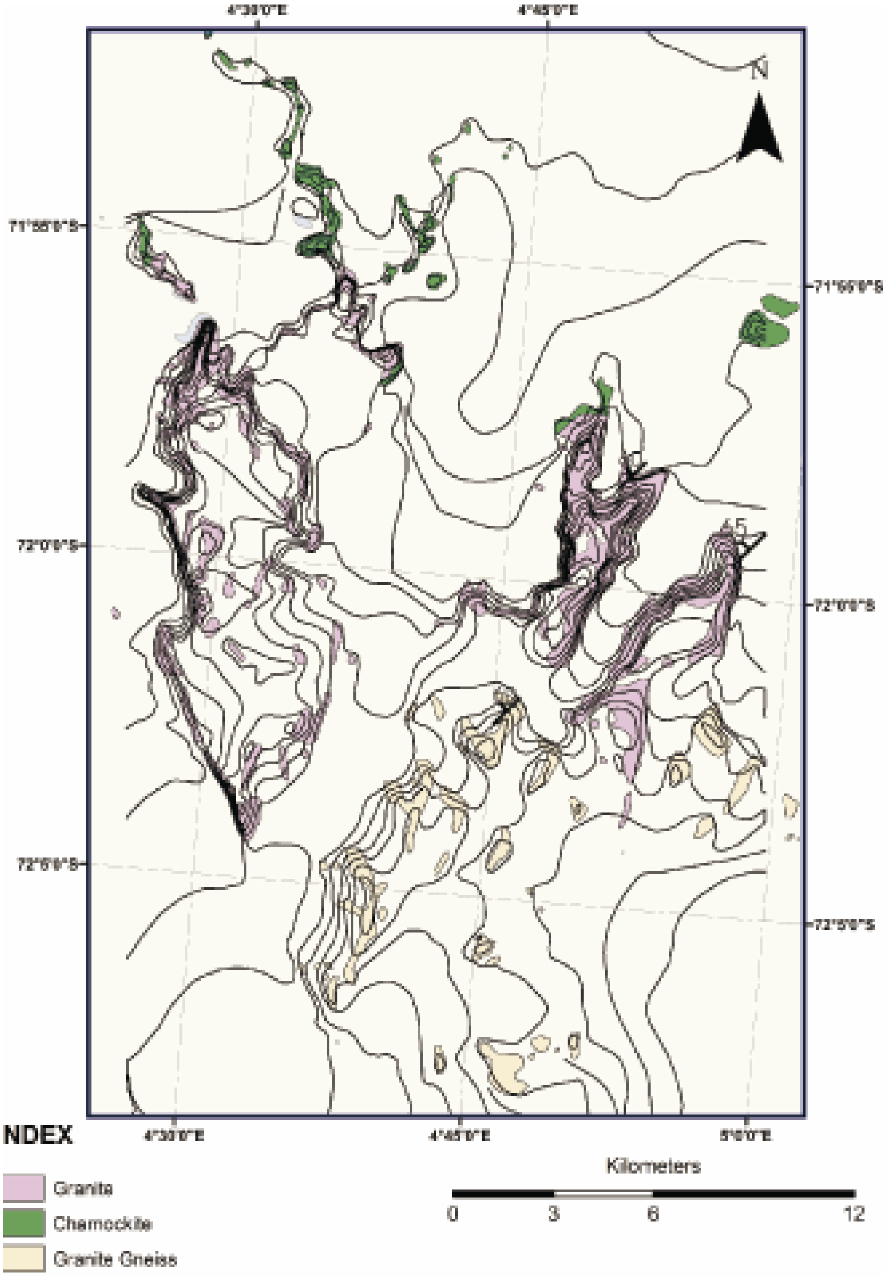

Fig. 1: Geological Map of part of Muhlig Hofmannfjella, East Antarctica

1995; Jacobs et al., 1998; Ravindra and Pandit, 2000). The present study deals with the geochemistry of granite and charnockite to explain their origin.

The grey coloured granite pluton of Muhlig Hofmannfjella is coarse grained, porphyritic and undeformed. The mineralogy mainly consists of quartz (30-40%), K-feldspar (45-55%), plagioclase feldspar (10-20%) along with ferromagnesian minerals such as hornblende, biotite, and some opaques. Charnockite differs from granite in having orthopyroxene in its mineral assemblage. While charnockite is brownish grey in colour, granite is dull grey. Granite and charnockite form the cliffs and steep slopes in this area. Texturally, both granite and charnockite show distinct similarities.

Lithology

The area which could be accessed mainly consists of granite, granite gneiss, charnockite, pegmatite veins and metadolerite.

***Granite* :** The petrography of granitic body shows variation in composition ranging from biotite granite, biotite-hornblende granite, to hornblende granite. Granites of the central region and eastern region have been intruded by melanocratic dykes of two generations. The contact of the intrusive body with the country rock is chilled. Granite in turn, shows forceful intrusion into the country rock, which is evidenced by the matching of fractured grain boundary. Very coarse grained granite has well developed, extremely coarse feldspar crystals, with graphic intergrowth of quartz. Granites mainly consist of quartz, plagioclase feldspar (An_{10-25} and An_{40-52}), K-feldspar (orthoclase and microcline), hornblende, biotite, garnet with some heavy and opaque minerals. Texturally, this rock shows extremely coarse grained, interlocking and hypidiomorphic texture. Intergrowth between quartz and K-feldspar is also a common phenomenon. Inclusions of biotite and heavy minerals in plagioclase feldspar are found. Quartz grains show wavy extinction and myrmekitic texture in many sections. Alteration of K-feldspar, hornblende and biotite has also taken place. The twinned planes appear to be slightly deformed in orthoclase, plagioclase, microcline and biotite. Some thin sections show, inclusion of quartz, K-feldspar and some opaque minerals in megacryst of perthite/microcline. Modal analysis of some granites samples show, variation in composition from granite to alkali feldspar granite. Oval shaped dark coloured enclaves of basic composition are also found to occur in the granitic body. These enclaves are rich in biotite, amphibole and some ferromagnesian minerals. Crude foliation is also noticed in some of these enclaves.

***Charnockite* :** Charnockite mainly occupies the northern part of the mapped area. This forms jagged peaks and some of the most difficult locations to land. Besides this it is also found to occur in the western and to some extent in eastern part of the area. This rock body has a greasy appearance and comprises extremely coarse-grained minerals. Quartz, K-feldspar (microcline and orthoclase), plagioclase feldspar with some ferromagnesian minerals (orthopyroxene, clinopyroxene, biotite, amphibole etc), some opaque and heavy minerals are the main constituents of charnockite. Texturally, this rock is coarse grained and has allotriomorphic to hypidiomorphic interlocking texture. At many places the grains show triple junction contact between them. Alteration of perthite, plagioclase and ferromagnesian minerals like orthopyroxene, clinopyroxene, biotite, and amphibole has taken place, along the cracks and twin planes. Microcline and quartz show deformation as is evident from their undulose extinction. Quartz shows recrystallisation and myrmekitic texture. Plagioclase grains show deformation and twinning. Inclusion of heavy minerals in amphibole is also seen in a few thin sections.

***Granite gneiss* :** Gneissic bodies of this area are mainly of two types. These are migmatitic gneiss and augen gneiss. The general trend of the foliation in the gneissic bodies varies from NNE-SSW to ENE-WSW and dip from 40º to 68º towards WNW to NNW. However, in the eastern part of the area, due to local deformation, this foliation trend has changed to NNW-SSE and dip direction towards ENE. Mostly, migmatitic gneisses with leucosome, mesosome and melanosome, are highly deformed showing minor folds. Melanocratic intrusives have been emplaced parallel to the gneissic foliation. The younger intrusives are found to cut across these foliations. At many places, the migmatitic gneisses are intersected by pink coloured quartzofeldspathic bands. Augen gneisses are mainly found in eastern and central region of the area. The augens are about 2 to 5 cm long and 0.5 to 1.5 cm wide. Overall the gneissic bodies mainly consist of quartz, K-feldspar (orthoclase and microcline), plagioclase feldspar, biotite, amphibole, garnet, opaque and laths minerals. Texturally, these rocks show coarse grained foliated texture. Biotite grains are oriented parallel to dominant foliation plane. Inclusion of biotite and some heavy minerals in plagioclase and inclusion of quartz and biotite in garnet are also noticed. Garnet grains show honeycomb structure. Biotite, plagioclase and K-feldspar show alteration to clay mineral. Two generations of sillimanite and two phases of spinel and magnetite are present in gneissic rock. Also concentric growth rings have been noticed in a zircon grain from the migmatitic gneiss exposed of the southern part of the area.

***Pegmatite veins* :** These veins have mainly intruded the granitic mass with extremely large crystals of K-feldspar (orthoclase and microcline), plagioclase feldspar and quartz. These veins are youngest in the as most of them are straight presenting a cross cutting relationship.

***Meta diorite* :** These dark coloured intrusives are of two generations, as is evident from their field relationship with the country rock. At many places the earlier intrusives have been emplaced almost parallel to the foliation of gneissic rock body. Crude foliations are also visible in these intrusive bodies. Under the microscope these intrusive bodies show interlocking texture between biotite, amphibole, plagioclase feldspar and quartz. Biotite grains are oriented along dominant foliation plane. Alteration of amphibole to biotite is common feature as seen in the thin section. Also, inclusion of plagioclase in biotite and zoning in plagioclase are present. Alterations of microcline along the cracks are found in some thin sections. Alteration of hornblende has developed the 'Honey comb' like structure. Undulose extinction in quartz indicates strained or ductile deformation.

Geochemistry

Whole rock analyses of -200 mesh size powdered samples were done using a Phillips XRF Spectrometer at the Petrology, Petrochemistry and Ore Dressing (PPOD) laboratory, Airborne Mineral Survey and Exploration (AMSE) wing, Geological Survey of India, Bangalore. Trace elements were analysed using ICP-AAS at the Geological Survey of India, Faridabad, while Rare Earth Element (REE) analyses were carried out using instrumental NAA at Geological Survey of India, Pune. All the analyses are shown in the **Tables 1 to 3**.

DISCUSSION

The sub-alkaline granite, as shown by the plot between Na_2O+K_2O vs SiO_2 (**Fig. 2**; Peacock 1931). Based on FeOt/FeOt+MgO vs SiO_2 plot (after Frost et al., 2001), these granitoids have been defined as ferroan A-Type granitoids (**Fig. 3**).According to A/NK versus A/CNK diagram (**Fig. 4**; Maniar and Piccoli 1989), granitoids of Muhlig Hofmannfjella are predominantly metaluminous. The plot of K_2O versus SiO_2 (**Fig. 5**; Rickwood 1989) showed shoshonitic field for granitoids and charnockites. SiO_2 content in granitoids of Muhlig-Hofmannfjella varied from 52.09% to 75.88% as indicated by Harker's plot. The plots between CaO, MgO,

Table 1—Whole rock analysis of MH granites

Sl. No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Sample No.	**L11**	**12**	**13**	**15**	**18**	**24/3**	**24/6B**	**24/7**	**24/8**	**24/9**	**24/11**	**24/13**	**24/14**	**24/14C**	**24/16**	**24/22A**
SiO_2	67.72	66.97	70.38	59.38	69.64	66.41	69.24	64.31	61.25	66.02	62.72	68.96	70.48	66.98	65.78	57.81
TiO_2	0.51	0.73	0.72	2.86	0.08	0.75	0.46	0.66	1.07	0.89	0.87	0.47	0.33	1.03	0.94	1.95
Al_2O_3	15.77	14.63	12.43	12.05	16.18	13.89	14.39	15.94	15.57	14.11	16.12	13.99	14.27	14.18	14.01	12.85
Fe_2O_3t	5.15	5.19	4.24	8.89	1.43	7.04	3.83	4.83	7.66	5.55	6.09	4.58	2.76	4.82	5.99	11.58
MnO	0.09	0.07	0.04	0.12	0.01	0.13	0.03	0.06	0.09	0.05	0.08	0.05	0.03	0.06	0.08	0.14
MgO	2.13	0.88	0.89	2.37	0.25	0.56	0.73	0.79	1.32	1.03	1.06	0.39	1.31	1.16	1.06	2.7
CaO	3.23	2.48	2.02	4.02	0.96	1.97	1.7	2.44	2.91	2.08	2.62	1.79	1.41	1.82	2.47	3.48
Na_2O	2.84	3.02	3.43	2.52	3.18	3.43	2.81	3.41	2.68	2.68	2.97	2.71	2.94	2.86	3.01	2.36
K_2O	1.92	5.32	4.96	4.39	7.63	5.14	5.61	6.28	6.11	6.41	6.51	6.29	5.69	5.76	5.59	5.61
P_2O_5	0.12	0.27	0.39	1.73	0.03	0.23	0.24	0.34	0.56	0.36	0.43	0.14	0.15	0.5	0.34	1.03
NiO	0.02	0.02	0.02	0.01	0.01	bld	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01
BaO	0.03	0.06	0.04	0.04	0.03	0.03	0.04	0.07	0.07	0.04	0.08	0.06	0.04	0.03	0.06	0.03
LOI	0.19	0	0.02	1.07	0.33	0.21	0.73	0.66	0.47	0.6	0.27	0.41	0.46	0.66	0.33	0.12
Total	**99.99**	**99.99**	**99.98**	**99.98**	**99.99**	**99.99**	**99.99**	**99.98**	**100**	**99.98**	**99.99**	**99.99**	**100**	**99.99**	**99.98**	**99.98**

Table 2—Whole rock analysis of MH charnockites

Sl. No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Sample No.	**17**	**24/2**	**24/4**	**24/5**	**24/17**	**24/20**	**24/21A**	**24/15**
Field Ident.	Charnock	Charnock	Charnock	Charnock	Charnock	Charnock	Charnock	Charnock
SiO_2	63.79	69.78	64.63	61.21	71.56	68.32	67.29	68.24
TiO_2	0.59	0.56	1.13	1.22	0.36	0.44	0.52	0.66
Al_2O_3	16.57	13.03	13.66	13.86	12.51	14.44	13.26	13.34
Fe_2O_3t	5.64	5.48	6.95	9.33	4.33	4.79	6.34	6.18
MnO	0.14	0.08	0.08	0.09	0.06	0.06	0.09	0.08
MgO	0.31	0.31	1.21	1.69	0.15	0.31	0.47	0.38
CaO	1.66	1.29	2.42	2.34	1.79	2.01	2.22	2.23
Na_2O	4.09	3.32	3.5	2.83	2.58	3.15	2.7	2.65
K_2O	6.44	4.86	5.19	6.01	5.41	5.77	6.11	5.37
P_2O_5	0.13	0.24	0.52	0.69	0.08	0.18	0.21	0.24
NiO	bld	0.01	bld	bld	0.01	bld	0.01	0.02
BaO	0.02	0.03	0.04	0.04	0.05	0.06	0.05	0.06
LOI	0.31	0.68	0.39	0.51	0.83	0.27	0.54	0.22
Total	**99.99**	**99.98**	**99.99**	**99.99**	**100**	**99.97**	**99.98**	**99.99**

Table 3—Trace element analysis of MH charnockites

Elements (ppm)							
Charnockite							
Ba	944	339	1790	3095	2636	3412	2139
Sr	163	97	336	429	294	450	287
Y	39	28	66	47	23	39	86
Zr	376	1206	453	469	444	424	427
Nb	23	29	28	27	26	24	29
Th	1.9	17	16	31	31	27	77
Zn	106	93	171	103	67	87	120
V	11	10	18	12	13	14	14
Cr	13	<10	<10	320	240	<10	<10
Hf	16	36	22	23	16	26	19
Sc	6	10	14	10	6.6	8.5	12
Ta	0.8	1.6	2	2.5	1.2	0.44	0.96
Co	<5	<5	<5	5	<5	<5	<5
Ni	<10	<10	<10	134	98	<10	<10
Ce	135	412	253	428	403	339	685

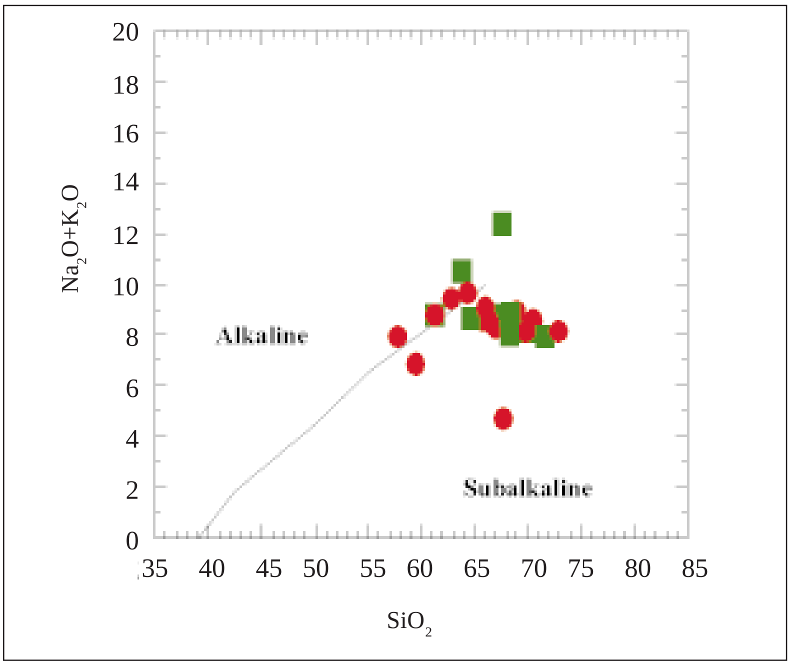

Fig. 2: Plot between Na2O+K2O vs SiO2 (wt%) (Peacock 1931)

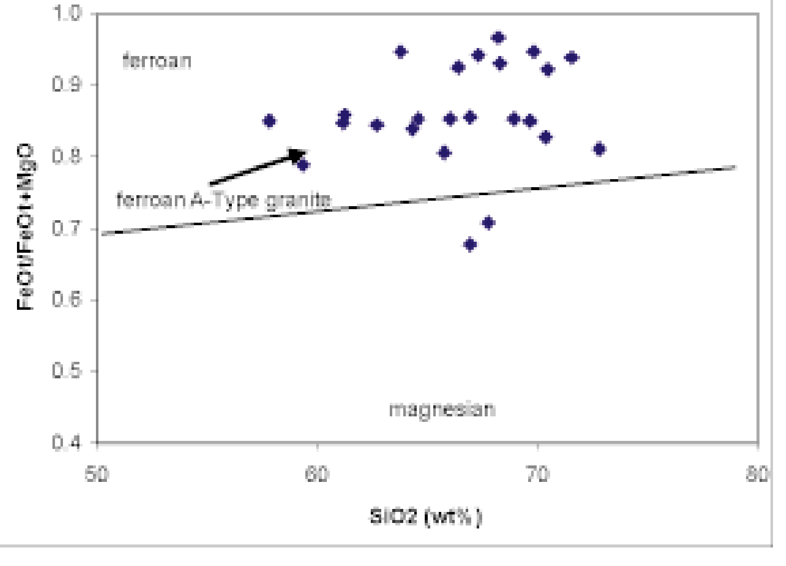

Fig. 3: Plot between FeOt / FeOt + MgO vs SiO2 (wt%) (Frost et al. 2001)

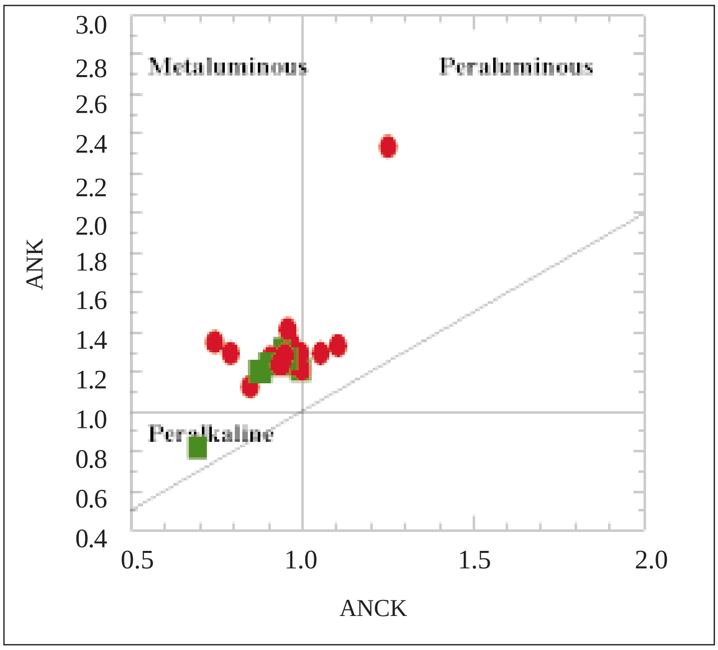

Fig. 4: Maniar and Piccoli (1989) plot showing metaluminous character

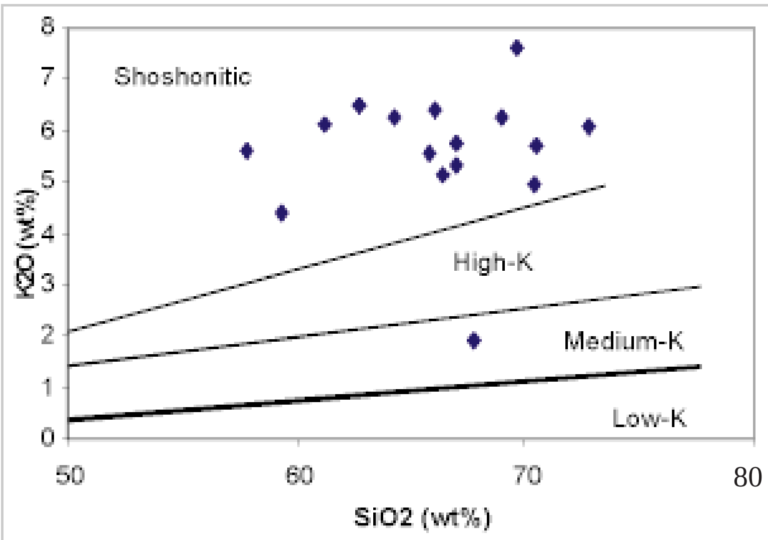

Fig. 5 : Plot between K2O vs SiO2 (wt%) (After Rickwood 1989)

and K_2O vs. SiO_2 showed consistent trends, which decreased with the increase of SiO_2 (**Figs 6 a & b**). These plots of granitoids and charnockites have almost the same trends, indicating that these rocks were part of same source. Also, both these rock types have remarkable similarities in their textural properties and in their outcrop patterns. The plot between Na_2O+K_2O-CaO vs SiO_2 (wt%) (**Fig. 7**: Frost et al., 2001) showed their dominant alkali calcic character.

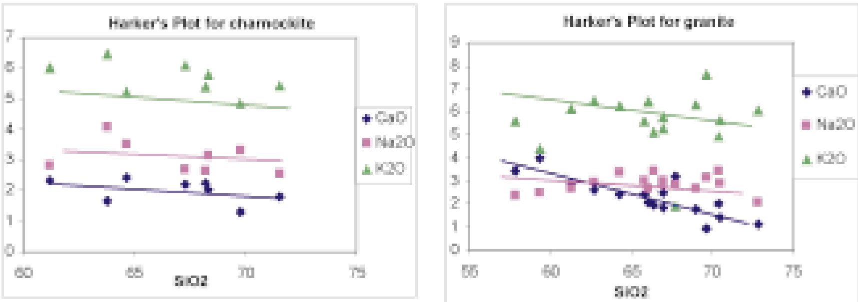

Fig. 6 a & b: Harker's Plot (Harker, 1909) showing linearly decreasing trends of CaO, Na_2O and K_2O with increasing SiO_2 in charnockite and in granitoid

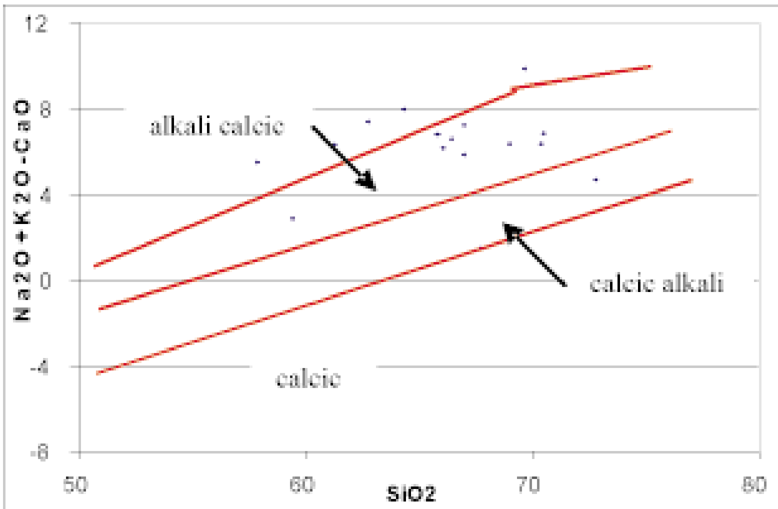

Fig. 7: Plot between Na_2O+K_2O-CaO vs Sio_2 (wt%) (Frost et al 2001)

The trace element tectonic discrimination diagram (**Fig. 8**; Pearce et al. 1984) between Nb and Y showed remarkable similarity in trends between charnockite and granite. These plots represent within plate granite and charnockite. According to R1 and R2 plot (**Fig. 9**; Batchelor and Bowden's1985), granite and charnockite of Muhlig-Hofmannfjella range were syn-collision to late orogenic in nature. Further, these rocks have high (La/Yb) N ratio suggesting fractionated HREE/LREE trends. Negative Eu anomaly suggests crustal origin / contamination of this source (**Fig. 10a & b**; Nakamura 1977).

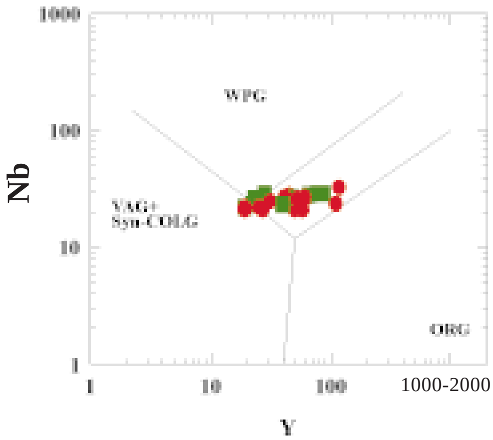

Fig. 8: Trace element tectonic discrimination Diagram Nb vs Y (Pearce et al. 1984)

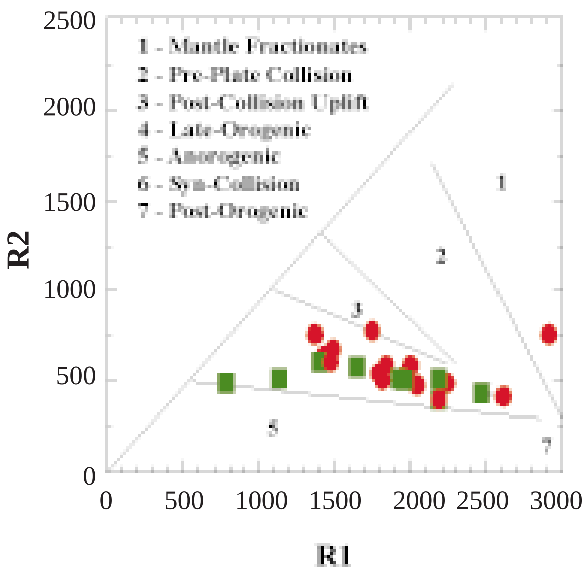

Fig. 9 : R1-R2 diagram (Bachelor and Bowden - 1985) showing tectonic setup of granitoids and charnockites

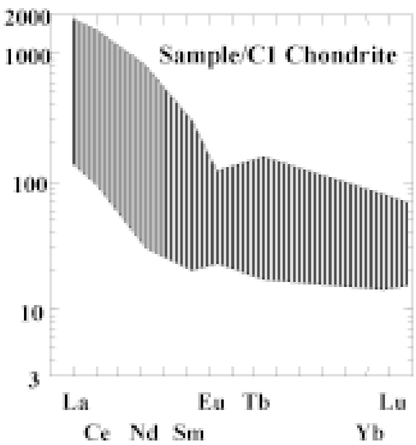

Fig. 10a : Chondrite normalized REE spidergram for granite (normalizing value after Nakamura 1977)

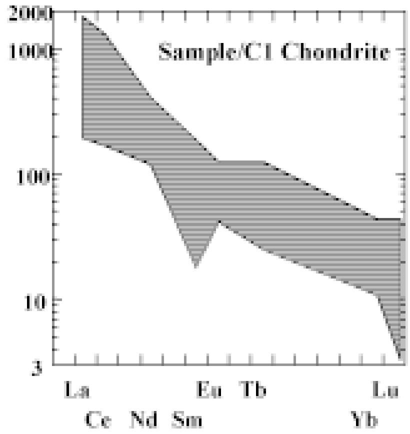

Fig. 10b : Chondrite normalized REE spidergram charnockite (normalizing value; Nakamura 1977)

Based on the mineral assemblages of charnockite and granite, available geochemical data and a comparison with other ferropotassic A-type granites of the neighboring area (Bogaerts et al. 2003; Guimaraes et al. 2000; Ferre et al. 1998; Roland 1999; D'Souza et al., 2006) an anhydrous to H_2O-undersaturated parent magma with igneous crustal component is considered as a possible source rock for Muhlig-Hofmann granitoids. The involvement of igneous crustal source in the generation of magma is considered to accommodate the transalkaline potassic and ferriferous character of these rocks. Melting of such igneous crustal components must have occurred at high temperature and very low almost constant oxygen fugacity to crystallize pyroxene. As the magma slowly cooled and moved towards upper part of the earth, it suffered fractional crystallization. During this process, the melt may attain water (Bucher and Frost 1993). The resultant increase in the oxygen fugacity leads to the crystallization of ilmenite and magnetite, instead of pyroxene. The increased H_2O activity was conducive for the formation of biotite-hornblende bearing granitic assemblage. Hence charnockite represents an early crystallised phase of Muhlig Hofmann pluton. The plot between TiO_2 vs. SiO_2 and (P_2O_5/TiO2) vs. (MgO/CaO) also supports the origin of charnockite from a primary magma source **(Figs 11 & 12)**.

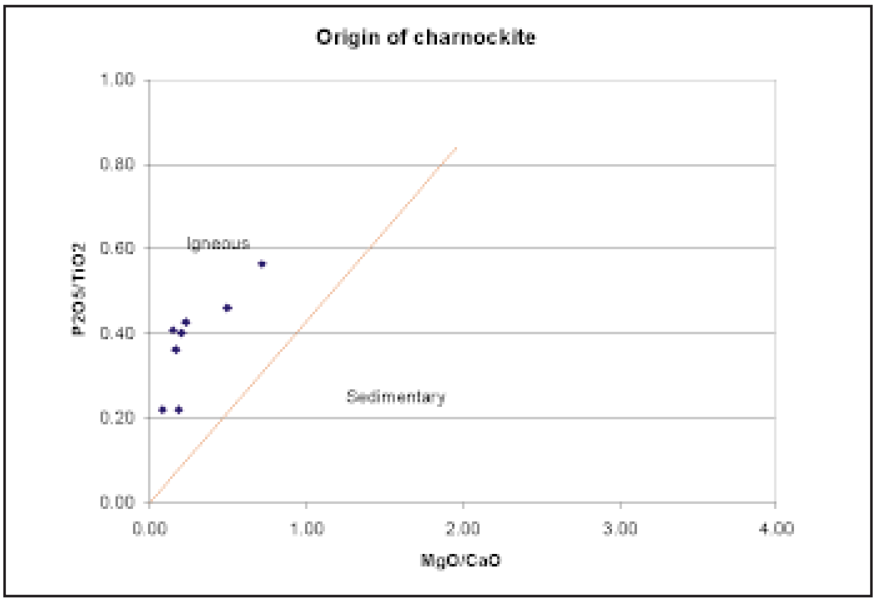

Fig. 11 : Plot between P2O5/TiO2 vs MgO/CaO (wt%) (Harker, 1909) for origin of charnockite

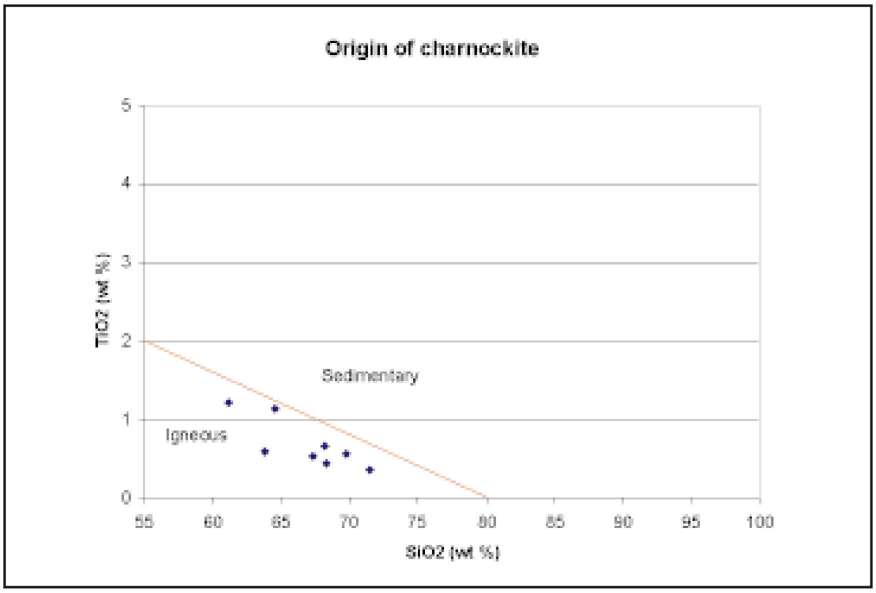

Fig. 12 : Plot between TiO2 vs SiO2 (wt %) MgO/CaO (wt%) (Harker, 1909) of charnockite

CONCLUSION

The sub-alkaline, ferroan, A-Type, shoshonitic, metaluminous with dominant alkali calcic character Muhlig-Hofmann granite show absence of any deformational or metamorphic feature and hence, are considered as post tectonic / post collisional. The within plate feature and Late Orogenic feature as reflected by Nb vs. Y and R1-R2 diagram respectively, conform to this conclusion. Various plots suggest that both granite and charnockite have originated from same source. Charnockite represents an early crystallized phase of Muhlig-Hofmann pluton governed by an anhydrous to H_2O-undersaturated parent magma with high temperature and very low almost constant oxygen fugacity. The plots between TiO_2 vs. SiO_2 and (P_2O_5/TiO_2) vs. (MgO/CaO) also support the origin of charnockite from a primary source. Textural characters and outcrops also indicate an igneous source for these rocks. The increased H_2O activity at later stage was responsible for the formation of biotite-hornblende bearing granitic assemblage.

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