*Twenty First Indian Expedition to Antarctica, Scientific Report, 2007*
*Ministry of Earth Sciences, Technical Publication No. 19, pp 155-171*

# Geological Mapping of Muhlig-hofmann Mountains, Cdml, East Antarctica

**A.V. Keshava Prasad and M.P. Gaur**

Geological Survey of India, Antarctica Division, Faridabad

## Abstract

Coarse grained porphyritic charnockite and coarse porphyritic granite are exposed in the northern and southern parts respectively of central Muhlig-Hofmannfjella. Detailed petrography reveals that their mineral assemblage is markedly different. Hypersthene, ferrosilite, fayalite, diopsidic augite and biotite are the ferro-magnesium minerals in charnockite, while biotite and hornblende are the only ferromagnesium minerals in granite. The charnockite has signatures of a Charnockite Magmatic Suite'(CMS) as well as that of A-type granite derived from fractionation of tholeiitic basalt. While presence of inverted pigeonite, high K, Ti and P, low Ca are indicative of CMS, the presence of ferrosilite and fayalite are features of A-type granite fractionated from a tholeiitic magma. Harker plots of $Si0_2$ vs. CaO, $K_20$ and $Ti0_2$ for both granite and charnockite are almost identical. In the light of these results, it is surmised that although granite and charnockite occur in the field as distinct entities albeit closely associated, they share common crystallization history and perhaps are parts of a single pluton.

**Keywords:** charnockite, granite, Muhlig-Hofmannfjella, CDML, E. Antarctica.

## Introduction

Geological mapping in the central part of the Muhlig-Hofmann (MHM) range between 5°45' and 6°20' E longitude; 71°40' and 72°05' S latitudes was carried out during the summer period of XXI Indian Antarctic Expedition (2001-02). The area covered is about 1000 sq. km and mapping was done by selected helicopter drop points on 1:50,000 scale.

The geology of Central Dronning Maud Land spaning the Wohlthat Range, Orvin Range and Muhlig-Hofmann Range was first described by Ravich & Solov'ev (1966) and later by Indian and German geologists (loshi et al. 1991, D'Souza et al. 1996). Studies have indicated that the exposed part of CDML crust has a very large component of Grenvillian (-1000 Ma) crust which has been extensively modified by later (500-600 Ma) Pan-African event (Jacobs, 1998). The Pan-African event is associated with dominant magmatic activity, which started with intrusion of massif anorthosite and AMCG suite of rocks in the Wohlthat Mountain and possibly culminated in huge plutonic intrusion of granitoids in different parts of CDML (Ravindra & Pandit, 2000; D'Souza & Keshava Prasad, 2003).

The central Muhlig-Hofmann is dominated by coarse-grained porphyritic chamockite and coarse grained porphyritic biotite-hornblende granite with its variant constituents. Chamockite is exposed in the northern part of the mapped area while in the southern part of mapped area, grey coloured biotite-hornblende granite is predominant (Fig. 1). This is in

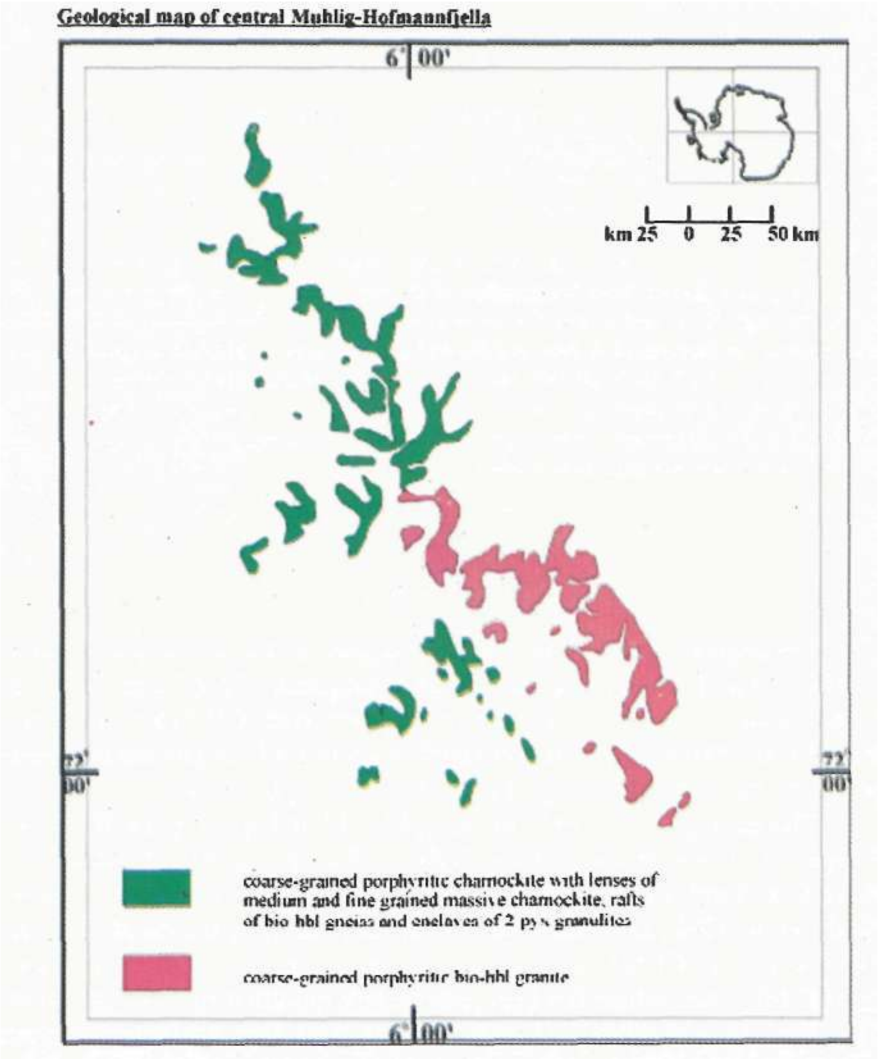

*Fig. 1: Geological map of central part of Muhlig-Hofmannfjella*

contrast with the lithological set-up adjacent to the east of the present area ie., eastern Muhlig-Hofmannfjella, where the two rock types occur as closely intertwined irregular shaped bodies with distinct colour contrast but with textural continuity across the margins (D'Souza & Keshava Prasad, 2003).

The coarse porphyritic chamockite is massive and grayish/reddish brown in colour (Fig. 2). The K-feldspar phenocrysts are very coarse and measure up to 10 cm. The ferro-magnesium minerals, quartz and feldspars occupy the interstitial space of the phenocrysts. At places, the chamockite is medium grained non-porphyritic and greenish grey and such masses occur as huge lensoidal patches (Fig. 3). Leucocratic and fine grained charnockites occur as rounded to elongated enclaves (Fig. 4). The host chamockite contains a variety of other enclaves. These include 2-pyroxene granulite, banded gneiss and a few gabbroic enclaves. The 2-pyroxene granulite enclaves are melanocratic and medium to fine grained. Rafts of gneissic enclaves, measuring up to tens of meters show clear banding of biotite-hornblende rich layers and quartzo-feldspathic layers. Aplite and a few basic dykes, which can be traceable up to 200 m, intrude the charnockites.

*Fig. 2: Coarse porphyritic Chamockite*

*3: Lenses of medium grained non-porphyritic charnockite (light coloured) within, the brownish porphyritic charnockite*

*Fig. 4: Fine grained charnockite enclave within coarse porphyritic charnockite*

In the southern part of the mapped area, greyish, coarse porphyritic granite is exposed (Fig. 5). K-feldspar phenocrysts are set in quarz-feldspar-biotite-hornblende matrix. Phenocrysts measure up to 4-5 cm. At places, patches of medium grained, homogenous non-porphyritic granite are also exposed. Rafts of gneisses, measuring up to several meters in length occur in these granites also.

*Fig. 5: Coarse porphyritic granite*

## Petrography

**Coarse Porphyritic charnockite**: It is the dominant rock type in the northern parts of the mapped area; it exhibits the following mineral assemblages:

opx+fay+hbl+Kfs±plag+qz+ opaques
opx+fay±cpx+ (inv. Pigeo.)+hbl+Kfs±plag+qz+ opaques
opx+cpx+ (Aug./Di.)+hbl+Kfs±plag+qz+ opaques.

The orthopyroxene grains are feebly pleochroic and have interference colours ranging from grey to second order. Fayalite grains are similar to opx grains but have higher birifrengence. Augite and diopside grains are also similar to opx grains but often show 2 sets of cleavages and inclined extinction. Inverted pigeonite is found in several samples (1/XXI, 9/XXI). The cpx lamellae are at high angles to the cleavage planes of the opx regions with in the grains (Fig. 6). Late stage reaction of opx/cpx to hornblende at the rims and at places almost completely (Fig. 7) is observed. Exsolutions of iron oxide is commonly seen in opx grains (Fig. 8). This can be explained by the reactions.

$$\text{opx+plag+ } H_2 0 \text{———hbl}$$
$$\text{cpx++plag+}H_2 0 \text{ ——hbl}$$

*Fig. 6: Inverted pigeonite in charnockite sample No. 9/XXI*

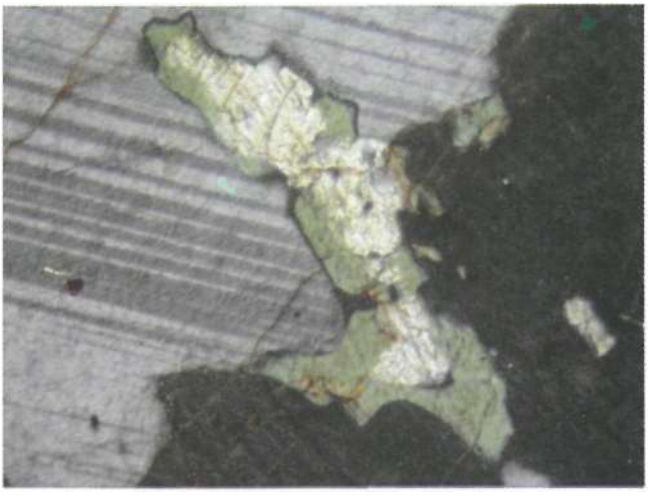

*Fig. 7: Retrogression of clinopyroxene to hornblende*

*Fig. 8: Perthite and exsolution of iron hydroxide from opx grain in the Chamockite*

K-Feldspars form the bulk of feldspar population and occur as big grains enclosing the small subhedral, ferromagnesium mineral grains. It is invariably perthitic in nature. Plagioclase is tabular/subhedral and not as big as the K-feldspars and at places antiperthitic blebs. Zircons and opaques complete the accessory mineral population.

The non-porphyritic, medium to fine grained chamockite has an assemblage of opx+bio+Kfs±plag+qz+ opaques.

**Coarse Porphyritic granite:** The granite, which is exposed in the southern part of central Muhlig-Hofmannfjella, has essentially two assemblages-

bio+Kfs (perth.)+plag+qz and
bio+hbl±cpx++Kfs (perth.)+plag+qz.

Myrmekites (Fig. 9) are quite common Orthoclase is almost always perthitic and Cpx whenever present, is in very minor amounts and diopsidic in nature.

The medium grained non-porphyritic granite, which occurs as irregular shaped patches in the dominant porphyritic granite, has assemblage of bio+Kfs+microcline+plag+qz. The K-feldspar is invariably perthitic in nature. The granite as compared to the chamockite in the north has fewer enclaves, which are rafts of gneiss, and some mafic pods, rich in biotite. The gneiss has a mineral assemblage of bio+hbl+plag+Kfs+qz.

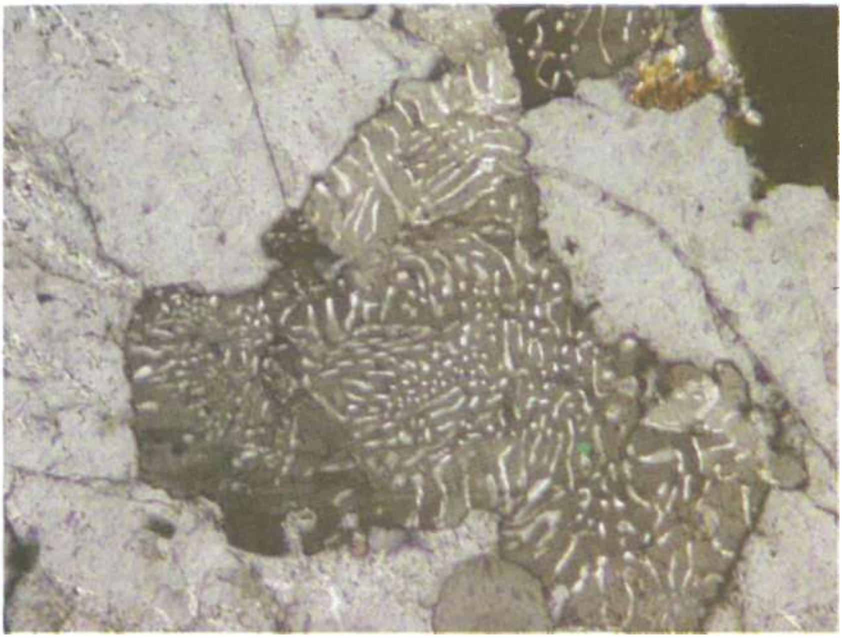

*Fig. 9: Myrmekite in granite.*

**2-pyx granulite:** The 2-pyx granulite which occurs as enclaves within the coarse porphyritic charnockite is fine grained with granulose texture and has mineral assemblage cpx(aug/di)+opx+bio+plag+ Kfs(perth.)+qz. At places opx is seen reacting to form biotite at the rims.

## Geochemistry

Whole rock analyses was done using Phillips XRF at Petrology, Petrochemistry and Ore Dressing (PPOD) laboratory at Airborne Mineral Survey & Exploration (AMSE) Wing, Bangalore and trace and rare earth elements were analyzed by ICP-MS at Chemical Laboratory, GSI Hyderabad. Table 1 and Table 2 list the major, trace and rare earth element composition of representative samples of granite and charnockite respectively. It is clear from the tables that the coarse grained porphyritic charnockite and granite of central Muhlig-Hofmannfjella display remarkable similarity in their major element concentrations except $Na_20$. Granite has more $Na_20$ vis-a-vis Total Alkali content than charnockite.

The fine grained massive charnockite which occurs as huge lenses and rafts has slightly different relation with the host coarse porphyritic charnockite. While the fine grained charnockite is high on $Si0_2$ and $K_20$

vis-a-vis Total Alkali contents, the host coarse charnockite is high on Total Fe, CaO, $Ti0_2$, P2O5 and Total REE. $Na_20$ and $Al_20_3$ concentrations are similar in both nvk types.

The Central Muhlig-Hofmannfjella granite and charnockite are of alkali feldspar granite to granite composition (Fig. 10a & 10b) and plot in sub alkaline field in the TAS diagram (Fig. 11). The AFM plot shows that both granite and charnockite have calc-alkaline trend (Fig. 12). The Harker plots of various major element oxides of these rock types show overlapping trends (Fig. 13). While plots for CaO, MgO, $Fe_20_3T$, $Ti0_2$

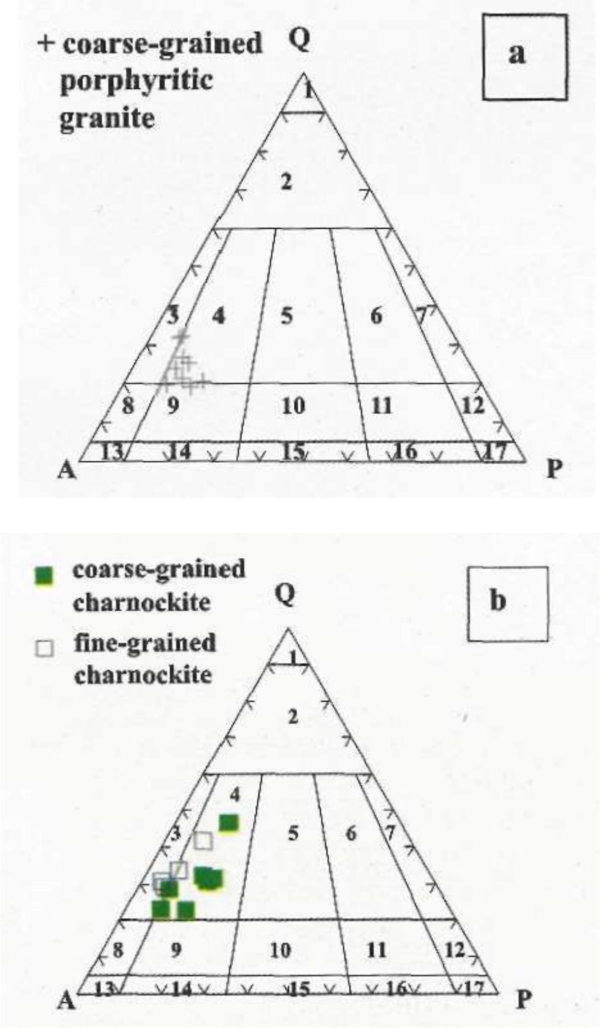

*Fig. 10: Molar QAP diagram of (a) coarse porphyritic granite and (b) coarse porphyritic and fine-grained charnockite*

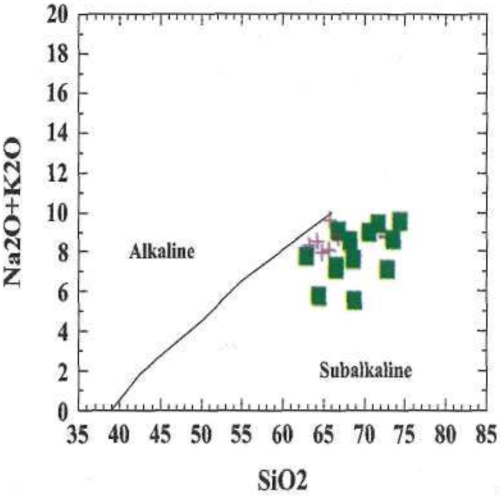

*Fig. 11: TAS diagram of coarse porphyritic granite and coarse porphyritic charnockite*

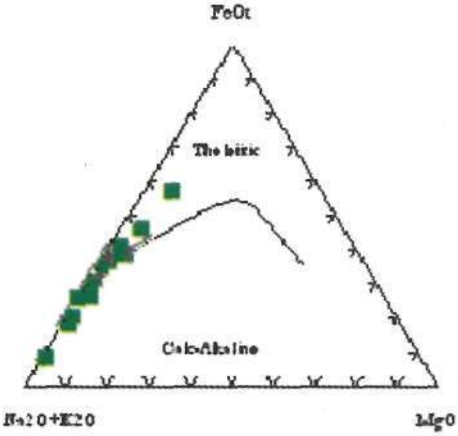

*Fig. 12: AFM diagram of coarse porphyritic granite and coarse porphyritic charnockite*

and $P_2O_5$ (and to an extent, $Al_2O_3$) define clear linear trends with steep negative slopes, plots for alkalis i.e., $Na_2O$ and $K_2O$ show high degree of scattering. The LREE and HREE concentrations of the rock types is also similar but for four granite samples (Nos. XXI-54A, 54B, 60 & 62A) which are highly enriched in LREE (Fig. 14 ).

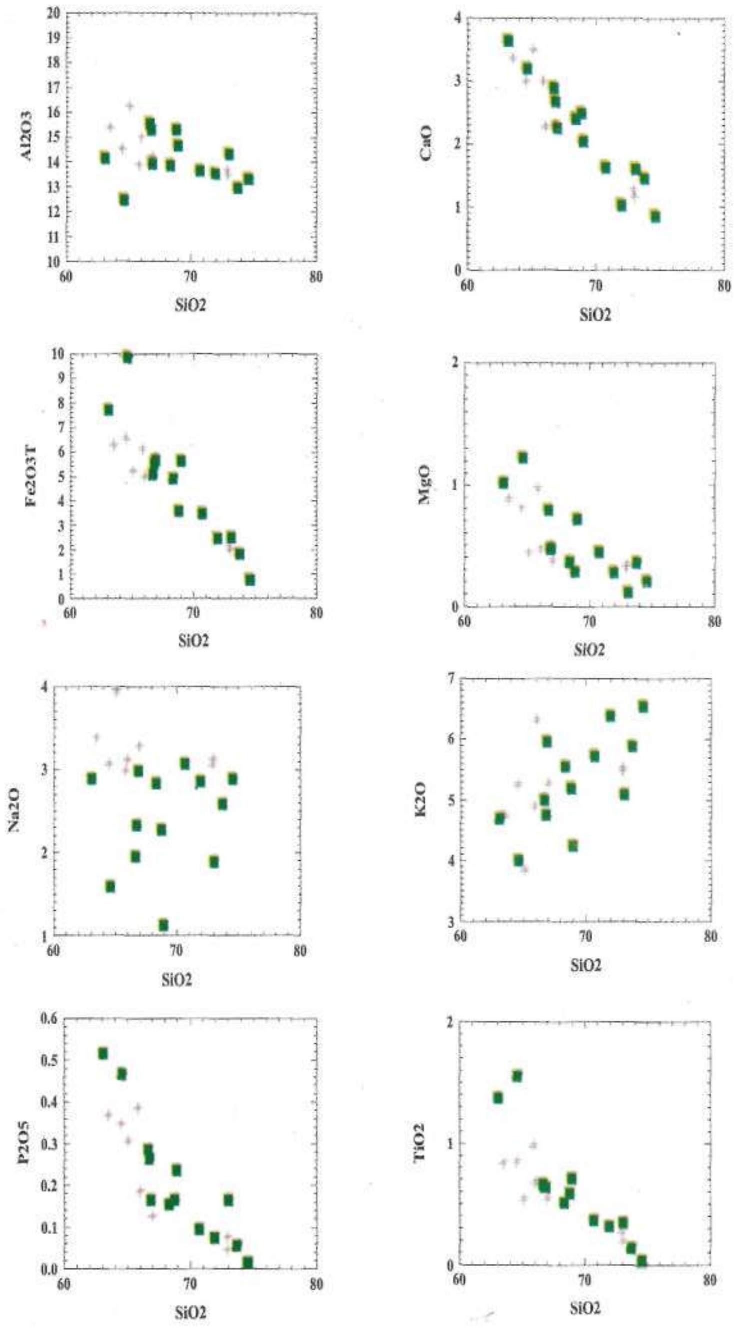

*Fig. 13: Harker diagrams of coarse porphyritic granite and coarse porphyritic charnockite*

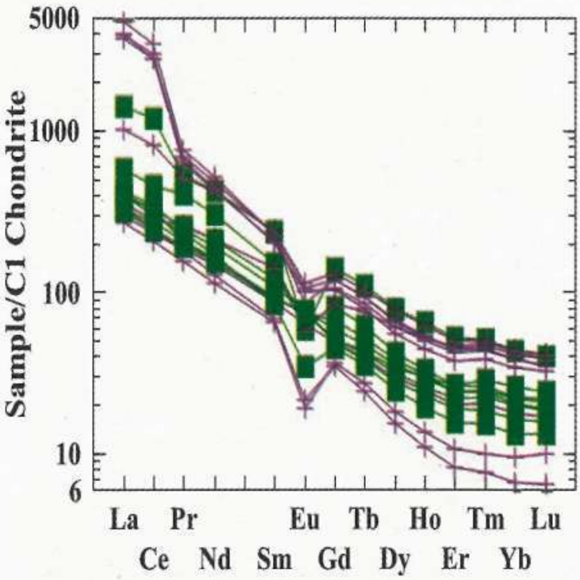

*Fig. 14: TAS diagram of coarse porphyritic granite and coarse porphyritic charnockite*

## Discussion

Based on the major,element chemistry, the granite and charnockite (including the fine grained massive types) are categorized as Ferroan A-type granites (nomenclature after Frost et al. 2001). On the other hand, going by the characteristics of a igneous charnockite as suggested by Kilpatrick JA, Ellis DJ (1992), the presence of inverted pigeonite, high K, Ti and P, low Ca in the central Muhlig-Hofmannfjella is indicative of a Charnockite Magmatic Suite (CMS). In the molar (K+Na)/Al vs. $Si0_2$ diagram these rock types plot in the sub-alkaline metaluminous granitoid field (after Liegeois & Black, 1987). The overlapping trends of these rocks in the Harker plots indicate that both charnockite and granite have similar fractionation pattern. The enrichment of total alkali in granite as compared to charnockite indicates possible alkali metasomatism during the granite emplacement. This also explains the scattering of $Na_20$ and $K_20$ vs. $Si0_2$ in the Harker plots. The total REE content of both rock types are also quite similar. All these observations suggest that the granite and the charnockite of central Muhlig-Hofmannfjella may belong to a single pluton. Further the $RiR_2$ diagram (Fig. 15) of Bachelor & Bowden (1985) indicate that while charnockites plot in the syn-collision to late-orogenic fields, the granites plot in the late orogenic field. But to suggest that the charnockite

**Table 1: Major, Trace and Rare Earth Element compositions of granites of Central Muhlig-Hofmannfjella**

| Sample | SiO2 | TiO2 | Al2O3 | Fe2O3T | MnO | MgO | CaO | Na2O | K2O | P2O5 | LOI | Total | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **XX1-31** | 64.93 | 0.55 | 16.35 | 5.32 | 0.06 | 0.45 | 3.52 | 3.95 | 3.87 | 0.31 | 0.3 | 99.61 | | | | | | | | | | |
| **XX1-54A** | 66.81 | 0.56 | 14.29 | 5.86 | 0.08 | 0.39 | 2.29 | 3.3 | 5.3 | 0.13 | 0.24 | 99.25 | | | | | | | | | | |
| **XX1-54B** | 65.69 | 0.99 | 13.98 | 6.21 | 0.08 | 0.98 | 3.02 | 3.01 | 4.92 | 0.39 | 0.29 | 99.56 | | | | | | | | | | |
| **XX1-60** | 63.34 | 0.85 | 15.49 | 6.33 | 0.09 | 0.9 | 3.4 | 3.4 | 4.77 | 0.37 | 0.26 | 99.2 | | | | | | | | | | |
| **XX1-62A** | 64.36 | 0.86 | 14.64 | 6.63 | 0.09 | 0.82 | 3.03 | 3.09 | 5.28 | 0.35 | 0.33 | 99.48 | | | | | | | | | | |
| **XX1-62B** | 74.43 | 0.06 | 13.43 | 0.87 | 0.02 | 0.23 | 0.91 | 2.91 | 6.59 | 0.02 | 0.23 | 99.7 | | | | | | | | | | |
| **XX1-64A** | 71.79 | 0.34 | 13.66 | 2.6 | 0.03 | 0.3 | 1.08 | 2.88 | 6.42 | 0.08 | 0.37 | 99.55 | | | | | | | | | | |
| **XX1-65** | 68.21 | 0.53 | 13.97 | 5.03 | 0.07 | 0.39 | 2.45 | 2.86 | 5.6 | 0.16 | 0.06 | 99.33 | | | | | | | | | | |
| **Sample** | **Li** | **Be** | **Sc** | **V** | **Ca** | **Ga** | **Ge** | **Rb** | **Y** | **Cs** | **W** | **Tl** | **Th** | **U** | **Zn** | **Nb** | **Mo** | **Cd** | **Sb** | **Hf** | **Ta** | **Pb** |
| **XX1-31** | 32.6 | 7.02 | 9.17 | 17 | 5.62 | 29.9 | 1.44 | 162 | 81 | 2.64 | 1.57 | 0.88 | 41.7 | 4.97 | 146 | 31.1 | 6.04 | 0.21 | 0.03 | 6.24 | 1.49 | 43.6 |
| **XX1-54A** | 28.1 | 4.53 | 9.5 | 5.28 | 4.43 | 27.3 | 1.6 | 212 | 65.9 | 2.92 | 1.46 | 1.52 | 63.8 | 4.82 | 157 | 38 | 21.8 | 0.19 | 0.08 | 6.23 | 1.78 | 75.1 |
| **XX1-54B** | 28.8 | 3.85 | 11.2 | 33.8 | 8.37 | 27.5 | 1.67 | 176 | 78.8 | 0.86 | 2.34 | 1.11 | 69.1 | 33.3 | 155 | 35.1 | 18.6 | 0.18 | 0.03 | 6.54 | 1.29 | 55.6 |
| **XX1-60** | 27.7 | 4.84 | 10.4 | 27.4 | 7.19 | 36.8 | 1.53 | 175 | 74.9 | 2.29 | 3.05 | 1.17 | 56.7 | 6.73 | 179 | 32.7 | 10.9 | 0.16 | 0.05 | 4.33 | 1.49 | 69 |
| **XX1-62A** | 31 | 4.77 | 13.1 | 23.3 | 7.98 | 27.8 | 1.69 | 198 | 78.4 | 2.67 | 6.94 | 1.34 | 61.9 | 8.08 | 200 | 38.3 | 17.1 | 0.21 | 0.05 | 6.39 | 1.73 | 69.5 |
| **XX1-62B** | 16.7 | 2.36 | 0.23 | 5.19 | 4.58 | 19.3 | 0.98 | 222 | 9.91 | 1.12 | 0.52 | 1.41 | 9.62 | 4.47 | 16.7 | 6.12 | 15.3 | 0.02 | 0.14 | 1.53 | 0.28 | 64.3 |
| **XX1-64A** | 11.6 | 1.56 | 4.89 | 16.5 | 6.49 | 19 | 0.95 | 198 | 11.5 | 0.36 | 0.43 | 1.19 | 37.9 | 1.36 | 79.7 | 12 | 24.2 | 0.03 | 0.05 | 6.01 | 0.49 | 39.6 |
| **XX1-65** | 18 | 3.69 | 11.8 | 11.5 | 6.12 | 28.1 | 1.63 | 177 | 85.3 | 0.63 | 0.47 | 1.07 | 17.6 | 1.94 | 163 | 40.2 | 18.3 | 0.2 | 0.04 | 4.59 | 1.28 | 60.4 |
| **Sample** | **La** | **Ce** | **Pr** | **Nd** | **Eu** | **Sm** | **Tb** | **Gd** | **Dy** | **Ho** | **Er** | **Tm** | **Yb** | **Lu** | | | | | | | | |
| **XX1-31** | 84.7 | 180 | 25.2 | 102 | 3.44 | 22.1 | 2.9 | 18.1 | 15.8 | 3.06 | 7.75 | 1.29 | 7.58 | 1.07 | | | | | | | | |
| **XX1-54A** | 905 | 1739 | 63.8 | 212 | 5.97 | 31.9 | 3.05 | 21.6 | 14.3 | 2.59 | 6.32 | 1 | 5.97 | 0.84 | | | | | | | | |
| **XX1-54B** | 1141 | 2162 | 74.7 | 246 | 5.03 | 36.1 | 3.61 | 25.2 | 17.1 | 3.04 | 7.48 | 1.16 | 6.65 | 0.91 | | | | | | | | |
| **XX1-60** | 968 | 1771 | 61.9 | 207 | 5.93 | 32.7 | 3.24 | 22.5 | 15.8 | 2.91 | 7.11 | 1.14 | 6.66 | 0.91 | | | | | | | | |
| **XX1-62A** | 947 | 1879 | 68.2 | 231 | 6.26 | 36.1 | 3.62 | 25.1 | 17.3 | 3.13 | 7.48 | 1.21 | 7.2 | 1.01 | | | | | | | | |
| **XX1-62B** | 16.9 | 29.8 | 2.72 | 8.83 | 1.19 | 1.85 | 0.19 | 1.14 | 1.19 | 0.25 | 0.69 | 0.12 | 0.75 | 0.11 | | | | | | | | |
| **XX1-64A** | 107 | 220 | 23.3 | 78.9 | 1.62 | 11.8 | 0.86 | 7.36 | 3.15 | 0.48 | 1.03 | 0.15 | 0.92 | 0.14 | | | | | | | | |
| **XX1-65** | 249 | 510 | 50.4 | 199 | 6.71 | 37.3 | 3.96 | 27.6 | 19.9 | 3.6 | 8.44 | 1.3 | 7.34 | 0.99 | | | | | | | | |

Table 2: Major, Trace and Rare Earth element compositions of charnockites of Central Muhlig-Hofmannfjella

| Sample | SiO2 | TiO2 | Al2O3 | Fe2O3T | MnO | MgO | CaO | Na2O | K2O | P2O5 | LOI | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **XX1-1** | 64.48 | 1.57 | 12.57 | 9.95 | 0.13 | 1.25 | 3.24 | 1.61 | 4.05 | 0.47 | 0 | 99.32 |
| **XX1-10** | 68.65 | 0.61 | 15.43 | 3.7 | 0.04 | 0.31 | 2.54 | 2.3 | 5.24 | 0.17 | 0.25 | 99.24 |
| **XX1-14A** | 72.88 | 0.37 | 14.46 | 2.63 | 0.04 | 0.14 | 1.65 | 1.91 | 5.13 | 0.17 | 0.23 | 99.61 |
| **XX1-14B** | 70.58 | 0.39 | 13.77 | 3.57 | 0.06 | 0.47 | 1.68 | 3.1 | 5.76 | 0.1 | 0.25 | 99.73 |
| **XX1-14D** | 62.96 | 1.39 | 14.25 | 7.8 | 0.09 | 1.04 | 3.69 | 2.91 | 4.74 | 0.52 | 0.13 | 99.52 |
| **XX1-19** | 72.73 | 0.29 | 13.75 | 2.3 | 0.03 | 0.33 | 1.3 | 3.07 | 5.54 | 0.08 | 0.35 | 99.77 |
| **XX1-22A** | 65.87 | 0.69 | 15.09 | 5.08 | 0.06 | 0.48 | 2.31 | 3.14 | 6.34 | 0.19 | 0.16 | 99.41 |
| **XX1-24A** | 72.78 | 0.21 | 13.58 | 2.09 | 0.04 | 0.36 | 1.2 | 3.15 | 5.54 | 0.05 | 0.57 | 99.57 |
| **XX1-25** | 66.78 | 0.66 | 14.06 | 5.76 | 0.07 | 0.5 | 2.31 | 3.01 | 5.99 | 0.17 | 0.13 | 99.44 |
| **XX1-5** | 66.51 | 0.68 | 15.68 | 5.19 | 0.05 | 0.81 | 2.94 | 1.98 | 5.03 | 0.29 | 0.21 | 99.37 |
| **XX1-54B** | 65.69 | 0.99 | 13.98 | 6.21 | 0.08 | 0.98 | 3.02 | 3.01 | 4.92 | 0.39 | 0.29 | 99.56 |
| **XX1-9** | 66.62 | 0.66 | 15.43 | 5.63 | 0.05 | 0.49 | 2.72 | 2.36 | 4.8 | 0.27 | 0.21 | 99.24 |
| **XX1-9B** | 73.55 | 0.16 | 13.1 | 1.95 | 0.03 | 0.38 | 1.51 | 2.61 | 5.93 | 0.06 | 0.29 | 99.57 |

| Sample | Li | Be | Sc | V | Co | Ga | Ge | Rb | Y | Cs | W | Tl | Th | U | Zn | Nb | Mo | Cd | Sb | Hf | Ta | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **XX1-1** | 14.8 | 2.54 | 18.2 | 48 | 13.7 | 24 | 2 | 116 | 93.5 | 0.47 | 1.24 | 0.66 | 18.4 | 3.84 | 265 | 36.4 | 15.4 | 0.33 | 0.26 | 4.34 | 0.9 | 30.7 |
| **XX1-10** | 29.8 | 4.29 | 6.92 | 15.1 | 5.74 | 23.8 | 1.16 | 192 | 52.5 | 2.34 | 0.51 | 1.51 | 26.2 | 6.66 | 110 | 23.2 | 13.6 | 0.14 | 0.03 | 6.17 | 1.08 | 45.4 |
| **XX1-14A** | 13.6 | 1.54 | 5.52 | 18.4 | 6.12 | 21.7 | 1.14 | 156 | 23.9 | 0.13 | 0.07 | 0.86 | 51.2 | 2.27 | 88.1 | 18.9 | 14.5 | 0.09 | 0.03 | 7.97 | 0.66 | 34.1 |
| **XX1-14B** | 14.1 | 1.83 | 5.88 | 19.4 | 6.74 | 22.2 | 1.18 | 18 | 25.9 | 0.16 | 0.42 | 0.98 | 23 | 2.44 | 95.2 | 24.1 | 19.5 | 0.12 | 0.04 | 9.11 | 0.66 | 9.91 |
| **XX1-14D** | 13 | 1.92 | 14.2 | 39.7 | 7.23 | 22.8 | 1.3 | 97.4 | 45.5 | 0.36 | 0.26 | 0.49 | 4.69 | 0.76 | 168 | 27 | 9.55 | 0.18 | 0.03 | 1.72 | 1.13 | 29.1 |
| **XX1-19** | 18.2 | 2.02 | 3.97 | 14.2 | 4.26 | 18.8 | 0.94 | 200 | 15.4 | 0.53 | 0.07 | 1.13 | 31.5 | 3.26 | 64.7 | 11.8 | 17.9 | 0.06 | 0.05 | 7.57 | 0.38 | 33.4 |
| **XX1-22A** | 14.4 | 1.97 | 7.91 | 20.3 | 5.39 | 23.1 | 1.19 | 157 | 35.4 | 0.33 | 0.22 | 0.83 | 4.03 | 1.02 | 144 | 28.1 | 7.9 | 0.14 | 0.05 | 2.8 | 0.98 | 34.2 |
| **XX1-24A** | 36.1 | 2.19 | 4.82 | 10.3 | 3.8 | 20.2 | 1.12 | 246 | 20.4 | 1.01 | 0 | 1.55 | 34.2 | 5.83 | 69.5 | 17.8 | 19 | 0.07 | 0.02 | 9.18 | 0.61 | 50.9 |
| **XX1-25** | 14.5 | 2.18 | 10.6 | 11.7 | 5.19 | 24 | 1.38 | 146 | 47 | 0.55 | 1.1 | 0.81 | 28.7 | 3.32 | 131 | 28.8 | 11.5 | 0.17 | 0.04 | 5.17 | 0.95 | 35.6 |

*(Contd.)*

Table 2: Major, Trace and Rare Earth element compositions of charnockites of Central Muhlig-Hofmannfjella (*Contd.*)

| Sample | Li | Be | Sc | V | Co | Ga | Ge | Rb | Y | Cs | W | Tl | Th | U | Zn | Nb | Mo | Cd | Sb | Hf | Ta | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **XX1-5** | 22.8 | 2.92 | 8.46 | 23.1 | 7 | 25.3 | 1.24 | 136 | 43.5 | 1.22 | 1.32 | 0.77 | 12.6 | 3.23 | 142 | 27.4 | 9.39 | 0.17 | 0.05 | 3.69 | 1.05 | 38.5 |
| **XX1-54B** | 28.8 | 3.85 | 11.2 | 33.8 | 8.37 | 27.5 | 1.67 | 176 | 78.8 | 0.86 | 2.34 | 1.11 | 69.1 | 33.3 | 155 | 35.1 | 18.6 | 0.18 | 0.03 | 6.54 | 1.29 | 55.6 |
| **XX1-9** | 14.6 | 2.21 | 7.69 | 18.1 | 7.03 | 23.6 | 1.11 | 103 | 33.2 | 0.44 | 0.33 | 0.52 | 5.71 | 1.4 | 135 | 24.3 | 15.6 | 0.14 | 0.03 | 2.72 | 0.84 | 30.9 |
| **XX1-9B** | 12.4 | 1.32 | 3.88 | 15.8 | 4.62 | 17.7 | 1.1 | 126 | 11.9 | 0.32 | 0 | 0.64 | 1.39 | 1.01 | 49.1 | 5.32 | 10.3 | 0.04 | 0.03 | 2.3 | 0.11 | 30.3 |

| Sample | La | Ce | Pr | Nd | Eu | Sm | Tb | Gd | Dy | Ho | Er | Tm | Yb | Lu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **XX1-1** | 343 | 750 | 52.3 | 207 | 3.53 | 37.6 | 4.26 | 29.8 | 20.8 | 3.8 | 8.9 | 1.35 | 7.6 | 1.06 |
| **XX1-10** | 96.5 | 205 | 20.09 | 74.5 | 4.5 | 14.2 | 1.68 | 10.8 | 8.96 | 1.75 | 4.59 | 0.76 | 4.53 | 0.63 |
| **XX1-14A** | 129 | 250 | 30.7 | 104 | 1.4 | 15.3 | 1.4 | 10.8 | 6.4 | 1.08 | 2.35 | 0.34 | 1.94 | 0.28 |
| **XX1-14B** | 99.3 | 185 | 22.7 | 82.6 | 2.07 | 13.4 | 1.37 | 9.69 | 6.57 | 1.15 | 2.67 | 0.4 | 2.35 | 0.35 |
| **XX1-14D** | 98.6 | 205 | 25.2 | 102 | 4.5 | 19.3 | 2.02 | 14.2 | 10.1 | 1.8 | 4.18 | 0.63 | 3.58 | 0.5 |
| **XX1-19** | 79.7 | 158 | 17.7 | 61.7 | 1.29 | 10.7 | 0.93 | 7.28 | 4.03 | 0.64 | 1.4 | 0.2 | 1.17 | 0.17 |
| **XX1-22A** | 71.9 | 148 | 17.9 | 71.7 | 3.77 | 13.8 | 1.51 | 10.4 | 7.77 | 1.43 | 3.42 | 0.54 | 3.13 | 0.44 |
| **XX1-24A** | 65.9 | 130 | 15.1 | 54.9 | 1.13 | 10.2 | 1.06 | 7.79 | 4.72 | 0.79 | 1.8 | 0.26 | 1.64 | 0.26 |
| **XX1-25** | 143 | 290 | 40.1 | 147 | 3.73 | 23.9 | 2.38 | 17.2 | 11 | 1.93 | 4.53 | 0.69 | 3.94 | 0.57 |
| **XX1-5** | 105 | 218 | 24 | 92.4 | 4.63 | 16.9 | 1.85 | 12.6 | 9.33 | 1.71 | 4.18 | 0.65 | 3.88 | 0.55 |
| **XX1-54B** | 1141 | 2162 | 74.7 | 246 | 5.03 | 36.1 | 3.61 | 25.2 | 17.1 | 3.04 | 7.48 | 1.16 | 6.65 | 0.91 |
| **XX1-9** | 78.2 | 156 | 18.8 | 73.8 | 4.57 | 14.2 | 1.48 | 10.4 | 7.39 | 1.34 | 3.23 | 0.49 | 2.9 | 0.41 |
| **XX1-9B** | 33.2 | 67.5 | 5.45 | 19.9 | 2.06 | 4.03 | 0.46 | 2.99 | 2.49 | 0.48 | 1.21 | 0.2 | 1.28 | 0.19 |

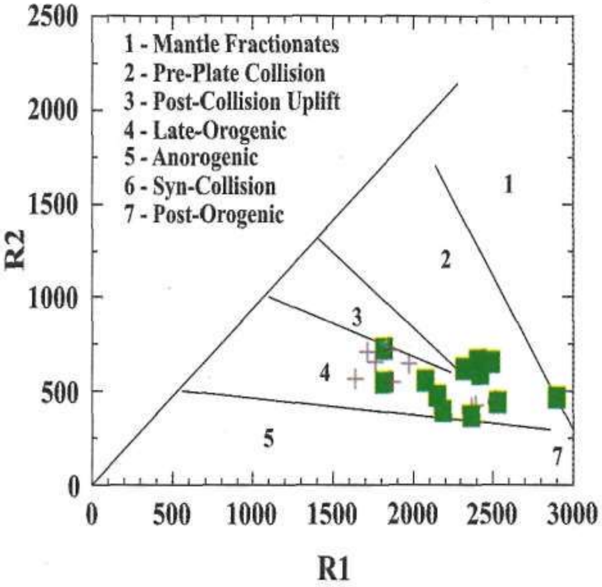

*Fig. 15: R1R2 Diagram of coarse porphyritic granite and coarse porphyritic charnockite indicating their tectonic setting*

and the granite of central Muhlig-Hofmannfjella are co-magmatic and charnockites represent the early crystallized component of the parent magma is a bit far-fetched idea in view of the limited chemical data and absence of clinching geochronological evidence.

## Acknowledgements

The authors are greatly indebted to Sri Rasik Ravindra, Director, Antarctica Division, GSI, Faridabad for encouragement and support. The authors duly acknowledge Sri RP Lal, Leader of XXI IAE for providing logistic facilities and co-operation during the expedition. The work was carried out in the 21st Indian Antarctic Expedition, under the aegis of NCAOR, Goa.

## References

Bachelor, R.A. and Bowden, P. (1985): Petrologic interpretetion of granitoid rock series using multicationic parameters. Chem Geol. 48:43-55.

D'Souza, M.J., Kundu A. and Kaul, M.K. (1996): The geology of Central Dronning Maud Land (cDML), east Antarctica. Ind Min 50: 323-338.

D'Souza, MJ. and Keshava Prasad A. V. (2003): Ferropotassic A-Type granitoids of Miihlig-Hofmannfjella, Central Dronning Maud Land, E. Antarctica: Implication on their genesis (accepted for publication in Volume on 9th Int. Sym. on Antarctic. Earth Science, 2003).

Frost, B.R., Barnes, C.G., Collins, W.J., Arculus, R.J., Ellis, D.J. and Frost, CD. (2001): A geochemical classification for granitic rocks. J Petrol 42:2033-2048.

Jacobs, J., Fanning, CM., Henjes-Kunst R, Olesch, M. and Paech, H.J. (1998): Continuation of the Mozambique Belt into East Antarctica: Grenville-Age metamorphism and polyphase Pan-African high grade events in Central Dronning Maud land. J Geol 106: 385-406.

Joshi, A., Pant, N.C. and Parimoo, M.L. (1991): Granites of Petermann ranges, east Antarctica and implication on their genesis. J Geo Soc Ind 38:169-181.

Kilpatrick, J.A. and Ellis, D.J. (1992): C-type magmas: igneous charnockites and their extrusive equivalents. Trans Royal Soc of Edinburgh. 83:155-164.

Liegeois, J.P. and Black, R. (1987): Alkaline magmatism subsequent to collision in the Pan-African belt of the Adrar des Iforas. In Fitton JG, Upton BGJ (Eds) Alkaline Igneous rocks.Geol Soc, Blackwell, Oxford: 381-401.

Ravich, M.G. and Soloviev, D.S. (1966): Geology and petrology of the mountains of Central Dronning Maud Land (eastern Antarctica). Trans Sci Res Institute of Arctic Geol., Ministry of Geology (translated in Jerusalem, 1969).

Ravindra, R. and Pandit, M.K. (2000): Geochemistry and geochronology of A-type granite from Northern Humboldt Mountains, East Antarctica: Vestige of Pan-African event. J Geol. Soc. Ind 56:253-262.