Chapter 4

ARCHAEAN TO EARLY PROTEROZOIC GRANITOID GNEISSES OF THE ZIMBABWE CRATON

4.1 Introduction

The Archaean to Early Proterozoic granitoids occur within the western half of the study area (Fig. 2.1). Mineralogically two types of rocks were identified, namely, biotite and hornblende bearing varieties. The biotite-bearing rocks occupy most of the area whereas the hornblende gneisses are exposed as small occurrences possibly intrusive into the former.

The Archaean granitoids, which include both mineralogical types, are grouped together as Vumba Granite Gneiss. Two ages were determined in the Vumba granitoids, namely, the 3385±255 Ma and the 2527±632 Ma (Manuel, 1992) north and south of the Manica greenstone belt respectively.

The biotite bearing granitoid gneisses are of Proterozoic age and are grouped into the Messica Granite Gneiss. The Messica Granite Gneiss has an Early Proterozoic age of 2348±267 Ma.

4.2 Field Description

4.2.1 Vumba Granite Gneiss

The Vumba Granite Gneiss surrounds the Manica Greenstone Belt in its northern and southern parts and locally contains inclusions of serpentinite. It is intruded by mafic rocks (Carta Geologica da Regiao de Vila Manica-Vila Gouveia, 1:250 000, 1969) (Fig. 2.1).The Archaean granitoids in Manica have been collectively, but informally, termed the Vumba Granite after the Vumba Mountain. In the Vumba locality, the granitoid varies from homogeneous types to intensely foliated, folded, and jointed varieties and is cut by quartz and quartzo-feldspathic veins and dolerite dykes. The gneiss contains plagïoclase in excess of K-feldspar, quartz and locally chloritized biotite and hornblende. The gneisses are equigranular

medium-grained. In the M'Kwananda area, a strong planar fabric is developed. Here, the rock is intensely sheared, banded and cut by quartzo-feldspathic veins, foliated, folded and faulted and contains enclaves of fine-grained foliated amphibolite (Fig. 4.1). The planar foliation defined by preferred orientation of biotite and hornblende, is faulted and folded suggesting polyphase deformation in this granitoid. In Gecua, east of Vumba locality (Fig. 2.2), the granitoid is homogeneous. It is grey with black spots, with mineralogy consisting of grey plagioclase, quartz and hornblende. It is coarse-grained and has a planar the foliation defined by porphyritic euhedral hornblende grains up to 10 mm long.

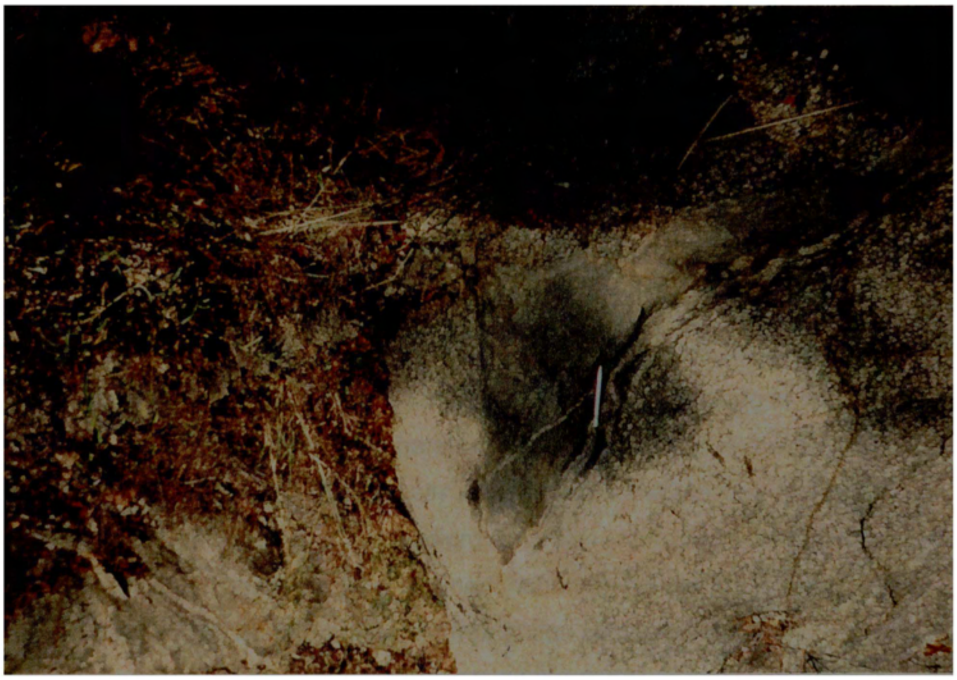

Figure 4.1: Fine-grained amphibolitic enclaves in the M'Kwananda exposure of the Vumba Granite Gneiss.

4.2.2 Messica Granite Gneiss

The Messica Granite Gneiss occurs east of the Vumba Granite Gneiss and the Manica Greenstone Belt and shares geologic boundaries with the Mozambique Metamorphic Province migmatites in the east. It is overlain by Frontier Formation metasediments. It is also intruded by mafic dykes along a N-S axis near Garuzo (Fig. 2.2). The formation includes what previous authors described as "remobilised porphyroblastic granite" (Carta Geologica da Regiao de Vila Manica-Vila Gouveia, 1:250 000, 1969; Pinna *et al.*, 1986). This granitoid type is grey to locally pinkish grey. The minerals include plagioclase, porphyritic K-feldspar, quartz and biotite. Porphyritic K-feldspar is easily recognized on weathered surfaces, but is less obvious in fresh rock. The rocks exhibit variable degrees of deformation with the western exposures showing only weak planar fabrics while in some localities appear undeformed. The intensity of fabric increases toward the east where the rock is strongly foliated and locally exhibits augen textures defined by feldspar, which can be up to 25 mm long. Quartz is commonly deformed and elongated parallel to the foliation direction. The foliation is defined by preferred orientation of biotite which wraps around the feldspar augens. The non-porphyritic granitoid has the same minerals as the porphyritic varieties but is medium-grained and less deformed. The foliation varies from being incipient with different orientations to more pervasive and consistent in a N-S direction with steep dips towards both W and E. Towards the extreme east boundary, where the granite is also commonly porphyritic, two foliations, namely an E-W S_1 fabric and a younger N-S S_2 are distinguishable. The granite is cut by quartz and pegmatitic veins that are commonly oriented N-S. Many exposures of non-porphyritic granite contain mafic enclaves characterized by plagioclase, hornblende and quartz.

4.3 Petrography

The texture of the Vumba Granite Gneiss is typically hypidiomorphic granular (Shelley, 1993, p. 422) except in samples from M'kwananda (MkG, sheared rock) in which a strong foliation has been developed and in the hornblende-bearing varieties in which hornblende shows a preferred orientation. The Vumba Granite Gneiss consists of K-feldspar, plagioclase, quartz, biotite and hornblende and accessory minerals epidote, allanite, sphene, apatite, chlorite and zircon (Fig. 4.2). This mineralogical composition as well as the proportions in which they occur are shown on Table 4.1. Plagioclase exceeds K-feldspar by ~1.5:1 to 2:1 indicating that these rocks are granodioritic to tonalitic in composition. K-feldspar varies in grain size from medium (1-2 mm) to coarse (2-4) and is essentially microcline, locally sericitized and characterized by anhedral grains exhibiting cross-hatch twinning. Plagioclase grains are anhedral, locally saussuritized and are characterized by complex Carlsbad-Albite polysynthetic twins and are medium (±1.5 mm) to coarse (±2 mm) in grain size. Quartz is represented by two types namely, strained, anhedral, medium (±2 mm) to coarse (±2-3 mm) grains and fine-grained (±0.25-0.5 mm) strain-free grains commonly exhibiting a fine-grained granoblastic texture and occurring along cracks and grain boundaries.

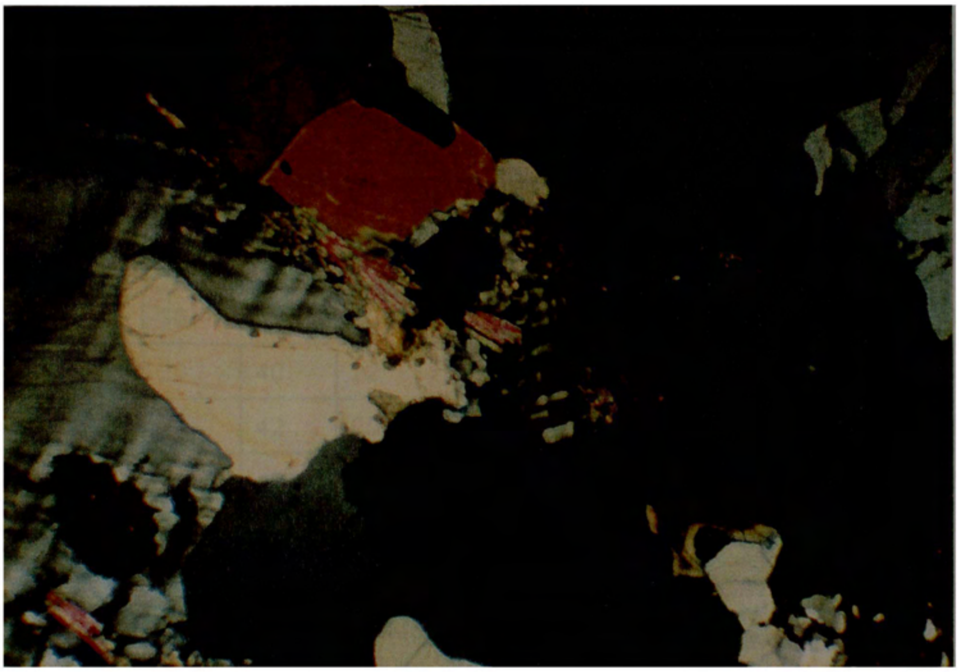

Figure 4.2: Anhedral quartz, microcline (with cross-hatch twinning), plagioclase (with combined polysynthectic and Carlsbad twinning), biotite (locally altered to muscovite and titanite (included in microcline) in the Vumba Granite Gneiss. Crossed nicols, width of field 3.0 mm.

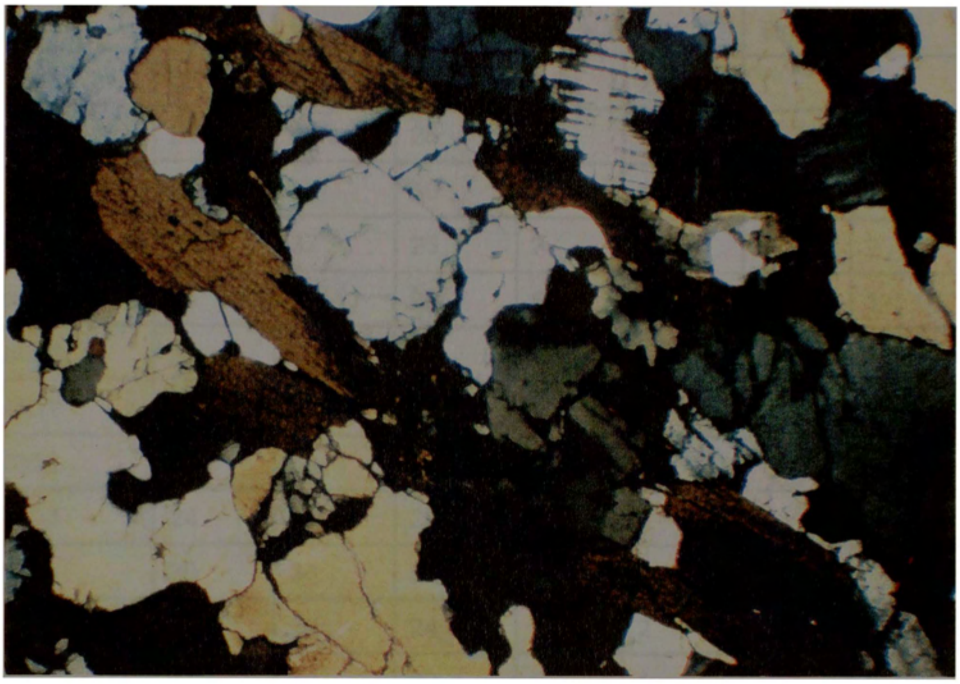

Figure 4.3: Feldspar (with biotite wrapped around) with microcline (exhibiting typical cross-hatch twinning) and fine grains of quartz in the Messica Granite Gneiss. Crossed nicols, width of field 7 mm.

Table 4.1: Mineralogical composition of the Vumba Granite Gneiss.

sample	K-fld	Plg	Qtz	Hbl	Bt	Ep	Ttn	Ap	Aln	Chl	Zr
VGI	20	45	25	2	5	1	1	-	1	-	-
VGII	15	48	30	-	3	1	1	1	1	-	-
VGIII	30	35	30	-	2	-	-	1	1	1	-
VGIV	32	34	28	-	2	1	-	1	-	2	-
VGV	30	35	30	-	2	1	-	1	1	-	-
VG31	20	40	22	8	5	1	1	1	1	-	1
VG32	21	42	20	7	6	1	1	1	1	-	-
VG33	20	46	20	6	5	-	1	-	1	-	1
MpG	25	43	25	-	5	2	-	-	-	-	-
MkG	20	37	20	6	15	1	-	-	1	-	-

Numbers indicate mineral proportions. K-fld- potassic feldspar; Plg- plagioclase, Qtz- quartz, Bt- biotite, Ms- muscovite, Zr- zircon Ttn-titanite, Ep- epidote, Ap- apatite, Aln- allanite Chl- chlorite.

Table 4.2: Mineralogical assemblage of Messica Granite Gneiss. Modal proportion expressed as percentages.

Sample	K-fld	Plg	Qtz	Bt	Ms	Ttn	Opm
PdGr1	22	40	27	6	2	1	2
PdGr2	21	42	28	5	1	2	1
PdGr3	18	40	30	8	1	1	2
PdGr4	26	37	25	7	2	1	2
PdGr5	24	38	28	6	2	1	1
PdGr6	28	34	28	6	2	1	1
CNO1	28	35	30	4	1	1	1
CNO2	27	38	25	5	2	1	2
CNO3	24	38	28	5	3	1	1
CNO4	30	36	22	6	2	2	2
CNO5	28	36	24	7	2	1	2
CNO6	21	42	30	5	1	-	1
MGn3	25	38	25	7	2	1	2
Mgn5	25	42	24	5	2	-	2
M'SKg	28	38	20	12	-	1	1

Abbreviations as in Table 4.1.

These finer grained zones are thought to represent strain-related recrystallisation of the larger grains.

Biotite occurs as isolated grains or grain aggregates and may be subhedral. It is locally poikilitic and partially altered to chlorite. In deformed samples from the M'Kwananda region, biotite together with deformed quartz, defines a planar foliation. Hornblende occurs as euhedral to subhedral coarse grains and exhibits a preferred orientation that defines the foliation. Epidote is commonly associated with plagioclase of which it is a reaction product. Allanite occurs as isolated long pseudohexagonal crystals commonly exhibiting pleochroic haloes or as fine inclusions in plagioclase. Titanite is included in plagioclase and hornblende. Apatite forms euhedral hexagonal crystals included in plagioclase and amphibole. Zircon is included in plagioclase.

The Messica Granite Gneisses are commonly medium-grained equigranular to porphyritic in which feldspars constitute the phenocrysts >5 mm in grain size. The fabric varies from randomly oriented feldspar phenocrysts to one in which strong preferred orientations of deformed quartz and feldspar porphyroclasts are seen (Fig. 4.3) Biotite flakes wrap around the feldspars in the deformed samples similarly defining a planar fabric. Locally, finer quartz and feldspar grains exhibit polygonal textures (Fig. 4.4). Myrmeckite is also common in these granitoids.

The mineralogy of the Messica Granite Gneiss is composed of K-feldspar, plagioclase, quartz, biotite, muscovite, zircon, titanite, apatite and opaque minerals. Table 4.2 provides modal estimates of the mineral proportions. K-feldspar, commonly microcline,is locally perthitic while plagioclase exhibits combined Carlsbad and albite twins. Both feldspars are commonly poikilitic, enclosing finer quartz and feldspar grains, and are anhedral. The grain size is, on average, ±2 mm. Quartz, exhibits irregular crystal faces, is poikilitic with inclusions of finer quartz and feldspar grains and has the same grain size as the feldspars. Biotite occurs as isolated grains or grain aggregates with subhedral grain shapes (Fig. 4.5). Some chloritized biotite grains exhibit needle intergrowths of rutile. Muscovite occurs as small grains associated with biotite (Fig. 4.5) and as inclusions in feldspar. These relationships are interpreted to represent an alteration product resulting from retrogressive reactions. Zircon occurs as isolated prismatic grains. Titanite occurs as short prismatic irregular anhedral isolated grains and as grain aggregates. Apatite commonly occurs as small hexagonal euhedral crystals. Opaque minerals occur as euhedral to anhedral grains, commonly associated with biotite and titanite and, in some cases titanite forms embayments to these opaque minerals grains.

The occurrence of plagioclase-epidote, biotite-muscovite, feldspar-sericite and biotite-chlorite associations is an indication of a subsequent retrogressive metamorphism (hydration reactions) possibly at low grade greenschist facies. The presence of foliation defined by plagioclase porphyroclasts, of strained, elongated coarse quartz and strain-free fine quartz with granoblastic texture suggests deformation and metamorphism.

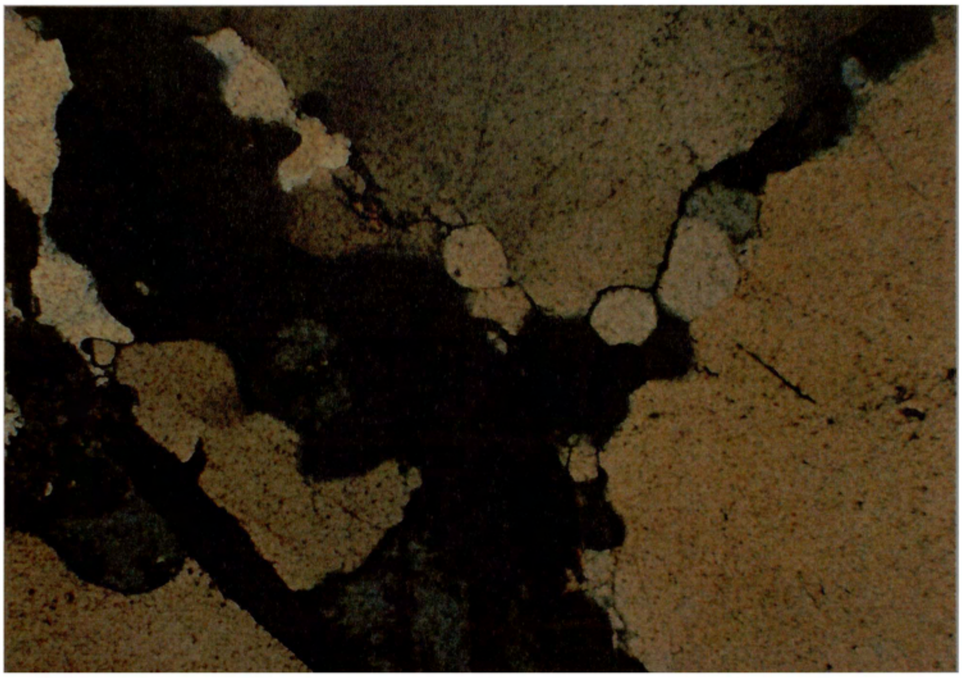

Figure 4.4: Fine quartz grains exhibiting polygonal texture in the Messica Granite Gneiss. Crossed nicols, width of field 3 mm.

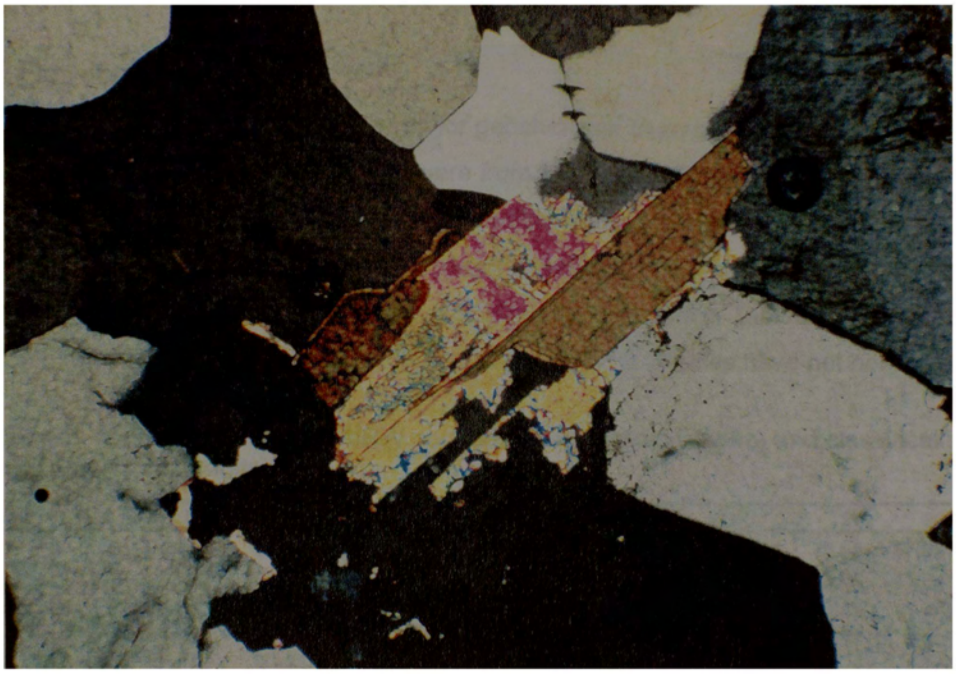

Figure 4.5: Biotite laths occurring at quartz grain boundaries in the Messica Granite Gneiss. The intervening grain with high interference colours is muscovite. Crossed nicols, width of field 3. mm.

4.4 Chemistry

4.4.1 Introduction

Twenty one samples were analysed for geochemical characterization of the Archaean to Early Proterozoic granitoids. Of these, nine were from the Vumba and the remaining twelve from the Messica granitoids. In addition data of 10 samples from the Vumba Granite Gneiss, analysed by Manuel (1992) are also included. The major element and normative data are shown in Table 4.3, the trace element and the REE data in Table 4.4 and the radiogenic isotope data in Tables 4.5 and 4.6 .Analyses of some samples have low totals that are attributed to the fact that volatiles have not been determined.

Table 4.3: Major elements and CIPW normative compositions (norm) and classification of Archaean to Early Proterozoic granitoids.

SAMP	VGR3-1	VGR3-2	VGR3-3	VGR3-4	VGR3-5	VGR3-6	VGRI	VGRIII	VGRIV	127	90	81
SiO_2	65.64	66.66	66.3	66.24	66.52	64.87	70.35	75.43	73.34	70.85	67.95	72.4
Al_2O_3	16.14	16.87	15.92	16.96	15.89	15.61	14.44	12.33	13.62	13.66	15.84	14.61
Fe_2O_3	1.67	1.63	1.68	1.61	1.66	1.62	1.06	0.43	0.68	1.45	1.44	1.19
FeO	2.55	2.58	2.67	2.56	2.60	2.59	1.65	0.49	0.79	2.57	2.30	1.75
MgO	1.6	1.65	1.71	1.62	1.67	1.64	0.76	0.14	0.22	1.6	1.4	0.55
CaO	4.36	4.31	4.37	4.38	4.34	4.47	3.27	0.5	1.03	3.68	4.2	2.62
Na_2O	4.09	3.9	3.88	3.85	3.93	3.93	4.19	3.49	3.36	2.99	3.64	4.08
K_2O	2.2	2.06	2.06	2.11	2.15	2.04	1.75	4.94	4.94	1.77	2.11	2.16
TiO_2	0.48	0.48	0.49	0.48	0.49	0.49	0.32	0.1	0.19	0.45	0.41	0.23
P_2O_5	0.16	0.16	0.17	0.16	0.17	0.17	0.12	0.03	0.06	0.11	0.12	0.06
MnO	0.06	0.06	0.07	0.06	0.06	0.06	0.03	0.02	0.04	0.06	0.06	0.05
total	98.95	100.36	99.32	100.03	99.48	97.49	97.94	97.9	98.27	99.23	99.47	99.64
norm												
Q	21.16	23.46	23.15	23.05	23.02	21.78	30.57	34.72	32.05	35.32	26.71	33.16
Or	13.03	12.2	12.2	12.5	12.73	12.08	10.37	29.25	29.32	10.49	12.5	12.8
Ab	34.61	33	32.83	32.57	33.25	33.25	35.45	29.53	28.43	25.3	30.8	34.52
An	19.18	20.57	19.93	20.93	19.36	18.91	15.41	2.46	4.91	17.74	20.29	12.78
Di	1.34	0	0.71	0	1.07	1.95	0.35	0	0	0	0	0
Hy	5.97	6.83	6.75	6.73	6.34	5.86	3.4	0.77	1.21	6.87	5.97	3.32
Mt	2.42	2.37	2.44	2.34	2.41	2.35	1.54	0.62	0.98	2.11	2.08	1.72
Il	0.91	0.91	0.93	0.91	0.93	0.93	0.61	0.19	0.36	0.85	0.78	0.44
Ap	0.38	0.38	0.41	0.38	0.41	0.41	0.29	0.07	0.15	0.26	0.29	0.14
Q	24	26	26	26	26	25	33	36	34	40	30	36
A	15	14	14	14	14	14	11	30	31	12	14	14
P	61	60	60	60	60	61	55	33	35	48	57	51
rock	granod	granod	granod	granod	granod	granod	granod	mzgr	mnzgr	granod	granod	granod

SAMP	150	124	14	253	403	404	406	M'SKGn	PDGR1	PDGR2	PDGR3
SiO_2	68.04	71.08	72.45	74.03	74.31	77.44	75.96	70.32	71.04	71.31	71.16
Al_2O_3	16.37	14.95	14.24	13.49	14.27	12.88	12.89	14.5	14.17	14.35	14.2
Fe_2O_3	1.40	1.34	1.20	0.67	1.06	0.65	1.03	0.93	1.03	1.12	0.98
FeO	2.14	1.93	1.67	0.87	1.52	0.81	1.42	1.09	1.16	1.27	1.09
MgO	1.34	1.16	1.08	0.4	0.47	0.11	0.06	0.64	0.62	0.64	0.54
CaO	3.69	1.78	1.53	1.56	2.47	1.08	1.63	1.54	1.67	1.75	1.63
Na_2O	3.96	4.92	4.18	3.49	4.35	3.8	4.12	3.62	3.62	3.75	3.68
K_2O	2.25	1.62	2.62	3.88	1.98	3.73	2.52	4.73	5.19	4.98	5.27
TiO_2	0.4	0.41	0.32	0.23	0.22	0.09	0.16	0.27	0.31	0.32	0.32
P_2O_5	0.1	0.09	0.08	0.04	0.06	0.03	0.03	0.1	0.11	0.09	0.11
MnO	0.04	0.05	0.06	0.04	0.05	0.02	0.04	0.02	0.03	0.03	0.02
total	99.73	99.62	99.43	98.75	100.76	100.64	100.14	97.76	98.95	99.61	99

norm	150	124	14	253	403	404	406	M'SKGn	PDGR1	PDGR2	PDGR3
Q	25.66	30.05	32.6	34.62	34.77	38.22	38.2	26.62	25.54	25.55	25.32
Or	13.33	9.59	15.52	22.98	11.74	22.09	14.92	28.02	30.73	29.48	31.2
Ab	33.51	41.63	35.37	29.53	36.8	32.15	34.86	30.63	30.63	31.73	31.14
An	17.92	8.43	7.26	7.68	12	5.29	8.05	7.31	7.1	7.63	6.68
Di	0	0	0	0	0	0	0	0	0.64	0.64	0.82
Cm	0.01	0	0	0	0.01	0	0.01	0	0	0	0
Hy	5.51	4.74	4.34	1.73	2.82	1.1	1.4	2.44	2.06	2.22	1.65
Mt	2.04	1.95	1.75	0.98	1.53	0.95	0.15	1.34	1.5	1.63	1.43
Il	0.76	0.78	0.61	0.44	0.42	0.17	0.3	0.51	0.59	0.61	0.61
Ap	0.24	0.22	0.19	0.1	0.14	0.07	0.07	0.24	0.27	0.22	0.27
Q	28	34	36	37	36	39	40	29	27	27	27
A	15	11	17	24	12	23	16	30	33	31	33
P	57	56	47	39	51	38	45	41	40	42	40
rock e	granod	granod	granod	mzgr	granod	mnzgr	granod	mzgr	mzgr	mzgr	mzgr

SAMP	PDGR4	PDGR5	PDGR6	CNOGN1	CNOGN2	CNOGN3	CNOGN4	CNOGN5
SiO_2	72.08	71.98	70.91	72.5	74.14	73.56	71.97	71.71
Al_2O_3	14.6	14.86	14.84	14.36	13.82	13.53	15.03	14.1
Fe_2O_3	0.94	0.69	0.90	0.82	0.68	0.79	0.81	0.78
FeO	1.03	0.73	1.01	0.78	0.74	0.83	0.88	0.90
MgO	0.53	0.51	0.58	0.33	0.35	0.37	0.47	0.44
CaO	1.51	1.88	1.56	1.45	1.5	1.51	1.63	1.59
Na_2O	3.67	3.88	3.77	3.6	3.56	3.64	3.77	3.5
K_2O	5.21	5.42	5.13	6.64	5.3	5.66	5.35	4.99
TiO_2	0.28	0.25	0.29	0.23	0.21	0.23	0.26	0.24
P_2O_5	0.09	0.09	0.09	0.07	0.07	0.07	0.09	0.08
MnO	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
total	99.96	100.31	99.1	100.8	100.39	100.21	100.28	98.35
norm								
Q	26.52	24.19	24.92	23.17	29.48	27.47	25.21	27.96
Or	30.84	32.09	30.37	39.3	31.38	33.51	31.68	29.54
Ab	31.05	32.83	31.9	30.46	30.12	30.8	31.9	29.61
An	7.22	7.14	7.46	3.39	6.08	3.85	7.78	7.61
Di	0	1.55	0	2.59	0.95	2.82	0	0
Hy	2.03	0.93	2.11	0	0.91	0.1	1.72	1.76
Mt	1.36	1	1.31	1.19	0.98	1.15	1.18	1.13
Il	0.53	0.47	0.55	0.44	0.4	0.44	0.49	0.46
Ap	0.22	0.22	0.22	0.17	0.17	0.17	0.22	0.19
Q	28	25	26	24	30	29	26	30
A	32	33	32	41	32	35	33	31
P	40	42	42	35	37	36	41	39
rock	mzgr	mzgr	mzgr	mzgr	mzgr	mzgr	mzgr	mzgr

Samples from m'skagn throughout cnogn5 are from Messica granitoid and the remaining from Vumba granitoids. mzgr- monzogranite and granod- granodiorite.

4.4.2 Major Element Chemistry

The rocks are typically granitoids with SiO_2 contents 65-76 %, Al_2O_3 12-18 % and (FeO_{total}+ MgO)< 6 %. Na_2O contents in the Vumba and Messica Granite Gneiss are similar (Fig. 4.6). However, the Messica Granite Gneiss has higher K_2O contents of 5-5.5wt% compared to values of 3.5-4 wt% in the Vumba Granite Gneiss. K_2O contents in the Vumba Granite Gneiss show a marginal increase with increasing SiO_2 (Fig. 4.6).

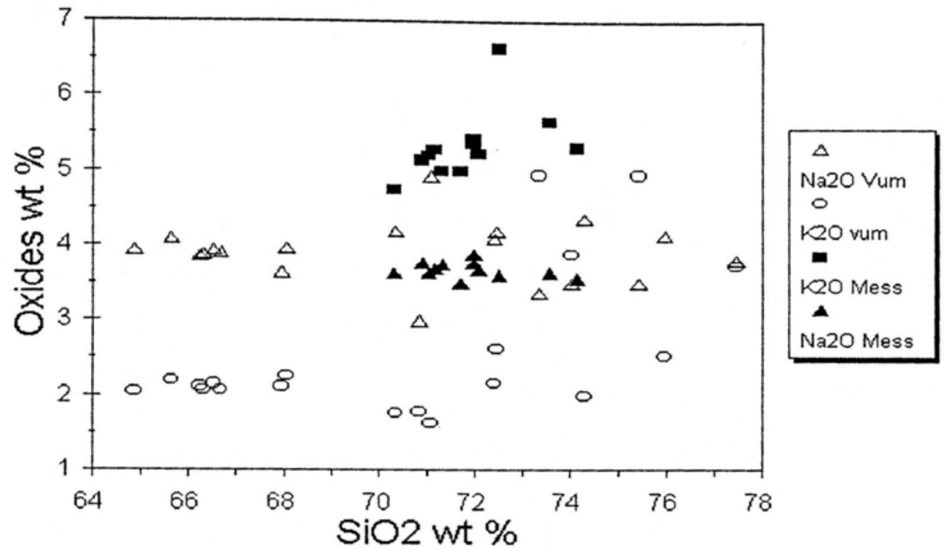

Figure 4.6: Variation diagram plotting Na_2O and K_2O versus SiO_2. Vum- Vumba Granite Gneiss and Mess- Messica Granite Gneiss.

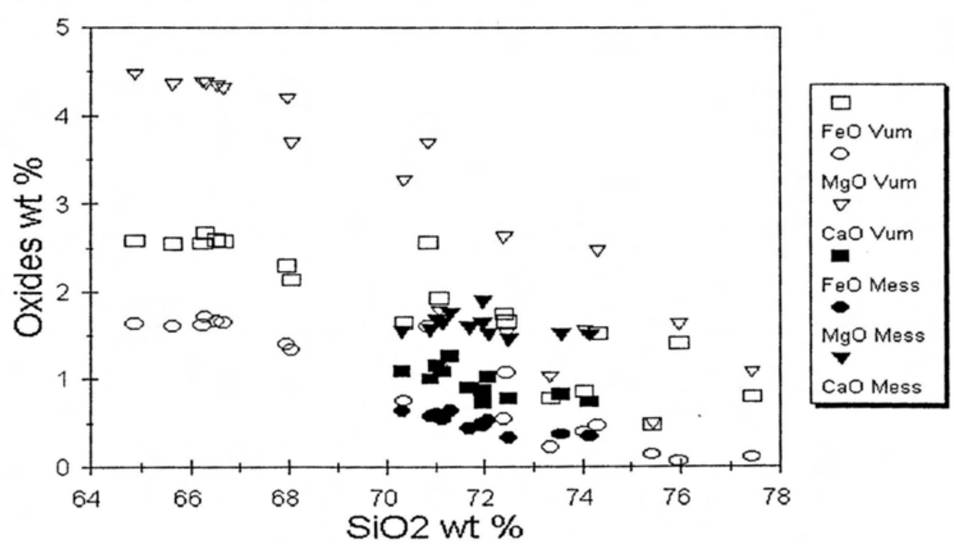

Figure 4.7: Variation diagram plotting FeO, MgO and CaO. Symbols as in Figure 4.6

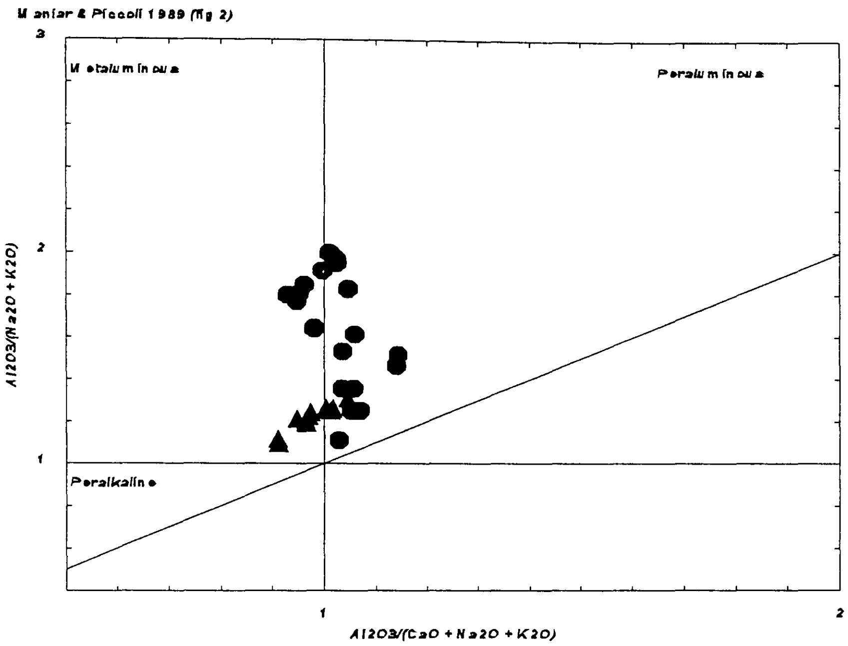

Figure 4.8: Aluminum-saturation ratios diagram (after Shand, 1947) of the Vumba (filled circles) and the Messica (filled up triangles) Granite Gneisses.

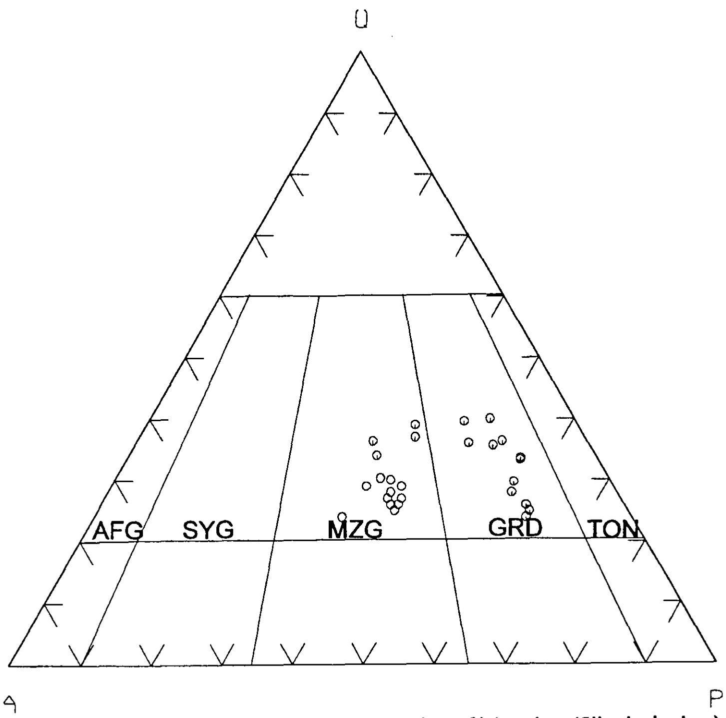

Figure 4.9: Streckeisen (1976) QAP plot of Vumba (filled circles) and Messica granitoids (open circles). AFG- alkali feldspar granite, SYG- syenogranite, MZG- monzogranite, GRD- granodiorite, TON- tonalite.

The variation diagram in Figure 4.7 shows that the Messica granitoids compared with the Vumba granitoids are characterized by lower contents of FeO, MgO and CaO and a more limited SiO_2 composition. In addition, it is observed that the oxide contents decrease with increase in SiO_2 giving rise to negative correlations. CaO contents of the Vumba Granite Gneiss are significantly higher than those for the Messica Granite Gneiss (Fig. 4.7). The combined contents of total alkalis, CaO and Al_2O_3, result in the granites varying from metaluminous to peraluminous on the basis of the aluminum-saturation ratios (Shand,1947) (Fig. 4.8). Similarly $\sum$FeO contents in the Vumba Granite are distinctly higher than the Messica Granite Gneiss whereas MgO contents are similar to marginally lower than the Messica Granite Gneiss .

On the basis of normative mineralogy in the QAP diagram of Streckeisen (1976) (Fig 4.9), the Vumba granitoids are classified as granodiorites and monzogranites while the Messica granitoids are classified as monzogranite (Table 4.3).

Data plotted in the AFM tholeiite/calc-alkaline discriminant diagram after Irvine & Baragar (1971) (Fig.4.10) suggests that all the granites are typically calc-alkaline. This figure is however not well suited to granitic rocks because, in rocks with high alkali contents with respect to the ferro-magnesian components, all acid rocks plot in the same area within the calc-alkaline field of the AFM diagram. However, the calc-alkaline nature is supported by the Jensen (1976) discriminant diagram (Fig. 4.11) which is better suited to discriminating between calk-alkaline and tholeiitic granitoid rocks.

4.4.3 Trace Element Chemistry

Trace element compositions, including REE, of the Vumba Granite Gneiss are shown in Table 4.4.

Table 4.4: Trace elements compositions of the Messica and Vumba granitoids.

SAMPL	VGR3-1	VGR3-2	VGR3-3	VGR3-4	VGR3-5	VGR3-6	VGRI	VGRIII	VGRIV	127	90	81
Ba	501	482	491	516	538	482	1141	592	564	394	551	472
Li	23	27	26	23	27	25	49	12	16	nd	nd	nd
Nb	6	6	6	6	6	7	6	4	9	nd	nd	nd
Sc	8	8	9	9	9	9	2	2	3	nd	nd	nd
Sr	266	269	266	275	271	277	232	43	107	256	247	131
Rb	64	65	66	65	61	65	61	145	319	73	88	93
Y	14	14	14	16	16	16	5	12	26	Nd	Nd	Nd
Zr	183	176	207	186	171	155	173	91	133	128	152	157
La	17	34	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Ce	32	62	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Pr	4	7	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Nd	15	22	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Sm	3	3	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Eu	1	1	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Gd	2	3	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Dy	2	2	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Ho	0	0	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Er	1	1	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Yb	1	1	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Lu	0	0	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd

SAMPL	150	124	14	253	403	404	406	MSIKGN	PDGR1	PDGR2	PDGR3	PDGR4
Ba	525	504	505	626	385	422	495	868	938	868	937	918
Li	Nd	Nd	Nd	Nd	Nd	Nd	Nd	19	15	15	13	13
Nb	Nd	Nd	Nd	Nd	Nd	Nd	Nd	5	4	5	6	4
Sc	Nd	Nd	Nd	Nd	Nd	Nd	Nd	2	2	2	2	2
Sr	324	139	149	80	101	36	59	244	203	223	203	204
Rb	77	50	95	132	89	107	78	154	134	126	132	131
Y	Nd	Nd	Nd	Nd	Nd	Nd	Nd	16	7	8	9	7
Zr	135	135	106	130	186	101	210	172	209	229	210	190
La	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	71	90	Nd	Nd
Ce	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	129	165	Nd	Nd
Pr	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	13	16	Nd	Nd
Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	38	49	Nd	Nd
Sm	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	4	6	Nd	Nd
Eu	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	1	1	Nd	Nd
Gd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	2	3	Nd	Nd
Dy	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	1	2	Nd	Nd
Ho	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0	0	Nd	Nd
Er	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0	0	Nd	Nd
Yb	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0	1	Nd	Nd
Lu	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0	0	Nd	Nd

SAMPL	PDGR5	PDGR6	CNOGN1	CNOGN2	CNOGN3	CNOGN4	CNOGN5
Ba	901	889	797	772	793	840	710
Li	13	14	13	14	15	15	15
Nb	3	4	4	4	4	4	4
Sc	2	2	1	2	1	1	2
Sr	253	194	159	158	156	165	154
Rb	132	129	151	142	138	144	135
Y	6	7	7	7	6	5	7
Zr	183	204	189	140	165	190	203
La	Nd	Nd	49.62	78.38	Nd	Nd	Nd
Ce	Nd	Nd	95	149	Nd	Nd	Nd
Pr	Nd	Nd	10	15	Nd	Nd	Nd
Nd	Nd	Nd	32	47	Nd	Nd	Nd
Sm	Nd	Nd	5	6	Nd	Nd	Nd
Eu	Nd	Nd	1	1	Nd	Nd	Nd
Gd	Nd	Nd	2	3	Nd	Nd	Nd
Dy	Nd	Nd	1	1	Nd	Nd	Nd
Ho	Nd	Nd	0	0	Nd	Nd	Nd
Er	Nd	Nd	0	0	Nd	Nd	Nd
Yb	Nd	Nd	0	0	Nd	Nd	Nd
Lu	Nd	Nd	0	0	Nd	Nd	Nd

Nd- not determined and nd- not detected.

Ba, Rb and Zr contents in the Vumba Granite Gneiss are typically lower than in the Messica Granite Gneiss. Conversely, Nb, Y and Sc contents in the Vumba Granite Gneiss are higher compared with the contents in the Messica Granite Gneiss. Sr contents in both granites are similar.

Although it is uncertain to what extent plate tectonic processes operated in the Archaean and Proterozoic times, the differences between the Rb, Nb and Y contents of the Vumba and Messica Granite Gneisses result in the Vumba and Messica Granite Gneisses plotting in the field of the volcanic-arc granitoids of Pearce *et al.* (1984) (Fig. 4.12).

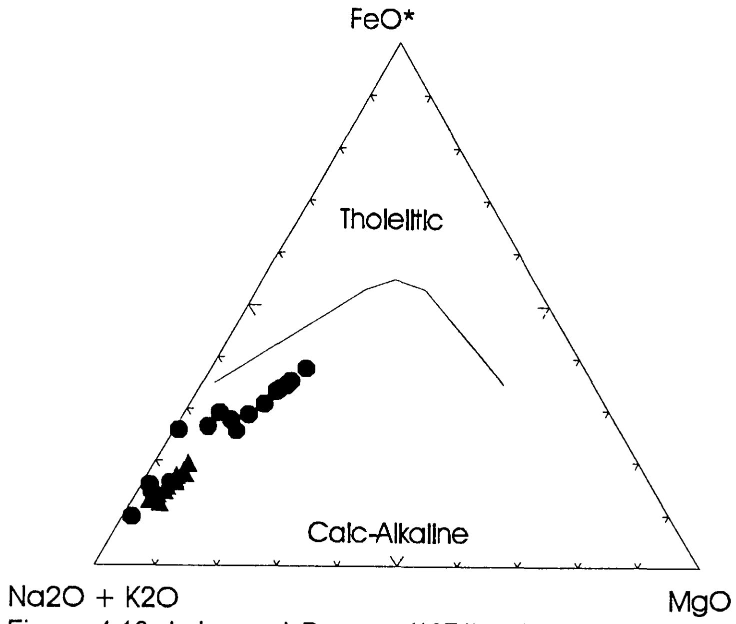

Figure 4.10: Irvine and Baragar (1971) calc-alkaline versus tholeiite discriminant diagram plot of Vumba (filled circles) and Messica (filled triangles) granitoids.

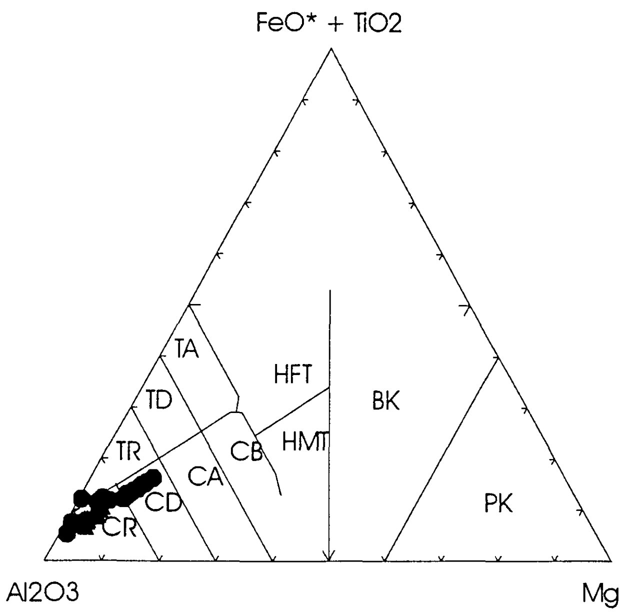

Figure 4.11: Vumba (filled circles) and Messica (filled triangles) granitoids plotted in the Jensen (1976) cationic diagram. TA-tholeiitic andesite, TD-tholeitic dacite, TR-tholeiitic rhyolite, CR- calc-alkaline rhyolite, CD- calc-alkaline dacite, CA- calc-alkaline andesite, CB- calc-alkaline basalt, HHT- high iron tholeiite, HMT- high magnesium tholeiite, BK- basaltic komatiite and PK-peridotitic komatiite.

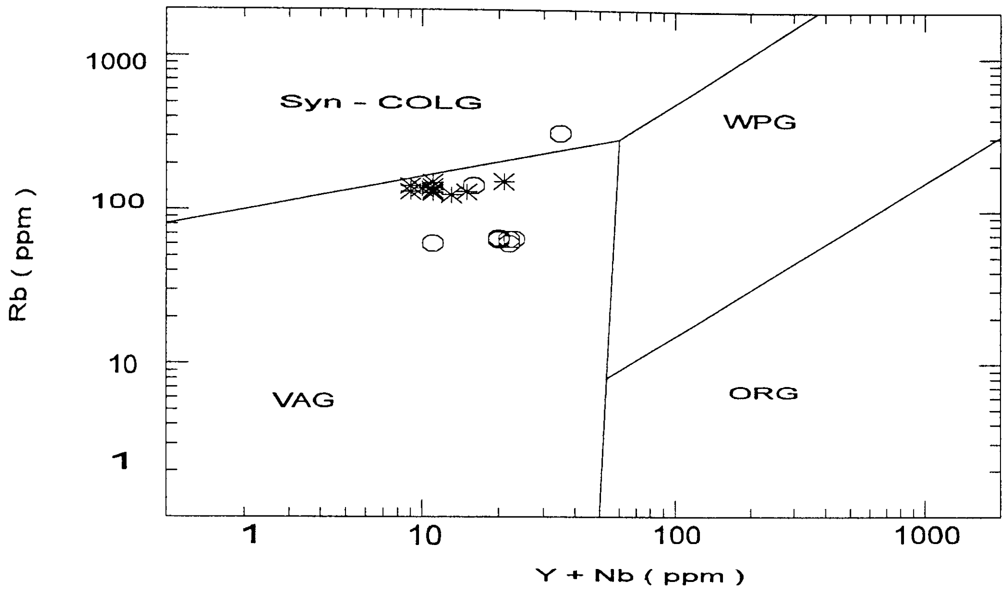

Figure 4.12: Plot of Vumba and Messica granitoids in the tectonic discriminant diagram after Pearce et al (1984). Asterix- Messica granitoids and open circle Vumba granitoids. Syn-Colg- Syn-collisional granitoids, WPG- within-plate granitoids, VAG- volcanic-arc granitoids and ORG- orogenic granitoids.

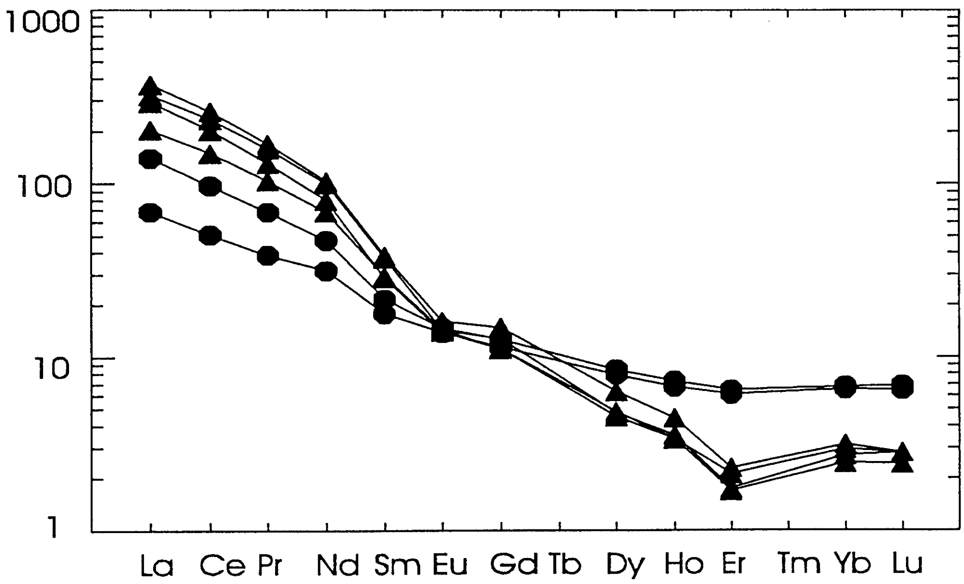

Figure 4.13: Chondrite normalized REE abundance diagram for Vumba (filled circles) and Messica (filled triangles) granitoids.

Six samples from the Vumba and Messica Granite Gneisses were analysed for the REE by Dr. N. Walsh (Royal Holloway, University of London) using the ICP method. The data are presented in the conventional chondrite-normalized diagram (normalising values after Evensen *et al.*, 1978) in Figure 4.13. The Messica Granite Gneiss samples show a pattern characterized by higher light REE and lower heavy REE contents compared to the Vumba Granite Gneiss samples. The Messica Granite Gneiss samples are characterized by a weak negative Eu anomaly suggesting either feldspar fractionation or residual feldspar in the restite whereas the Vumba Granite Gneiss samples have no Eu anomaly suggesting insignificant feldspar fractionation and/or insignificant feldspar residues in the source of the granite. The higher contents of heavy REE in the Vumba Granite Gneiss samples may suggest that garnet and/or hornblende fractionation or garnet and/or hornblende in the restite resulted in the depletion of these elements in the Messica Granite Gneiss compared to the Vumba Granite Gneiss.

4.4.4 Radiogenic isotope chemistry

For whole rock geochronology by the Rb - Sr method, 6 samples of Messica granitoids were analysed during the present study for their contents in Rb and Sr radiogenic isotopes (Table 4.5). The rocks were analysed by Dr. F.J. Kruger at the Bernard Price Institute, University of the Witwatersrand.

Table 4.5: Radiogenic isotope data of Messica granitoids.

Sample	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
pdgr1	134	203	2.0873	0.7824
pdgr2	126	223	1.8155	0.7749
pdgr3	132	203	2.1574	0.7863
pdgr4	131	204	2.0024	0.7797
pdgr5	132	253	1.6790	0.7691
pdgr6	129	194	1.9900	0.7842

Rb and Sr contents are in ppm.

Table 4.6: Radiogenic isotope data of Vumba granitoids.

Sample	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
S365	68	288	0.6820	0.7279
S150	56	279	0.5850	0.7303
S372	68	239	0.8260	0.7365
S90	81	235	1.1140	0.7374
S149	43	46	2.720	0.8122
S373	84	82	3.0780	0.8125
N14	88.2	153.6	1.6720	0.7753
N81	74	127.4	1.6920	0.7792
N407	80.4	74.2	3.180	0.8533
N406	76.8	65.6	3.4350	0.8592
N408	70.9	83.5	2.4830	0.8190

Data are from Manuel (1992). Rb and Sr contents are in ppm. An S prefix to the sample name denotes southern suite whereas an N denotes northern suite.

Regression of the data using the computer program GEODATE , written by Harmer and Eglington (1987) produced an errorchron of 2579Ma ± 468Ma with MSWD=6.611 and an initial $^{87}Sr/^{86}Sr$ =0.7054. Exclusion of sample Pdgr6, which is distinctly displaced from the other points (Fig. 4.14), from the regression calculation yields an isochron of 2348 Ma±267 Ma with MSWD=1.198 and an initial $^{87}Sr/^{86}Sr$ =0.7124. The sample can be excluded due to its apparent alteration and chloritization of biotite which may have affected the distribution of Rb. These data are compared with those of the Vumba granodiorite and tonalites from Manuel (1992) shown in table 4.6. The southern Vumba Granite Gneiss suite of Manuel (1992) was collected close to the Messica Granite Gneiss and the age they yielded (2527 Ma±632) is close to the date of 2348±267 of the Messica granitoids (Fig. 4.14).

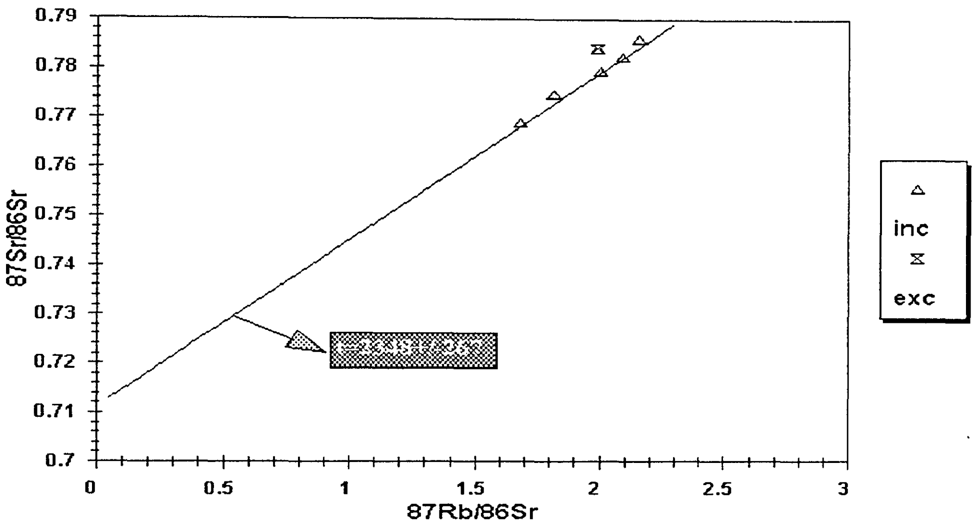

Figure 4.14: Rb/Sr isotopic diagram with the isochron t=2348±267 indicated. inc stands for data included and exc for data excluded.

The Rb contents of the Messica granitoids are ~2X higher than those from the Vumba granodiorites and tonalites whereas Sr is higher in most of the samples from the Vumba granodiorites and tonalites. With the exception of samples 149 and 373, the samples of Messica granitoids are characterized by higher $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios which is compatible with the Rb and Sr contents in these samples. The oldest granitoids in the study area are located north of the greenstones and were investigated by Manuel (1992) and Table 4.5 shows the corresponding radiogenic isotope analyses. The radiogenic isotope ratios of the oldest Vumba granites are of the same order of magnitude as those of Messica granitoids whereas Rb and Sr contents are approximately half the contents of the Messica Granite Gneiss.

The $^{87}Sr/^{86}Sr_i$ of 0.6947±0.0083 for the ~3385 Ma Vumba granitoids (Manuel, 1992), is similar to 0.6990 ± 0.00003 (McCulloch and Black, 1984) of the bulk earth, here taken as BABI (Basaltic Achondrite Best Initial), suggesting fractionation of these granitoids from the mantle. Conversely, the

^{87}Sr $^{86}Sr_i$ of 0.7124±0.0037 and 0.7122±0.0340 of the younger Messica and Vumba granitoids respectively, are significantly higher than that which granitic crust would have had if it separated from the mantle ca. 2.7 Ga ago (Rollinson, 1993) and higher than today's BABI of 0.7047-0.7050 ratios (Allegre *et al.*, 1983a), suggesting a derivation of these rocks from an environment with continental crust influence. In addition, the fact that the $^{87}Sr/^{86}Sr_i$ ratios of these granitoids are higher than present day's 0.7211 ratio of continental crust (Rollinson, 1993) is an indication that partial melting might have taken place in an already Rb enriched crust which, given the refractory nature of Sr, would give rise to a magma of an even higher relative Rb concentrations.

4.4.5 Discussion and Conclusions

The rocks are classified as granodiorites (Vumba granitoids) and monzogranites (Messica granitoids). Manuel (1992) described the Archaean Vumba granitoid as being tonalites and granodiorites, which combined with the findings of the present study, defines a tonalite-trondhjemite-granodiorite association often abbreviated to TTG (Jahn *et al.*, 1981), provided the definition of trondhjemite as a leucocratic tonalite (Barker, 1979) holds. This association is typical of many Archaean granitoid suits irrespective of their age and geographical position (Martin, 1987; Clarke, 1992, p. 198). Pinna *et al.* (1986), following previous workers, defined the Messica granitoid around Revue river as "remobilised porphyroblastic" and Manuel (1992) described the occurrence of a granite-gneiss north of the greenstones. It was found that the granitoids around the Revue river are typically porphyritic and foliated but are not banded. Elsewhere the Messica granitoid may be foliated but banding is not a common characteristic. In the Vumba granitoids, the hornblende granitoids exhibit a weak foliation defined by preferred orientation of hornblende crystals whereas the M'Kwananda locality shows a strong foliation and folding as well as jointing caused by deformation. Locally small shear zones occur but the common texture is that of a typical granite.

The Archaean TTG radiogenic isotope signatures are similar to those of the mantle (Clarke, 1992, p. 198) so that the initial $^{87}Sr/^{86}Sr_i$ ratio of the older Vumba granitoid of 0.694±0.0089 (Manuel, 1992) which is similar to 0.6989 ± 0.00003 (McCulloch and Black, 1984) of BABI suggests that they are product of mantle fractionation. This suggestion agrees with the results of the investigations into the petrogenesis of Archaean TTG from Eastern Finland carried out by Martin (1987). On the other hand the initial $^{87}Sr/^{86}Sr_i$ ratio of the Messica Granite Gneiss of 0.7124±0.00366 and of the younger late Archaean Vumba Granite Gneiss of 0.7212±0.0340 (Manuel, 1992) are too high and can'nt be assigned a mantle derivation suggesting that these granitoids were derived from a crust already enriched in Rb. The Messica monzogranites are younger and chemically more evolved, with higher $^{87}Sr/^{86}Sr_i$ ratios and a negative Eu anomaly. These characteristics would be consistent with them being a partial melt of a TTG rock suite in which feldspar would have been left in the residue.

In conclusion, it is proposed that the older TTG suite originated as partial melt of basaltic mantle material and the younger Vumba and Messica granitoids originated from partial melting of the older TTG suite.

Chapter 5

FRONTIER FORMATION

5.1 Introduction

The Frontier Formation has been viewed as a supracrustal sequence to the Mozambique Belt by previous workers (eg. Afonso, 1978). During the present study, however, it was found that this metasedimentary sequence only overlies the Early Proterozoic Messica Granite Gneiss around Garuzo and the greenstones in the Chimezi areas respectively (Fig. 2.1). Rocks in the sequence consist of quartzite and pelitic schists. No whole-rock chemical analyses were conducted with only selected minerals being analysed for the purposes of thermobarometry to be discussed later.

5.2 Field Description

The Frontier Formation rocks occur in the Garuzo region where they overlie the Messica Granite Gneiss and in Chimezi where they overlie serpentinites and schist of the Macequece Formation. In both localities, the exposures are oriented N-S (Fig. 2.1). The Frontier Formation consists of quartzite and mica schist. Quartzite is the predominant rock type and forms prominent ridges, very resistant to erosion (Fig. 5.1). Muscovite flakes exhibit a preferred foliation. Quartz grains are deformed and elongated along foliation planes. The rock is affected by conjugate joints. Texturally, the quartzite is equigranular coarse-grained. In the Chimezi area, the quartzite is grey and composed of very fine-grained quartz and muscovite interlayered with sillimanite/kyanite schist.

Figure 5.1: Resistant quartzite ridge in the Frontier Formation.

Around Garuzo, the schists are composed of alternating bands and lenses of quartz and sillimanite on one hand, and biotite and garnet on another. Sillimanite and biotite exhibit a preferred orientation. Quartz is deformed along foliation planes. The schist shows folding defined by felsic bands.

5.3 Petrography

Besides microscopic mineral identification, X-Ray diffraction methods were also used, particularly in fine grained samples (samples 31chgr1 and 31chgr2) collected in Chimezi (Fig. 2.2). The rocks have granoblastic and schistose textures in quartzite and mica sillimanite-bearing rocks respectively. They are coarse grained (±2 mm) at Garuzo and very fine grained at Chimezi. The mineralogy of the samples is shown in Table 5.1. The samples are all quartz rich, and they contain sillimanite+biotite and kyanite+sillimanite in Garuzo and Chimezi respectively. Garnet appears in samples from Garuzo whereas sericite is recognised in samples from Chimezi.

Table 5.1: Mineralogical assemblage of the Frontier Formation.

Sample	Qtz	Bt	Sil	Ky	Grt	Ms	Ser	Opm
GQZ	64	10	24	-	1	-	-	1
GSC	70	10	20	-	-	-	-	-
GCMX	72	10	15	-	2	-	-	1
GAQZ1	93	-	-	-	-	6	-	1
CHQZ	94	-	-	-	-	5	-	1
31CHQ1	85	-	3	10	-	-	2	-
31CHQ2	87	-	2	8	-	-	3	-

Qtz- quartz, Bt- biotite, Sil- sillimanite, Ky- kyanite, Grt- garnet, Ms- muscovite, Ser- sericite and Opm- opaque minerals.

Three parageneses are recognised, all being quartz-rich. The parageneses are (1) Qtz+Bt+Sil±Grt (2) Qtz+Ms (3) Qtz+Ser±Sil±Ky. Paragenesis (3) characterizes samples from Chimezi and the remaining paragenesis characterize samples from Garuzo. Quartz grains define granoblastic textures and show undulatory extinction resulting from high strain. Some samples have lenticular quartz grains which define a strong schistose planar fabric. Biotite exhibits a strong planar fabric defining a lepidoblastic texture. Sillimanite needles are parallel to biotite flakes with which they are commonly associated and are very fine grained in the west. The foliation defined by sillimanite and biotite wraps around garnet indicating that garnet was pre-tectonic and sillimanite+biotite probably syn-tectonic (Fig. 5.2) (Spry, 1979, p. 252-253; Shelley, 1993, p. 304-307). Kyanite occurs as anhedral fine grains with some larger grains exhibiting the typical two cleavages at about 75°. Irregular garnet grains contain inclusions of quartz. Muscovite occurs as flakes in and along quartz grain boundaries. Sericite is very fine-grained. Opaque minerals occur as fine xenoblastic to idioblastic grains as inclusions in quartz or associated with biotite.

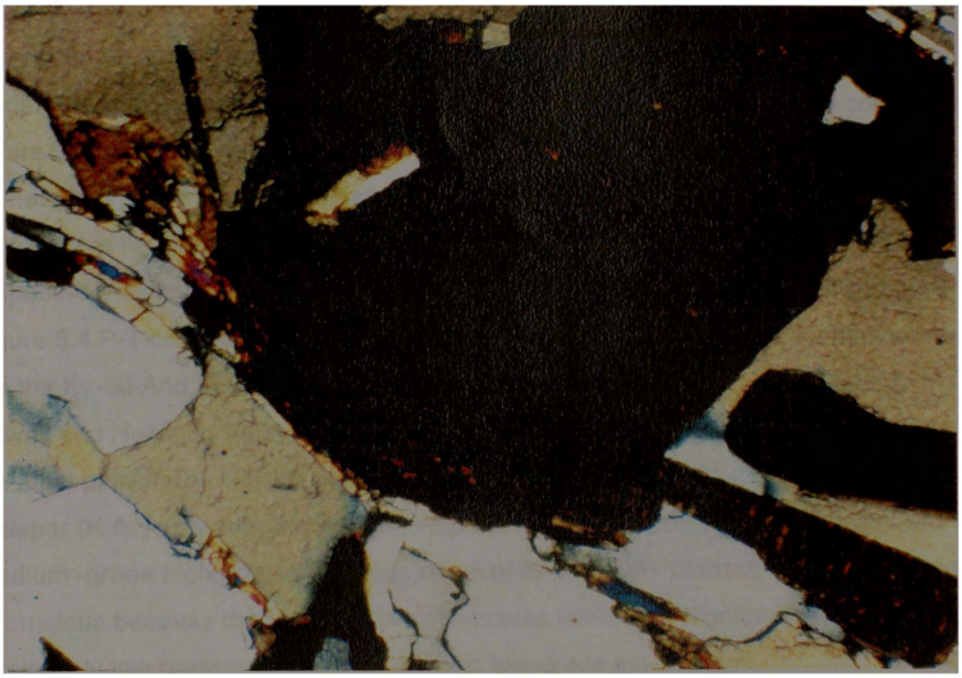

Figure 5.2: Biotite flakes (brown and partially extinct) and sillimanite needles (high birefringence) forming a foliation which wraps around a garnet grain (black). Crossed nicols; width of field 3 mm.

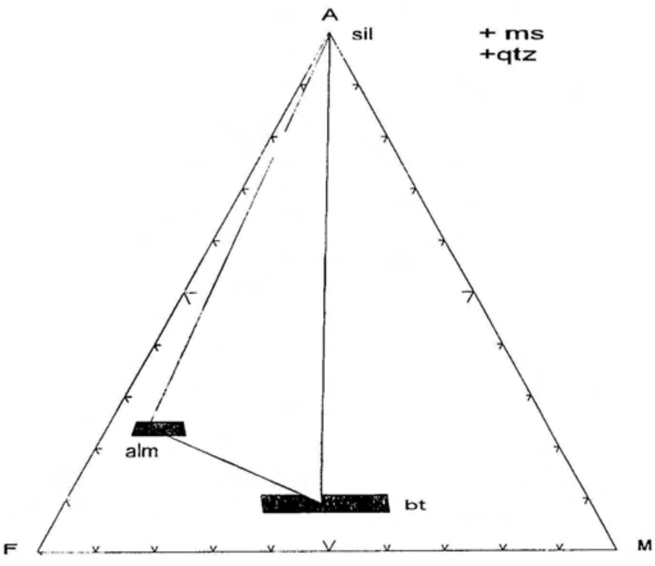

Figure 5.3: The medium- to high-grade mineral assemblage (bt+sil+alm) from the Frontier Formation, around Garuzo, plotted in an AFM diagram. Alm- almandine, bt- biotite, sil- sillimanite, qtz- quartz and ms- muscovite.

5.4 Interpretation

The assemblage (Bt+Sil+Grt) in the presence of quartz and muscovite (Fig. 5.3) is typical of upper medium-grade to high grade metamorphism (Winkler, 1974, p. 216). These conditions were attained before the tectonism/deformation that gave rise to the planar foliation since this wraps around cracked garnet (Spry, 1969). Application of computer programs of Powell and Holland (1988) and Berman (1991), give Ky-And-Sil triple points of P=~4.9 kbar and T=~582 °C, and P=~3.8 kbar and T=~506 °C respectively, calculated on the basis of mineral activities which are entered into the programs. In Figure 5.4 P-T conditions relevant to the metamorphism in the Frontier Formation are shown. Plotted are the Ky-Sil-And triple point and the equilibrium reaction Ms+Qtz->Kfld+Al_2SiO_5+H_2O calculated after Powell and Holland (1988). The diagram suggests that metamorphic conditions were below and above the triple point in the Garuzo and the Chimezi areas respectively. On the other hand, the absence of K-feldspar (K-fld) may suggest that the temperatures were not high enough to produce this mineral. The medium -grade high pressures assemblage of Sil+Ky in the Chimezi area can be considered anomalous because the Frontier Formation rocks overlie the Manica Greenstone Belt rocks which have a relatively low pressure andalusite-bearing low-grade assemblage.

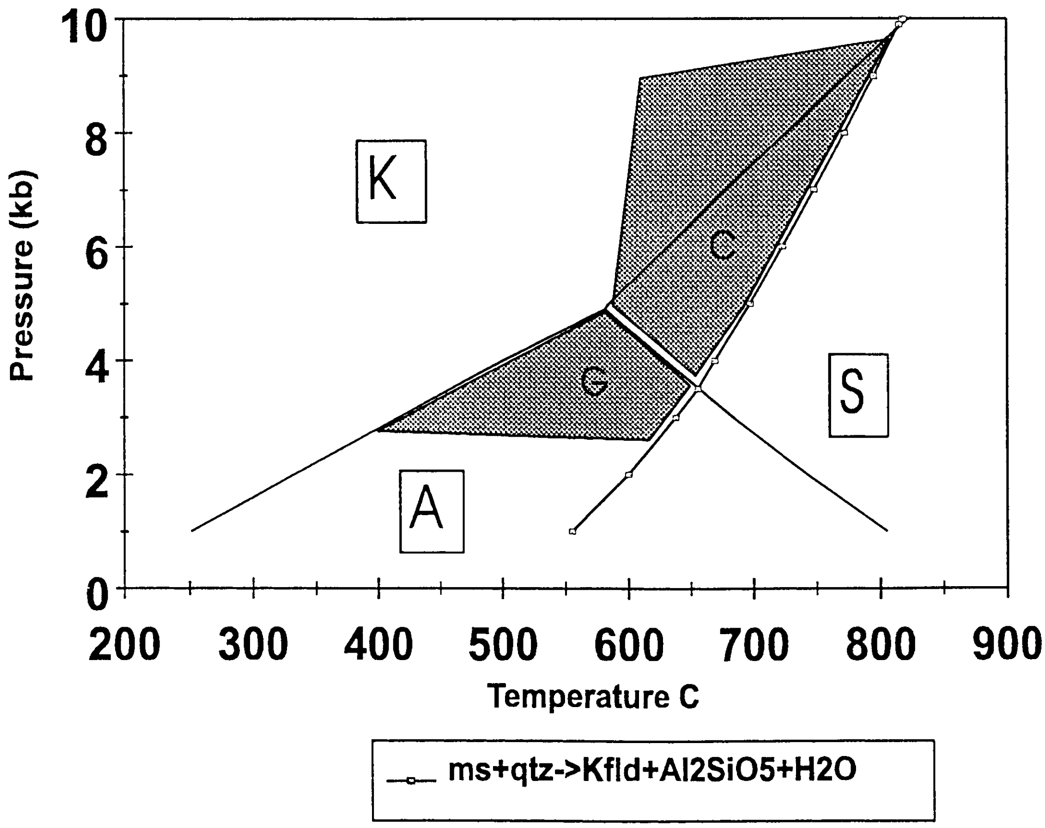

Figure 5.4: P-T conditions relevant to the Frontier Formation metamorphism in the Garuzo (G) and Chimezi (C) areas. And-Sil-Ky triple point as well as the reaction curve are afeter Powell and Holland (1988). Shown also are the fields of stability of kyanite (K), andalusite (A) and sillimanite (S).