Eighteenth Indian Expedition to Antarctica, Scientific Report, 2002
Department of Ocean Development. Technical Publication No.17. pp 109-134

GEOLOGY AND GEOCHEMISTRY OF THE ZWEISSKL AREA, CENTRAL DRONNING MAUD LAND, EAST ANTARCTCA

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Abstract

The southern most part of the Zweissel area is dominated by granitoid rocks indicating a plutonic/metamorphic domain during the evolution of this part of Wohlthat Mountains in Central Dronning Maud Land. On the basis of Held and petrographic studies, these granitoids are divided in to three types viz. Quartzo-felspathic gneiss (Hbl-Bio gneiss), foliated granite and undeformed porphyritic granite. These granitoids have been emplaced in several stages and contrasting environments during complex cratonisation process associated with the Pan-African orogeny.

INTRODUCTION

The central Dronning Maud Land [cDMLJ occupies the centre stage due to its critical position in the reconstruction of Gondwanaland Supercontinent and the enigmatic role it plays in the early Cambrian Pan-African orogeny.

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 (Grew. 1978: Tingey.1991: Sengupta.1988: Ravich and Kamenev.1975). The Wohlthat mountains occurring in southern part of the Circum East Antarctic Mobile Belt (CEAMB) of Yoshida. 1995, is divided in to three sectors i) The Gruber massif consisting mostly of anorthosites and related intrusives in the Hast (Mukerji et al. 1988; Pant et al. 1991): ii) Humboldt mountains composed chiefly of ortho- and para-gneisses with older metamorphic enclaves and younger intrusions in the West (D'Soua et al.1995,1997); and iii) Perermann ranges composed chiefly of ortho- and para-gneisses and younger intrusives in the central part (Kaul et al. 1991: Pant et al,199|).

The rocks of the Wohlthat mountains record a poly-deformational history where an earlier(Grenvillian) granulite facies metamorphism is superimposed by later (Pan-African) amphibolitc lacies metamorphism (Sengupta. 1988.93: D'Souza etal. 1995: Mikhalsky et al. 1997: Kavikant et al. 1997). Pelitic and semipelitic schists and mafic intrusives that occur as enclaves within the dominant felsic gneisses preserve record of the Grenvillian 900-1100 Ma event. The Pan-African 500-540 Ma event is represented by the foliated ortho- and para-gneisses along with related malic to acidic intrusives. Intrusive anorthosite. granitoids and alkaline intrusives form the last phases of plutonic activity.

GEOLOGY

The Zweissel area occurs in the southernmost parts of the Pctermann ranges between at. $71^0 51'$ to $72^0 05''$ S and long. 12°05' to $12^0 40'$E. It comprises of isolated nunataks and peaks near the polar ice cap with an average height of 2700 m 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 50 km to the Southeast ofthe area (Fig la.b).

The dominant lithology of the area is quartzo-feldspathic gneiss. At Oloymdehorten and in the nunataks East of Hortenset mafic rich granitic gneiss is exposed. The rock is coarse to medium grained and mesocratic. The compositional bands vary in thickness from place to place alongwith concentration of malics. Development of foliation is quite irregular and at places migmatitic patches are also observed. The trend of the foliation plane, defined by parallel alignment ol'mafics. varies from N30W-S30E to N50W-S50E. Augens of K-feldspar are also aligned parallel to the foliation plane. At places 2-5 cm long quartz-feldspar clots and dioritic enclaves with or without reaction rims with the surrounding rock are observed within this unit (Fig 2). Amphiboiite bands/enclaves having sharp contacts with the host rock occur embedded within the country gneiss (Zl). These are fine grained in nature and show highly foliated, thin laminated structure where the mafic bands arc 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 arc conspicuously absent. The malic bands are discontinuous and are composed only of biotite.

The country gneiss has been intruded by a medium grained foliated granite well exposed at peak-2650 Hast 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 country granite-gneiss indicate its intrusive nature.

There are several generations of quartz and pegmatite veins traversing through the country rock (gneiss) and the foliated granite. Some of the pegmatite and quartz veins arc highly fractured and folded with axial planes parallel to regional fabric indicating their pre- to 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 granite is undeformed and hence clearly post-tectonic in nature. The rock is light to medium in colour with phenocrysts of feldspar embedded in a quartzofeldspathic matrix. It rarely consists of clots and patches of mafics. Rafts and lenses of the country gneiss are randomly distributed within this granite.On the basis of field association and relationship the strati graphic succession tentatively worked out in the Zweissel area is as follows:

Unit 3	Coarse grained, porphyritic, undeformed granite
Unit 2	Fine to medium grained foliated granite
Unit 1	Quartzo-felspathic gnosis, Hornblende-Biotite Gnesis and Biotite leucognesis with migmatised Patches and amphibolite enclaves

PETROGRAPHY

There is a close match between modal and normative Q-A-P plots of Zweissel granitoids. The ortho-gneiss plots in the monzo-granite field while the later foliated and undeformed granitoids plot in the syeno-granite field. Under microscope the country gneiss 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 granite are

Kf + Qz + Pl + Hb + Bt and accessories Ap + Zr + Op
Perthite + Qz + Pl + Bt + Hb and accessories Ap + Op
Qz + Perthite + P1 + Bt and accessories Zr + Ap + Gt +A11 (Allanite) ± Spl

The plagioclase is sodic in nature. Commonly occurring perthite phenocrysts and myrmekitic growths indicate slow cooling at depth to allow exsohution reactions to take place (Fig 3a). K-feldspar comprises 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 textures (Fig 3b). In some sections microfolds/crenulations defined by the mafics (especially biotite) and relict zircon fragments are discernible. The fold axis is at an angle to the foliation. The amphibole is hornblendic in nature and often shows alteration to biotite. 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 and opaques form other accessories. Zircon occurs both as fragmentary (restitic) and primary, prismatic, subhedral grains (Fig 3c). In (wo thin sections (Z4A1# & Z4B). rounded and fragmentary garnet (almandine) occurs as an accessory mineral (Fig 3d). It usually occurs as inclusions witliin K-leldspar (pertliite) and quartz witli little alteration along borders. It may be restitic in origin and may represent incompletely digested ' mineral of the source rock.

The fine to medium grained, intrusive foliated granite shows typical granitic texture. The mineral assemblage is Kf + Qz + P1 + Bt + Opq + Zr + Ms. Microcline is predominant and the feldspars are more or less altered to sericile. Feldspar and quartz occur as phenocrysts and are aligned parallel to the foliation plane. Biotite defines two sets of foliations at acute angles (8^0 to25^0). Muscovite (primary?) appears as an accessory mineral. This granite appears to be genetically related to the country gneiss. That it may be a more fractionated late pulse of same melt is suggested by the presence of biotite as the only mafic mineral. This granite seems to have undergone the same deformational episode as the host country gneiss.

Dioritic enclaves occurring within the homblende-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, In some cases a rim of quartzo-feldspathic material envelopes the enclaves while in other late stage feldspar phenocrysts have been observed within the enclaves indicating that the enclaves were not fully solidified during the intrusion of the granitic fluid. The mineral pangenesis of these enclaves is P1 + Amp+Perthite + Qz + Opq + Ap + Zr + All. The rocks plot in the monzonite field on the Q-A-P diagram (Fig. 12). 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 which could not mix and get digested during the subsequent history of crystallisation.

The fine-grained, mafic enclave within the country granite shows equigranular, subidiomorphic texture where the mafics exhibit strong preferred orientation. The mineral paragenesis is as follows Amp + Pl + Bt + Cpx + Qz + Zr. The pyroxene is altered to amphibole and biotite (Fig 3e). The amphibole occurs as euhedral to subhedral crystals and is strongly pleochroic in shades of brown. Plagioclase occurs as subhedral intersutial grains and also as aggregates forming augens aligned parallel to the foliation. Clinopyoxencs occur as clear, angdrak grains within a matrix of plagioclase and biotite/

altered amphibole (Fig 3f, 3g). 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 pangenesis is as follows Pl + Kf + Qz + + Bt + Ap + Op + Sph + Fl + All. Perthite and biotite 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. One thin section [Z4A2] shows anhedral crystals offluorite associated mostly with biotite and plagioclase (Fig 3h).

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.

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 homblende-biotite gneiss is enriched in TiO_2 (1.26wt%), FeO'(7.43wt%), MnO (0.09wt%), CaO (5.2wt%), K_2O (5.2wt%), P,0, (0.85wt%) and depleted in MgO (0.51wt%) and NaO (3.44wt%) as compared to average granite, The biotite gneiss shows marginal depletion in SiO, (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 FeO^t, MgO and CaO and enrichment in SiO, and Na_2O as compared to the homblende-biotite gneiss. The dioritic enclave is basic in nature (SiO,wt%=54.4) with higher FeO' and significantly high CaO(5.54wt%) and MgO(1.4wt%). The mafic [SiO_2(45.8 to 47.6wt%)] enclaves occurring within die hornblende gneiss show low Al_2O_3, and K_2O. They show enrichment in FeO^t, CaO, MgO and TiO_2 and plot in the tholeiite field of Irvine and Baragar, 1971, in the A-F-M diagram. They are chemically similar to low-alumina-alkali olivine tholeiites.

The foliated granite shows slight increase in SiO, (68.1wt%) with positive correlation with alumina and alkalis. It is depleted in CaO, FeO and MgO. It shows slightly higher alkali content with K_2O dominant over Na_2O. 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 composition with the gneiss except that it is having slight depletion in Al_2O_3 and CaO and slight enrichment in K_2O.

There is distinct alkali enrichment in the foliated granite and the undeformed granite as compared to the gneiss. The granitoids plot in the adamelllte field in the K_2O Vs Na_3O diagram (Fig 4) reflecting the higher K_2O/Na_2O ratio. All the rock types including the gneiss, foliated granite, post-tectonic granite and enclaves are distinctly metaluminous in nature (Fig 5). The Zweissel granitoids are calcic in nature as against the alkali-calcic nature of the monzonite enclaves. The granitoids fall in the subalkaline field in the total alkali Vs SiO_2 (Irvine and Baragar, 1971) discrimination diagram (Fig 6). Harker type variation diagrams of MgO, FeO', CaO, TiO_2, P_2O_5 and MnO show linear variation against SiO_2 vt%. $A1_2O_3$ and alkalis do not show any correlation with the SiO_2 wt% (Fig7).

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 8). 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 offractions during their genesis. The monzonite enclaves have low La/Yb (~11, Yb = 7). The granitoid rocks show a well marked negative Eu anomaly which 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.

DISSCUSSION

The geology of the Zweissel area is dominated by granitoid rocks indicating a plutonic/metamorphic domain during the evolution of this part of Wohlthat Mountains, CDML. On the basis of field and petrographic criteria these granitoids can be divided in to three types viz.: Quartzo-felspathic gneiss (Hbl-Bt gneiss, Bt-gneiss), Foliated granite and undeformed. porphyritic granite.

The coarse grained hornblende-biotite gneiss occurring as the country rock shows granulose to gneissic. 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 $FeO^{t}/(FeOt+MgO)$ Vs SiO_2 discrimination diagram of Maniar and Piccoli (1989), the granitoids plot in the RRG + CEUG field (Fig 9a). But in their FeO^{t} Vs MgO and FeOt + MgO Vs CaO diagrams the rocks indicate IAG + CAG + CCG field (Fig 9b, 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_2O, iv) absence of normative corundum, v) igneous (mafic) xenoliths vi) linearity in variation diagrams and 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 unit. This alongwith 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 negative 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 (eg- 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 of the granites. Maniar and Piccoli's (op cit.) tectonic discrimination plots suggest mixed characters indicative of complex cratonisation processes. The ternary Th-Ta-Hf/3 ternary diagram (Fig 10) also corroborates this 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 11). In the R1-R2 multi-element discrimination diagram of Batchelor and Bowden (1985), the Zweissel granitoids plot in the late orogenic field with syn-collision affinities of the biotite gneisses.

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 el 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 (op cit) describe an orthogneiss 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-tectonic origin to this orthogneiss unit and describe 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 clinopyroxene. These show 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 by Ravikant et al (1997). They assign pre-Grenvillian age to these enclaves and contend that an earlier granulite facies (M1/D1) has been superimposed by amphibolite facies during subsequent deformation (M2/D2). Ravikant et al (opcit) 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 tectonothermal rejuvenation affecting CDML. They have obtained an Rb-Sr whole rock age of 0.75Ga for the Payer orthogneiss.

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 regional 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 undeformed 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. Presence of late stage, undeformed granites and syenites is wide spread in CDML.

Conclusion

It is thus proposed that these granitoids have been emplaced in several stages and contrasting environments during complex cratonisation processes associated with the Pan-African orogeny. A part of the gneisses exposed today have resulted from extensive 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 oogenetic 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 Barker diagrams of TiO_2, AL_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 authors are thankful to the Director General, Geological Survey of India for permission to participate in the expedition. We express our sincere gratitude towards Shri MK Kaul and R. Ravindra, the then and the present Directors, Antarctica Division, for their guidance and supervision. Shri Ajay Dhar, Leader of the Expedition is thankfully acknowledged for his ever-willing support in execution of the work. The co-operation received from the fellow members during the course of field work is very much appreciated.

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	Quartzo-feldspathic gneiss				Average granite	foliated granite	post-tectonic granite		dioritic mafic enclave enclave		
SAMPLE FeO^T	XVIII / Z1/A	XVIII / Z2	XVIII / ZA/A1	XVIII / Z4/B	(LeMaitre ,1976)	XVIII / ZA/B	XVIII/Z3	XVIII / ZA/A2	XVIII / Z2/A	XVIII / Z1/C	XVIII / Z1/C2
SiO_2	62.00	63.20	70.50	68.20	71.30	68.10	67.10	68.10	54.40	45.80	47.60
TIO_2	1.37	1.15	0.30	014	031	0.14	0.55	0.50	223	1.80	1.68
Al_2	14.50	13.60	13.60	15.04	14.32	15.00	13.99	14.95	14.18	12.80	12.52
FeO^T	7.62	7.24	4.08	377	2.73	3.67	5.53	3.00	9.40	11.45	1129
MnO	0.10	0.08	0.06	0,08	045	0.04	0.05	042	0.13	020	024
MgO	0.52	0.50	0.15	0.20	071	020	0.35	0.35	1.40	1220	1171
CaO	2.85	270	1.65	1.82	1.84	1.64	2.00	150	5.54	10.15	9.49
Na_20	3.51	3.3G	3.15	3.99	368	3.73	3.23	3.29	241	222	221
K_20	5.17	523	4.68	5.23	447	6.18	525	6.80	6.30	1.05	070
$P_2{}^O5$	0.80	0.90	0,05	0.05	012	0.05	0.10	0.30	1.50	025	0,30
LOI	0.46	072	0.52	0.70		0.52	142	074	0.86	0.60	066
TOTAL	99.05	98.85	99.11	99.36		89.36	99.35	99.56	98.81	9871	98.58
Ta	2.20	1.00	1.50	170		0.80	170	1.30	1.40	0.80	070
Hf	24.40	14.00	12.00	1040		1240	21.00	10.00	15.00	3.10	3.10
Ti	1.00	1.00	000	040		0.00	0.00	040	140	1.00	140
Th	6.40	7.80	1.80	1740		163.00	6140	21040	2.90	2.40	1.40
Cr	870	3.00	8.40	13040		570	8.40	1540	140	70540	65040
Ni	25.00	25.00	20.00	2040		20.00	20.00	2040	3040	19040	19040
Co	8.40	6.50	1.40	1.10		3.50	440	1.50	12.00	62.00	62.00
So	15.00	12.00	6.30	570		6.00	13.00	7,00	17.00	3540	36.00
Cu	20.00	15.00	10.00	10.00		10.00	1540	1040	25.00	2040	1540
Pb	30.00	30.00	35.00	35.00		4040	50.00	4040	3040	35.00	3540
Zn	25.00	120.00	10040	8540		90.00	130.00	80.00	17040	130.00	11040
La	65.00	42.00	80.00	9240		216.00	284.40	160.00	8240	1440	1240
Ce	127.00	92.00	160.00	15240		308.00	466,00	285.00	14740	26.00	2540
Nd	75.00	52.00	79.00	80.00		11040	12040	120.00	75.00	1440	1340
Sm	18.00	11.00	18.00	20,00		2540	27.00	2840	20.00	3.50	3.60
Eu	3.60	230	3.30	3.30		1.40	2.50	220	270	110	120
Tb	2.90	1.40	3.80	3.90		2.50	4.50	5.00	3.00	0.60	0.66
Yb	530	3.40	11.00	1740		2.60	8.00	1340	7.00	1.90	190
Lu	075	0.48	1.50	2.50		032	1.10	1.60	100	0.28	0.28

Q	13.68	16.79	27.35	19.86		17.69	22.02	18.16	087	0.00	0.00
C	0.00	0.00	0.02	0.00		0.00	0.00	0.16	000	0.00	0.00
OR	30.99	31.49	2986	31.32		36.95	31.55	40.66	38.01	6.32	422
AB	30.12	28.97	27.05	34.22		3193	27.79	28.17	2427	5.52	19.10
AN	8.65	6.69	8.31	7.77		5.99	8.29	5.55	761	2227	22.63
NE	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	738	0.00
DI	0.35	0.85	0.00	0.92		1.68	0.99	0.00	8.99	22.07	18.93
HY	9.52	.8.37	5.75	347		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	216	2.47	1.07	2.04		129	2.58	0.07	0.95	2.84	2.59
IL	2.84	2 23	0.58	027		027	1,06	0.96	4.32	3.48	3,26
AP	1.77	2.00	0.00	0.11		0.11	022	0.66	3.34	0.56	0.67
DJ	74.79	77.25	84.26	85.40		86.56	81.36	86.99	63.15	1923	23.32

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

EXPLANATION TO THE FIGURES

la. Location map of the area.

lb. Geological map of the study area.

2. Diorite enclave within the Quartzo-felspathic gneiss along with late stage granite and aplite veins (Loc. Z2).

3a. Photomicrographs of granitic gneisses showing myrmekite bordering K-feldspar along with adjacent quartz and biotite. Loc. Z2; XNicols (4x)

3b. Biotite crystallised within amphibole showing symplectitic texture. Note the

sharp intergranular boundaries. Top right corner shows typical eaten up texture of amphibole. Matrix is quartz and K-feldspar. (Loc. Z2; PPL, 4x)

3c Fragmentary zircon and Apatite needles associated with mafics (Hb+Bt) showing poorly aligned orientations. Loc. Z1, Aii, PPL[x4]

3 d. Restitic rounded garnet within kf. The garnet shows some alteration along

borders. Loc. Z4 B; PPL [x4]

3e. Later developed Bt growing over amphibole and plaginclase showing preferred alignment. Amphibolite enclave Loc. ZlCiv, PPL [x4]

3f. Clinopyroxene within Plagioclase & Amphibole matrix showing granulite texture. The Cpx is marginally altered to amphibole. Loc. Zl Cii, PPL [x4]

3g. The same under crossed nicols. Loc. Zl Cii, x nicols [x4]

3h. Euhedral biotite enclosing flnorite and allanite along with K-feldsnar. Loc. Z4 A2#, PPL [xlO]

4. Classification based on Na2O-K2O variation diagram

5. Classification based on alumina saturation index after Maniar and Piccoli: (1989).

6. Classification based on total alkali Vs SiO2 discrimination diagram after Irvin and Baragar (1971).

7. Harker variation diagram for major elements.

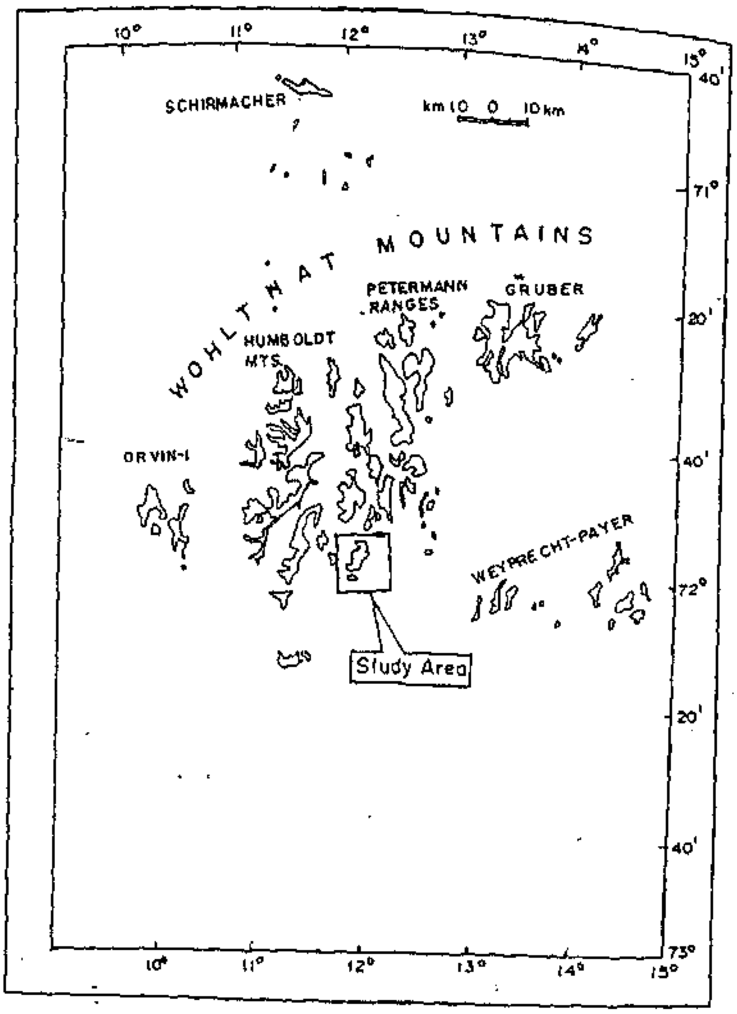
8. Chondrite normalised pattern of Zweissel granitoids (normalising values after Taylor and Mclennan 1985)

9a-c Tectonic discrimination plots after Maniar and Piccoli, 1989.

10 Th-Ta-Hf/3 diagram after Woods 1980. A-MORB, B-e MORS, C-alk WPB, D-Destructive plate margin basalt.

11 Ta-Yb tectonic discriminations plot after Pearce, 1984.

12 Modal and normative plots of Zweissel granitoids, note the close match between the two Streickesen, 1976).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MOUNTAINS
WOHLTHAT
PETERMANN RANGES
GRUBER
20'
HUMBOLDT MTS.
ORVIN-I
40'
WEYPRECHT-PAYER
72°
Study Area
20'
40'
73°
10°
11°
12°
13°
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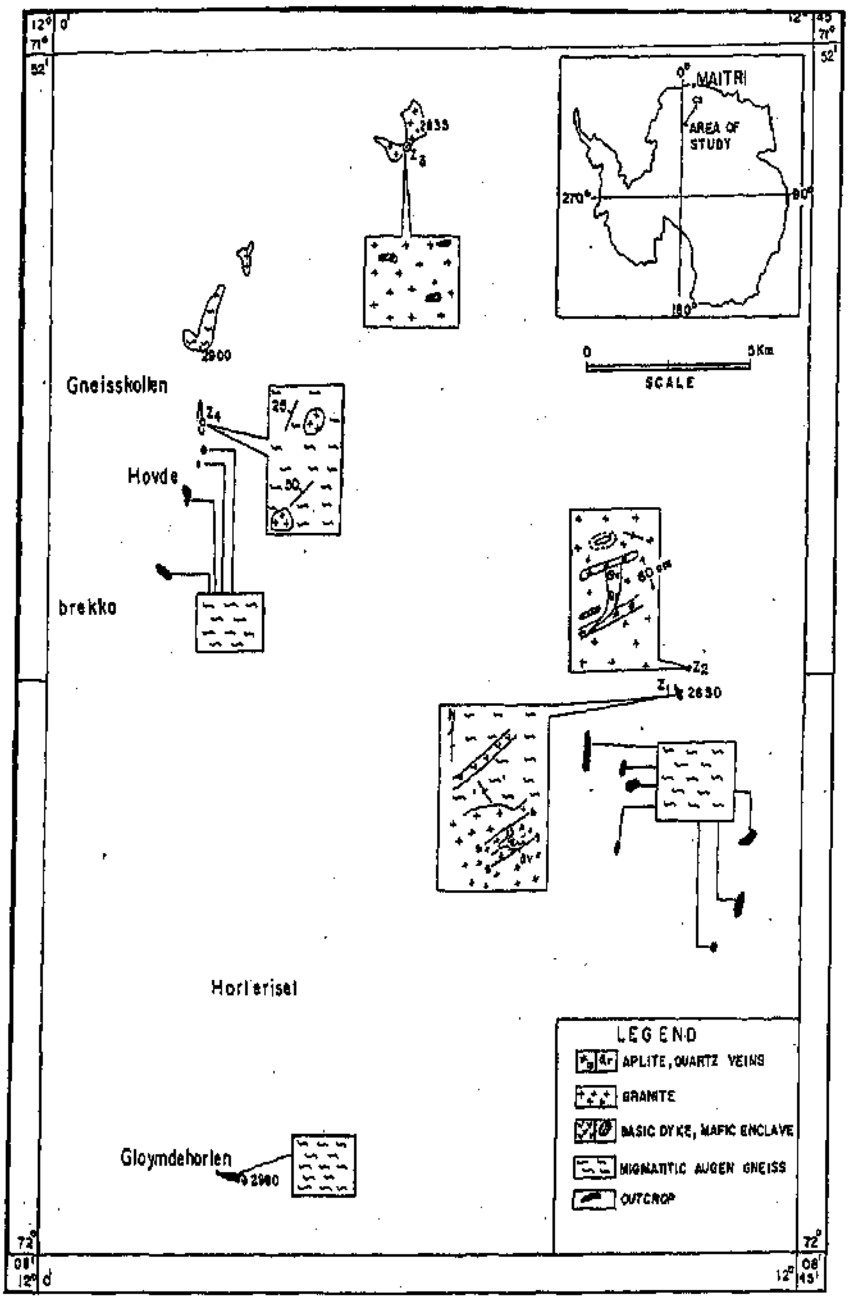
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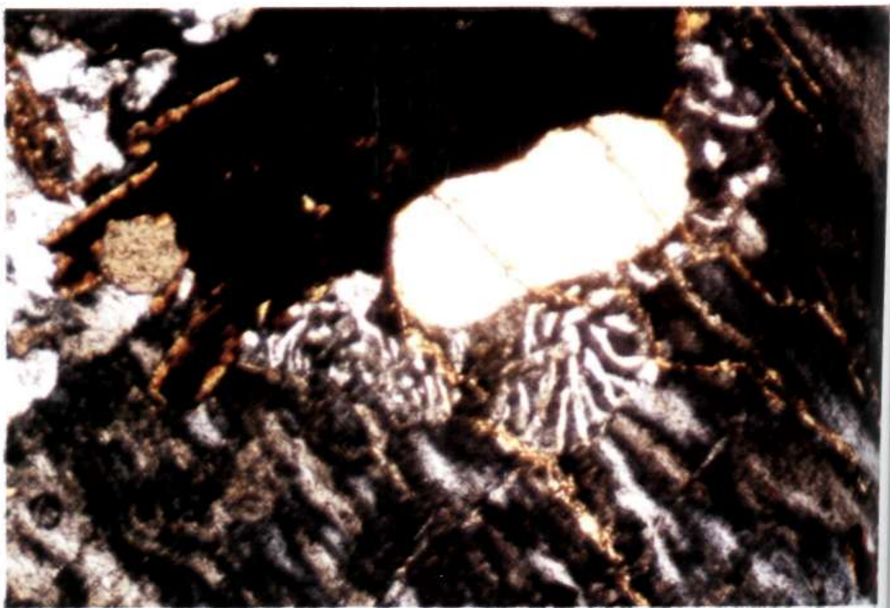
2900
Gneisskollen
Hovde
brekko
2830
Horl'erisel
Gloymdehorlen
2980
LEGEND
APLITE, QUARTZ VEINS
GRANITE
BASIC DYKE, MAFIC ENCLAVE
MIGMATITIC AUGEN GNEISS
OUTCROP

Fig. 2



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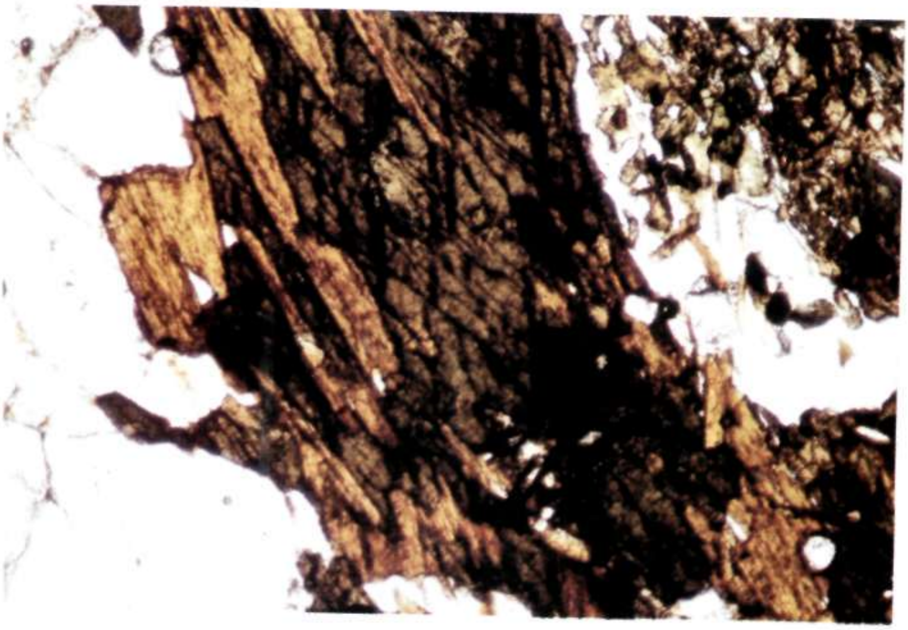


Fig. 3b

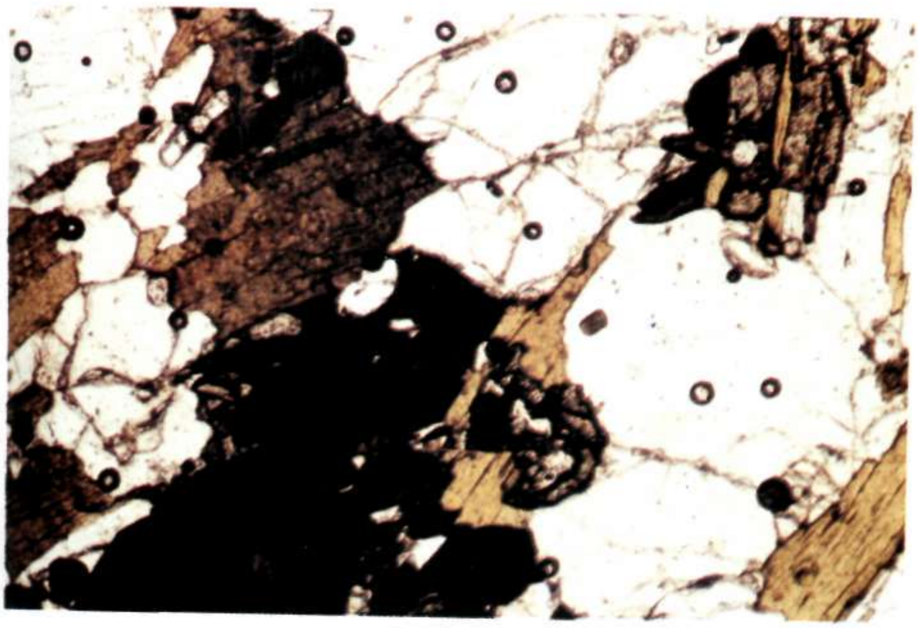
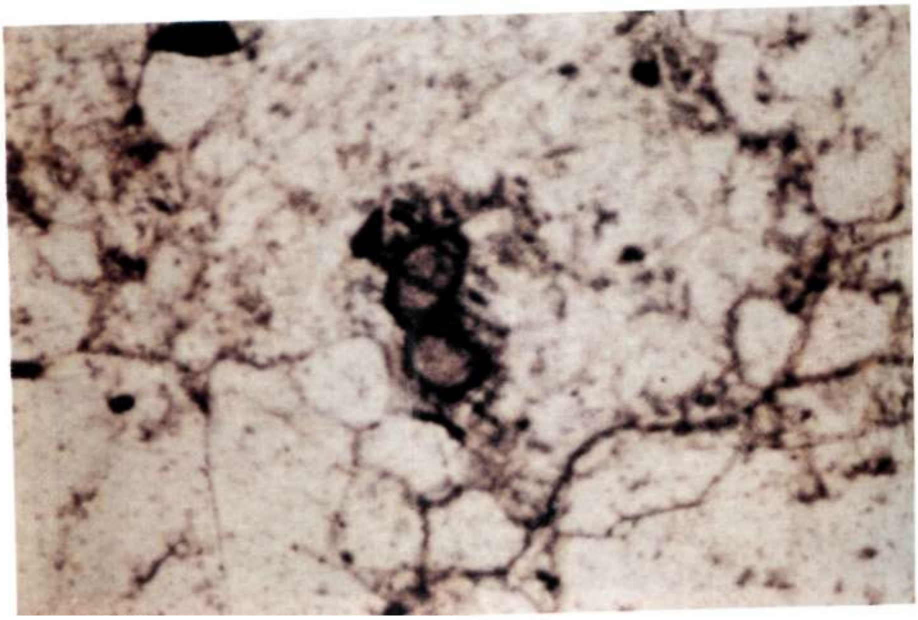


Fig. 3c



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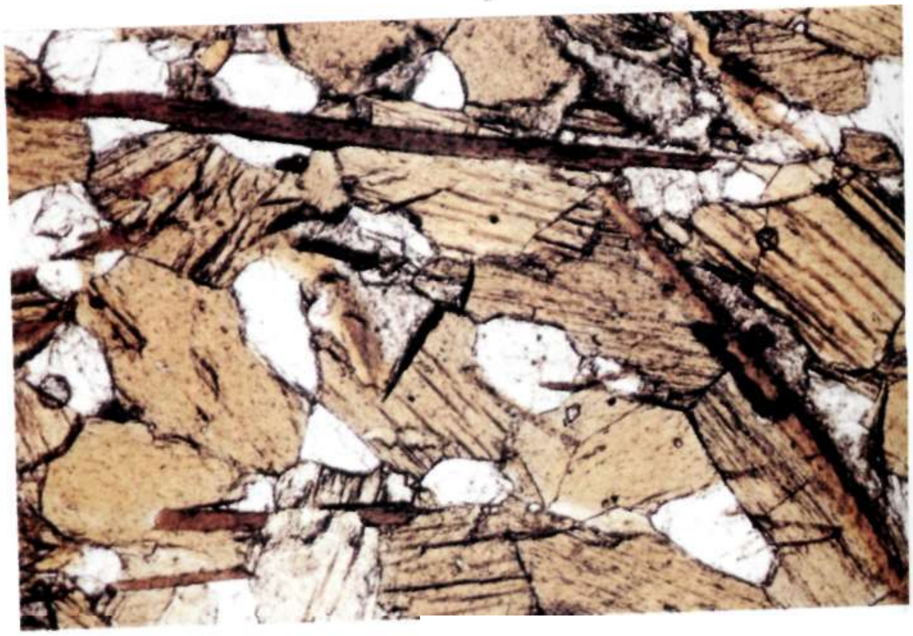

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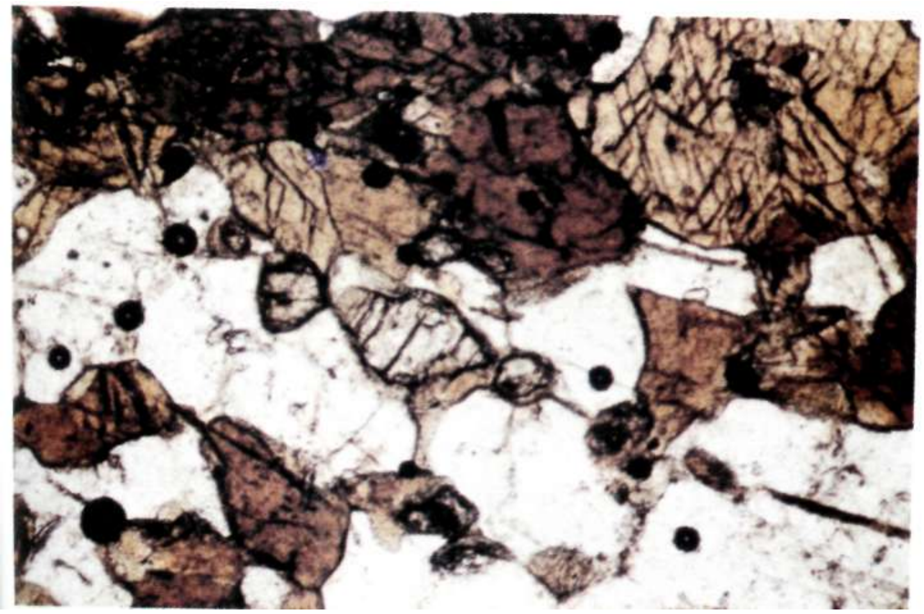

Fig. 3f

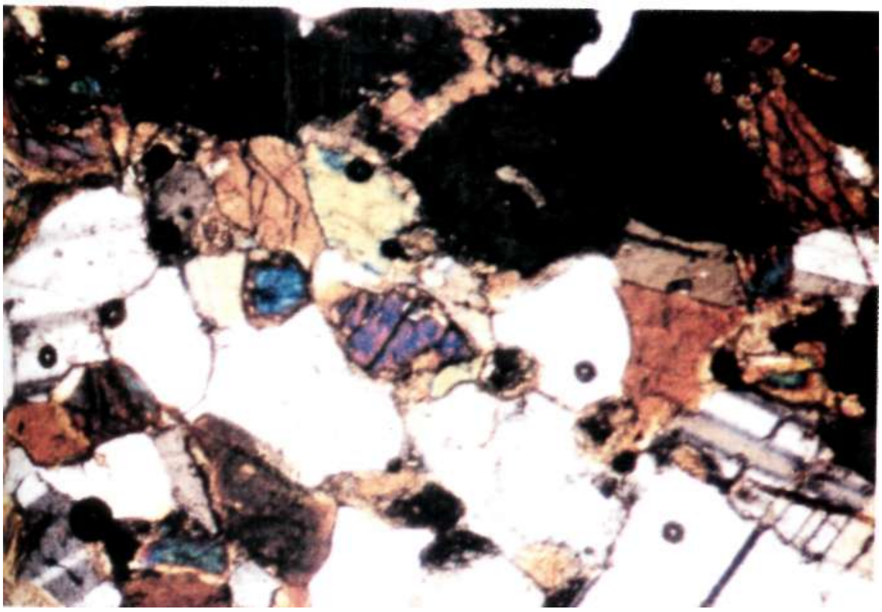

Fig 3g

Fig. 3h
Fig. 3 a-h photomicrographs

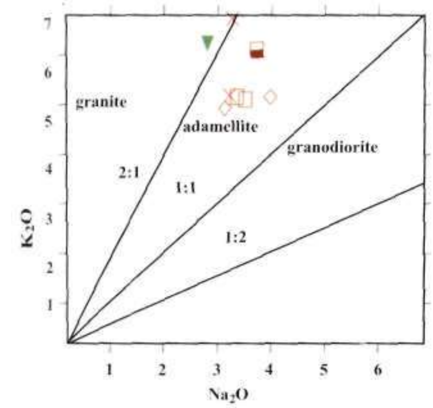

Fig 4. Classification based on Na2O-K2O variation diagram.

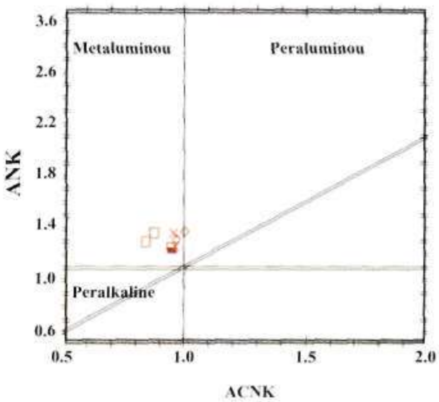

Fig 5. Classification based on alumina saturation index after Maniar and Piccoli (1989)

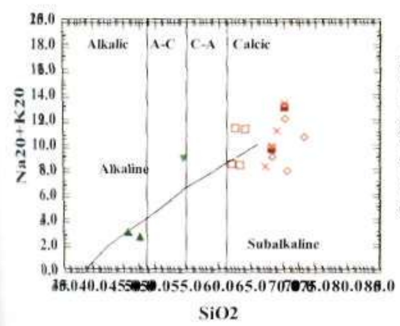

Fig 6. Classification based on total alkali Vs SiO2 discrimination diagram after Irvin and Baragar (1971)

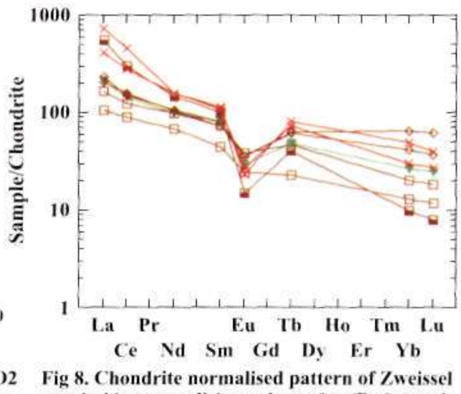

Fig 8. Chondrite normalised pattern of Zweissel granitoids (normalising values after Taylor and McLennan, 1985

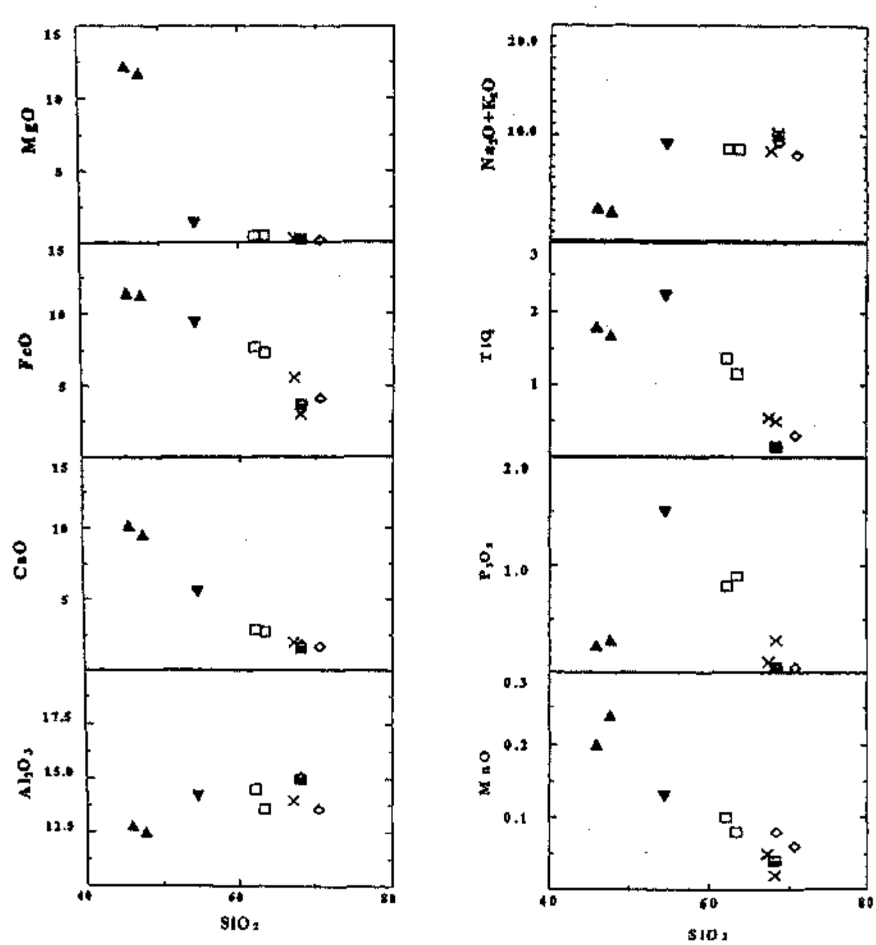

Fig 7. Barker variation diagrams for major elements

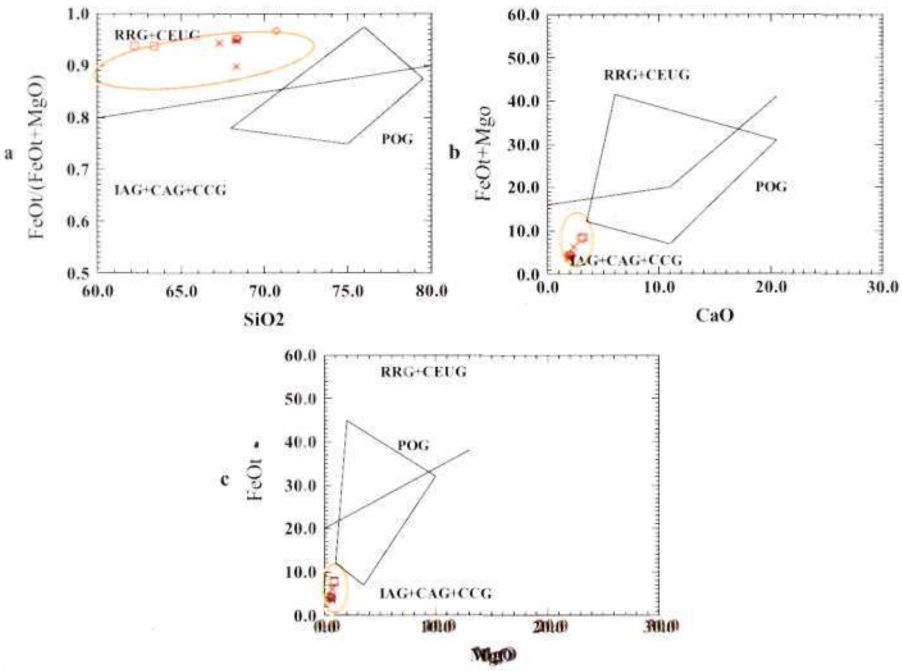

Fig9. Tectonic discrimination plots after Maniar and Piccoli, 1989.

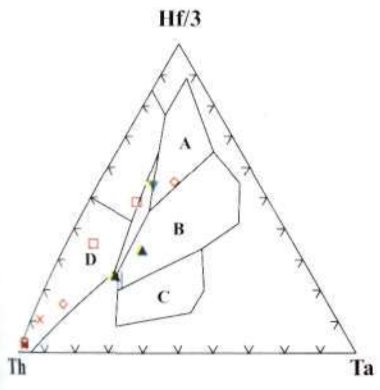

Fig 10. Th-Ta-Hf/3 diagram after Woods, 1980. A-nMORB, B-eMORB, C-alkWPB, D-Destructive plate margin basalt

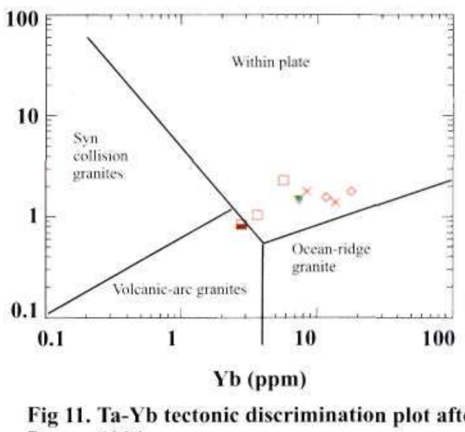

Fig 11. Ta-Yb tectonic discrimination plot after Pearce 1984

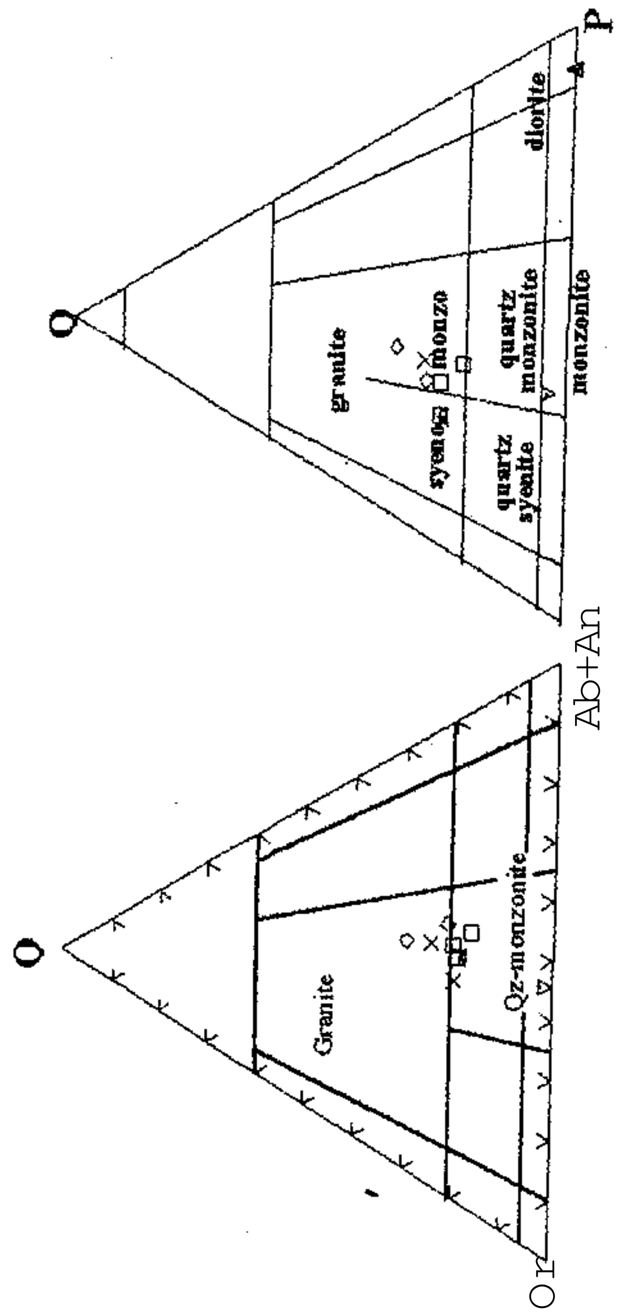
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FIGURE-12