On the Zweissel Granitoids, Central Dronning Maud Land, East Antarctica

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Abstract

The Zweissel area forming the southernmost part of Petermann Ranges cDML, Antarctica, has undergone complex geological history involving several phases of deformation and metamorphism. Locally the area mapped is dominated by gneissic granite with enclosed amphibolitic and granulitic enclaves and a porphyritic undeformed granite .The lithology of the area alongwith adjacent areas is dominated by plutonic component of the crustal ensemble. A tentative lithostratigraphic sequence is worked out on the basis of field association and mutual relationships. A preliminary petrographic studies indicate following mineral assemblages qz + pl + kf + hb + bt accessories ap + zr + ms + op qz + perthite + pi + bt + hb accessories ap + op amph + (cpx) + bt + pl accessories qz + zr amph(hb) + qz + kf accessones ap + zr qz + pl + kf + bt accessories ap + op ± sph qz + pl + kf + bt accessones zi + ap + fl .The mineral paragenesis and monotony in the occurrence of orthogneiss points towards its igneous origin. The strong foliation developed in this unit indicates its syntectonic nature. The medium grained foliated granite is younger and probably genetically related to the country gneiss. It may represent a later more fractionated phase of the same pulse. The undeformed porphyritic granite has been intruded after a considerable time gap in an entirely different tectonic set up .The gneisses show heterogenous geochemical signatures usually with hihgerTiO_2, FeO ,MnO ,CaO, K20 and P_2O5 and depleted in MgO and Na_2 0 as compared to average granite. Generally the REE abundances are high in the granitoids with enrichment in LILE.

Keywords: Gondwanaland, Pan African , orthogneiss , cDML , granite, geochemistry , granitoid

Introduction

The central Dronnmg Maud Land [cDML] has become a centre of attraction recently due to its critical position in the Gondwanaland Supercontinent and the enigmatic role it plays in the early Cambrian Pan African orogeny. This paper describes the geology and geochemistry of the Zweissel granitoids forming the southernmost part of the Petermann ranges comprising the central part of the Wolthat Mountains. An attempt is also made to elucidate its relationship with the break up of Rodinia and assembly of Gondwanaland during the Proterozoic - early Cambrian evolution of this part of the crust.

Regional Geology

Antarctica is divided in to Phanerozoic West Antarctica and Archean-Proterozoic East Antarctica. East Antarctica is mostly composed of Precambrian crystalline rocks which have undergone a complex geological history involving several phases of deformation and related metamorphism and plutonism (Ravich and Kamenev, 1975; Sengupta, 1988; Tingey, 1991). The Wolthat mountains [fig 1, inset] forming the southern portion of the Circum East Antarctic Mobile Belt (CEAMB) of Yoshida, 1995, are divided in to three sectors i) The Gruber massif consisting mostly of anorthosites and related intrusives in the East (Mukerji et al, 1988; Pant et al.1991); ii) Humboldt mountains composed chiefly of ortho and paragneisses with older metamorphic enclaves and younger intrusions in the West (D'Souza et al. 1995,1997); and in) Petermann ranges

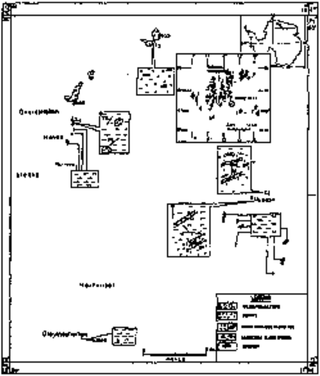

Fig. 1 . *Geological map of the area*

composed chiefly of ortho- and para-gneisses and younger intrusives in the central part (Kaul et al, 1991).

The rocks of the Wolthat mountains record a poly-deformational history where an earlier (Grenvillian) granulite facies metamorphism is superimposed by later (Pan-African) amphibolite facies metamorphism (Sengupta, 1988; Mikhalsky et al. 1997; Ravikant et al. 1997). Record of the Grenvillian 900-1100 Ma event is preserved by pelitic and semipelitic schists and mafic intrusives, which occur as enclaves within the dominant felsic gneisses. The Pan-African 500-540 Ma event is represented by the foliated ortho-and para-gneisses alongwith related mafic to acidic intrusives. Intrusive anorthosite, granitoids and alkaline intrusives form the last phases of plutonic activity.

Geology

The Zweissel area lies in the southernmost parts of the Petermann ranges between lat. 71° 51' to 72° 05' S and long. 12° 05' to 12° 40' E. It comprises of isolated nunataks and peaks near the polar ice cap with an average height of 2700m above msl. The hills have a general NE - SW trend and exhibit subdued topography. It is bound towards East by the Gruber mountains and towards West by the Humboldt mountains. The Payer - Weyprecht mountains are situated about 50km to the Southeast of the area [fig 1].

The dominant lithology of the area is quartzo-feldspathic augen gneiss typically exposed at Gloymdehorten and in the nunataks East of Horteriset. The coarse to medium grained, mesocratic ortho-gneiss usually occurs as smooth rounded outcrops. The compositional bands vary in thickness from place to place so as the concentration of mafics. Development of foliation is quite irregular and at places, migmatitic patches are observed. The trend of the foliation plane, defined by parallel alignment of mafics and k-feldspar augens, varies from N30W-S30E to N50W-S50E. At places 2-5cm long quartz-feldspar clots and dioritic enclaves with or without reaction, runs are observed within this unit. Amphibolite bands/enclaves having sharp contacts with the host rock occur embedded within the country gneiss. These are fine grained in nature and show highly foliated/ thin laminated structure where the mafic bands are separated by thin feldspathic bands. The foliation within the enclave is generally conformable with the regional foliation. In the Gneisskolten-Hovde area, leucogneiss is exposed. The gneissic banding is well developed. The foliation, defined by alternate dark and light bands, varies from NNE-SSW to NE-SW. Feldspar augens are conspicuously absent. The mafic bands are discontinuous and are composed only of biotite.

The country gneiss has been intruded by medium grained foliated granite well exposed at peak-2650 East of Horteriset. The foliation is defined by parallel alignment of mafics and is conformable with the regional foliation. The veins and apophyses of this granite within the coarse augen gneiss indicates its intrusive nature.

There are several generations of quartz and pegmatite veins traversing through augen gneiss and the foliated granite .Some of the pegmatite and quartz veins are highly fractured and folded with axial planes parallel to regional fabric indicating their syn tectonic origin.

A coarse to medium grained, nonfoliated, porphyritic granite occurs in the Gneisskolten-Hovde area intruding within the biotite gneiss. This phase is well exposed in the peak-2835 nunatak towards northeast .This granitoid is undeformed and hence clearly post tectonic in nature. The rock is light to medium in colour with phenocrysts of feldspar embedded in a quartzo-feldspathic matrix. Rarely it consists of clots and patches of mafics Rafts and lenses of ortho-gneiss are randomly distributed within this granite.

On the basis of field association and relationship the stratigraphic succession worked out in the Zweissel area is as follows.

Unit 3	Coarse grained, porphyntic, undeformed granite
Unit 2	Fine to medium grained foliated granite
Unit 1	Hornblende-Biotite gneiss and Biotite leucogneiss with migmatised patches and amphibolite enclaves (orthogneiss)

Petrography

The ortho-gneiss normally shows inequigranular, hypidiomorphic, porphyritic texture.Augens composed of quartz-feldspar are commonly observed on outcrop and hand specimen scale. Typical mineral assemblages observed within the gneisses are

Kf + Qz + PI + Hb + Bt and accessories Ap + Zr + Op
Perthite + Qz + PI + Bt + Hb and accessories Ap + Op
Qz + Perthite + PI + Bt and accessories Zr + Ap + Gt +A11 + - Spl

The amount and concentrations of mafic phases vary greatly within the orthogneiss. The plagioclase is sodic in nature Commonly occurring perthite phenocrysts and .myrmekitic growths (fig 2a,c) indicate slow cooling at depth to allow exsolution reactions to take place K feldspar compnses of both orthoclase and microcline in variable amount. The mafics may or may not show strong preferred orientation on the thin section scale and are composed of biotite and amphibole showing intergrowth texture (fig. 2b) In some sections microfolds/ crenulations defined by the mafics (especially biotite) and relict zircon fragments are discernible. The crenulation axis is at an high angle to the foliation .The

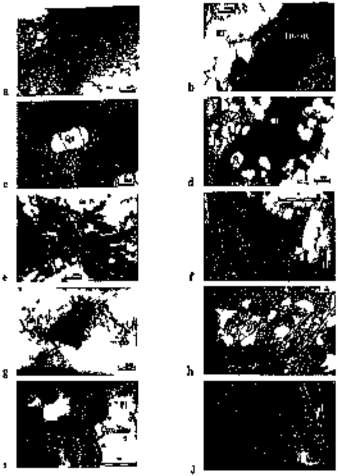

Fig. 2.

a. *Myrmehtic front advancng fiom plagwclase wllun perthite in orthognem BCN*

b. *Amphibole and biohte showing mtergranular texture Typical eaten up texture shown by amphibole (bottom rhs) orthogneiss PPL*

c. *Myrmehte developed between perthite and qmrtz orthognem BCN*

d. *later developed bwtite poikihtikally enclosing early quartz Matrix composed of quartz+feldspar bwtite gneiss PPL*

e. *Subrounded fragmentary reshtic zircon associated with euhedral apatite and subhedral opaques n bwtite rich clots bwtite gneiss PPL*

f. *Euhedral prismatic zircon enclosed within allamte closely associated with bwtite*

g. *Fragmentary reshtit garnet (almandine) with bwtite gneiss PPL embayed margins mthm alkali feldspar bwtite gneiss PPL*

h. *Late stage [retrograde] bwtite laths growing mer amphlbole Note the granJobiaJc texture of amphibole and plagwclase amphibohi enclave PPL*

. *Clinopyroxene rimmed with alteration prodict (FeO + Chl 9) surrounded by plagwclase amphibolite PPL*

} *Vle same mder cwssed mcols*

amphibole is hornblendic in nature and often shows alteration to biotite. In section Z3 the mafics, composed entirely of biotite, often poikilitikally encloses earlier quartz grains indicating its late stage growth (fig. 2d). In some of the thin sections muscovite occurs as small euhedral to subhedral crystals, associated with quartz, K-feldspar and biotite. It shows alteration and its nature is doubtful in the sense that it may be of secondary origin. Zircon, deuteric apatite, allanite and opaques form other accessories (fig .2f). Zircon occurs as fragmentary (restitic) and primary, prismatic, subhedral grains (fig 2e). In two thin sections (Z4A1# & Z4B), rounded and fragmentary garnet (almandine) occurs as an accessory mineral. It usually occurs as inclusions within K-feldspar (perthite) and quartz with little alteration along borders. It may be restitic in origin and represent incompletely digested mineral of the source rock (fig 2g).

The fine to medium grained, intrusive foliated granite shows typical granitic texture and the mineral assemblage is Kf + Qz + PI + Bt + Opq + Zr + Ms. Microcline is predominant and the feldspars are more or less altered to sericite. Feldspar and quartz occur as phenocrysts and are aligned parallel to the foliation plane. Biotite defines two sets of foliation at acute (8° to 25°) angles. Muscovite (primary?) appears as an accessory mineral. This granite appears to be genetically related to the country gneiss. Only biotite as the mafic mineral and predominance of K-feldspar suggest that this granite may be a more fractionated late pulse of same melt. This granite seems to have undergone the same deformational episode as the host country gneiss.

There is close match between modal and normative Q-A-P plots of Zweissel granitoids [fig 3]. The ortho-gneiss plots in the monzo-granite field while the later foliated and undeformed granitoids plot in the syeno-granite

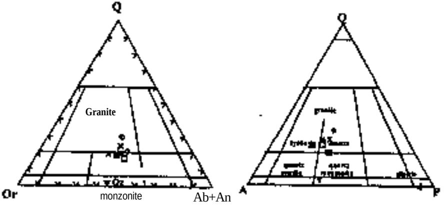

Fig.3. *Model and normative plots of Zweissel granitoids show a close match .Open squares-Hbi-Bt orthogneiss, filled squares-foliated granite, inverted triangle-monzonite enclave, crosses-underformed granite, open diamond-B t gneiss.*

field. The monzonitic enclaves occurring within the hornblende-biotite gneiss are usually oval with longer diameter (10-30cm) parallel to the regional foliation.. These enclaves show varying degrees of reaction with the host rock. Some enclaves have gradational boundaries where as some have sharply defined boundaries. At places a rim of quartzo-feldspathic material envelops the enclaves. In some cases late stage feldspar phenocrysts are observed within the enclaves indicating that the enclaves were not fully solidified during the intrusion of the granitic fluid. Typical mineral paragenesis of these enclaves is PI + Amph + Perthite + Qz + Opq + Ap + Zr + All. The amphiboles appear as anhedral grains with high relief and are usually associated with opaque (magnetite) phases. Such amphiboles are thought to have formed after pyroxenes during the course of crystallisation. .These enclaves may represent an early-crystallised portion of the same melt that could not mix and get digested during the subsequent history of crystallisation.

The fine-grained, mafic enclave within the country granite shows equigranular, subidiomorphic, granuloblastic texture where the mafics exhibit strong preferred orientation. The mineral paragenesis is as follows Amph + PI + Bt + Cpx + Qz + Zr. The pyroxene is altered to amphibole and biotite [fig 2i,j]. Retrogression is indicated by growth of biotite laths, without any preferred orientation, over amphibole [fig 2h]. The amphibole occurs as euhedral to subhedral crystals and is strongly pleochroic in shades of brown. Plagioclase occurs both as subhedral interstitial grains and also as aggregates forming augens aligned parallel to the foliation. The amphibole (hornblende) often shows compositional zoning indicating chemical disequilibrium during their formation. Some of the amphibole may be primary. This may represent a xenolithic enclave indicative of the country rock into which the granite intruded..

The nonfoliated intrusive granite shows intergranular, hypidiomorpic to allotriomorphic, porphyritic textures in thin sections. The commonly observed mineral paragenesis is as follows PI + Kf + Qz + PI + Bt + Ap + Op + Sph + Fl + All. Perthite and hiotite occur as anhedral phenocrysts randomly distributed within a matrix of pl+kf+qz+bt. Perthite often consists of subhedral plagioclase inclusions. Both orthoclase and microcline occur in subequal amounts, usually in the matrix. Myrmekitic growths of quartz along rims of feldspars are common. Accessory fluorite is associated mostly with biotite and plagioclase.

Geochemistry

Major and trace element analyses of representative samples were carried out at the central chemical laboratory, Geological Survey of India, Calcutta. The REE analyses were done by instrumental neutron activation analysis (INAA) technique at chemical laboratory, Geological Survey of India, Pune. The analytical results are presented in Table 1.

Table 1 Major element (wt %) , REE (ppm) analyses, and norms of selected samples, Zweissel area, Central Dronmng Maud Land, E Antarctica

SAMPLE	Quartzo feldspathic gneiss				Average granite	foliated granite	post tectonic granite		Monzon enclave	mafic xenolith	
	XVIII / Z1/A	XVIII / Z2	XVIII / Z4/A1	XVIII / Z4/B	(LeMaitre 1976)	XVIII / Z1/B	XVIII / Z3	XVIII Z4 A2	XV Z2 A	XV Z1 C	XV [illegible]
SiO_2	62 00	63 20	70 50	68 20	71 30	68 10	67 10	68 10	54 40	45 8	[illegible]
TO_2	1 37	1 15	0 30	0 14	0 31	0 14	0 55	0 50	2 23	1 8	[illegible]
Al_2O_3	14 50	13 60	13 60	15 04	14 32	15 00	13 99	14 95	14 18	[illegible]	[illegible]
FeO^T	7 62	7 24	4 08	3 77	2 73	3 67	5 53	3 00	9 40	45	[illegible]
MnO	0 10	0 08	0 06	0 08	0 05	0 04	0 05	0 02	[illegible]	[illegible]	[illegible]
MgO	0 52	0 50	0 15	0 20	0 71	0 20	0 35	0 35	1 40	2 2	
CaO	2 85	2 70	1 65	1 82	1 84	1 64	2 00	1 50	54	[illegible]	3 49
Na_2O	3 51	3 36	3 15	3 99	3 68	3 73	3 23	3 29	2 8	2 22	
K_2O	5 17	5 23	4 98	5 23	4 07	6 18	5 25	6 80	6 30	[illegible]	
P_2O_5	0 80	0 90	0 05	0 05	0 12	0 05	0 10	0 30	1 50	[illegible]	[illegible]
LOI	0 46	0 72	0 52	0 70		0 52	1 02	0 74	0 86	[illegible]	[illegible]
TOTAL	99 05	98 85	99 11	99 36		99 36	99 35	99 56	98 81	98	[illegible]
Ta	2 20	1 00	1 50	1 70		0 80	1 70	1 30	1 40	8	[illegible]
Hf	24 00	14 00	12 00	10 00		12 00	21 00	10 00	15 00	3 10	[illegible]
Ti	1 00	1 00	0 00	0 00		0 00	0 00	0 00	1 00	[illegible]	[illegible]
Th	6 40	7 80	1 80	17 00		163 00	61 00	210 00	2 90	2 40	[illegible]
Cr	8 70	3 00	8 40	130 00		5 70	8 40	15 00	1 90	[illegible]	[illegible]
Ni	25 00	25 00	20 00	20 00		20 00	20 00	20 00	30 00	190 00	[illegible]
Co	8 40	6 50	1 40	1 10		3 50	4 00	1 50	[illegible]	62 0	[illegible]
Sc	15 00	12 00	6 30	5 70		6 00	13 00	7 00	17 00	35 00	[illegible]
Cu	*20 00*	*15 00*	*10 00*	*10 00*		*10 00*	15 00	10 00	[illegible]	[illegible]	[illegible]
Pb	30 00	30 00	35 00	35 00		40 00	50 00	40 00	30 00	35 0	[illegible]
Zn	25 00	120 00	100 00	85 00		90 00	130 00	80 00	170 00	130 00	[illegible]
La	65 00	42 00	80 00	92 00		216 00	284 00	160 00	82 00	[illegible]	[illegible]
Ce	127 00	92 00	160 00	152 00		308 00	466 00	285 00	147 00	26 00	[illegible]
Nd	75 00	52 00	79 00	80 00		110 00	120 00	120 00	75 00	14 00	[illegible]
Sm	18 00	11 00	18 00	20 00		25 00	27 00	28 00	20 00	3 50	3 6
Eu	3 60	2 30	3 30	3 30		1 40	2 50	2 20	2 70	1 10	[illegible]
Tb	2 90	1 40	3 80	3 90		2 50	4 50	5 00	3 00	0 60	0 66
Yb	5 30	3 40	11 00	17 00		2 60	8 00	13 00	7 00	1 90	1 90
Lu	0 75	0 48	1 50	2 50		0 32	1 10	1 60	1 00	0 28	0 28
Q	13 68	16 79	27 35	19 86		17 69	22 02	18 16	0 87	0 00	0 00
C	0 00	0 00	0 02	0 00		0 00	0 00	0 16	0 00	0 00	0 00
OR	30 99	31 49	29 86	31 32		36 95	31 55	40 66	38 01	6 32	[illegible]
AB	30 12	28 97	27 05	34 22		31 93	27 79	28 17	24 27	[illegible]	19 10
AN	8 65	6 69	8 31	7 77		5 99	8 29	5 55	7 61	22 2	22 63
NE	0 00	0 00	0 00	0 00		0 00	0 00	0 00	0 00	7 38	0 00
DI	0 35	0 85	0 00	0 92		1 68	0 99	0 00	8 99	22 07	8 93
HY	9 52	8 37	5 75	3 47		4 08	5 47	5 54	11 40	0 00	11 53
OL	0 00	0 00	0 00	0 00		0 00	0 00	0 00	0 00	24 65	16 90
MT	2 16	2 47	1 07	2 04		1 29	2 58	0 07	0 95	2 84	2 59
IL	2 64	2 23	0 58	0 27		0 27	1 06	0 96	4 32	3 48	3 26
AP	1 77	2 00	0 00	0 11		0 11	0 22	0 66	3 34	0 56	0 67
D I	74 79	77 25	84 26	85 40		86 56	81 36	86 99	63 15	19 23	23 32

The quartzo-feldspathic gneiss forming the country rock in the area is silica saturated but the SiO_2 content (62 to 70.5wt%) is lower than average granite. The hornblende-biotite gneiss is enriched in TiO_2(1.26wt%), FeO' (7.43wt%), MnO(0.09wt%), CaO(5.2wt%), K_2O(5.2wt%), P_2O_5(0.85wt%) and depleted in MgO(0.51wt%) and Na_2O(3.44wt%) as compared to average granite. The biotite gneiss shows marginal depletion in SiO_2(69.35wt%), CaO(1.74wt%) and significantly low MgO(0.18wt%), TiO_2(0.22wt%) and P_2O_5(0.05wt%). The biotite gneiss is closer to average granite in composition and shows substantial depletion in FeOt, MgO and CaO and enrichment in SiO_2 and Na_2O as compared to the hornblende-biotite gneiss. The dioritic enclave is basic in nature(SiO_2wt% = 54.4) with higher FeOt and significantly high CaO(5..54wt%) and MgO(1.4wt%). The amphibolite enclaves [SiO_2 (45.8 to 47.6wt %)] occurring within the hornblende gneiss show low $A1_2O_3$, and K_2O. They show enrichment in FeO^1 , CaO, MgO and TiO_2 and plot in the tholeiite field in the A-F-M diagram (fig 4). They are similar to low-alumina-alkali olivine tholeiites in over all chemical composition.

The foliated granite shows slight increase in SiO_2(68.1wt%) with positive correlation with alumina and alkalis. It is depleted in CaO, FeO and MgO. It shows slightly higher alkali content with *K2O* dominant over NajO. This is indicative of the higher role of fractional crystallisation during their evolution. The post-tectonic granite is silica depleted in comparison with average granite and comparable in over all composition with the ortho-gneiss except slight depletion in $A1_2O_3$ and CaO and slight enrichment in K_2O.

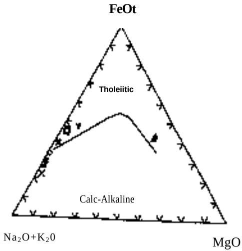

Fig. 4. *A-F-M diagram showing thoelittic affinities of zweissel granitoids, after Irvine and Baragar (1971)*

There is distinct enrichment in alkali content in the foliated granite and the undeformed granite as compared to the gneiss. The granitoids plot in the adamellite field in the K_2O Vs Na_2O diagram reflecting the higher K2O/Na2 0 ratio [fig 5]. All the rock types including the ortho-gneiss, foliated granite, post-tectonic granite and enclaves are distinctly metaluminous in nature [fig 6]. The Zweissel granitoids are calcic in nature as against the alkali-calcic nature of the monzonite enclaves [fig 7]. Harker type variation diagrams of MgO, FeO^1, CaO, TiO_2, P_2O_5 and MnO show linear variation against SiO_2wt%. $A1_2O_3$ and alkalis' do not show any correlation with the SiO_2wt% [fig 8]. The granitoids fall in the subalkaline field in the total alkali Vs SiO_2 discrimination diagram (Irvine and Baragar, 1971).

The salient features of the REE concentrations (normalised w.r.t Chondrite) in various rock types of Zweissel can be seen in the spidergram [fig. 9]. In general the REE abundances are high in the granitoids with enrichment in LILE. Relative concentrations of incompatible elements like REE remain largely unaltered during processes operating after the formation of a rock and their ratio e.g.-La/Yb can be used as an index of differentiation in granitoids. The foliated intrusive granite shows higher La/Yb (~83, Yb=2.6) ratios indicating higher fractionation of this phase as compared to the country gneiss (La/Yb ~12, Yb=4.35). Biotite gneiss has a low La/Yb(~6.34, Yb~14) pointing towards lesser role of fractions during their genesis. The monzonite enclaves have low La/Yb (~11, Yb=7). The granitoid rocks show a well-marked negative Eu anomaly that increases in magnitude from monzonite to gneiss to foliated and undeformed granites indicating progressive depletion (removal) of plagioclase. The enclave samples show REE concentrations more akin to lower crust rather than mantle with a slight enrichment trend in HREE (Lu). The country gneiss shows REE values between lower and upper crustal REE abundances where as the undeformed granite has REE values similar to upper crust.

Geochronology

Most of the DML consists of Grenville age basement rocks comprising ortho- and para-gneisses and associated granitoid suites (Moyes et al, 1993). These have been variably overprinted by a dominantly thermal imprint resetting the isotopic clocks during the Pan-African orogeny at ~500Ma (Groenewald et al. 1991). U-Pb zircon dates of ~570Ma from felsic gneisses in the Humboldt mountains are obtained by Mikhalsky et al, 1995. They also report an age of ~512Ma for post-tectonic syenite in the same region. Ohta et al, 1990 have reported an age of ~500Ma (Rb-Sr whole rock) for undeformed syenite in the western Muhlig-Hoffman mountains. Recently, detailed geochronological studies in cDML were carried out by Jacobs et al, 1998 under the German Geomaud expedition. They have analysed and calculated U-Pb zircon(core and rim) ages of various rock types exposed in the Conradbirge-Dallmanfjella-Humboldt area

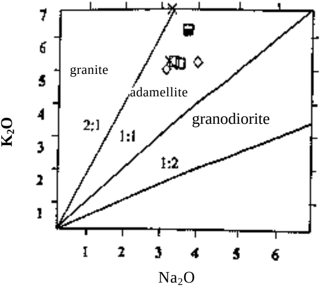

Fig. 5. *Classification based on Na_2O K_2O variation diagram*

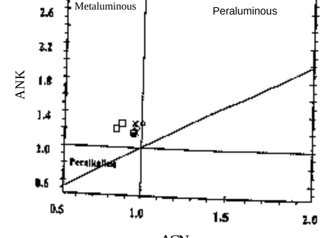

fig. 6. *Classification based on alumina saturation index after Maniar and Piccoli (1989).*

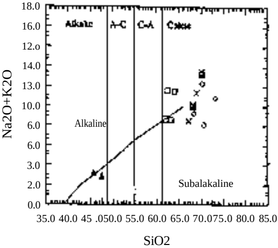

Fig. 7. *Classification based on alumina saturation index after Maniar and Piccoli (1989).*

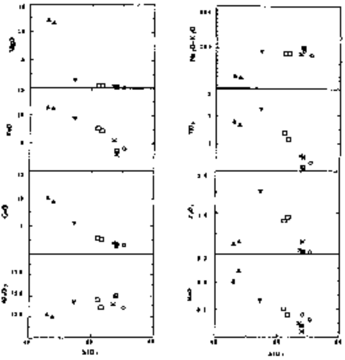

Fig. 8. *Harker variation diagrams for major elements.*

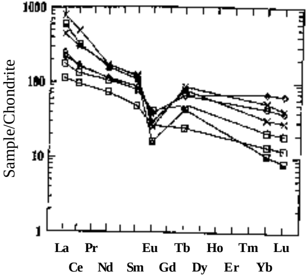

Fig. 9. *Chondrite normalised pattern of Zweissel granitoids [normalising values after Taylor and McLennan (1985)]*

of cDML. These authors report an concordant age of 1086+20Ma for magmatic zircon growth and 570+25Ma for the metamorphic zircon rims from the augen ortho gneiss. This gneiss is quite similar to the Zweissel ortho-gneiss in occurrence and character .They further contend that there are two major stages of deformation and associated metamorphism recorded in the cDML rocks. The older (Grenvillian) occured at ~1100Ma. where as the younger (Pan-African) deformation was episodic and covered a time span of ~585Ma to ~530Ma.

Discussion

The geology of the Zweissel area is dominated by granitoid rocks indicating a plutonic/metamorphic domain during the evolution of this part of Wolthat mountains, CDML .The Zweissel granitoids plot in the monzonite field in the Q -A- P diagram and can be broadly divided in to three types viz: Quartzo feldspathic gneiss (Hbl- Bt gneiss, Bt gneiss), Foliated granite and undeformed, porphyritic granite.

The coarse grained ortho gneiss occuring as a country rock in the area shows granulose to gnessis, inequigranular texture . The mineral paragenesis suggests amphibolite facies conditions during emplacement. Absence of zoning in zircon suggests that major reworking has not taken place.In the FeOt/(FeOt/MgO) vs SiO2 discrimination diagram of Maniar and Piccoli(1989),the granitoids plot in the RRG+CEUG field[fig 10a].However, in their FeOt Vs

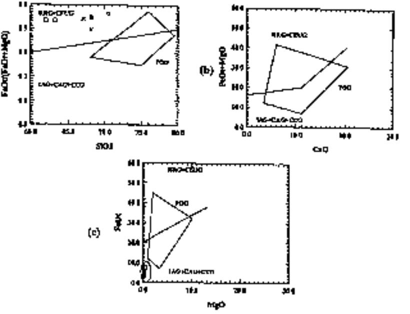

Fig.10 *Tectonic discrimination plots after Maniar and Piccoli, 1989.*

MgO and FeOt+MgO Vs CaO diagrams the rocks indicate IAG + CAG + CCG field [fig 10 b,c]. They have attributed such mixed signatures to complex craton stabilising accretionary processes. The ortho-gneiss shows predominantly I-type characters such as :- i) metaluminous nature, ii) Hornblende in the mafic phase, iii) relatively high Na_2 O, iv) absence of normative corundum, v) igneous (mafic) xenoliths, vi) linearity in variation diagrams, vii) total absence of metasedimentary enclaves. Hornblende is absent from the biotite gneiss and the bulk chemical composition also differs considerably from the hornblende-biotite gneiss suggesting that it may be a distinct granitic pulse. This along with the presence of restitic garnet in this rock unit points towards a garnet rich source rock such as garnet granulite, eclogite or assimilation of crustal contaminants (Sawka, 1990). Granites with-ve Eu anomalies, high concentration of REE and high LREE/HREE ratios require sources with abundant amounts of garnet, amphibole or pyroxene in the source rock (e.g.- quartz-diorite, tonalite, siliceous granulite) [Henderson, 1984]. Hence the Zweissel granitoids may have, in part, evolved from partial to complete reworking of earlier crust.

Subsolvus evolution of the granitic melt giving rise to the Zweissel granitoids is indicated by the presence of predominant perthite, myrmekitic and other exsolution reactions. The higher alkali enrichment with predominance of K over Na points towards crustal origin for the granites. Maniar and Piccoli

(1989) tectonic dicsrimination plots suggest mixed characters indicative of complex cratonisation processes.This is also corroborated with the ternary Th-Ta-Hf/3 ternary diagram [fig .11] where most of the rock types plot in the subduction related field In the Ta Vs Yb discriminatory plot of Pearce et al (1984) the granitoids plot in volcanic arc granitoids and ocean ridge granitoid fields [fig .12].

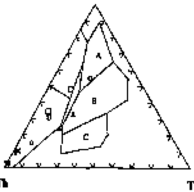

Fig. 11. *Th Ta -Hf /3 diagram after Woods. 1980* .A-n *MORB,,B- eMORB , C- alk WPB, D -Destructive plate margin basalt*.

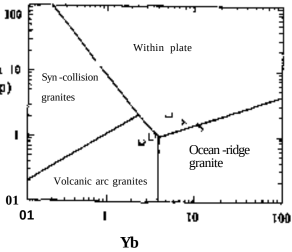

Fig. 12 . *Ta Yb tectonic discrimination plot after Pearce 1984*

The gneissic unit of Zweissel area is comparable in occurrence and character with the foliated, syntectonic granite described in the Skeids area by D'Souza et al (op cit) except for the absence of modal pyroxene in Zweissel gneiss. They assign igneous origin to the Skeids gneiss unit and give a syn-deformational (D2) status with development of strong, pervasive S2 foliation. Bejarniya et al (1993) describe an orlhogneiss unit with similar occurrence and character from the Payer-Weyprecht Mountains which lie to the southeast of the Zweissel area. They have also assigned syn-tectomc origin to their orthogneiss unit and the regional foliation as S2 cleavage, axial planar (to F2) associated with the D2 deformation.

The amphibolite enclaves occurring in this area show ultrabasic characteristics and a distinctly granuloblastic texture. The amphiboles appear to have more or less completely replaced Cpx. It shows tholeiitic evolutionary trend and are low-Al, high-Mg alkali-olivine tholeiites with Fe/Mg ratio varying from 0.93 to 0.96. They have higher concentrations of Ni and Cr indicating mantle affinities. Granulitic and amphibolite enclaves of similar composition have been reported from the Payer mountain orthogneiss by Ravikant et al (1997). They assign pre-Grenvillian age to these enclaves and contend that an earlier granulite facies (Ml/Dl) has been superimposed by amphibolite facies during subsequent deformation (M2/D2). They have also obtained an Rb-Sr whole rock age of 0.75Ga for the Payer orthogneiss and suggest that the Payer orthogneiss unit shows I-type characteristics and are probably emplaced in continental arc,setting associated with the early phases (800-650Ma) of Pan-African teetonothermal rejuvenation affecting cDML.

The fine to medium grained foliated granite shows intrusive relationship with the country gneiss. Absence of amphibole and predominance of k-feldspar in this unit as well as the evolved REE pattern indicate a higher degree of fractionation in comparison with the gneiss. Development of foliation parallel to the legional trend however suggests that this granite is syntectonic in nature and may be genetically related to the gneissic granite. Development of biotite along a foliation at moderate angles to the dominant foliation probably reflects imprint of a later episode of deformation.

The undeformcd granite intrusive is clearly post tectonic in origin. Myrmekitic growths and perthite point towards extended cooling history in an undisturbed environment to allow the exsolution reactions to proceed. High total alkali content reflects syenitic affinity of this unit. Presence of fluorite indicates the highly volatile nature of the magma. These criteria suggest an intracratonic setting and 'A' type nature of the granite.

Summary and Conclusions

From the available data it can be concluded that these granitoids have been emplaced in several stages and contrasting environments during complex cratonisation processes associated with the Grenvillian orogeny .Though the bulk of the ortho- gneiss bears dominantly mantle signatures(I type) a part of the gneisses(especially biotite gneiss) exposed today have resulted from atleast partial reworking of earlier crust during complex orogenic processes associated with the breakup of Rodinia and amalgamation of the Gondwanaland .The linear inter element variation amongst different granitoids suggest that they may be cogenetic with the bulk composition of the monzonite closer to that of the source rock .The mafic enclaves may be of completely different origin as indicated by Harker diagrams of TiO_2 ,$A1_2O_3$,FeO and total alkali. They may represent remnants of the country rock in to which the granitoids intruded as indicated by their chemical / mineralogical composition and nature of occurrence as xenolithic enclaves.

Acknowledgement

The present work is the result of studies earned out during the course of 18 th Indian Antarctic Expedition 1998- 99 .The authors are indebted to Mr. M .K Kaul Director(retd) Antarctica Division GSI, Faridabad for his help and guidance throughout the expedition .The authors extend there sincere thanks to NCAOR[DOD] Goa for providing logistic support during the above studies. We are thankful to Mr Rasik Ravindra Director and other colleagues from the Antarctica Div. For their encouragement and technical support throughout the write up of the present paper.

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