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GRANITES OF ZAMBESIA (MOZAMBIQUE)

(6 Figs., 2 Tabs.)

Abstract: A chain known as the Namama Thrust Belt (NTB), itself a satellite of the larger Lurio Belt, developed towards the southern end of the Mozambique Belt about 1000 Ma ago. This orogenic development was preceded, accompanied and followed by the emplacement of various types of granite with different degrees of deformation, degrees of recrystallisation, emplacement mechanisms and levels, types of transition to the host rock, mineralogies and metallogenetic characters. They are thus distinguishable cartographically, albeit with a margin of uncertainty in individual bodies.

The petrographic and field data have been integrated with a chemical study, resulting in identification of the geodynamic setting of these rocks, all of which can be classed as subalkaline, mesoaluminous granites.

The Early Lurian granites were emplaced in a tensional phase immediately prior to the development of the NTB and accompanied by extrusion of a thin rhyolitic cover. They have a high HREE content, a low LREE-HREE ratio and a pronounced negative Eu anomaly. Their genesis appears to be referable to a process in which contributions from the mantle triggered limited melting in the deep crust.

In later of the orogeny, granite domes emplaced in a thickened crust. These are less evolved granites, with a higher Ca content and K/Na ratio: the negative Eu anomaly cannot be compared with that of the preceding granites. This array of characters (including the previously reported variation in strontium isotopic composition) points to an origin predominantly from deep crust materials. These granites appear to be coeval with a thermal peak most characteristically expressed in the metamorphic country basement as anhydrous parageneses with clinopyroxene and garnet.

Lastly, in Pan-African time s. s. (about 500 Mago), granites formed in discordant, shallow-emplaced bodies. Here some of the data (enrichment in LILE and LREE) indicating substantial crustal contamination and the establishment of a new extensional regime, but increased HFSE and HREE + Y point to a subcrustal contribution.

Key words: granites, Zambesia (Mozambique), geochemical characteristics, petrogenesis.

Introduction

Our previous papers have described the geology of a sector of the Mozambique crystalline basement located in the foreland of the already defined Lurio belt (Jourde, 1985). One particular feature of this work has been the identification of a Namama Thrust Belt (NTB) that developed in the Upper Proterozoic (1 Ga ago; Sacchi et al., 1984) in the footwall

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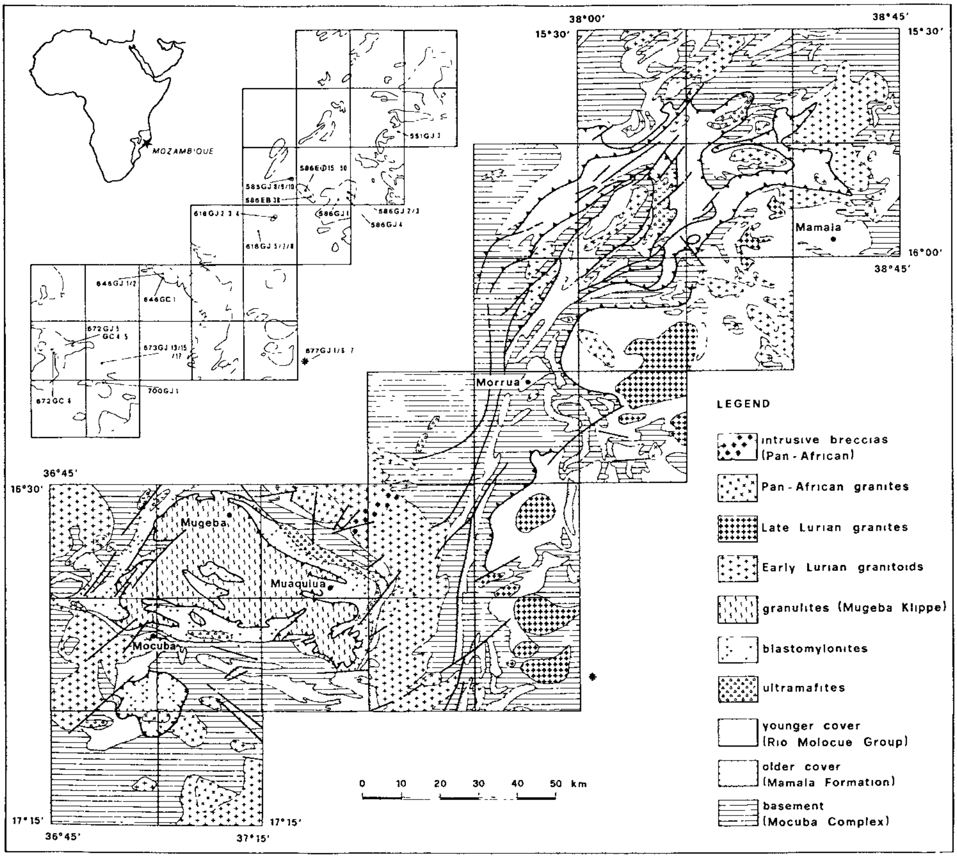


Fig. 1. Geological sketch map of the Namama Thrust Belt (Mozambique). Inset: outline of granite bodies and location of samples.

of the Lurio thrust. Some notable characteristics of its tectonic and metamorphic evolution have also been described (Cadoppi et al., 1987).

These papers pointed out that emplacement of granitic rocks both preceded and followed the compressive phase responsible for formation of the NTB. Both the field evidence and the radiometric data agree on this. The granites generated in different stages of the orogenic process are recognisable in the field, though not always and not without a certain degree of uncertainty. This recognition is based on both their relationship to the country rock, suggesting different depths of emplacement, and their stage of deformation. This paper presents further information on their chemical, mineralogical and textural features. The work involved has also led to the compilation shown in Fig. 1.

A brief account of the geology of this basement is necessary prior to giving a detailed description of the granites. The source of the following radiometric data is a paper by Costa et al. (1988), to which the reader should refer for more datailed information. As already stated, the NTB developed about 1000 Ma ago. At that time, the crust was composed of:

1. A crystalline basement (Mocuba Complex) consisting essentially of "biotite- and biotite hornblende gneiss with a diffuse, supposedly pre-Lurian migmatitic texture indicative of the attainment of a rather deep amphibolite grade" (Sacchi et al., 1984, p. 144; see also Cadoppi et al., 1987). Its deformation bears evidence of a complex evolution in which distinction of the Lurian and pre-Lurian effects is not always simple. These terrains are cut by basic dikes (now amphibolite), typically absent in the overlying units. The Mocuba Complex was mainly formed at the expense of magmatic rocks, whose short crustal residence is demonstrated by low SrRi values ($\approx$0.703). The whole-rock Rb-Sr regression line gives ages of 930 to 1000, regarded as the age of metamorphic re-equilibration. Costa et al. (1989) analysed four "mega-samples" defined by the mean 87Sr/86Sr and Rb/Sr ratios of four groups of samples, each group having been collected on a relatively small domain. The four megasamples yielded a regression line of 1560 $\pm$ 169 Ma, which the authors take to be the maximum age of the basement rocks (i.e., the age of their differentiation from the mantle).

2. A mainly rhyolite cover (now the meta-rhyolitic gneiss of the "Mamala Formation"), moderately deformed, massive to thinly bedded, leucocratic gneiss whose chemistry and (poorly preserved) primary textures suggest a rhyolite to rhyolite-tuff protolith.

3. A younger, epicontinental, thin, detrital cover (Molocue Group), composed of pelites and various sandstones, whose sedimentation was probably interrupted by the Lurian compressive tectonics. This Group included a sequence with ophiolitic affinity (the Morrua Complex), consisting (Sacchi et al., 1984, p. 145) of "ultramafic rocks (. . .) transformed into amphibolite asbestos with anthophyllite or an actinolitic amphibolite, or both (. . .); metagabbro with a well-preserved texture; various, generally fine-grained amphibolites (meta-basalts?); highly impure quartzite alternating and intermingled with pyroxene-amphibole-epidote layers that suggest a derivation from siliceous sediments with pyroclastic additions". Only the ultramafites are shown in the geological sketch map of our Fig. 1, since other lithologies are not exposed over a mappable area.

The original relationship of the Morrua Complex to the associated metasediments is now obliterated by thrust tectonics. The same authors hold that it was generated during an extensional phase in a thinned crust domain destined to determine the location of the future NTB. Rocks from units 2 (metarhyolitic gneiss) and 3 (impure quartzite of the Morrua Complex) yielded Rb/Sr, whole-rock isochron, ages of 1003 $\pm$ 24 and 963 $\pm$ 23 respectively, taken as dating the peak of "Lurian" metamorphism.

4. Granite and granodiorite intrusives in (1) (here called Early Lurian). Two isochron ages of c. 1060 Ma are regarded as ages of emplacement (Costa et al., 1988).

5. An allochthonous, granulitic unit (Mugeba Klippe). It can be assumed, on metamorphic grounds, that this Klippe extended to the site of the NTB (Cadoppi et al., 1987).

The NTB consists of a pile of thrust sheets composed of basement and cover rocks. We have already described the associated metamorphism (Cadoppi et al., 1987), namely high-gradient assemblages pointing to rapid erosion of the still forming chain.

The thermal peak is clearly postkinematic on fabric grounds (Sacchi et al., 1984). Development of the NTB took place after emplacement of the Early Lurian granitoids and before the thermal peak. It is thus bracketed in the period 1060–960 Ma.

The undeformed granites were emplaced after this tectonism. Their characters enable two types to be distinguished (Late Lurian and Pan-African).

The granites

Early Lurian granitoids

Their deformation and metamorphism make it clear that these are the oldest of the three types. They form very extensive bodies primarily located in the NTB hinterland, where their outcrop pattern points to control by early structures trending NW–SE. The subsequent development of the NTB makes this pattern unclear; this point will be discussed later.

Early Lurian granites typically display stretching and/or planar fabric with development of platy quartz. Biotite forms thin seams less frequently than scattered, parallel lamellae. This deformation picture is not universal, however, and is relatively simple compared with that of the surrounding metamorphites. Stretching lineation displays little scatter around a WNW-ESE regional maximum, which we have interpreted as a transport direction. Dome-like structures are occasionally preserved. A more substantial, clearly metamorphic, flaser-type, planar fabric is observed in the NTB.

The main type is a microcline biotite (hornblende) granite (to granodiorite), often rich in melanocratic schlieren, locally greenish owing to its epidote content, often showing ghost migmatitic textures. The grain size is medium to coarse in the aphyric type, but there are porphyric granites as well.

The microfabric is generally granoblastic; the metamorphic hornblende displays a random orientation and all the features of a late-phase growth.

Hornblende is not the only post-kinematic mineral. There are indications that these granites pre-date the growth of the andradite–hedenbergite assemblage described by Cadoppi et al. (1987) as the product of the uplif-related, thermal peak of the Lurian-age metamorphism.

Late Lurian granites

This group comprises granites forming large dome-like structures in the NTB foreland. In the field, their substantial absence of deformation distinguishes them from the Early Lurian granites. Planar anisotropy (when present) is weak and restricted to the periphery. These granite bodies induce modifications in the country rock (generally a leuco-gneiss of the Mamala Formation) observable over a considerable distance (up to 1 km) from the granite boundary. The parallel texture of the gneiss is, in fact, obliterated or is preserved only as relics and ghosts giving the gneiss a migmatitic (nebulitic) appearance. The grain size is highly variable in these domains; the presence of pegmatite-like, quartz-feldspar mobilizates is frequent. The modifications fade away from the granite boundary, resulting in an indistinct gradation into "normal" country rock. Altogether, we are faced with implications of partial melting and/or metasomatic alteration. Small bodies of (hornblende and biotite) granodiorite are confined to the southern portion of the NTB.

These granites lack the metamorphic assemblages found in the Early Lurian granites and mainly consist of rather fine-grained, locally porphyritic, microcline-, biotite- leucogranites with a very little amount of accessory minerals. They are regarded by Cadoppi et al. (1987) as Lurian-cycle end-products, roughly coeval with the thermal peak and with the uplift and erosion stage.

The Sr isotope ratios for this group of rocks did not yield an isochron. According to Costa et al. (1988), they indicate that the age of these granites is greater than that of the Pan-African event, but less than that of the Lurian event.

Pan-African granites

This group comprises granites whose characters and radiometric dates enable them to be

Table 1
Chemical data

	MAMALA FORMATION				PAN-AFRICAN GRANITES												
					646			UAPE'			677			MAMASSUPA			700
	618GJ5	618GJ7	618GJ8	551GJ3	646GC1	646GJ1	646GJ2	585GJ8	585GJ9	585GJ10	677GJ1	677GJ6	677GJ7	586E15	586E50	586EB38	700GJ1
SiO_2	73.09	75.05	74.25	77.00	71.03	72.37	70.50	73.87	71.75	68.71	73.95	72.22	70.17	72.33	71.07	72.96	69.78
TiO_2	0.22	0.14	0.27	0.18	0.31	0.29	0.46	0.21	0.24	0.29	0.31	0.27	0.40	0.30	0.25	0.27	0.55
Al_2O_3	13.01	12.44	12.79	12.14	14.18	14.46	14.25	14.09	13.82	13.81	12.61	13.62	14.00	13.74	14.03	14.18	14.71
FeO^*	1.92	1.45	2.29	1.81	2.26	2.23	2.67	1.90	1.68	2.16	1.91	2.07	2.60	1.81	1.65	1.84	3.25
MnO	0.06	0.05	0.05	0.04	0.03	0.08	0.08	0.04	0.04	0.05	0.04	0.05	0.06	0.05	0.05	0.05	0.09
MgO	0.27	0.15	0.29	0.00	0.43	0.50	0.61	0.31	0.30	0.32	0.26	0.33	0.60	0.47	0.35	0.48	0.65
CaO	0.55	0.26	1.17	0.36	1.32	1.18	1.41	1.16	1.17	1.17	1.01	1.36	1.57	0.51	0.93	0.94	1.55
Na_2O	3.99	3.79	3.50	3.71	3.10	2.86	3.31	3.73	3.77	3.72	2.91	3.26	3.31	3.54	3.70	3.67	3.51
K_2O	5.00	4.87	4.45	4.70	5.84	5.50	5.44	5.15	4.86	4.66	4.98	4.83	4.88	5.16	5.11	5.08	4.91
P_2O_5	0.04	0.02	0.02	0.03	0.07	0.11	0.14	0.06	0.09	0.17	0.07	0.12	0.17	0.14	0.12	0.11	0.17
H_2O+	0.43	0.53	0.51	0.48	1.15	0.87	1.19	0.45	1.84	1.00	0.69	1.58	1.72	1.63	2.27	0.58	0.87
Total	98.58	98.75	99.59	100.45	99.72	100.45	100.06	100.07	99.56	96.06	98.74	99.71	99.48	99.68	99.53	100.16	100.04
Ba	554	153	279	419	1065	–	–	865	951	1315	585	785	894	795	785	738	–
Sr	25	16	67	35	224	204	216	397	440	551	164	231	266	261	274	223	287
Rb	170	217	158	215	263	242	244	304	241	252	175	188	191	328	333	317	282
Y	53.27	45.49	46.50	94.46	9.05	10.50	11.47	22.06	25.33	18.04	11.78	18.05	22.33	25.05	17.17	32.47	14.81
La	49.78	40.33	46.23	43.56	92.95	106.85	127.24	81.39	86.32	146.87	46.73	43.76	62.09	112.07	47.24	70.42	114.50
Ce	107.76	103.34	93.14	94.17	160.79	171.61	214.10	140.99	142.68	244.88	86.31	81.33	113.13	156.79	101.24	111.78	169.40
Nd	55.27	42.60	45.54	44.18	56.84	67.80	79.29	60.44	55.56	87.41	33.23	34.18	45.38	67.61	32.48	42.26	62.87
Sm	11.28	8.94	9.45	10.48	8.25	10.11	11.53	10.18	9.34	12.72	5.68	6.22	8.02	10.40	5.96	7.82	9.57
Eu	1.49	0.60	0.80	0.72	1.28	1.03	1.50	2.05	1.83	2.64	0.87	1.19	1.30	1.48	1.06	1.19	1.66
Gd	9.38	7.43	7.88	9.21	4.53	5.50	6.28	6.05	5.90	7.29	3.71	4.48	5.57	6.67	4.23	6.06	5.69
Dy	8.58	7.14	7.38	11.10	1.70	2.09	2.29	3.68	3.83	3.16	2.03	3.04	3.78	3.82	2.56	4.32	2.60
Er	4.54	3.94	3.90	6.94	0.78	0.89	0.99	1.64	1.83	1.26	0.95	1.36	1.72	1.82	1.25	2.12	1.06
Yb	4.83	4.46	4.22	8.72	0.80	0.91	0.96	1.68	2.02	1.16	1.04	1.25	1.58	1.90	1.35	2.23	0.94
Lu	0.61	0.62	0.59	1.26	0.11	0.13	0.16	0.29	0.27	0.16	0.17	0.20	0.25	0.27	0.19	0.34	0.16
ΣREE	253.52	219.40	219.13	230.34	328.03	366.92	444.34	308.39	309.58	507.55	180.72	177.01	242.82	362.83	197.56	248.54	368.45
La/Yb	10.31	9.04	10.95	4.99	116.19	117.42	132.54	48.45	42.73	126.61	44.93	35.01	39.30	58.98	34.99	31.58	121.181

continuation of Tab. 1

	LATE LURIAN GRANITES							EARLY LURIAN GRANITOIDS				PRE-LURIAN MIGMATITES		
	586				618									
	586GJ1	586GJ2	586GJ3	586GJ4	618GJ2	618GJ3	618GJ4	672GJ5	672GC4	672GC5	672GC6	673GJ13	673GJ15	673GJ17
SiO_2	71.64	71.33	69.42	69 60	72 22	70.31	71.42	71.95	73 68	73 58	73 73	69 95	68 90	68.04
TiO_2	0.33	0.46	0.33	0 32	0 27	0.32	0.23	0.23	0 21	0.20	0 17	0 49	0 38	0.44
Al_2O_3	15.11	14.43	15.10	14 70	14.36	15.32	14.35	13 14	13 35	13 47	13.59	15 63	15 11	16.46
FeO*	2.03	2 96	2 38	2 24	1 73	2.42	1.84	2 55	2 32	2 19	1 92	2 32	2 16	2 77
MnO	0.04	0.06	0 05	0 04	0.03	0.05	0.04	0.06	0 04	0 04	0.03	0 05	0 05	0 06
MgO	0.48	0 86	0.88	0.36	0.70	1 10	0 84	0 13	0.13	0.13	0.12	0.75	0.35	0.83
CaO	1 90	1.62	2 22	2.01	1.74	2.31	1.67	0.82	0.88	0.88	0.83	2.38	1.93	2.64
Na_2O	4 18	3.68	4.40	4.17	4.29	4.41	4.13	3.41	3.29	3.23	3.53	4.90	4.68	4.84
K_2O	3.37	4.12	2.98	3.42	3 29	3.19	3.70	5.45	5.76	5.76	5.75	2.77	3.11	1.87
P_2O_5	0.12	0.20	0.14	0.10	0 18	0 08	0.04	0.02	0.03	0.03	0.03	0 14	0.12	0 09
H_2O+	0 57	0.68	1.65	1 68	1 28	0 60	0 49	0 79	0.39	0 55	0 35	0 69	1 71	0 90
Total	99 77	100 40	99 55	98 64	100.09	100.11	98 75	98 55	100 08	100 06	100.05	100.07	98 50	98.94
Ba	766	1261	728	815	643	925	749	329	–	–	–	555	638	384
Sr	250	234	303	274	280	360	289	60	50	50	46	494	370	587
Rb	125	188	122	118	117	122	136	187	191	189	209	54	50	46
Y	8 38	12.94	7.49	8.81	5 86	10.83	8.52	52 82	43 67	30 89	26 70	12 73	11 37	16 42
La	25.97	42.12	26 65	36 06	15.50	23.96	20.40	98.92	88 35	75 27	61 74	16.62	15.54	26.48
Ce	53.04	75.10	57.32	63.89	25.96	42.08	36.75	173 26	155 43	138.38	128 20	32.64	30.05	46.05
Nd	20.43	30.57	20 69	25 65	8.88	16.33	14.59	73 99	66.55	60 57	54.19	16.22	13.62	25.42
Sm	3.63	5.01	3 56	4.51	1.69	3.18	2.64	13 83	12.35	11 64	10.01	3.26	2.83	5.14
Eu	0.67	0.85	0.86	0.86	0.64	0 78	0.71	1.32	0.99	1 11	0 87	0 87	0 82	1 09
Gd	2.37	3.46	2.42	2.95	1 20	2.36	1.83	10.18	8 72	9 02	6 68	2 43	2.23	3 77
Dy	1.45	2.09	1.22	1.44	0.79	1.62	1.27	7.71	6.84	7.52	5 04	1 84	1 54	2.68
Er	0.66	0.95	0.58	0.71	0 48	0 82	0.69	3.94	3.17	3 81	2 33	0 94	0.87	1.28
Yb	0.61	0.97	0.72	0.72	0 57	0.91	0.79	4.18	3 31	3 61	2 65	1.08	1.01	1.22
Lu	0.11	0.17	0.10	0 12	0 10	0.13	0.06	0.61	0 49	0 49	0 36	0.16	0.17	0.20
ΣREE	108.94	161 29	114 12	136.91	55.81	92 17	79.73	387 94	346.20	311.42	272.07	76.06	68.68	113 33
La/Yb	42 57	43.42	37.01	50.08	27.19	26.33	25.82	23.67	26.69	20.85	23 30	15 39	15 39	21.70

Table 2

Average values for the single granitic groups. Nb (*) and Zr (*) data are averaged from a set of samples representative of the same lithologic units but not the same as those used to average the other chemical data

	MAMALA FORMATION	PAN-AFRICAN GRANITES					LATE LURIAN GRANITES		EARLY LURIAN GRANITOIDS	PRE--LURIAN MIGMATITES
		646	UAPE'	677	NAMASSUPA	700	586	618		
SiO_2	74.85	71.30	71.44	72.11	72.12	69.78	70.50	71.32	73.24	68.96
TiO_2	0.20	0.35	0.25	0.33	0.27	0.55	0.36	0.27	0.20	0.44
Al_2O_3	12.60	14.30	13.91	13.41	13.98	14.71	14.84	14.68	13.39	15 73
FeO^*	1.87	2.39	1.91	2.19	1.77	3.25	2.40	2 00	2.25	2.42
MnO	0.05	0.06	0.04	0.05	0.05	0.09	0.05	0.04	0.04	0.05
MgO	0.18	0.51	0.30	0.40	0.43	0.65	0.65	0.88	0.13	0.64
CaO	0.59	1.30	1.17	1.31	0.79	1.55	1.94	1.91	0.85	2.32
Na_2O	3.75	3.09	3.74	3.16	3.64	3.51	4.11	4.28	3.37	4.81
K_2O	4.76	5.59	4 89	4.90	5.12	4.91	3.47	3.39	5.68	2.58
P_2O_5	0.03	0.11	0.11	0 12	0.12	0.17	0.14	0.10	0.03	0.12
H_2O^+	0.49	1.07	1 10	1.33	1.49	0.87	1.15	0.79	0.52	1.10
Total	99.37	100.07	98.86	99 31	99.78	100.04	99.61	99.66	99.70	99.17
Ba	351	1065	1044	755	773	–	893	772	329	526
Sr	36	215	463	220	253	287	256	310	52	484
Rb	190	250	266	185	326	282	138	125	194	50
Y	59.93	10.34	21.81	17.39	24 90	14.81	9.41	8.40	38.52	13 51
Nb(*)	–	–	43	–	–	–	24	–	–	–
Zr(*)	–	–	244	–	–	–	210	–	–	–
La	44.98	109.01	104.86	50.86	76.58	114.50	32.70	19 95	81.07	19.55
Ce	99.60	182.17	176.18	93.59	123.27	169.40	62.34	34.93	148.82	36.25
Nd	46.90	67.98	67.80	37.60	47.45	62.87	24.33	13.27	63.83	18.42
Sm	10.04	9.96	10.75	6.64	8.06	9.57	4.18	2.50	11.96	3.74
Eu	0.90	1.27	2 17	1.12	1.24	1.66	0.81	0.71	1.07	0.93
Gd	8.47	5.44	6.41	4.59	5.65	5.69	2.80	1.80	8.65	2.81
Dy	8.55	2.03	3.56	2.95	3.57	2.60	1.55	1.23	6.78	2.02
Er	4.83	0.89	1.58	1.34	1.73	1.06	0.73	0.66	3.31	1.03
Yb	5.56	0.89	1.62	1.29	1.83	0.94	0.76	0.76	3.44	1.10
Lu	0.77	0.13	0.24	0.21	0.27	0.16	0.13	0.10	0.49	0.18
ΣREE	230.60	379.77	375.17	200.19	269.65	368.45	130.33	75.91	329.42	86.03
La/Yb	8.09	122.48	64.73	39.43	41.85	121.81	43.03	26.25	23.57	17.77

regarded as the youngest of the series; cf. the ≈ 500 Ma isochron from the Mt. Uapé body, reported by Costa et al. (1988). They are usually rather coarse-grained, isotropic, sometimes porphyritic, sometimes with red feldspar, and sometimes with host-rock xenoliths. Biotite is the only mafic mineral. Orthoclase is occasionally preserved; elsewhere all that remains is its shape and albite-Karlsbad twinning, whereas the mineral has gone into microcline. An hypidiomorphic structure, too, may sometimes be observed.

Pan-African granites form small, typically discordant bodies, mapped with subcircular outlines. Their passage to the country rock is usually abrupt, sometimes via a band rich in feldspar megacrysts. A very clear picture of stoping associated with hydraulic fracturing is sometimes noted (in Fig. 1 "intrusive breccias"). The country rock near the contact occasionally displays a reduction of grain size and a hornfels appearance.

Cadoppi et al. (1987) consider that these granites were emplaced under postkinematic conditions at a shallow level following substantial uplift and erosion of the NTB.

Geochemistry

A number of chemical analyses were performed on representative samples of these intrusive bodies, migmatites and metavolcanics. Major and trace elements, as well as REE, were determined in the CRPG Laboratory at Nancy (France).

The plots and the Tab. 1 report a set of 31 representative chemical analyses, whilst averaged values for the different units are also shoun in Tab. 2.

Geochemical characteristics

All samples analyzed can be classified as subalkaline (Fig. 2) meta-aluminous (1<A/CNK<1 . 1), granitic rocks (SiO_2 69 ÷ 79%) (Tabs. 1 and 2).

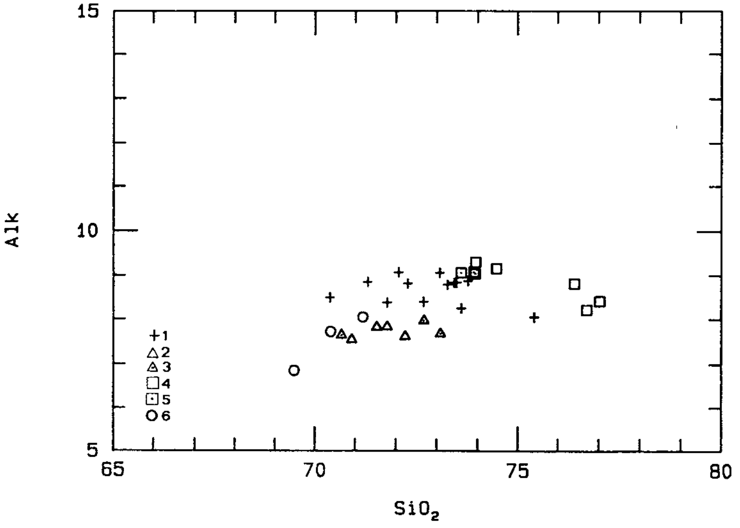


Fig. 2. Total alkalies vs silica diagram.
Symbols: 1 – Pan-African granites; 2 – Late Lurian granites ("586 group"); 3 – Late Lurian granites ("618 group"); 4 – Mamala Formation; 5 – Early Lurian granitoids; 6 – Pre-Lurian migmatites.

For the sake of completeness, we also analysed samples of some migmatites of granitic composition from the Mocuba Complex. These are clearly characterized by their high CaO, Na_2O and Sr and low Rb contents (Figs. 3 and 4), suggesting a plagioclase-rich (somewhat restitic) character.

The low LREE/HREE (Fig. 5b) ratio and the virtual absence of Eu anomaly could be due to a limited episode of depletion, leaving a plagioclase + amphibole + biotite-enriched assemblage.

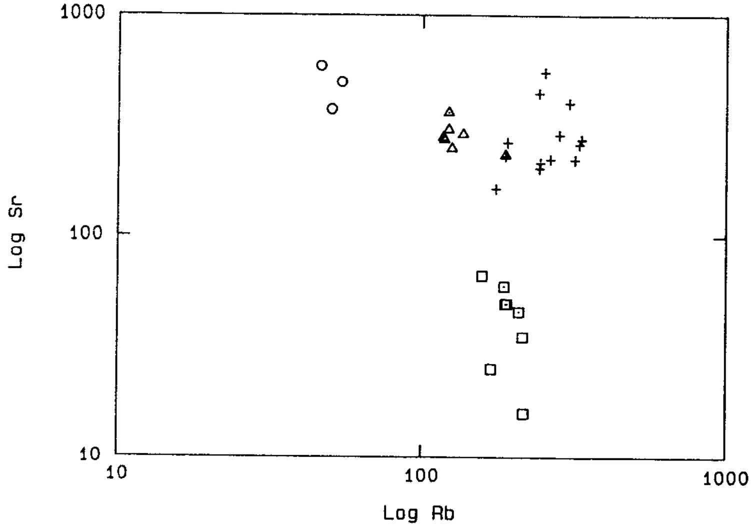


Fig. 3. Log Rb vs Log Sr.
Symbols as in Fig. 2.

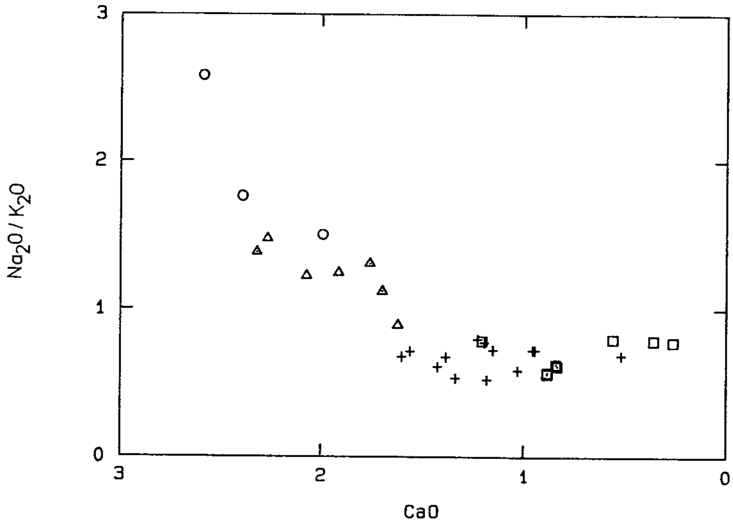
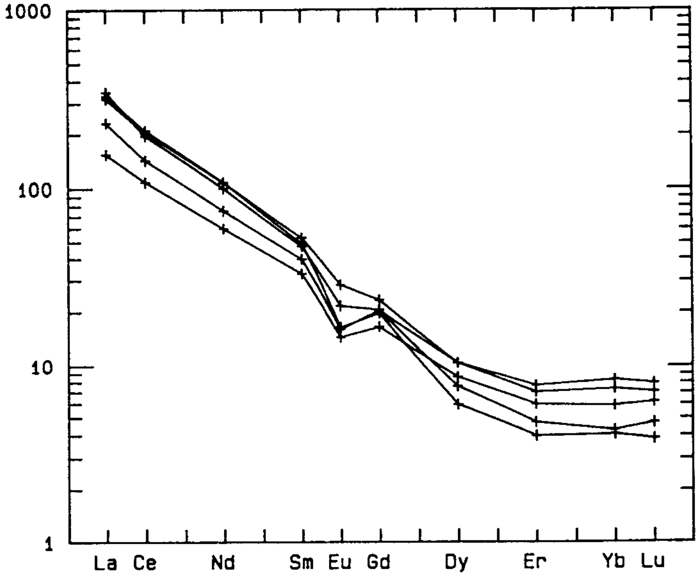


Fig. 4 Na_2O/K_2O ratio against CaO content.
Symbols as in Fig. 2.



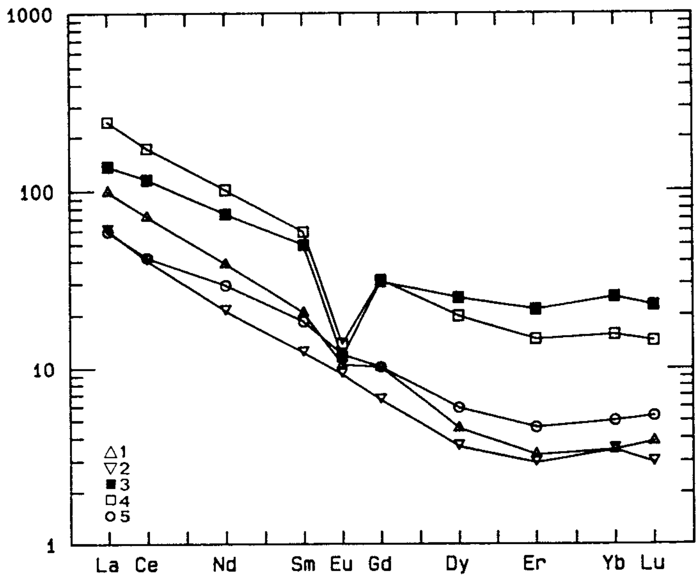


Fig. 5. Chondrite normalized REE patterns. The single curves average several values from the same body (5a) and the same granite type (5b).

a) Pan-African granites.

b) 1 – Late Lurian granites ("586 group"); 2 – Late Lurian granites ("618 group"); 3 – Mamala Formation; 4 – Early Lurian granitoids; 5 – Pre-Lurian migmatites. Dashed area: variation field of the Pan-African granites (from Fig. 5a).

Early Lurian granitoids and meta-rhyolites

The Early Lurian granitoids and the metavolcanic rocks of the Mamala Formation are represented by the more evolved samples. It is interesting to point out that there is a strong similarity in all their geochemical characteristics and trends.

This cogenetic relationship has been already suggested by Costa et al. (1988), on geological and radiometric grounds.

The most important feature is represented by a rather high HREE content and low LREE/HREE ratio (Fig. 5b); feldspar fractionation played an important role in the differentiation, as clearly seen in the marked Eu anomaly.

Late Lurian granites

Late Lurian granites were separated on the ground of geological and petrological data. By comparison with the Early Lurian granites, they are less evolved, with a higher CaO content and a higher K_2O/Na_2O ratio (Fig. 4).

Despite their granitic character, they do not display a negative Eu anomaly comparable with that of the Early Lurian granitoids of the Mamala Formation.

Groups of granitoids that can be geochemically likened to the Late Lurian granites are the samples from Sheet 618 (GJ2/3/4, Tab. 1; these form the Mt. Morrua pluton (SE of Morrua village)), their state of deformation is similar to the Pre-Lurian granitois in the field.

Pan-African granites

The Pan-African granites as a whole show similar geochemical characteristics, even if some scatter is present in the LILE elements data.

The single granitic bodies show minor differences, especially in LILE content, but give consistent REE patterns, with marked LREE enrichment and high LREE/HREE ratio.

Some petrogenetic considerations

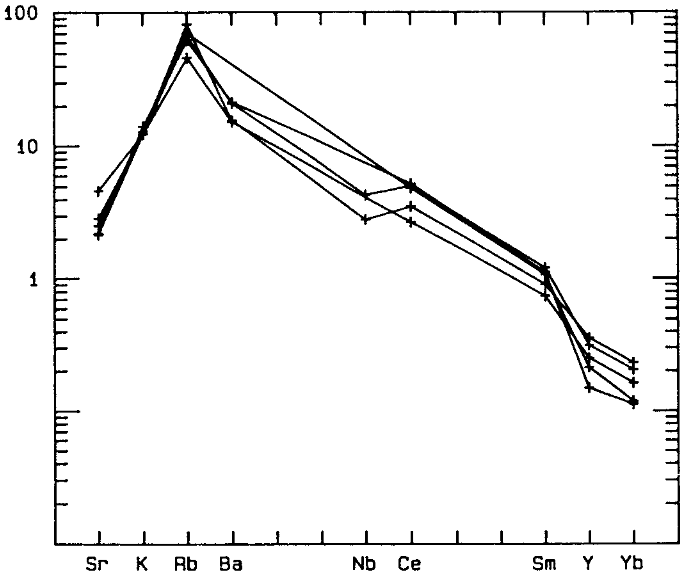
Following the suggestions of Pearce et al. (1984) and Harris et al. (1986), we plotted the averaged values of own samples in a "spidergram" form, normalized to an hypothetical ocean-ridge (ORG) granite (Fig. 6).

Early Lurian and Mamala rocks show a limited LILE enrichment with respect to the HFSE, with ≈ 1*ORG values from Ce to Yb.

The field evidence suggests the association of this cogenetic granitic rhyolitic suite with intermediate intrusives; the radiometric geochronological data suggest that a relation can also be established with the basic magmatism represented in the Morrua Complex. We could regard the relatively high HFSE and HREE contents as "mantle derived" features; a "two-step" process, with mantle melts triggering and reacting with limited lower crustal melt could account for all the above characteristics.

For the Late Lurian granites, even in the absence of an isotopic Sr initial ratio, we can suggest as the main source material a lower crustal sequence, as indicated by the isotopic heterogeneity reported by Costa et al. (1988).

The patterns of the "Sheet 618" group are more difficult to interpret. We can rule out any close genetic relationship with the Early Lurian and Mamala Formation rocks; the more depleted HREE and HFSE patterns can only be explained if by assumingme different sources. Their close similarity with the Late Lurian granitoids has already been stressed; a similar genetic interpretation could be applied, too.



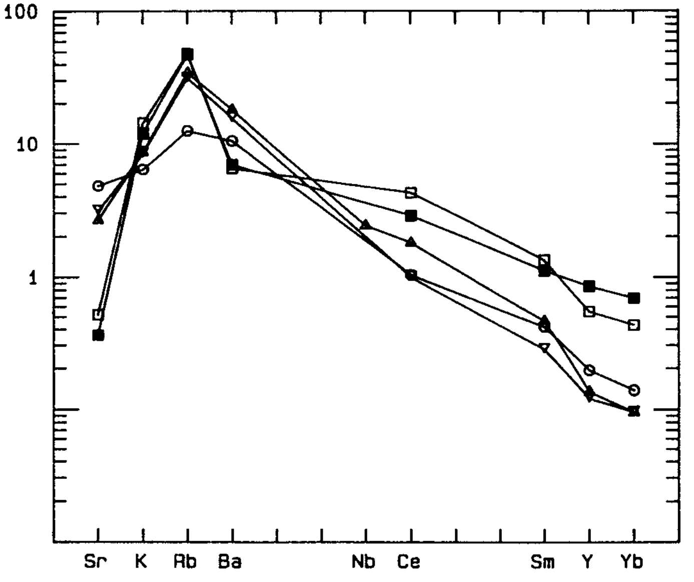


Fig. 6. Average values of the different granitic groups normalized to Ocean Ridge Granites (Harris et al., 1986).

a) Pan-African granites.

b) All the groups (symbols as in Fig. 5b).

The Pan-African granites show an overall character of a LILE and LREE enriched source; on isotopic grounds, we can again assume a crustal contribution as the main controlling factor of the geochemistry. Nevertheless, a limited increase in the HFSE and HREE + Y could indicate a possible contribution of subcrustal melts with a geochemical signature suggesting the incoming of a new, extensional regime with growing influence of "intraplate", HFSE-rich subcrustal magmas.

Conclusions

A tentative interpretation of the long history of granite intrusion in the Province of Zambesia can be advanced in the light of the geological and geochemical evidence set out above.

The most ancient granites (Early Lurian) were emplaced during a phase only a few tens of Ma earlier than the establishment of an orogenic regime.

An island arc origin would seem less likely in view of the substantial absence of andesitic magmatities l. s.

In addition, the (meta)-rhyolites of the Mamala Formation are also part of the Early Lurian granites cycle. Stratigraphically speaking, they underlie (with no detectable temporal break) a sequence also emplaced in an extensional regime evidenced by an embryonic ocean development (the Molocue Group plus the Morrua Formation). Taken as a whole, this is indicative of substantial bimodality.

Lastly, when seen in the field, certain Early Lurian occurrences display an undeniable link with the migmatites, and appear to have been derived from them by partial melting in situ.

Taken together these characters indicate genesis in a pre-orogenic extensional regime arising from the partial melting of a LILE depleted deep crust, coupled with a mantle contribution in the form of mafic melts and the surplus heat needed to bring about extensive crustal fusion.

Cadoppi et al. (1987) have underscored the affinities between this episode and that in the Burundi Kibaran chain described by Klerkx et al. (1984).

Structural thickening associated with formation of the NTB does not appear to have been itself responsible for the generation of granite melts, since there are no granites indicative of genesis in an intermediate crust environment. The second generation of granites was produced under late (or possible post-) orogenic conditions. This is clear from their lack of deformation, signs of a genetic link with the development of post-kinematic, hot, anhydrous, prograde parageneses, and the absence of distinctly "concordant" granite bodies. The geochemistry points to a deep crust genesis with possible contributions from the mantle. The form of the granites – large, dome-shaped bodies – is itself a hint of emplacement in non-shallow conditions, prior to the establishment of an extensional stress regime (cf. Castro, 1987). The width of the belt within which these granite bodies have induced changes in the host rock also suggests a deep environment of emplacement.

One must thus ask what kind of geodynamic process could have produced this sequence of granites. In an earlier paper (Cadoppi et al., 1987), we cited the "Damara model" as the prototype of the evolution we described. The Late Lurian granites are comparable with those of phase 5 of the episode described by Kröner (1982, p. 1502): "Subcrustal heating following delamination and lateral spreading of asthenospheric material, combined with crustal thickening as a result of continental subduction, caused partial melting in the crust and at the crust/mantle boundary, thereby producing the family of syn- to post-tectonic granites of the Damara belt between about 650 and 450 Ma ago".

Our Late Lurian granites, however, display a less marked crustal character in keeping with genesis in deeper, depleted crust and hence a greater influence of deep heat-source compared with that of radioactive heating.

As pointed out by Cadoppi et al. (1987), in the Damara chain emplacement of comparable with our Late Lurian granites virtually marks the end of the geological evolution of this orogen. In Zambesia, on the other hand, the evolution was longer than in the Damara Chain. The radiometric data suggest that: a peak of metamorphism was reached at ca 1000 Ma; the crust was very hot much later (500 Ma ago); it hosted a shallow emplacement of granite bodies 450 Ma ago. The geochemical evidence suggests that these granites (Pan-African) are a normal evolutionary step towards an intraplate alkaline magmatism. In Zambesia, this finale was never reached, since the evolution goes no further than a calc-alkaline granite with occasional signs of an alkaline tendency. One can do no more than speculate about the geological evolution that took place in the long period running from the conclusion of the Lurian tectonogenesis to emplacement of the Pan-African granites, i.e. what geodynamic process was responsible for the Lower Palaeozoic event, which appears to have involved little more than the emplacement of minor granite bodies (besides resetting of the mineral age). The evidence from the rock records in Zambesia is insufficient to answer the question.

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REFERENCES

CADOPPI, P. – COSTA, M. – SACCHI, R., 1987: A cross section of the Namama Thrust Belt (Mozambique). *J. African Earth Sci.,* 6 (4), pp. 493–504.

CASTRO, A., 1937: On granitoid emplacement and related structures. A review. *Geol. Rdsch.* (Stuttgart), 76/1, pp. 101–124.

COSTA, M. – FERRARA, G. – TONARINI, S. – SACCHI, R., 1988. Rb-Sr dating from the Upper Proterozoic basement of the Zambesia (Mozambique): a re-appraïsal. *28th I.G.C. Abstracts,* Washington.

HARRIS, N. B. W. – PEARCE, J. A. – TINDLE, A. G., 1986. Geochemical characteristics of collision-zone magmatism. In: Coward, M. P. – Ries, A. C. (eds.) – *"Collision Tectonics" Geol. Soc. Spec. Publ.,* 19, pp. 67–81.

JOURDE, G., 1983: La chaîne du Lurio (Mozambique): un témoin de l'existence de chaînes kibariennes en Afrique Orientale. *12° Colloquio di Geol. Africana.* Tervuren (Belgium), *Abstracts,* p. 50.

KLERKX, J. – LAVREAU, J. – LIÉGEOIS, J.-P. – THEUNISSEN, K., 1984: Granitoides Kibariennes précoces et tectonique tangentielle au Burundi: magmatisme bimodal lié a une distension crustale. In: Klerkx, J. – Michot, J. (eds.) – *"Géologie Africaine" Mus. royal Afrique centrale Tervuren,* Belgium, pp. 29–46.

KRÖNER, A., 1982: Rb-Sr geochronology and tectonic evolution of the Pan-African Damara belt in Namibia, south-western Africa. *Amer. J. Sci.* (New Haven), 282. pp. 1471–1507.

PEARCE, J. A. – HARRIS, N. B. W. – TINDLE, A. G., 1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *J. Petrology* (Oxford), 25, pp. 956–983.

SACCHI, R. – MARQUES, J. – COSTA, M. – CASATI, C., 1984: Kibaran events in the southernmost Mozambique Belt. *Precamb. Res.,* 25, pp. 141–159.

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