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Geological Studies in Western Muhlig-Hofmann Mountains, Central Dronning Maud Land, East Antarctica

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Geological Survey of India

INTRODUCTION

In pursuance of its long term program of mapping the entire Wohlthat ranges in cDML, East Antarctica, geological mapping was carried out in the western parts of Muhlig-Hofmann Mountains during the 22nd Indian Antarctic Expedition. About 1000 sq km area bounded by Longitudes 5°00' and 5°45' East and Latitudes 71°45' and 72° 10' South was covered during the austral summer of 2002-03. The study area lies more than 170NM WSW of Maitri station and the fieldwork was carried out using helicopters by taking drop-points in the area.

GEOLOGICAL SETTING

The East Antarctic shield is mostly composed of Precambrian crystalline rocks and has undergone a complex tectono-metamorphic history (Ravich & Kamenev, 1975; Sengupta, 1988; Tingey, 1991; D'Souza et al., 1997). The cDML basically consists of polymetamorphosed metasedimentary rocks represented by garnet-biotite schists, hornblende gneisses, metapelites, calc-silicates etc. These are intruded by various inagmatic units like anorthosite, granodiorite, granite, monzonite, charnockite and other minor instrusives. The deformational record of the region indicates a granulite facies metamorphism (Grenvillian) superimposed by later Pan-African (amphibolite to granulite) event. Record of the earlier Grenvillian event is preserved in the pelitic/ semipelitic schists and mafic granulites. (Jacobs et al., 2003).

The Muhlig-Hofmann Mountains occurring in the western part of cDML are dominated by magmatic phase with large plutons of charnockite, granite and syenite forming the intrusive phase. The country rocks comprise banded gneisses and pelitic/semipelitic schists, which are mainly exposed further southeast in Gjelsvikfjella (Ohta et al., 1990). The central and eastern parts of the Muhlig-Hofmann Mountains expose a suite of undeformed magmatic rocks, mainly chamockite and granite (D'Souza et al., 2004; Prasad and Gaur, 2003). The present area occurs in the western part of Muhlig-Hofmann Mountains. A general geological map is shown in Fig.l. Coarse-grained chamockite (Fig.2a) dominates the northern portion of the area while the central and southern portions expose coarse, poiphyritic granite. Banded gneisses occur in the southwestern part and as enclaves/rafts within the granitoids.

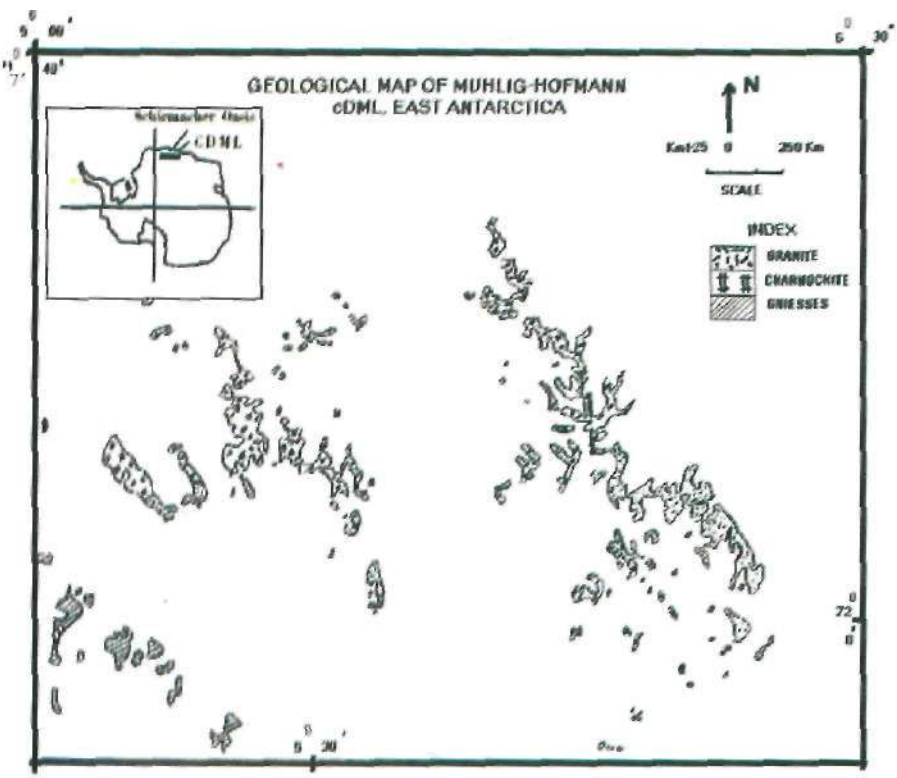
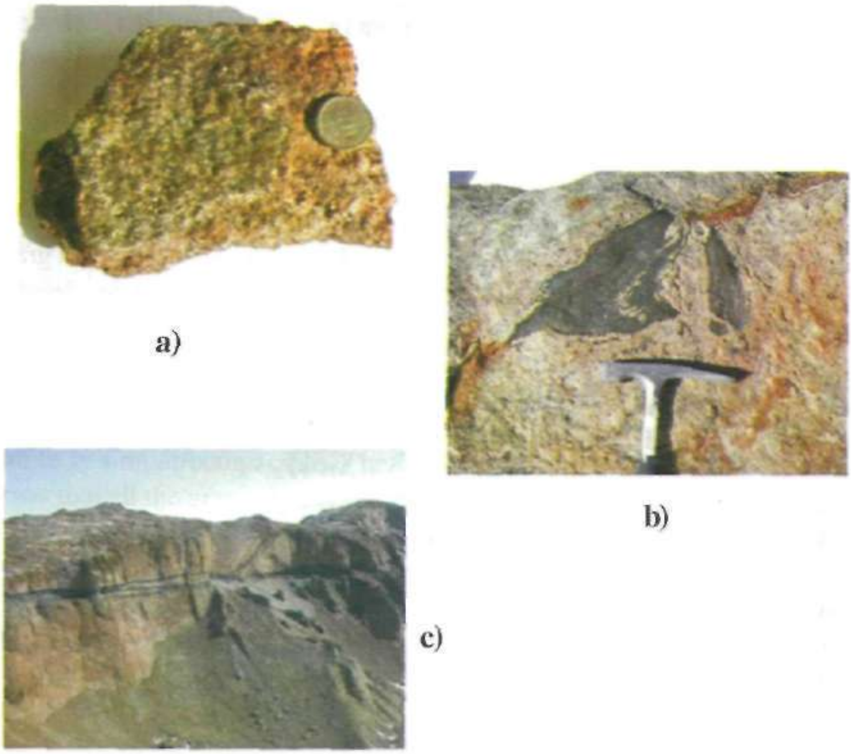


Fig. 1: Geological map of the area

LITHOLOGY

Charnockite

Coarse to medium-grained, massive, porphyritic charnockite occupies the northern part of the present area. It is greasy, brownish in colour and



Fig, 2 : a) Coarse grained chamockite and granite in textural continuity; b) Fragments of older, folded and boudinaged mafic dyke within the gneiss; c) Younger mafic dykes and sills intruding the country gneiss

contains phenocrysts of Kf (>5cm). The charnockite is undeformed and intimately associated spatially with medium-grained pink granite and coarse hbl-granite. Pale coloured irregular patches of granitic composition are often observed within the coarse-grained chamockite. The boundary between the chamockite and granite is marked only by difference in colour but there is no textural difference. The common mineral assemblage in the chamockite is Kf(perthite)+Pl+Opx+Cpx+Qz+Amp+Bt+Opq+Ap+Zr. The phenocrysts of potash feldspar often show exsolved quartz blebs. At places myrmekitic growths are observed indicating slow cooling at high pressure. The plagioclase is antiperthitic in nature and occurs as subhedral to anhedral grains. Opx is often occluded with Fe oxide along cracks and exsolved iron oxide. The amphibole is pseudomorphed after pyroxene. Development of Bt+Qz symplectite around Opx is also observed at places.

Granite

It is brownish to pink to pale in colour, medium to coarse-grained and intimately associated with the charnockite. There is no textural variation between the two rock types except in their colour index. The granite is not uniform at different locations. Some locations visited expose porphyritic granite with megacrysts of Kf (>5cm). At places a phase of pink granite is observed showing sharp boundaries with the normal grey/brownish granite. The granite is intruded by younger, mafic dykes some of which are deformed. At places concentration of mafic restitic material in the country granite is also observed. Petrographic studies indicate following common assemblages:

1. Kf + PI + Qz + Amp + Bt + Ap + Zr.
2. Perthite + Qz + Bt + Ap.
3. Pl+Kf+Qz + Bt + Amp + Opq + Ap+Zr.
4. Kf (perthite) + Qz + Opx + Opq + Ap + Zr.
5. Bt + PI + Kf + Qz +Ap + Aln + Fl.

The Opx occurring within the granite at some locations shows pleochroism from greenish to brown and occurs as very small, restitic grains often altered to Bt/Chl. Myrmekitic growths are commonly observed especially along the contact between Kf and PI. Deformation in the granite is observed in the form of granulation along the boundaries of phenocrystic Kf and undulose extinction in Kf and Qz. The mafic clots/enclaves within the granite show the following assemblage:

PI + Kf + Bt + Opx +Cpx + Amp + Opq + Ap + Zr.

The Kf is perthitic and often encloses subhedral plagioclase grains. Amphibole is often pseudomorphed after Opx and Cpx. At some places Cpx core is observed rimmed by amphibole. Biotite is lath-shaped and seems to be a product of retrogression of mafic minerals.

BANDED GNEISS

Medium-grained banded gneiss is exposed in the southwestern part of the area. The banding is irregular and varies in thickness from a few mm to several cm. At places the gneiss is migmatitic in nature. Fragments and enclaves of this gneiss within granite / charnockite (Fig.2b) indicate that it has been intruded by the latter. The foliations within the gneiss vary from N15°E to N60°W dipping westerly and southerly by variable amounts. At one place (location D-153) a rootless fold with fold axis trending N60°E and plunging moderately towards S, is observed. At places, usually foliation parallel granulitic mafic bands [cm to decimeter scale] are observed within the gneisses. Younger mafic dykes and sills have intruded through the gneiss (Fig.2c).

GEOCHEMISTRY

Whole rock analysis was done using Phillips-XRF at PPOD Laboratory, AMSE Wing, GSI, Bangalore and the trace elements and REE were analyzed at **ICP-MS** at Chemical Laboratory, GSI, Hyderabad. **The results are** presented in Table-1.

The granitoids (charnockite and granite, **all** variations) range in composition from granodiorite to monzonite to syeno-granite as shown by the normative Q-A-P plot (Fig.3). It can be noted from the data that the bulk chemical composition of the coarse, porphyritic charnockite and porphyritic granite is similar/comparable. The TAS diagram [Peacock, 1931] (Fig.4) shows that all the granitoids are calcic in nature. The A-F-M plot (Fig.5) of the rocks shows a highly evolved nature along calc-alkaline trend. Higher degree fractionation is also suggested by the REE Spidergram (Fig.6). The $Si0_2$ content of the charnockite as well as granite varies from 64 wt% to 80 wt%. The banded gneisses show slightly lower $Si0_2$ content and marginally higher $A1_20_3$ and MgO. The Harker plots of various oxides versus $Si0_2$ is presented in Fig.7. These plots indicate that $Ti0_2$, $A1_20_3$, Fe_20_3 and CaO show a negative correlation with SiO, while the alkalis do not show any trend vis-a-vis silica. The gneisses and granites generally have higher Na_20 as compared to the charnockites.

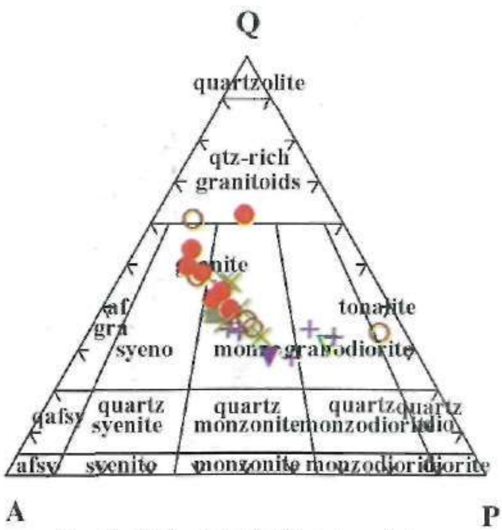


Fig. 3: QAP plot of different rock types

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Sample	101A Pink granite	103A Pink granite	120 Pink granite	133 Pink granite	133A Pink granite	136 Pink granite	137C Pink granite	42A Pink granite	44D Pink granite	44E Pink granite	110A Foliated granite	120B Grey granite	159B Foliated granite	159D Foliated granite	38 White granite	50B Foliated granite	124A Charno ckite	124B Charno ckite
SiO_2	74.32	75.74	74.59	68.66	75.61	77.26	73.15	66.52	59.83	70.74	73.08	77.33	72.83	72.03	67.26	67.88	78.69	80.73
TiO_2	0.19	0.2	0.21	0.41	0.17	0.18	0.35	0.73	0.09	0.27	0.22	0.01	0.09	0.19	0.62	0.65	0.23	0.22
Al_2O_3	13.19	12.77	12.95	15.21	13.22	11.64	13.66	15.2	13.97	14.26	14.27	12.86	15.69	14.89	15.11	13.19	10.6	9.24
Fe_2O_3t	2.05	1.58	2.04	3.94	1.81	1.53	2.9	5.94	9.01	3.81	2.31	0.56	0.82	1.95	5.17	6.62	1.91	2.35
MaO	0.65	0.01	0.02	0.04	0.02	0.02	0.42	0.61	1.05	0.7	0.24	0.01	0.01	0.03	0.07	0.09	0.02	0.03
MgO	0.28	0.09	0.35	0.14	0.41	0.14	0.28	1.89	1.78	0.16	0.14	0.18	0.27	0.45	0.32	0.38	0.24	0.16
CaO	1.04	1.26	1.31	2.47	1.28	0.99	1.33	1.55	4.58	1.59	1.34	0.93	2.23	2.45	2.99	2.68	0.89	1.05
Na_2O	2.11	2.16	2.03	1.98	1.98	2.14	2.64	2.55	1.74	2.24	2.34	2.09	4.08	4.61	1.73	2.16	0.97	1.37
K_2O	5.73	4.77	6.09	5.61	4.94	5.45	4.89	4.55	3.95	5.67	5.66	5.62	3.16	2.44	5.24	5.27	5.55	3.11
P_2O_5	0.18	0.21	0.19	0.27	0.22	0.22	0.22	0.2	0.19	1.43	0.17	0.18	0.14	0.17	0.51	0.33	0.17	0.16
LOI	0.08	0.6	0.07	0.13	0.27	0.35	0.05	0.16	0.24	0.1	0.1	0.17	0.13	0.25	0.5	0	0.58	0.3
Total	**99.82**	**99.39**	**99.85**	**98.86**	**99.93**	**99.92**	**99.87**	**99.89**	**99.67**	**99.71**	**99.88**	**99.9**	**99.48**	**99.46**	**99.52**	**99.25**	**99.85**	**99.17**
A	0.13	0.13	0.13	0.15	0.13	0.11	0.13	0.15	0.14	0.14	0.14	0.13	0.15	0.15	0.15	0.13	0.01	0.09
CNK	0.11	0.11	0.12	0.14	0.11	0.12	0.12	0.12	0.15	0.12	0.12	0.11	0.14	0.14	0.14	0.14	0.09	0.08
NK	0.09	0.09	0.1	0.09	0.08	0.09	0.09	0.09	0.07	0.1	0.1	0.09	0.1	0.08	0.09	0.09	0.07	0.06
A/CNK	1.18	1.18	1.08	1.07	1.18	1	1.08	1.25	0.93	1.17	1.17	1.18	1.07	1.07	1.07	0.93	1.11	1.13
A/NK	1.44	1.44	1.30	1.67	1.63	1.22	1.44	1.67	2.00	1.40	1.40	1.44	1.50	1.50	1.88	1.44	1.43	1.50
Q	38.41	43.84	37.46	32.52	43.31	43.01	37.39	29.96	27.49	33.83	36.07	42.11	32.76	31.25	33.56	32.12	51.3	59.87
or	34.69	29.02	36.85	35.01	29.86	32.88	29.84	28.69	25.84	35.01	34.35	33.52	18.97	14.84	33.03	33.65	33.72	19.06
e	2.04	2.26	1.05	2.06	2.81	0.89	2.08	3.9	1.73	1.98	2.28	1.95	1.88	0.58	0.38	0	1.77	1.27
Diwo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.31	0	0
Diea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.24	0	0
Difs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0
Hyen	0.72	0.23	0.9	0.37	1.05	0.36	0.72	5.04	4.92	0.42	0.36	0.45	0.69	1.16	0.85	0.79	0.62	0.41
Hyfs	0.92	0.02	0.04	0.08	0.04	0.04	0.21	1.21	2.16	0.89	0.09	0	0.02	0.06	0.14	0.14	0.04	0.06
il	0.37	0	0	0	0	0	0.69	0	0	0.54	0.43	0.02	0	0	0	0	0	0
ap	0.4	0.47	0.42	0.62	0.49	0.49	0.45	0.44	3.45	0.39	0.4	0.31	0.38	0.38	1.19	0.78	0.38	0.36

Table -1 (Contd.)

159 charno ckite	41 charno ckite	45A charno ckite	50 charno ckite	50A charno ckite	128A migmat ite	150 augen gneiss	153 banded gneiss	154A banded gneiss	157 banded gneiss	159E gneiss	144D mafic intrusive	144E ultramafic	159C mafic enclave
69.38	65.02	76.27	70.25	74.44	54.19	72.92	7.01	66.12	70.59	69.51	71.91	42.09	63.770
0.96	1.01	0.35	0.7	0.28	1.51	0.59	0.19	1.01	0.53	0.36	0.27	0.74	0.63
12.19	15.26	10.65	12.35	11.8	14.33	11.96	11.49	14.39	13.72	15.58	12.6	11.06	12.52
6.86	6.91	3.36	5.94	3.73	6.46	5.54	1.82	5.52	3.52	3.27	4.31	27.64	6.25
0.08	0.75	0.35	0.06	0.04	0.06	0.63	0.02	0.05	0.03	0.06	0.57	2.56	0.1
0.72	0.44	0.25	0.28	0.07	1.06	1.99	0.74	2.69	1.33	1.15	0.01	1.43	4.3
2.71	3.55	0.91	2.79	1.57	2.61	1.19	0.88	2.86	2.19	4.34	2.02	11.16	5.27
1.19	1.08	1.06	1.11	1.11	3.62	0.36	1.51	2.06	2.45	4.38	1.71	0.01	3.03
4.95	4.85	5.91	5.54	5.48	3.83	4.26	5.78	4.35	4.77	0.81	5.9	2.79	2.22
0.49	0.57	0.18	0.45	0.19	0.72	0.25	0.24	0.49	0.41	0.33	0.2	0.18	0.41
0.24	0	0.55	0.25	0.47	1.49	0.11	0.26	0.29	0.31	0.16	0.33	0.3	0.6
99.77	**99.44**	**99.04**	**99.72**	**99.18**	**99.88**	**99.8**	**99.94**	**99.83**	**99.85**	**99.95**	**99.83**	**99.96**	**99.1**
0.12	0.15	0.1	0.12	0.12	0.14	0.12	0.11	0.14	0.13	0.15	0.12	0.11	0.12
0.12	0.13	0.1	0.13	0.1	0.15	0.07	0.1	0.13	0.13	0.16	0.13	0.23	0.17
0.07	0.07	0.08	0.08	0.08	0.1	0.05	0.09	0.08	0.09	0.08	0.09	0.03	0.07
1	1.15	1	0.92	1.2	0.93	1.71	1.1	1.08	1	0.94	0.92	0.48	0.71
1.71	2.14	1.25	1.50	1.50	1.40	2.40	1.22	1.75	1.44	1.88	1.33	3.67	1.71
40.79	35.36	47.51	39.86	46.31	25.12	52.6	44.66	30.35	33.77	31.84	37.05	20.01	24.93
31.59	31	36.44	35.04	34.13	24.64	26.76	34.94	27.37	29.38	4.96	36.66	22.91	14.23
1.06	3.22	1.28	0.43	1.66	1.11	5.43	1.68	2.26	1.47	0.31	0.14	0	0
0	0	0	0	0	0	0	0	0	0	0	0	10.08	4.42
0	0	0	0	0	0	0	0	0	0	0	0	4.96	3.77
0	0	0	0	0	0	0	0	0	0	0	0	4.91	0.07
1.94	1.19	0.65	0.75	0.18	2.88	5.28	1.89	7.15	3.46	2.98	0.03	0	7.89
0.16	1.51	0.08	0.12	0.08	0.12	0.21	0.04	0.1	0.06	0.12	0.65	0	0.14
0	0	0.69	0	0	0	1.19	0	0	0	0	0.54	1.95	0
1.15	1.34	0.41	1.05	0.44	1.71	0.58	0.54	1.14	0.93	0.75	0.46	0.55	0.97

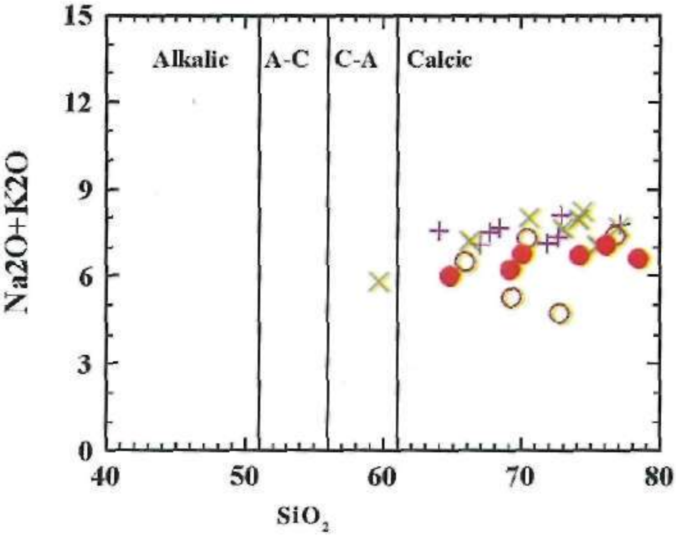


Fig. 4: TAS Plot of the rocks

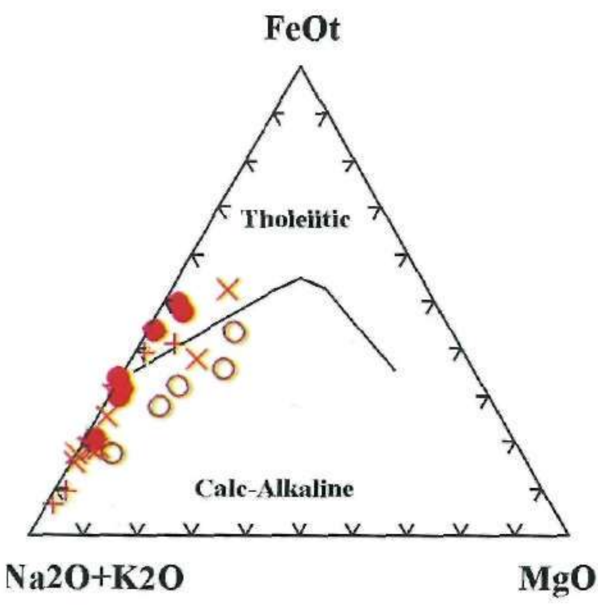


Fig. 5: A-F-M Plot showing an evolved calc-alkaline trend

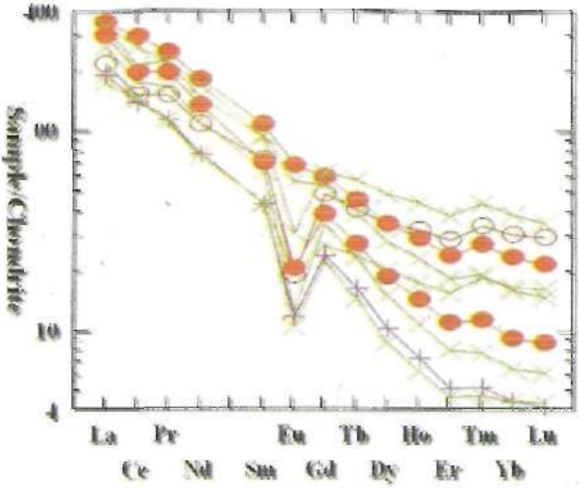


Fig. 6: Spidergram of REE showing a pronounced Eu anomaly

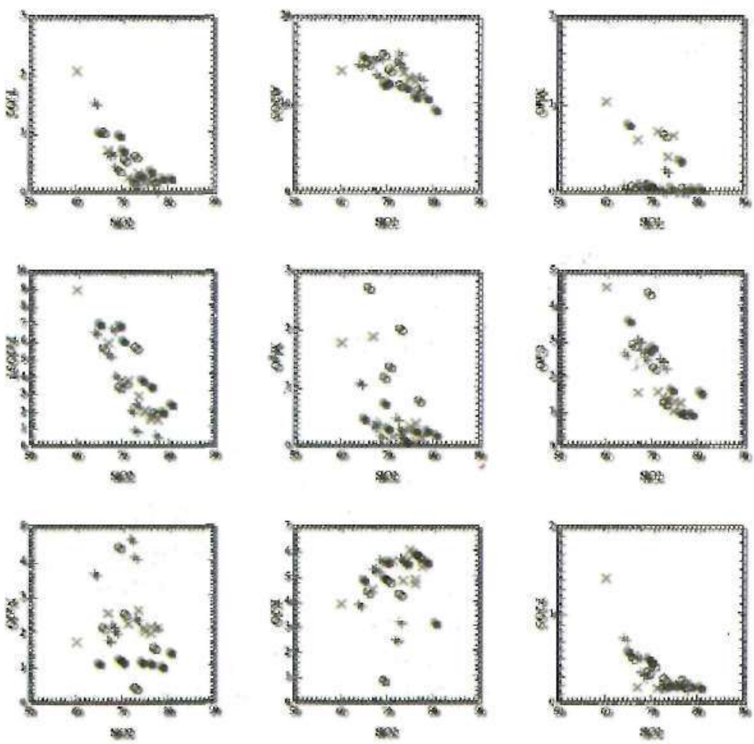


Fig. 7: Harker plots of different major exides versus silica

DISCUSSION

The central Muhlig-Hofmann Mountains are dominated by granite-charnockite magmatism indicative of dominance of plutonic phase. The host rocks to the granitoids i.e. banded gneisses show a polydeformational history as indicated by development of banding and foliation, migmatisation etc. Presence of deformed and fragmented mafic dykes of at least two generations within the gneisses indicates that they have intruded the gneisses prior to the granite, during an earlier deformational episode. Ohta et al. (1990), based on their studies in Gjelsvikfjella, concluded that the Muhlig-Hofmann region shows a two stage igneous-metamorphic history comprising metasupracrustals and chamockite batholith. The undeformed, intrusive nature of the granite and chamockite points towards their late to post-tectonic emplacement. Age of the emplacement of the voluminous charnockite-granite suite as per earlier available dates is ~500Ma (K-Ar whole rock, Ravich and Krylow, 1964). The variation in the grain size in both the chamockite and granite is indicative of the inhomogeneity of conditions within the magmatic chamber. The coarse-grained porphyritic texture as well as development of myrmekitic growths along perthite boundary suggest that these granitoids are hypersolvus and formed due to slow cooling at high temperatures. The predominantly peraluminous nature, strong Eu anomaly and higher silica content of Muhlig-Hofmann granitoids indicate significant contribution of crustal component during their formation. The Harker plots indicate that the chamockite and the granite have similar differentiation pattern. The slight enrichment of Na_20 in the granites may be attributed to alkali metasomatism during their formation. The occurrence of granitic patches and their textural as well as bulk compositional similarity with the chamockite suggest a common parentage. Alternatively, the origin of granite may be the result of late stage hydration of the chamockite. Partial assimilation of granite by chamockite may also produce this kind of association. Such observations were also made by various workers from other parts of Muhlig-Hofmann Mountains (D'Souza et al, 2004; Ohta et al., 1990; Jacobs and Bauer, 2001; Prasad and Gaur, 2003). In the R1-R2 discrimination diagram of Batchelor and Bowden (1985), the Muhlig-Hofmann granitoids plot in the syn-collision field (Fig.8). In the $A1_20_3$ vs $Si0_2$ and the FeO/(FeO+MgO) discrimination diagrams of Maniar and Piccoli (1989), the granites show a clear post-tectonic signature whereas the chamockite exhibits a mixed (post-orogenic and continental epeirogenic uplift) signatures (Figs 9 a & 9b). The granitoids from this part of Muhlig-Hofmann are mostly peraluminous with A/CNK greater than 1.1. Some varieties, however, fall in the metaluminous category (Fig.10). More inputs, particularly in the form of isotopic and geochronological studies, will go a long way to establish the exact nature of relationship between the granite and charnockite of Muhlig-Hofmann area.

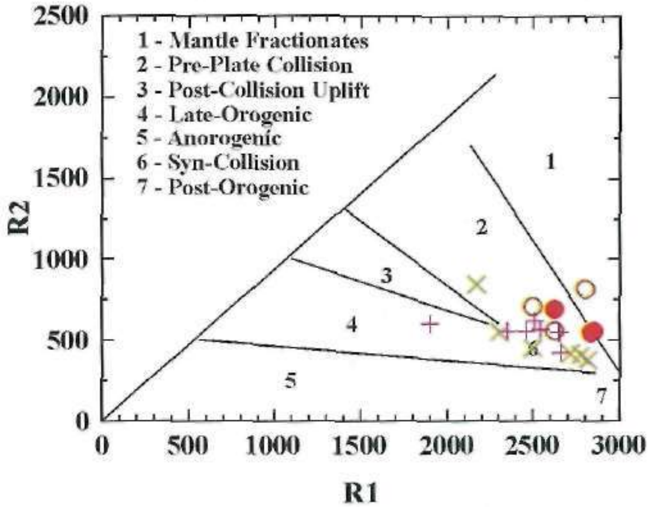
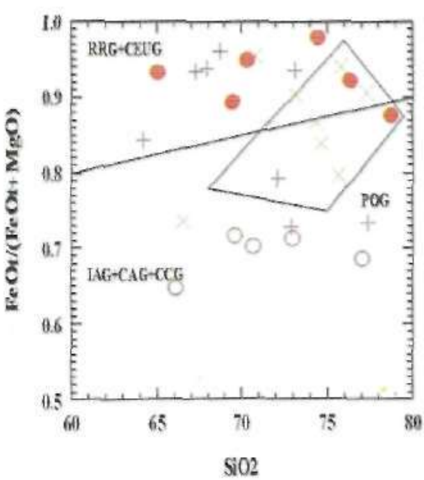


Fig. 8: Most of the granitoids of Muhlig-Hofmann area plot in the syn-collision field in the R1-R2 malticationic discrimination diagram after Batchelor & Bowders (1985)



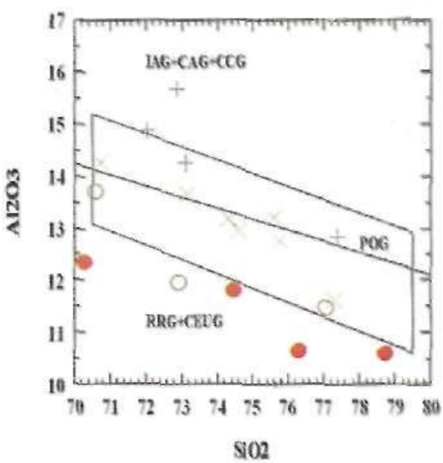


Fig. 9: a) The granitoids of Muhlig-Hofmann area plot in the post-orogenic field in the FeO/FeO+MgO versus SiO2; and b) Al2O3 versus SiO2 discrimination diagrams (after Maniar and Piccoli, 1989)

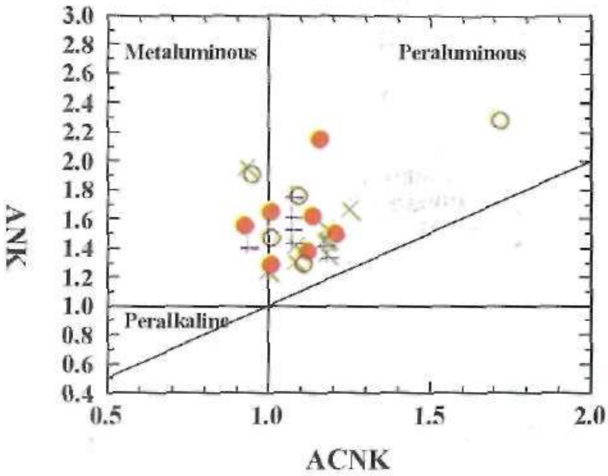


Fig. 10: The rocks plot in the peraluminous and metaluminous fields as shown by the ANK -ACNK plot

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