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Geological, Geochemical, Geochronological and Palaeomagnetic Studies on the Rocks from Parts of East Antarctica

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Abstract

Geological, geochemical, geochronological and palaeomagnetic studies were carried out on some of the rocks from Schirmacher oasis region and Petermann ranges of Dronning Maud Land of East Antarctica. The gneisses from Schirmacher could be broadly divided into three types, namely, garnet - biotite gneiss, augen gneiss and leucogneiss. Preliminary Rb/Sr age data of the garnet biotite gneiss and leucogneiss indicate a Late Proterozoic age for these gneisses. The garnet-biotite gneiss has higher Sr, Ba, V, Cr, Nb, Ta, Ba/Sr and Th/U and lower Rb/Sr compared to the leucogneiss. The REE patterns exhibit a broad negative Eu anomaly. The granites from Petermann ranges show a strong negative Eu anomaly and are enriched in Rb, Sr and Ba. Palaeomagnetic studies of amphibolites from Schirmacher region have indicated either Palaeozoic or Late Precambrian age for these rocks.

Introduction

The Antarctic shield has geological similarities with the Indian shield (Crawford, 1974; Federov *et al.,* 1982). Geological, geochemical, geochronological and geophysical studies of the Antarctic shield have helped in understanding the evolution of Precambrian shield of Gondwanaland and the hypothesis of plate tectonics. Palaeomagnetic studies, in particular, have been useful in reconstructing the precise movements and to decipher the rate of shifting of the continents. The geological set up of Antarctica agrees with the established history of southern hemisphere, which supplies the missing link in the chain of events recorded in India, South America and Australia. However, the new kinematic theory proposed by Storetvedt (1990) challanges the conventional view that the peninsula was part of an alleged Gondwanaland. He *(ibid)* contends that India was palaeogeographically part of Eurasia.

Integrated geoscientific studies, initiated by the scientists of the National Geophysical Research Institute on Antarctic rocks, since the Second Expedition, have yielded a few important results. For example, palaeomagnetic data on the oriented samples of ,gabbros and basalts, collected by the scientists of the institute in the earlier expeditions, have given a virtual geomagnetic pole position and an age of 270-300 Ma. Besides these, geochronological studies on the gneisses from Schirmacher oasis have given an age around 500 Ma (Verma *et al.,* 1987). Geochemical studies on the Petermann I ranges have indicated that the bed rock of these ranges is an alkali-feldspar granite porphyry and quartz-alkali-feldspar-syenite porphyry (Hussain, 1989). With this background; geological, geochemical, geochronological and palaeomagnetic studies were attempted during the Tenth Expedition to Antarctica on rocks from Schirmacher oasis and Petermann ranges to understand the processes related to evolution of the Antarctic continent and the secular compositional variations in the Precambrian lithologies of Antarctica.

Geological Setting

Schirmacher Oasis

The Schirmacher oasis (Lat. 70° 44' 30" - 70° 46' 30" S; Long. 11° 22' -11° 54' E) consists of the Precambrian crystalline basement of the Antarctic platform (Ravich and Kamenev, 1975; Hussain, 1989). Here, granulite and. amphibolite facies rocks are exposed consisting of polymetamorphosed garnet-biotite gneiss (also sillimanite and graphite bearing), augen gneiss, leucogneiss, amphibolite and metabasite. These are traversed by numerous pegmatites, basic sills and younger dolerite dykes. Minor intercalations of calc-silicate rocks are also reported (Grew, 1982; Hussain, 1989).

A number of workers have considered the Schirmacher oasis as belonging to the "East Antarctic Charnockite Province" (Ravich, 1972; Ravich and Kamenev, 1975; Kamenev, 1982). These rocks are related to the Precambrian epoch, when regional metamorphic and ultrametamorphic transformations of rocks near the boundary of granite-basalt layers of the crust were typical (Ravich, 1972). Hence, a precise age determination of these rocks is critical in understanding the relationship of East Antarctica with the other Gondwana areas having charnockite of comparable age and composition.

Petermann Ranges

The Petermann ranges (Lat. 71° 20' - 71° 38'S; Long. 12° 03'-12°50' E) occur in close proximity to the Gruber anorthosite massif in the Wohlthat region of Central Dramming Maud Land of East Antarctica. Based on lithology and tectonic setting, the Wohlthat region has been assigned a Middle Proterozoic age (Grikurov *et al.,* 1972; James and Tingey, 1983). The Petermann ranges occur as three linear belts and are named as Petermann I, II and III from east to west. The predominant rock formation of the Petermann ranges is a coarse grained megacrystic pink granitoid, which forms the high mountains. A grey variety also occurs, somewhat less abundantly, and is seen mostly in the moraines of the valleys. These granites intrude into a polymetamorphic basement and were termed as granosyenites (Ravich and Kamenev, 1975).

Petrography

Gneiss from Schirmacher Oasis

The gneiss from Schirmacher oasis broadly consists of quartz, K-feldspar, plagioclase, perthite, myrmekite, hornblende, biotite, pyrite, magnetite and ilmenite. Based on mineralogy, these gneisses can be broadly divided into garnet-biotite gneiss, augen gneiss and leucogneiss, the latter occurring as small patches in the garnet-biotite gneiss. The garnet-biotite gneiss contains quartz, plagioclase, biotite and garnet with minor amount of hornblende and sometimes hypersthene. The augen gneiss contains quartz and plagioclase augens in a fine grained matrix of quartz, feldspar, biotite and hornblende. The leucogneiss is a light coloured rock with parallel bands of quartz set in a fine grained granoblastic matrix of quartz and feldspar. At places, garnet occurs in minor amounts.

Amphibolite from Schirmacher Oasis

Ambhibolite occurs as veins, dykes, small pockets and lenses within the gneissic country. The trend of these bodies is generally northwesterly, showing sharp or gradational contact with the associated gneiss. Amphibolite contains quartz, hornblende, plagioclase, biotite, sphene, apatite, epidote and opaque ores and exhibits granoblastic texture.

Granite from Petermann Ranges

The granite from Petermann ranges consists of quartz, orthoclase, microperthite, plagioclase and myrmekite; ilmenite, zircon and apatite occur as important accessories. Mafic minerals are comparatively less in abundance, usually represented by hornblende and biotite. The granite exhibits porphyritic texture.

Geochemistry

Gneiss from Schirmacher Oasis

Trace and REE concentrations of garnet-biotite gneiss and leucogneiss have been determined by ICP- MS. Preliminary studies have indicated a higher Sr, Ba, V, Cr, Nb, Ta, Ba/Sr, Th/U and lower Rb/Sr in the garnet-biotite gneiss, compared to the leucogneiss while the other trace elements are more or less in comparable amounts (Table 1). The overall composition of the gneiss from Schirmacher oasis ranges from granodiorite to quartz diorite according to Hussain and Divakara Rao (1993).

Table 1: Trace and REE Concentrations of Gneisses from Schirmacher, East Antarctica

ppm	9	10	11	12	13	14	15	16	Ave.
Rb	139	123	161	121	133	117	126	105	128
Sr	167	150	131	155	168	145	131	193	155
Ba	559	660	741	785	750	717	680	683	697
Cr	22	26	18	17	30	34	20	19	23
V	91	55	81	80	64	69	109	90	80
Th	8	5	7	8	10	10	3	12	8
U	0.4	0.4	0.4	0.3	0.4	0.5	0,4	0.6	0.4
Nb	14.3	12.8	16.3	15,9	15.8	12.3	9.9	12.6	13.7
Ta	0.9	1.0	0.8	0.8	1.1	1.0	0.9	0.9	0.9
La	49.82	45.13	47.44	43.83	49.45	53.85	48.63	47.35	48.18
Ce	93.63	98.84	90.66	100.04	106.90	106.20	86,23	92.33	96.85
Pr	10.47	9.68	10.24	9.55	10.75	10.97	9.15	10.18	10.12
Nd	46.52	48.74	39.55	46.28	50.75	55.20	43.83	46.35	47.15
Sm	9.64	9.40	10.07	10.61	11.16	10.94	8.81	9.27	9.99
Eu	1.96	1.84	1.84	1.75	1.93	2.16	2,13	2,20	' 1.98
Gd	7.94	7.26	7.46	9,74	8.16	8.15	7.14	6.66	7.81
Uy	6.35	5.75	5.76	8.89	6.21	6.78	6.28	5.58	6.45
Er	2.83	3.33	3.36	7.04	3,74	3.47	3.51	2.69	3,75
Yb	2.63	2,71	2.67	5.05	2,63	2.99	2.79	1.90	2.92
Lu	0.29	0.34	0.32	0.71	0.34	0.33	0.35	0.27	0.37
Ratios:									
Ba/Sr	3.35	4.40	5.66	5.06	4.46	4.94	5.19	3.54	4.57
Rb/Sr	0.83	0.82	1.23	0.78	0.79	0.81	0,96	0.54	0.84
Th/U	20.00	12.50	17.50	26.67	25.00	20.00	7.50	20.00	18.65
REE	232.08	233.02	219.37	243.49	252.02	261.04	218.83	224.78	235.58
LREE/HREE	10.48	10.92	10.11	6.69	10.86	10.92	9.80	12.02	10.22
LaN/YbN	11.48	10.09	10.77	5.26	11.39	10.91	10.56	15.10	10.69
CeN/YbN	8.09	8.29	7.72	4.50	9.24	8.07	7.02	11.04	8.00
Eu/Eu	0.69	0.68	0.65	0.53	0.62	0.70	0.83	0.86	0.69

Contd.

Table 1: *Contd..*

ppm	9	10	11	12	13	14	15	16	Ave.
Rb	138	152	204	183	146	101	154	153	154
Sr	76	98	94	73	102	140	116	87	98
Ba	138	118	93	47	64	113	128	148	106
Cr	9	10	10	12	14	12	10	7	11
V	5	7	10	12	24	8	8	8	10
Th	10	4	4	3	8	4	8	5	6
U	2	2	1	2	1	2	2	1	2
Nb	2.8	1.9	3.6	3.4	4.0	2.5	3.7	3.0	3.1
Ta	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
La	8.76	8.16	6.81	5,27	7.52	5.66	5.38	6.51	6.76
Ce	23.96	18.24	16.50	12.90	19.84	15.97	18.56	17.49	17.93
Pr	2.68	2.08	1.96	1.36	2,27	1.59	1.92	1.78	1.95
Nd	10.52	8.34	7.01	5.91	8.60	6.99	8,69	7.52	7.95
Sm	1.82	1.65	1.99	1.45	2.35	1.41	1.65	1.42	1.72
Eu	0,23	0.43	0.27	0.19	0.21	0.22	0.20	0.34	0.26
Gd	2.24	1.99	1.90	1.71	2.18	1.35	1.92	1.55	1.85
Dy	3.03	3.09	3.11	3.13	3.26	1.80	1.92	1.70	2.63
Er	2.18	2.22	1.72	1.94	1,97	1.06	1.07	0.92	1.63
Yb	2.37	2.45	1.97	2.07	2,39	1.28	1.03	0.96	1.81
Lu	0.33	0.41	0.26	0.36	0,34	0.22	0.18	0.13	0.28
Ratios:									
Ba/Sr	1.82	1.20	0.99	0.64	0.63	0.81	1.10	1.70	1.11
Rb/Sr	1.82	1.55	2.17	2.51	1.43	0.72	1.33	1.76	1.66
Th/U	5	2	4	1.50	8	2	4	5	3.94
REE	58.12	49.06	43.50	36.29	50.93	37.55	42.52	40.32	44.79
LREE/HREE	4.70	3.79	3.82	2.92	4.00	5.54	5.91	6.60	4.66
LaN/YbN	2.24	2.02	2.09	1.54	1.91	2.68	3.16	4.11	2.47
Ce_N/Yb_N	2.30	1.70	1.90	1.42	1.89	2.84	4.09	4.14	2.53
Eu/Eu	0.35	0.73	0.43	0.37	0.28	0.49	0.35	0.71	0.46

1-8 Garnet-biotite gneiss; 9-16 Leucogneiss

Table 2 : Major, Trace and REE Concentrations of Granites from Petermann III Area, East Antarctica

Wt. %	1	2	3	4	5	6	7	8	9	Ave.
SiO_2	69.30	74.09	69.23	66.56	69.05	70.21	67.17	69.51	70.13	69.46
TiO_2	0.37	0.22	0.28	0.48	0.71	0.36	0.69	0.42	0.39	0.43
$A1_2O_2$	14.28	14.48	15.12	16.09	12.36	14.87	15.02	15.06	15.22	14.72
Fe_2O_3	4.09	1.93	3.87	5.16	5.50	3.68	5.46	4.12	3.96	4.20
MgO	0.02	0.01	0.02	0.01	0.02	0.04	0.03	0.04	0.03	0.02
MnO	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01
CaO	0.91	1.20	1.80	2.27	2.31	1.92	2.12	2.18	2.24	1.88
Na_2O	2.61	3.31	2.86	3.22	2.84	2.76	2.70	2.92	2.65	2.87
K_2O	6.63	6.26	5.89	6.90	6.33	5.79	5.33	5.89	6.01	6.11
P_2O_5	0.13	0.07	0.07	0.15	0.15	0.11	0.27	0.23	0.14	0.15
Total	98.32	101.56	99.15	100.83	99.27	99.75	98.76	100.38	100.78	
(ppm.)										
Rb	345	330	301	113	162	272	222	329	411	276
Sr	66	76	66	411	294	104	287	91	163	173
Ba	499	518	481	7097	4331	1417	1456	482	491	1863
Cr	8	5	5	5	4	3	7	10	4	6
V	8	8	7	6	12	4	20	26	7	11
Th	130	58	28	21	42	34	61	193	23	65
U	32	7	7	3	4	5	5	29	4	11
Nb	23	15	15	16	20	11	35	43	12	21
Ta	1.0	1.4	2.5	1.4	1.3	0.6	1.4	1.4	0.7	1.3
La	323.96	98.05	49.55	188.95	292.54	208.42	203.32	129.08	22.57	168.49
Ce	686.14	204.24	96.02	324.88	492.16	343.99	407.09	391.35	60.58	334.05
Pr	68.72	21.37	10.11	37.91	53.34	32.53	47.76	50.04	6.62	36.49
Nd	308.51	93.81	46.29	171.08	243.16	132.88	163.06	199.38	29.59	154.19
Sm	45.91	18.16	9.07	26.41	36.65	17.89	25.05	28.77	4.40	23.59
Eu	0.98	0.65	0.68	5.35	3.90	1.65	2.53	1.06	0.90	1.97
Gd	27.10	12.52	6.84	18.48	26.43	14.05	21.51	18.89	3.66	16.61
Dy	16.28	11.92	8.34	16.19	25.30	10.20	16.60	9.55	2.89	13.03
Er	2.78	2.11	1.99	3.19	5.67	2.07	6.57	3.04	1.24	3.18
Yb	3.51	2.96	3.83	5.24	8.30	2.87	4.87	1.62	1.07	3.81
Lu	0.32	0.20	0.25	0.42	0.55	0.27	0.58	0.21	0.16	0.33
(Ratios)										
La_N/Yb_N	55.94	20.08	7.84	21.85	21.36	4.01	25.30	48.29	12.78	26.38
Ce_N/Yb_N	44.43	15.68	5.78	14.09	13.48	27.24	19.00	54.90	12.87	23.04
Eu/Eu*	0.08	0.13	0.74	0.74	0.38	0.32	0.33	0.14	0.69	0.39

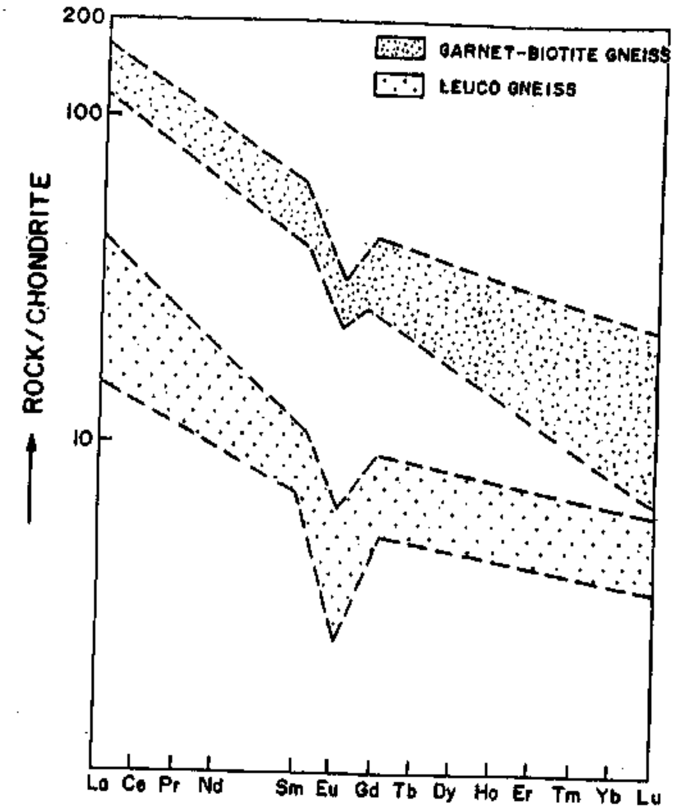

Fig. 1. Chondrite normalised REE pattern of the gneisses from Schirmacher area.

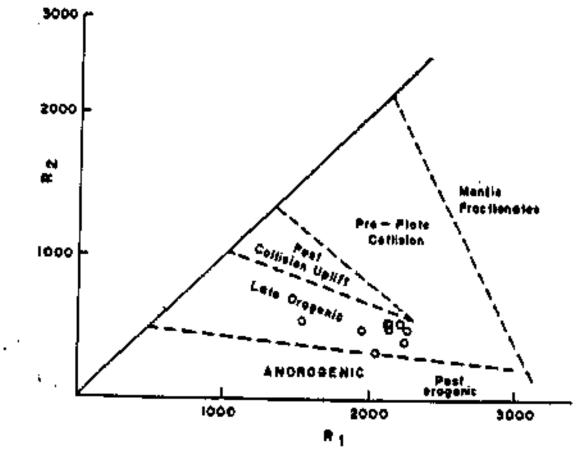

Fig. 2. R_1-R_2 Diagram for the Granites from Petermann - III area.

The REE patterns of these two phases of gneiss (Fig.l) show dissimilar characters in their total REE (garnet-biotite gneiss = 235.58; leucogneiss = 44.79), LREE/HREE (garnet-biotite gneiss = 10.22; leucogneiss = 4.66), La_N / Yb_N (garnet-biotite gneiss = 10.70; leucogneiss = 2.47), Ce_N/Yb_N (garnet-biotite gneiss = 8.00; leucogneiss = 2.53) exhibit a broad negative Eu anomaly (Eu/Eu in garnet-biotite gneiss = 0.69; Eu/Eu in leucogneiss = 0.46).

Preliminary geochronological studies on the garnet-biotite gneiss and leucogneiss by Rb-Sr method have given an age of 853 ± 51 Ma with an initial Sr ratio of 0.70858± 0.0018 for the former and 773+ 26 Ma with an initial Sr ratio of 0.7079± 0.0026 for the leucogneiss indicating a Late Proterozoic age for these gneisses.

Granite of Petermann Ranges

Representative samples from Petermann I and III were analysed for their major, trace and rare earth element concentrations (Table 2). These granites have high K_2O (-6.00%), low CaO (0.91-2.31%) and very low MgO (<0.05). A faint antipathic relationship was observed between SiO_2 and $Ti0_2$, Fe_2O_3 and CaO. The granites, in general, are enriched in Rb, Sr and Ba. All the samples show well fractionated REE patterns as can be seen by the La_N/Yb_N (7.84 - 55.94) and Ce_N/YbN (5,70 - 54.90) ratios and have a strong negative Eu anomaly (Eu/Eu =0.08 - 0.74). Joshi *et al,* (1991), based on their study of the granites from Petermann I and II areas, suggested that they resemble the A-type granites of Loiselle and Wones (1979) while Hussain and Divakara Rao (1992), using the R1-R2 relationship on the lines suggested by Batchelor and Bowden (1985) observed that these granites do not fall in the A- type granite field. The available chemical data when plotted in the R1-R2 relationship diagram of Batchelar and Bowden (1985) do not show the A-type nature of these granites (Fig.2). However, more data are required to establish this aspect.

Palaeomagnetic Studies

Oriented samples of amphibolite were collected from Schirmacher oasis using Sun Compass. Several specimens from the amphibolite were subjected to pilot study involving AF and thermal demagnetization techniques upto peak fields of 100 mT and temperatures of 600°C. Afterwards, 20 to 30 mT AF fields or 400-500°C temperatures were selected for blanket demagnetization and rest of the specimens were demagnetized at these fields or temperatures. The characteristic magnetization vector for each sample was obtained by averaging specimen vectors and for the amphibolites by averaging the sample vectors.

Preliminary results of palaeomagnetic study of amphibolite from Schirmacher area indicate a characteristic component of magnetization with D (Declination) = 147.3° ; I (Inclination) = +38.3°; K (Precision parameter) = 24.24 and α 95 (Radius of circle of confidence) = 10.05° after AF and thermal demagnetization. This direction of magnetization yields a Virtual Geomagnetic Pole (VGP) of either p = 37.2° S and L_P = 152.6° E or λ_P = 5.1°S and L_P = 18.6°W where λ_P= Latitude of pole and Lp =Longitude of pole" depending On either a clockwise or anti-clockwise rotation of Antarctica. This indicates an age of either Palaeozoic (Permian) or Late Precambrian (just below Cambrian) for the amphibolite.

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References

Batchelor, R.A. and Bowden, P. (1985): Petrographic interpretation of granitoid rock series using multicationic parameters. *Chem. Geol.v.48,* pp. 43-55.

Crawford, A.R. (1974): Indo-Antarctica, Gondwanaland and the distortion of granulite belt. *Tectonophysics,* V. 22, pp. 141-157.

Federov, L.V., Ravich, M.G. and Hofmann, J. (1982): Geologic comparison of southern peninsular India and Srjlanka with a part of East Antarctica. In: Antarctic Geoscience (Ed.) C. Craddock, Univ. of Wisconsin Press, Madison, pp. 73-78.

Grew, E.S. (1982): Geology of southern Prince Charles Mountains, East Antarctica. In: Antarctic Geoscience, (Ed.) R.J. Adie, Wisconsin, pp. 479-487.

Grikurov. G.E., Ravich, M.G. and Soloviev, D.S. (1972): Tectonics of Antarctica. In: Antarctic Geology and Geophysics (Ed.) R.J. Adie, Universitetsforlaget, Oslo, pp. 457-468.

Hussian, S.M. (1989): The nature of bedrock at Petermann I, Wohlthat range, Antarctica. *J. Geol. Soc, India,* V. 33, pp. 429- 436.

Hussain, S.M. and Divakara Rao, V. (1992): Granites of Petermann Ranges, East Antarctica and implications of their genesis Comment. *J. Geol. Soc. India,* V. 39, pp. 171-173,

Hussain, S.M. and Divakara Rao, V. (1993): Geochemistry and petrogenesis of metapelites from Schirmacher oasis East Antarctica. 29th Annual Convention, Indian Geophysical Union, Abs. p. 16.

James, P.R. and Tingey, R.J. (1983): The Precambrian geological evolution of the East Antarctica metamorphic shield. In: Antarctic Earth Sciences (Eds.) R.L. Oliver, P. R. James and J.B. Jago. *Aust. acad. Sci., Canberra,* pp. 5-10.

Joshi, A., Pant, N.C. and Parimoo, M.L. (1991): Granites of Petermann Ranges, East Antarctica and implications on their genesis. *J. Geol. Soc. India,* V. 38, pp. 169-181.

Kamenev, E.G. (1982): Regional metamorphism in Antarctica. In: Antarctic Geoscience (Ed.) C, Craddock, Univ. of Wisconsin Press, Madison, pp. 429-433.

Loiselle, M.C. and Wones, D.R. (1979): Characteristics and origin of anorogenic granites. Geol. Soc. Am. 92nd Annu. Meet, Abstracts. *Prog.,* V. 11 (7), pp. 468.

Ravich, M.G. (1972): The Charnockite problem. In: Antarctic Geology and Geophysics (Ed.) R.J. Adie, Oslo, pp. 523 - 526.

Ravich, M.G. and Kamenev, E. (1975): Crystalline basement of the Antarctic platform. John Wiley & Sons, New York, 582 p.

Storetvedt, K.M. (1990): The Tethys Sea and the Alpine Himalayan orogenic belt; mega elements in a new global tectonic system. *Phys. of the Earth and Planet Int.,* V. 62, pp 141-184.

Verma, S.K., Mital, G.S. and Dayal, A.M. (1987): K-Ar dating of some rocks from Schirmacher oasis, Dronning Maud Land, East Antarctica. Fourth Indian Scientific Expedition to Antarctica, Tech. Publ. No.4, Department of Ocean Development, pp. 43-54.