GRANITIC MAGMATISM AND RELATED GOLD MINERALIZATIONS IN TAPAJÓS MINERAL PROVINCE, AMAZONIAN AREA, BRAZIL

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ABSTRACT

Three granitoids suites have been recognised in Tapajós Mineral Province: (i) The early-syn tectonic granitoids (ESTG) – the Cuíu-Cuíu type that is interpreted as having formed in volcanic arc tectonic setting in the early history of the gneissic basement; (ii) The syn-late tectonic granitoids (SLTG) – the Parauari type that is interpreted as having formed during a complete orogenic cycle from the early subduction-related magmas to collision granites; and (iii) The late-post tectonic granitoids (LPTG)) – the Maloquinha granites are interpreted as having formed in post orogenic extensional regime.

These granitoids contain:(i) mesothermal lode gold deposit; and (ii) disseminated to stockwork gold mineralization (porphyry-gold deposit). The first type (i) is close associated with calc-alkaline magmatism that contains mafic/ultramafic and lamprophyre dykes, which is probably genetically linked to subduction-related tectonic processes in discrete volcanic arc. The second one (ii) is associated with calc-alkaline to alkaline magmatism, whose emplacement is related to extensional environment at a high crustal level, probably back-arc basin type.

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RESUMO

Na Província Mineral do Tapajós são reconhecidos três tipos de suítes graníticas consistindo nos seguintes tipos de granitóides: (i) os pre-sintectônicos, tipo Cuíu-Cuíu, os quais são interpretados como tendo sido formados em ambiente geotectônico do tipo arco vulcânico e geneticamente relacionados à formação do embasamento gnáissico; (ii) os sin-tarditectônico, tipo Parauari, que representam os granitóides originados durante um ciclo orogenético completo, abrangendo desde os granitóides relacionados a magma gerados nas fases iniciais de subducção até os colisionais; e (iii) os tardi-póstectônicos, tipo Maloquinha, os quais foram originados durante um regime extensional.

Esses granitóides contêm os seguintes tipos de mineralizações de ouro: (i) veios de quartzo portadores de ouro – depósitos mesotermais de ouro tipo 'lode gold'; e (ii) mineralizações disseminadas/stockwork – depósitos tipo 'porphyry gold'. No tipo (i) a mineralização é associada a diques máfico-ultramáficos e lamprofíricos intrudindo granitóides calcioalcalino, geneticamente relacionados a processos tectônicos de subducção, desenvolvidos em ambiente do tipo arco vulcânico incipiente. No tipo (ii) a mineralização de ouro é relacionada a um magmatismo calcioalcalino a alcalino extensional desenvolvido em ambiente de crosta superior, provavelmente bacia do tipo 'back-arc spreading'.

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INTRODUCTION

Many Precambrian shield areas, and some younger metamorphic terranes, contain gold-bearing quartz veins, the development of which seems to be related to more than one geological event. In Tapajós Mineral Province in the State of Pará, Amazonian area, Brazil, primary gold deposits are widespread and are of economic significance (Robert, 1996). Gold occurs in a variety of host-rock, such as: gneiss basement, granitoids, sediments, felsic volcanics and basic rocks. However, granitoids showing different deformation patterns and ages represent the most common host rock-type for the gold mineralization. A close genetic relationship between the granitoids and the gold mineralizations is suggested. Two types of gold occurrences are recognised: (i) gold-bearing quartz veins, the most common type; and (ii) disseminated to stockwork gold mineralization, identified at just a few sites.

The Precambrian Tapajós Mineral Province (90,000 km^2) located on the Brazil Central Shield extends northward from the Cachimbo graben to the Phanerozoic Cover of the Amazonian Basin. The province underwent a tectonic evolution at about 2.0 Ga similar to that of the Guiana Shield (Rogers, 1996) which has been important to the gold mineralization (Robert, 1996; Fig. 1).

However, despite extensive gold production (159 tonnes of gold for the period from 1958 to 1996: Araújo Neto, 1996), the area has many geological features that remain poorly understood. Although gold was first discovered in the province in the early 1950's and exploitation by *garimpeiros* (local prospectors) has continued for 50 years, no research has yet been attempted to determine the genesis of the gold mineralization.

The present study is a first approach in understanding the relationships between the magmatism and the gold mineralization in the Tapajós Mineral Province. A petrochemical study of host rocks of gold mineralization was developed including field investigations (structural, lithologies and wallrock alterations) of 15 mineralized sites or *garimpos* (mineralised areas worked by *garimpeiros* using rudimentary processes), whose distribution is shown in Figure 2. This study deals with the petrography and geochemistry of 44 samples of the granitoid marked by different deformation patterns and ages that are host to the gold. Twenty seven samples of the related granitoid wallrock alterations were also analysed. The samples were analysed by ICP (major and trace elements including REE) at the Royal Holloway College, London University, which data are shown in Table 1. Consideration of the likely geotectonic setting for the granitic rocks is discussed. The last section addresses the proposed gold mineralization model and evaluates the magmatism, the wallrock alteration and the gold mineralization relationships.

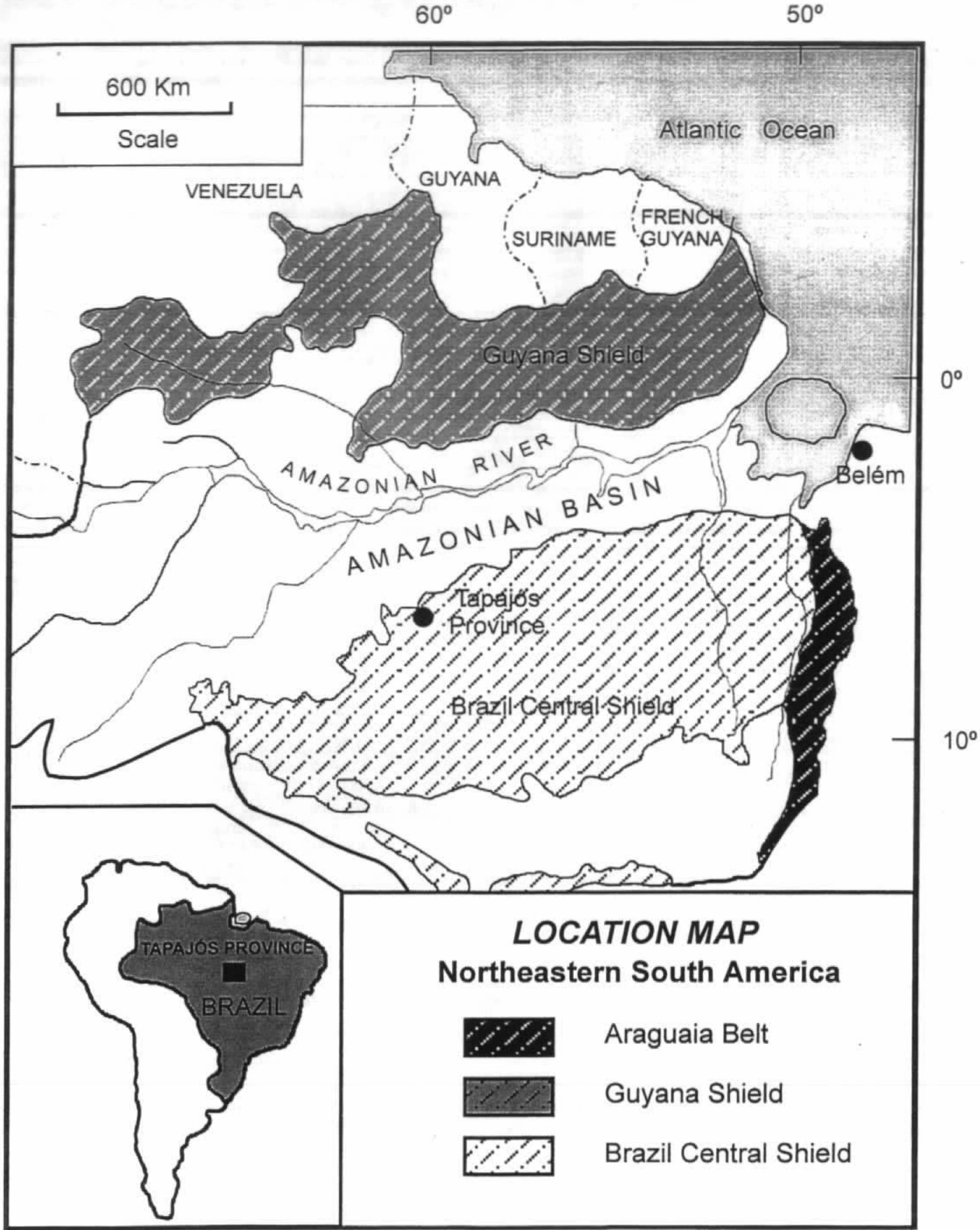

Figure 1 Tapajós Mineral Province location.

TABLE 1

	GEOCHEMICAL DATA: MALOQUINHA GRANITOIDS								GEOCHEMICAL DATA: PARAUARI GRANITOIDS			
GARIMPO	BATALHA			MAMOAL		SANTA ISABEL	MAJESTADE		DAVI		GOIANO	
Sample	MG-R-01b	MG-R-03bI	MG-R-03bII	MG-R-52bII	MG-R-53bI	MG-R-92e	MG-R-99eI	MG-R-99eII	MG-R-06bI	MG-R-06bII	MG-R-69b	MG-R-71b
SiO_2	82.87	76.50	76.81	78.08	78.61	78.55	76.13	72.25	72.45	75.00	72.86	73.57
Al_2O_3	8.99	12.11	11.99	12.04	11.85	12.08	13.35	14.33	14,56	14.05	14.60	14.98
Fe_2O_3	1.82	1.75	2.57	0.90	0.82	1.58	1.31	1.29	2.83	0.93	1.95	1.52
MgO	0.18	0.07	0.10	0.09	0.04	0.29	0.10	0.07	0.89	0.24	0.52	0.44
CaO	0.14	0.58	0.22	0.11	0.15	0.02	0.49	0.02	2.58	1.10	1.79	1.35
Na_2O	2.74	3.80	2.56	3.42	3.59	0.07	3.38	0.15	4.26	3.10	3.84	3.77
K_2O	1.47	4.64	5.26	4.55	4.37	5.76	5.06	5.24	1.56	5.26	3.35	3.55
TiO_2	0.08	0.11	0.19	0.10	0.09	0.20	0.16	0.19	0.28	0.10	0.21	0.22
P_2O_5	0.02	0.02	0.02	0.02	0.02	0.05	0.03	0.02	0.11	0.07	0.10	0.10
MnO	0.01	0.03	0.03	0.01	0.03	0.02	0.03	0.02	0.09	0.03	0.04	0.04
Ba	62	177	387	100	40	471	1250	1276	187	1061	431	455
Co	2	2	2	1	2	2	2	2	7	3	6	4
Cr	5	4	5	4	3	10	4	2	15	5	9	9
Cu	2676	19	7	4	3	8	2	4	5	3	2	5
Li	12	6	17	4	44	12	10	8	40	14	59	28
Nb	12	21	23	25	48	15	9	10	8	6	9	9
Ni	5	5	6	3	2	3	1	3	10	5	8	8
Sc	1	1	2	1	1	4	5	4	7	3	5	5
Sr	8	23	33	35	14	26	121	85	303	241	243	236
V	4	3	6	3	2	15	2	3	34	7	19	18
Y	50	63	31	21	28	16	17	6	19	28	17	23
Zn	24	114	64	13	23	34	18	28	46	20	37	40
Zr	118	162	286	110	112	169	183	159	88	49	87	97
Cd	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Pb	< 2	27	23	21	29	36.0	29.0	30.0	15	29	20	21
Rb	121	274	321	190	349	441.0	142.0	157.0	138	258	156	204
La	32.66	42.76	12.56	42.63	7.87	53.76	52.6	18.9	24.86	25.44	20.79	21.42
Ce	70.26	96.46	33.84	86.84	18.18	102.51	97.36	31.16	51.2	49.01	44.04	44.36
Pr	8.1	11.44	3.28	8.95	1.97	12.4	11.85	3.35	5.81	5.81	5.07	5.15
Nd	28.8	41.5	11.5	26.56	6.82	41.9	37.17	10.29	21.1	20.00	17.85	18.16
Sm	5.94	8.78	2.58	4.25	1.8	6.82	5.86	1.59	4.17	4.14	3.53	3.56
Eu	0.31	0.46	0.43	0.24	1.1	0.54	1.09	0.29	0.77	0.88	0.68	0.65
Gd	6.37	8.96	2.8	3.17	1.95	4.96	4.36	1.31	3.98	4.04	3.30	3.45
Dy	8.04	10.19	4.02	3.3	3.59	3.78	3.46	1.2	3.48	4.16	3.02	2.97
Ho	1.73	2.15	0.91	0.69	0.82	0.71	0.64	0.25	0.69	0.84	0.59	0.59
Er	5.06	6.21	2.96	2.01	2.81	1.77	1.56	0.73	1.82	2.4	1.58	1.55
Yb	4.99	6.34	3.48	2.59	3.82	1.87	1.68	0.93	1.73	2.37	1.65	1.50
Lu	0.81	1.01	0.6	0.42	0.62	0.3	0.27	0.17	0.29	0.38	0.26	0.24
PETROGRAPHY	Granite	Alkali-feldspar granite granophyre	Alkali-feldspar granite granophyre	Alkali-feldspar granite	Leucomonzo-granite	Granite cataclastic	Microgranite	Microgranite	Microtonalite w/ bt & chl	Monzogranite w/ bt & chl	Monzogranite	Monzogranite w/ bt
Sample	MG-R-01b	MG-R-03bI	MG-R-03bII	MG-R-52bII	MG-R-53bI	MG-R-92e	MG-R-99eI	MG-R-99eII	MG-R0-6bI	MG-R-06bII	MG-R-69b	MG-R-71b

Observation: Major elements expressed in wt% and trace elements in ppm.
Abbreviations: Grd.= granitoid; bt = biotite; chl = clorite; hb = hornblende

	GEOCHEMICAL DATA: PARAUARI GRANITOIDS													
GARIMPO	CUIU-CUIU garimpo							BOM JESUS						
Sample	MG-R-21b	MG-R-24bI	MG-R-24bII	MG-R-25b	MG-R-26bI	MG-R-31b	MG-R-33bI	MG-R-32bIV	MG-R-32bIX	MG-R-60b	MG-R-63bI	MG-R-63bII	MG-R-63bV
SiO_2	74.93	56.20	56.22	53.47	48.89	69.50	74.00	65.46	73.33	66.35	58.46	66.43	66.15
Al_2O_3	13.74	18.99	19.20	19.47	14.18	15.31	13.85	16.17	14.07	15.72	15.94	15.71	15.44
Fe_2O_3	2.03	7.74	7.28	7.74	14.21	4.10	2.87	4.59	2.25	4.34	7.24	4.32	4.05
MgO	0.36	2.36	2.52	2.45	8.10	1.86	0.63	2.02	0.53	1.98	3.52	1.58	1.65
CaO	0.31	3.86	6.18	3.17	7.60	0.24	0.27	0.41	1.89	3.30	4.70	4.02	3.53
Na_2O	3.39	4.63	4.48	3.08	2.00	0.07	2.52	0.07	4.34	4.15	3.38	4.17	3.92
K_2O	4.88	2.62	2.09	3.48	0.96	4.85	5.18	5.35	3.23	2.10	4.54	2.08	2.42
TiO_2	0.21	0.85	0.77	0.90	1.71	0.40	0.41	0.44	0.27	0.49	0.86	0.50	0.46
P_2O_5	0.05	0.29	0.34	0.26	0.28	0.10	0.07	0.14	0.10	0.15	0.24	0.16	0.15
MnO	0.02	0.09	0.11	0.13	0.23	0.06	0.03	0.09	0.04	0.07	0.15	0.07	0.07
Ba	583	1540	2150	2009	365	1155	2466	723	698	526	1248	533	658
Co	3	13	17	17	41	7	4	20	5	12	20	13	13
Cr	8	19	34	25	275	23	10	29	9	26	36	22	23
Cu	3	34	31	42	35	88	43	205	4	13	115	7	6
Li	9	43	36	32	23	38	14	46	35	47	61	45	43
Nb	9	11	6	11	10	5	11	6	7	8	12	8	7
Ni	5	18	24	12	174	19	7	23	6	23	45	21	24
Sc	3	17	13	18	31	11	8	11	6	10	19	11	10
Sr	153	1007	1677	619	316	31	153	50	334	458	374	431	447
V	11	108	111	118	263	83	26	84	21	62	112	63	58
Y	14	38	30	36	42	20	14	21	18	17	39	17	15
Zn	28	74	77	87	133	329	31	388	37	57	92	53	51
Zr	145	291	143	286	179	129	305	153	110	173	114	138	152
Cd	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Pb	10	15	11	21	10	261	17	263	14	12	14	14	15
Rb	230	119	88	123	33	366	295	419	118	56	101	60	65
La	17.23	49.21	40.74	68.94	51.00	25.6	20.36	27.96	25.43	27.61	24.15	27.40	71.61
Ce	41.46	109.91	87.91	137.88	79.28	48.73	64.25	51.58	54.2	58.95	68.62	56.91	141.05
Pr	4.16	13.71	11.58	18.04	12.48	6.2	4.52	6.76	6.18	6.46	10.02	6.52	14.25
Nd	13.3	48.6	43.7	63.5	49.2	22.8	14.5	25.40	21.6	22.57	42.00	23.31	42.74
Sm	2.24	8.29	7.42	10.31	8.82	3.78	2.37	4.34	3.73	3.75	8.28	3.99	5.09
Eu	0.32	1.93	2.02	2.34	2.43	0.78	0.33	0.94	0.73	0.94	1.38	0.98	1.01
Gd	1.78	6.75	6.25	8.11	8.43	3.24	1.98	3.97	3.06	3.09	7.17	3.33	3.48
Dy	2.18	5.71	4.45	6.2	6.36	2.32	2.2	3.22	2.56	2,51	5.98	2.69	2.59
Ho	0.45	1.14	0.83	1.18	1.23	0.49	0.46	0.64	0.49	0.48	1.18	0.51	0.5
Er	1.35	3.02	2.01	2.89	3.09	1.37	1.32	1.73	1.28	1.23	3.06	1.32	1.13
Yb	1.56	2.79	1.56	2.59	2.58	1.27	1.57	1.62	1.25	1.24	2.85	1.32	1.14
Lu	0.25	0.43	0.23	0.41	0.39	0.21	0.27	0.26	0.19	0.20	0.43	0.21	0.18
PETROGRAPHY	Monzogranite cataclasitc	Granodiorite gneissic	Tonalite gneissic w/ bt & amph.	Granodiorite gneissic	Meta qz diorite	Granitoid cataclastic	Monzogranite cataclastic	Granodiorite altered	Monzogranite w/ bt	Monzogranite catacastic	Monzonite w/ hb	Monzogranite w/ bt & hb	Monzonite
Sample	MG-R-21b	MG-R-24bI	MG-R-24bII	MG-R-25b	MG-R-26bI	MG-R-31b	MG-R-33bI	MG-R-32bIV	MG-R-32bIX	MG-R-60b	MG-R-63bI	MG-R-63bII	MG-R-63bV

Observation: Major elements expressed in wt% and trace elements in ppm.
Abbreviations: Grd.= granitoid; bt = biotite; chl = clorite; hb = hornblende

	GEOCHEMICAL DATA: PARAUARI GRANITOIDS				GEOCHEMICAL DATA: CUÍU-CUÍU GRANITOIDS			
GARIMPO	JUTAI	CHICO TORRES	SÃO JOSÉ/PEPEU		Nª Sª CONCEIÇÃO	SÃO JOSÉ/PEPEU		CUÍU-CUÍU
Sample	**MG-R-39el**	**MG-R-41bII**	**MG-R-72bI**	**MG-R-72bII**	**MG-R-10bI**	**MG-R-48bII**	**MG-R-48bIII**	**MG-R-26bIII**
SiO_2	74.00	71.69	71.43	71.84	66.72	71.97	74.93	70.49
Al_2O_3	13.43	16.19	13.18	13.82	16.09	11.54	13.41	15.54
Fe_2O_3	1.92	2.46	2.69	2.43	4.24	5.66	0.74	2.57
MgO	0.44	0.65	0.59	0.45	1.18	0.24	0.08	0.53
CaO	0.10	0.02	1.50	1.69	3.67	0.16	1.14	1.79
Na_2O	2.03	0.07	3.01	3.31	3.67	0.84	2.75	3.20
K_2O	3.86	5.15	4.98	4.74	2.91	7.96	4.99	3.23
TiO_2	0.17	0.34	0.34	0.32	0.56	0.31	0.06	0.27
P_2O_5	0.03	0.05	0.10	0.10	0.18	0.03	0.03	0.07
MnO	0.04	0.02	0.06	0.04	0.04	0.05	0.01	0.03
Ba	471	2015	1028	909	1582	2165	1344	2023
Co	17	6	6	6	10	6	5	6
Cr	5	17	5	6	33	7	4	19
Cu	10	27	4	5	6	5	22	4
Li	7	14	19	14	49	8	7	15
Nb	23	12	10	14	6	7	2	3
Ni	7	10	5	8	15	4	4	10
Sc	5	8	4	5	4	1	0	3
Sr	123	32	239	220	611	403	405	457
V	25	36	26	21	61	78	6	17
Y	23	15	28	60	6	2	2	4
Zn	74	55	42	33	63	26	13	49
Zr	88	155	157	200	234	143	54	126
Cd	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Pb	60	37	23	23	23	20	20	25
Rb	218	253	153	140	93	198	132	95
La	23.1	47.8	55.75	49.87	52.94	8.82	9.03	25.63
Ce	45.08	78.39	113.28	101.54	101.41	38.72	15.68	47.24
Pr	4.5	9.45	12.52	13.01	11.18	1.8	1.45	5.12
Nd	14.5	30.00	41.26	48.09	35.7	4.62	3.99	16.00
Sm	2.52	4.69	6.54	9.80	4.49	0.61	0.54	1.78
Eu	0.56	0.56	1.20	1.43	1.39	0.31	0.42	0.79
Gd	2.42	3.67	5.10	9.23	2.57	0.41	0.41	1.05
Dy	2.67	2.91	4.24	8.99	1.34	0.37	0.36	0.63
Ho	0.58	0.56	0.84	1.80	0.27	0.05	0.06	0.11
Er	1.72	1.42	2.12	4.73	0.59	0.16	0.17	0.26
Yb	2.21	1.5	2.05	4.32	0.77	0.26	0.22	0.33
Lu	0.41	0.25	0.31	0.61	0.15	0.04	0.04	0.06
PETROGRAPHY	Tonalite fractured	Granitoid cataclastic	Monzogranite w/ bt	Monzogranite cataclastic	Tonalite gneissic w/ chl	Syenogranite foliated	Leuco granite gneissic	Granodiorite gneissic w/ bt
Sample	**MG-R-39el**	**MG-R-41bII**	**MG-R-72bI**	**MG-R-72bII**	**MG-R-10bI**	**MG-R-48bII**	**MG-R-48bIII**	**MG-R-26bIII**

Observation: Major elements expressed in wt% and trace elements in ppm.
Abbreviations: Grd = granitoid; bt = biotite; chl = clorite; hb = hornblende

GEOLOGICAL BACKGROUND

Regional Geology

As the central part of the Amazonian Craton, Precambrian rocks occupy most of the region of the Tapajós Mineral Province. According to the recent geological mapping, scale 1: 250,000 (CPRM, 1997), as shown in Figure 2, the stratigraphic column for the Tapajós Mineral Province is:

I. The Early Proterozoic units formed of polyphase folded rocks are the oldest in the area. Their metamorphic grade ranges from amphibolite to granulite facies. Mafic-ultramafic and granitic rocks intrude the metamorphic rocks. The main units are:

(i) The granitic-migmatitic basement – *Cuíu-Cuíu Metamorphic Complex* (Bizinella *et al.,* 1980) consists of granitic gneiss, migmatite, tonalite, diorite and monzonite. Recently, U/Pb study in complex zoned zircons of Cuíu-Cuíu tonalite has yielded ages of 2.016 Ga and 2.44 Ga (Santos *et al.*, 1997).

(ii) The supracrustal sequence – *Jacareacanga Metamorphic Suite* (Bizinella *et al.*, 1980), comprises mainly supracrustal rocks such as schist, metachert and iron-quartzite. Subordinate mafic rocks (amphibolite schists) highly foliated also occur and are suggested to be igneous origin-related (Bizinella *et al.*, 1980). However, according to David Groves from Western University (pers. comm., 1997), the Jacareacanga lithologies appear to be dominantly sedimentary origin-related. Mineral assemblage indicates that the rocks were subjected to greenschist to amphibolite facies conditions. A U/Pb concordia age of 2.1 Ga for zircon in schists has been reported (Santos *et al.*, 1997).

(iii) The magmatic intrusive suite – *Parauari Intrusive Suite* consists of three facies: granodioritic, monzogranitic and syenitic. These rocks cut the basement lithologies of the Cuíu-Cuíu Complex and those of the supracrustal Jacareacanga Suite. The Parauari

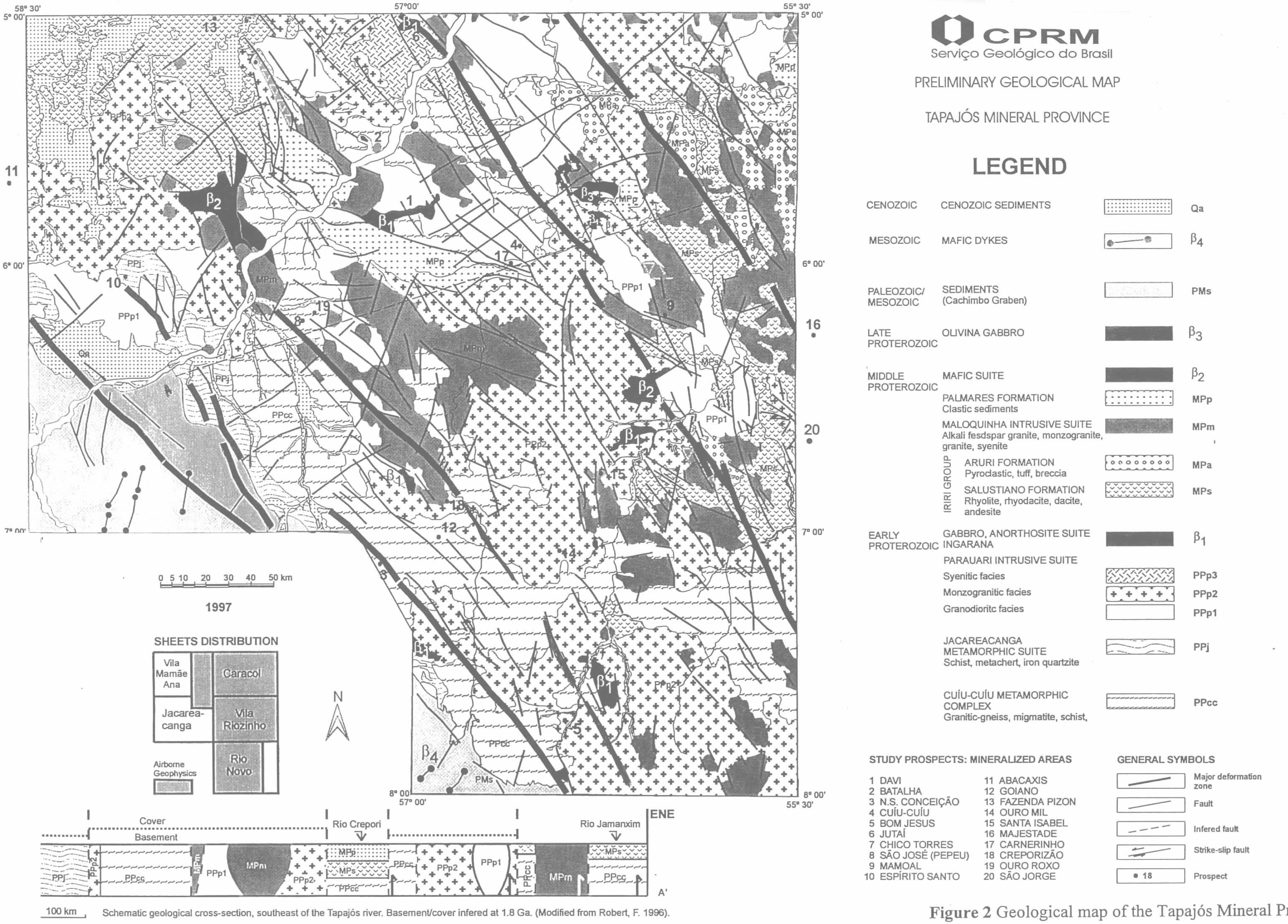

Figure 2 Geological map of the Tapajós Mineral Pro

Note the mineralised study areas location

Intrusive Suite is correlated with the syn-orogenic Juruena granitoid, related to the Trans-Amazonian thermal-tectonic cycle dated at 2.1-1.8 Ga (Silva *et al.*, 1974); and to the Jamanxim granodiorite, whose relationship with the Cuíu-Cuíu rocks suggests an Early Proterozoic age (Pessoa *et al.*, 1977). However, granitoids that occur in the Xingu region (southeast of the Tapajós Province), correlated with Parauari granitoids in Tapajós area are dated at 1.9 Ga (Macambira *et al.*, 1994). A Rb/Sr isochron has also yielded an age of 1.92 Ga, interpreted as a minimum age (Silva *et al.*, 1974).

(iv) The mafic-ultramafic unit – *Ingarana Intrusive Suite* (Pessoa *et al.*, 1977) formed by mafic-ultramafic rocks such as olivine gabbro, norite and anorthosite that intrude the basement rocks of the Cuíu-Cuíu-type. These rocks were dated at 1.80 Ga (Silva *et al.*, 1974) and 1.85 Ga (Santos *et al.*, 1997).

II. The Middle Proterozoic period is marked by the *Uatumã magmatic event*, dated at 1.9-1.7 Ga (c.f. Schobbenhaus *et al.*, 1984), characterised by an extensive calc-alkaline magmatism related to an extensional regime, which consisted of subaerial intermediate to felsic volcanic and subvolcanic rocks (Gibbs and Barron, 1993). These rocks form the *Uatumã Group* (Pessoa *et al.*, 1977) comprised of the following units:

(i) The volcanic rocks – *Iriri Subgroup* (Pessoa *et al.*, 1977) are dominated by a calk-alkaline volcanic sequence consisting of rhyolite, rhyodacite, dacite and andesite (*Salustiano Formation*) and pyroclastics, tuff and breccia (*Aruri Formation*). A Rb/Sr isochron in volcanics has given an age of 1.82 Ga. The $^{87}Sr/^{86}Sr$ initial ratio 0.702-0.703 plot on mantle evolution line for the Rb/Sr system (Santos *et al.*, 1997).

(ii) The magmatic intrusive suite – *Maloquinha Intrusive Suite* (Andrade *et al.*, 1978) represents subvolcanic rocks and consists of alkali-feldspar granite, monzogranite, granite and syenite. These granitoids are dated at 1.77 Ga (Santos *et al.*, 1975). More

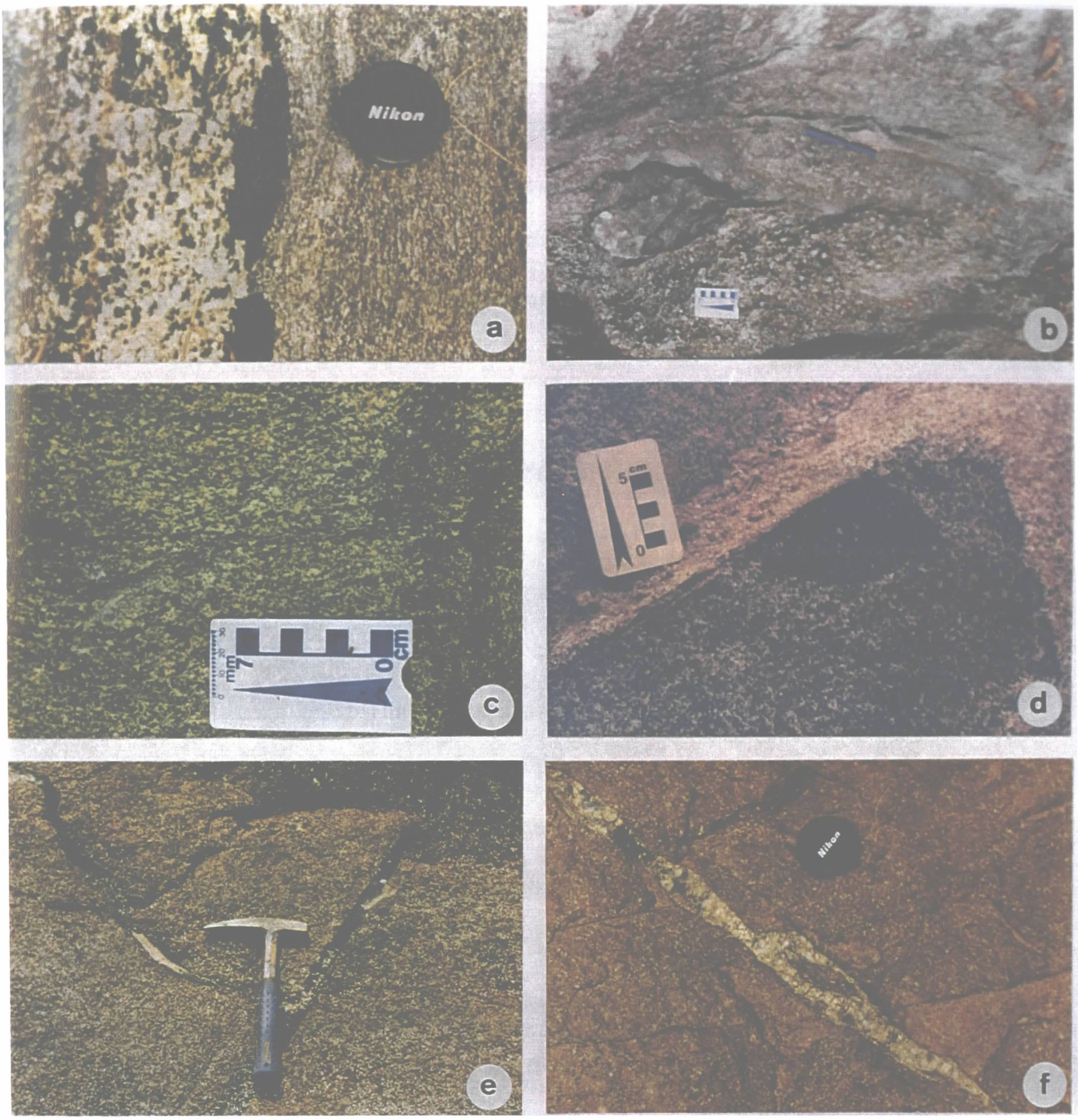

Figure 3 Granitoid out crops: (**a**) Tonalitic gneiss, Cuíu-Cuíu-type (N.S. da Conceição *garimpo*); (**b**) Cuíu-Cuíu granitoid – ESTG showing magmatic flow, where coarse and fine textures can be seen (texture banding). Note the mafic enclave, São José-Pepeu *garimpo*; (**c**) Deformed Parauari granitoid – SLTG, (São José village, near by the Pacu river); (**d**) Undeformed Parauari granitoid facies range; note the mafic enclave (on the middle), Bom Jesus *garimpo*; (**e**) Maloquinha granitoid – SLTG cut by andesitic dykes, Tapajós river, left margin; and (**f**) Maloquinha granitoid – SLTG, host of the quartz vein, which emplacement suggests extensional deformation. Note the brittle evidence, Tapajós river, left margin.

recently, a Rb/Sr isochron has yielded an age of 1.79 or 1.81 Ga, depending of the Yorkfit model used (Santos *et al.*, 1997).

(iii) The *post-Uatumã rocks* consist of *clastic sedimentary cover (Palmares Formation)* and *basic magmatism (Crepori magmatism).* This sedimentary rocks overly the Early Proterozoic basement and the Uatumã rocks and form very thick sequences, correlated with the Roraima Supergroup in the Guiana Shield (Middle Proterozoic in age). They consist mainly of quartzite, meta-siltstone, itabirite, and a minor amount of limestone.

(iv) The basic magmatism – the *Crepori magmatism* (Pessoa *et al.,* 1977), dated at 1.61 Ga and is correlated to the Takutu magmatism in the Roraima State dated at 1.5-1.6 Ga (Issler *et al.*, 1974), and to the Avanavero sill, Guiana Shield, age of which is 1.69 Ga (Gibbs and Barron, 1993). This magmatism occurs either as dykes or sills which intrude the clastic sediments.

III. The Late Proterozoic is represented by mafic to ultra mafic magmatism – *Cachoeira Seca magmatism* (Pessoa *et al.*, 1977), containing troctolite, gabbro and diorite dated by K/Ar at 1.2. to 1.0 Ga (c.f. Schobbenhaus *et al.,* 1984).

IV. The Phanerozoic units comprise Cenozoic sediments consisting of sedimentary cover or that of alluvial plains which are spread all over the area. These sediments are gold-rich and form the alluvial and the supergene gold deposits, both responsible for the main gold production in Tapajós.

Regional Structural

Based on the airborne geophysical data, satellite image studies and field relationships two structural regimes have been recognised: (i) the compressive regime that oriented the oldest units (the Pre-Uatumã units), consisting of the basement and the supracrustal rocks predominantly, according to NW-SE trends; and (ii) the extensional regime, predominantly brittle, that affected the Uatumã units , whose faulting patterns are: N-S to NNE-SSW; and ENE-WSW to NE-SW. In many cases the old structures extend over tens of kilometres and form extensive shear zones. In addition, the contact between the oldest units are fault-controlled, indicating that many of these structures are at least Early Proterozoic in age.

The structural pattern is consistent with the schematic geological cross-section SE of the Tapajós river based on the main stratigraphic relationships, demonstrated by Robert (1996) and shown in the Figure 2. In addition, Robert (1996) indicated that the brittle fault set is related to normal faulting developed during an extensional tectonic regime.

Furthermore, this study has employed structural analysis in regions of polyphase deformation (Ramsay, 1967). It is based on the recognition that the deformation of rock can be conveniently divided into a number of discrete events which occur in chronological order. So, the field features combined with the petrochemistry of the granitoids allow recognition of three granitic suites: (i) the early- syn tectonic granitoid (ESTG – Cuíu-Cuíu-type); (ii) the syn-late tectonic granitoid (SLTG – Parauari-type); (iii) the late-post tectonic granitoid (LPTG – Maloquinha-type; see Figs. 3a to f).

GRANITOIDS

Granitoids, like all other rocks, represent the final product of many physical chemical processes. Granitic intrusions, throughout their emplacement and cooling history have tried to achieve mechanical and chemical equilibrium with their surroundings into which they were intruded. However, most granitoids failed to reach this equilibrium and as a result such features as disequilibrium textures and mineral assemblages, enclaves and fluid inclusions, provide constraints on the granite body's history. Granitoids play an important role in crustal evolution, either by recycling of material within the crust, or by production of new crust from the mantle (Clarke, 1992) and during these processes many granitoids rocks generate associated mineralization (Sawkins, 1990). So, the study of granitoids and their mechanism of emplacement can be used to elucidate the source and the concentration of many metals, including the gold (see Sillitoe, 1991).

Regional Features

Remote sensing suggests two domains of granitic rocks: (i) the granitic-gneisses Cuíu-Cuíu (ESTG) and the Parauari granitoids (SLTG) form very flat areas; and (ii) the batholiths and stocks of Uatumã plutonism, the Maloquinha granitoids (LPTG), form isolated circular bodies (Valente, 1996).

Preliminary airborne magnetic-radiometric data (Misener, 1996) separate the Early Proterozoic granitoids of the Cuíu-Cuíu-type (ESTG) from the Parauari-type (SLTG), the latter being more radiogenic. Magnetic 'base level' for the Cuíu-Cuíu granitoids (ESTG) is higher. The Maloquinha granitoids (LPTG) are distinctly radiogenic, with obvious sub-circular anomalies elongated NW-SE (Fig. 4).

In the field the three types of granitoids have distinctive features. The Early Proterozoic granitoids (Cuíu-Cuíu – ESTG and Parauari – SLTG -types) are grey-white to pinkish-grey, although the colour index ranges from leucocratic for the ESTG to melanocratic for the SLTG. The Maloquinha-type (LPTG) is often red and leucocratic.

The structural features are a NW-SE foliation ranging from distinct to slight for the ESTG (Cuíu-Cuíu-type) and slight to very slight for the SLTG (Parauari-type). The LPTG (Maloquinha-type) has no foliation, although faulted contacts are very common. Basic enclaves are common in Parauari granitoids (SLTG; see Figs. 3a to f).

The features of the granitoids above discussed are summarised in the Table 2.

TABLE 2
FIELD, GEOPHISC AND STRUCTURAL FEATURES: TAPAJÓS MINERAL PROVINCE GRANITOIDS

Tectonic Event/ granite type age	Colour and Index Colour	Geophisc Features	Structural Features	Structural Relationships
Pre-Trans-Amazonian Orogeny (> 2.0 Ga) **Cuíu-Cuíu type 2.01- 2.44 Ga**	Grey-white to pinkish-grey Leucocratic	Huge flat bodies Less radiogenic areas	Distinctly to slight NW-SE foliated Mostly migmatite/ orthogneiss	Early and syn tectonic granitoid ESTG
Trans-Amazonian Orogeny (2.0-1.8 Ga) **Parauari type 1.90 Ga**	Grey-white to pinkish-grey Melanocratic	Huge flat bodies More radiogenic areas	Slight NW-SE foliated Basic enclave common	Syn-late tectonic granitoid SLTG
Uatumã Event (1.9-1.7 Ga) **Maloquinha type 1.79 - 1.81 Ga**	Often red Leucocratic	Batholiths and circular stocks elongated NW-SE	No foliated Fault contact very common	Late-post tectonic granitoid LPTG

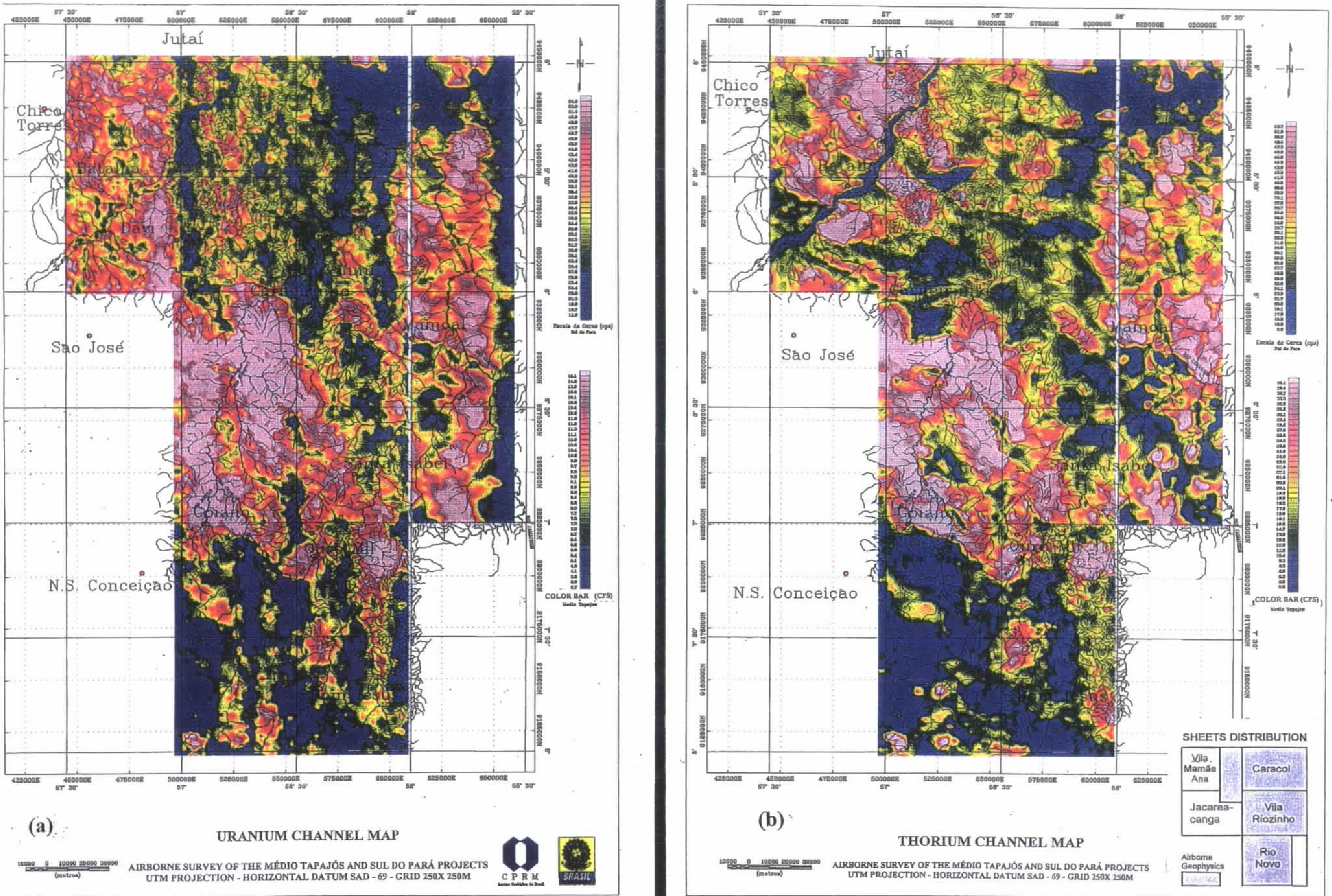

Figure 4 Airborne radiometric geophysic total count (**a**) uranium channel map and (**b**) thorium channel map. Compare to the granitic suites distribution shown in the geological map in Figure 2.

Based on the field relationships a 'transition' from Cuíu-Cuíu granitoids to the Parauari-type is suggested in the Creporizão *garimpo* area. Mafic/ultramafic intrusions cutting Cuíu-Cuíu granitoids were seen (São José-Pepeu and N.S. da Conceição *garimpos*). The Maloquinha-type is commonly cutting by syenitic, rhyolitic, quartz-feldspatic (aplite) and andesitic intrusions (predominantly as dykes) that may represent several magmatic pulses of the Uatumã magmatism as seen along the Tapajós river (left margin). The typical area study for these granitoids are: Cuíu-Cuíu-type (ESTG): São José-Pepeu and N.S. da Conceição *garimpos*; Parauari-type (SLTG): Bom Jesus *garimpo;* and Maloquinha-type (LPTG): Batalha and Mamoal *garimpos,* which locations are shown in Figure 2.

Petrography

Assignment of a granite to one of the three suites on the basis of petrographic data is not always unequivocal. However, many features common to each suite, when combined with field observations, often allow a confident classification. The suites are characterised by the following petrographic features as may be seen in the Table 3:

The Cuíu-Cuíu granitoid (ESTG) are commonly migmatite or gneissic at outcrop scale (Figs 5a and b). In thin section quartz is extended and a planar fabric is obvious. Even mesoscopically anisotropic tonalitic facies show a slight anastomosing fabric due to prefered orientation of mafic minerals such as amphibole and biotite. According to the modal analysis these rocks fall in the granodiorite, monzogranite and tonalite fields of the Streckeisen diagram (Fig. 6). Acessories minerals are zircon and allanite and chlorite, sericite and epidote occur as altered minerals.

The Parauari granitoids (SLTG) are granodiorite to monzogranite, with minor amounts of syenogranite (see the modal data distribution in Fig. 6). They are commonly grey in hand specimen and compared to the Cuíu-Cuíu are comparatively mafic (Figs. 5c

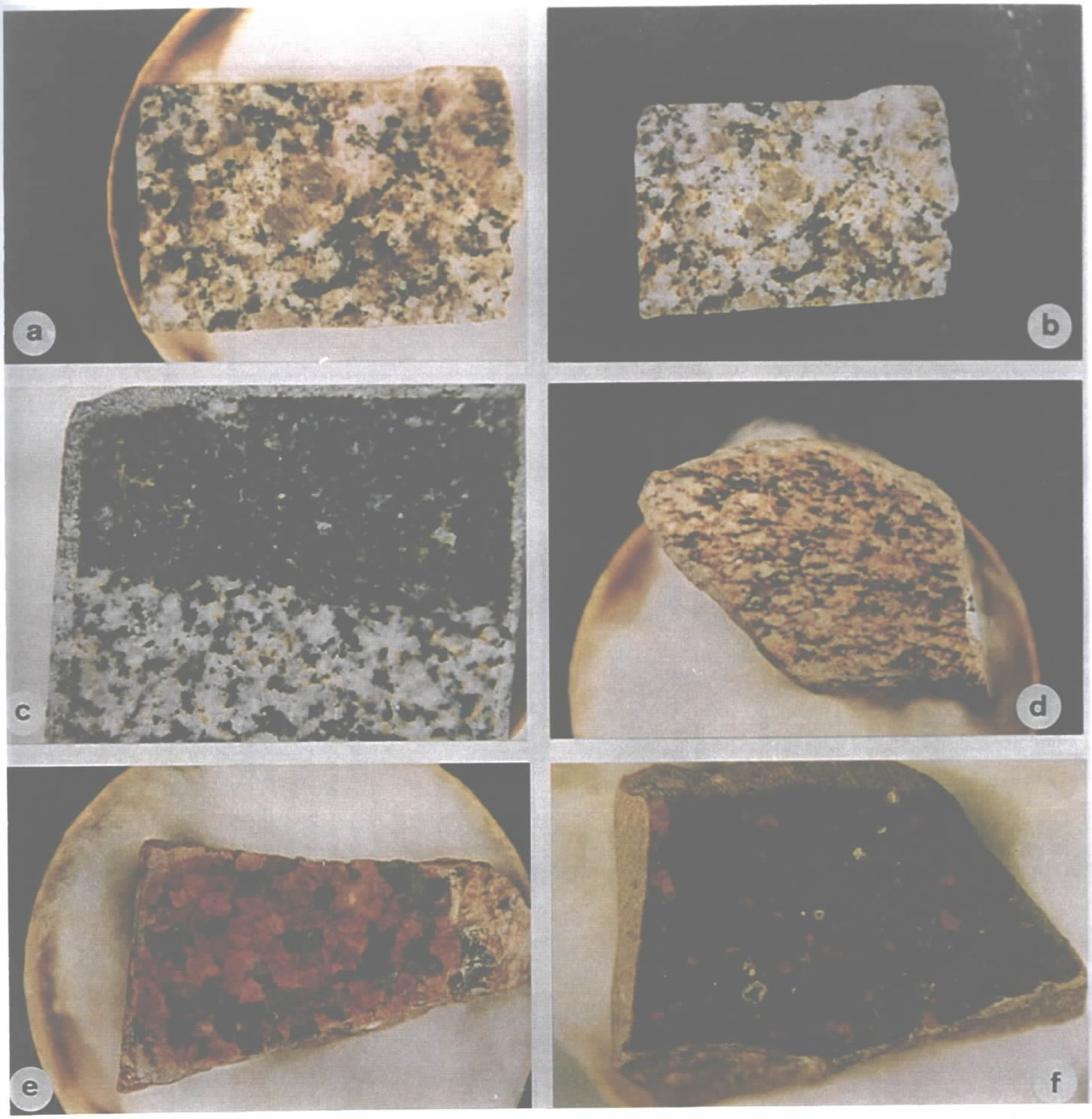

Figure 5 Granitoid hand specimens: (**a**) Cuíu-Cuíu granitoid-type – ESTG, shows a slight anastomosing fabric due to prefered orientation of mafic minerals, (Creporizão area); (**b**) Other view of (a); (**c**) Parauari granitoid-type – SLTG façies 'contact': coarse biotite monzonite (on the top) and fine-grained honrblende-biotite monzonite (on the bottom), Bom Jesus *garimpo*; (**d**) Deformed Parauari granitoid, see the oriented fabric, São José-Pepeu *garimpo*; (**e**) Maloquinha granitoid-type – LPTG, re-crystallised alkali-feldspar leucogranite, coarse grain polygonised; (**f**) Maloquinha altered porphyre – LPTG showing a few aggregate phenocrysts consisting of microcline grains (25% of the volume), Tapajós river, left margin.

TABLE 3
MINERALOGY AND PETROGRAPHIC FEATURES: TAPAJÓS MINERAL PROVINCE GRANITOIDS

Tectonic event/ granite type age	Mineralogy	Texture Features	Petrographic Classification
Pre-Trans-Amazonian Orogeny (> 2.0 Ga) **Cuiu-Cuiu type** **2.01 - 2.44 Ga**	Qz fine and extended in thin section Bt oriented Hb commun Plag calcic (andes ou olig) Microcline Accessories: tit, zir, allan, op Often fluorite-bearing	Anastomosing fabric (pressure-solution) Faintly to distinctly foliated Protomylonitic texture Annealed texture Igneous texture preserved Qz polygonised and shows undulose extinction Mrymekite occurs	Tonalite to granodiorite gneissic Minor syenogranite
Trans-Amazonian Orogeny (2.0-1.8 Ga) **Parauari type** **1.90 Ga**	Qz in sub-grains Plag calcic (andes to olig), zoned Hb very common Bt slight chloritised Golden bt clots w/ access. minerals Cpx and opx very local Primary opaque minerals (<1%) Accessories: tit, apat, zir, allan, mag, moly, leux, rut Hb-apat-bearing type	Protomylonitic texture Myrmekite very common Qz undulose extinction Mica slighty kinked Fluid inclusions abundant in qz	Granodiorite to monzogranite Minor monzonite Syenogranite Syenite Tonalite rare
Uatumã Event Event (1.9-1.7 Ga) **Maloquinha type** **1.79 - 1.81 Ga**	Qz bipyramidal at the subvulcanic type Plag sodic, unzoned (alb) Felds (orth) very commun Bt strong chloritised Hb very rare Accessories: tit, flu, zir, allan; apat, topz very rare Bt-bearing type	Even-grained most common Granophyre texture common Annealed texture Microperthite Fluid inclusions common in qz	Alkali-feldspar granite to syenogranite Minor monzogranite Syenite

Abbreviations:
alb = albite; allan = allanite; apat = apatite; bt = biotite; carb = carbonate; chlo = chlorite; epid = epidote; hb = hornblende; plag = plagioclase; qz = quartz; leux = leucoxene; mag = magnetite; moly = molybdenite; op = opaque minerals; orth = orthoclase; rut = rutile; ser = sericite; tit = titanite; zir = zircon
andes = andesina; olig = oligoclase; flu = fluorite; cpx = clinopyroxene; opx = orthpyroxene

and d). Hornblende is a common ferromagnesian mineral and biotite is commonly in clusters with accessory minerals (apatite, epidote/allanite, titanite). Plagioclase crystals, which are commonly zoned, have altered cores of sericite, carbonate, chlorite or epidote. Quartz is polygonised into sub-grains. Myrmekite is common. Parauari granitoids (SLTG) are the most obvious petrographically, largely due to their accessory minerals contents and proeminently zonal feldspars.

The Maloquinha granites (LPTG) tend to be leucocratic syenogranite to alkali feldspar granite (see the modal analysis results in Fig. 6) and are often red in hand specimen. They are isotropic, except near shear zones, commonly granophyric and plagioclase is not often zoned. Biotite is sparse and always chloritised and amphiboles are rare. Hematite pseudomorphs after pyrite have been observed in several specimens. In addition, Maloquinha suite, including the felsic dykes consists of at least more than one phase based primarily on textural differences. Intrusion of a fine-grained granite (aplite) was followed by a medium-grained porphyritic granitoid (Figs. 5e and f).

Petrogenesis

A single method may not identify an intrusion as belonging to one of the above suites, but a combination of field observation, petrography and geochemistry gives a confident result. Chemical data of the granite suites are displayed in Table 1 and the summary features are shown in the Table 4.

The Cuíu-Cuíu suite (ESTG) are 'unevolved' granitoids. They are peraluminous and have alkaline contents shown on the Shand diagram (as modified by Maniar and Piccoli, 1989: see Fig. 7) which define a composition consistent with their being continental arc granites, and apart from one analysis, they plot in the calc-alkaline field of the Sylvester (1989) diagram (Fig. 8). Rb/Sr ratio values are sistematically < 1 (0.1 to 0.4). Their Rb-Ba-Sr ratios (Pearce *et al.*, 1984) also indicate that they are volcanic-arc

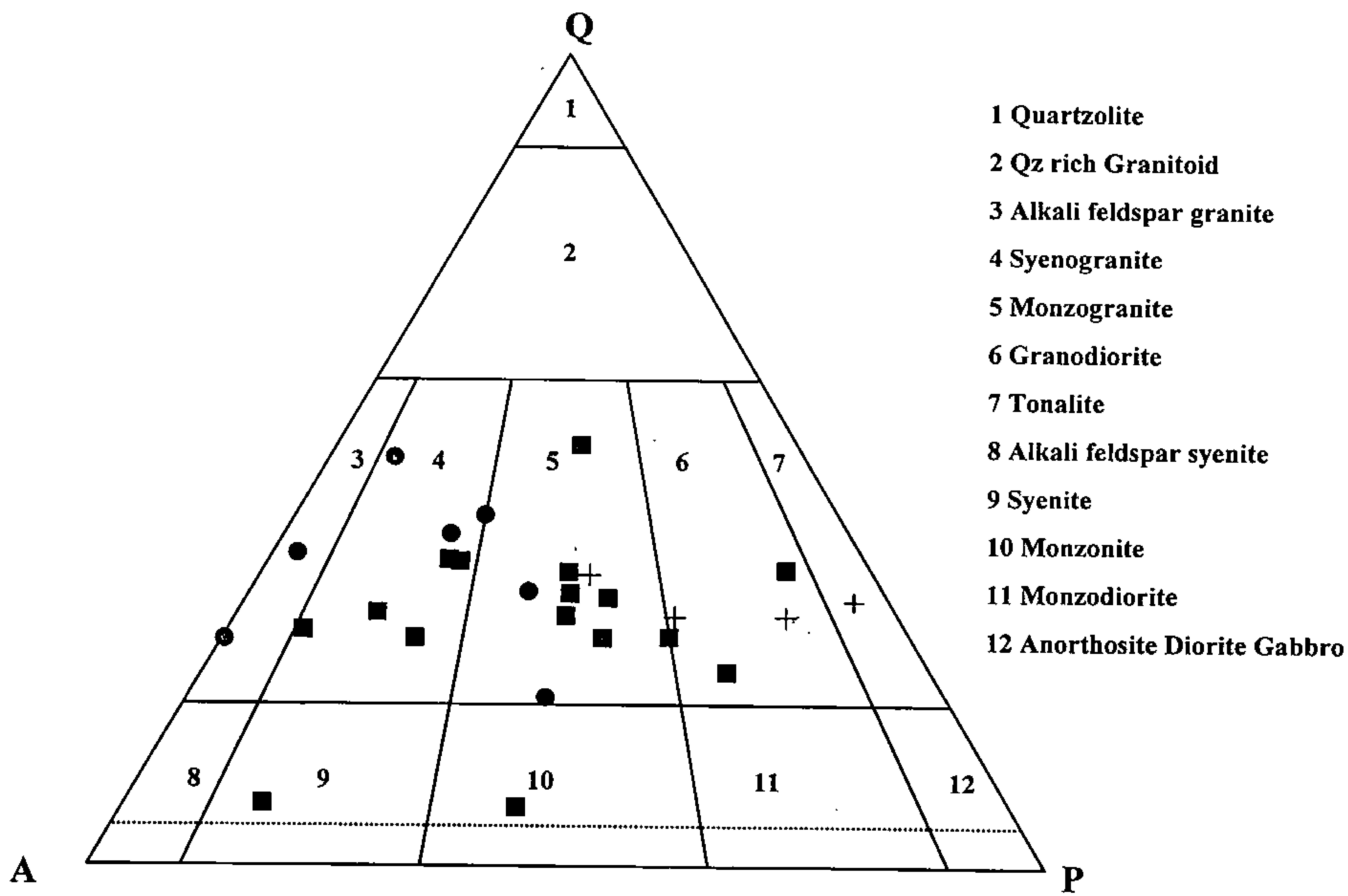

Figure 6 Modal values distribution (Streckeisen, 1974) for: (a) crosses: Cuíu-Cuíu granitoid-type – ESTG; (b) squares: Parauari granitoid-type – SLTG; (c) dots: Maloquinha granitoid-type – LPTG.

TABLE 4
GEOCHEMISTRY : TAPAJÓS MINERAL PROVINCE GRANITOIDS

Tectonic event/ granite type age	A/CNK	Rb-Ba-Sr	Sipergram Rb	Ba	Nb	K	Sr	Eu	Ti	REE HREE	Eu*/Eu	LREE
Pre-Trans-Amazonian Orogeny (> 2.0 Ga) **Cuiu-Cuiu type 2.01 - 2.44 Ga**	Peraluminous	Un-evolved granitoid Calc-alkaline	no anomaly	no anomaly	strong negative	slight positive	positive to weak negative	slight negative	slight negative	flat to depleted	positive,	flat to depleted
Trans-Amazonian Orogeny 2.0-1.8 Ga) **Parauari type 1.90 Ga**	Metaluminous and paraluminous	Evolved granitoid Calc-alkaline	slight positive	no anomaly	strong negative	slight positive	positive to negative	weak negative	variable negative	mostly flat	slight negative	weakly enriched
Uatumã Event (1.9-1.7 Ga) **Maloquinha type 1.79 - 1.81 Ga**	Peralumiouns	Fractionated Calc-alkaline to alkaline granite	obvious positive	none to negative	no negative	slight negative	strong negative	strong negative	strong negative	flat	strong negative	enriched

Abbreviations: LREE = light rare-earth element; HREE = haevy rare-earth element;

type of pluton (Fig. 9). The multi-element 'spidergram' shows them to have positive Eu anomalies consistent with an unfractionated nature. Low Nb contents (strong negative anomalies) are also consistent with they having only a minor crustal component (Fig. 10a). The REE plot (normalised to Nakamura, 1977, values) shows Eu distinct positive anomalies with a consistent gradient, except for Yb and Lu, which REE pattern distribution is very similar to the TTG associations present in many Archaean cratonic terranes. As can be seen in the Figure 11a, the Cuíu-Cuíu-type granitoids have a steep LREE/HREE profile, with (La/Yb)N >20, (Gd/Yb)N >2, positive Eu anomaly and a concave pattern distribution in the HREE. They occupy both 'volcanic-arc'and 'within-plate' fields on the Pearce *et al.* (1984) diagrams: Rb against (Nb+Y) and Nb against Y (Figs. 12a and b).

The Parauari granitoids (ESTG) have a much wider range of compositions (mataluminous to peraluminous) than the Cuíu-Cuíu specimens analysed in this study. The Rb/Sr ratio values are widespread with predominance of values > 1. Their major element compositions are indicative that these magmas might have been formed in a variety of tectonic setting from island arc to continent-collision, with both calc-alkaline and alkaline chemistries being evident (Figs. 7 and 8). Their trace elements chemistry is likewise variable: Rb-Ba-Sr ratios (Pearce *et al.*, 1984) indicate possible volcanic arc to collision setting (Fig. 9). Multi-element spidergram show a range from small Sr and Eu anomalies to proeminent negative Ti anomalies as well as some positive Rb, i.e. some of the plutons are fractionated (Fig. 10b). Their REE plots (Fig. 11b) show small negative Eu anomalies and steeper LREE than HREE gradients, indicating more fractionation or more evolved than in the Cuíu-Cuíu granitoids (see also Figs. 12c and d). The (La/Yb)N values are < 20, except one sample shows value up 41. The (Gd/Yb)N ratios range from 1 to 3, but there are values < 1 indicating very little HREE deplection. Twenty one samples show systematical Eu negative anomalies and a negative correlation between the

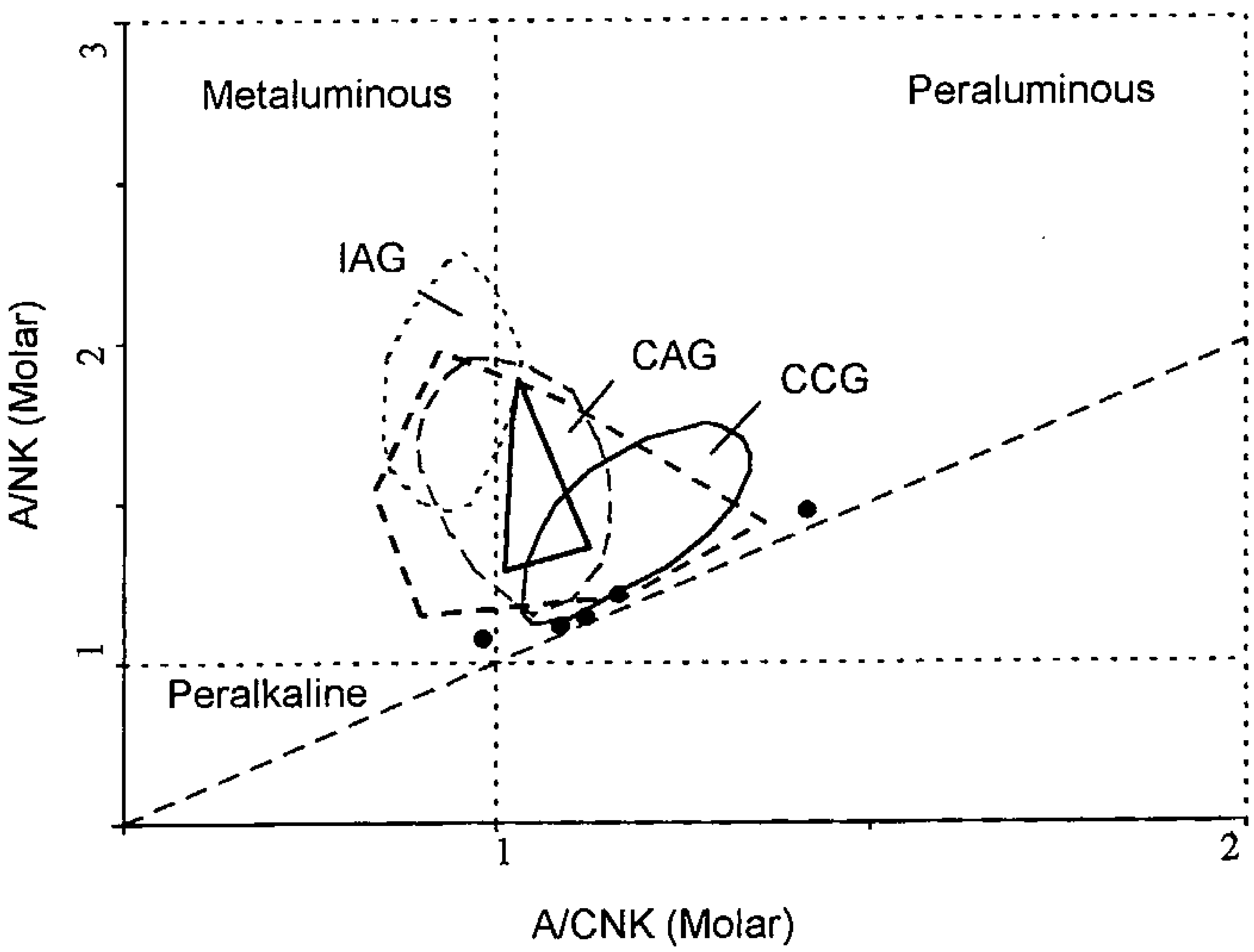

Figure 7 Shand diagram as modified by Maniar and Piccoli (1989). Fields are: IAG = Island-arc granite; CAG = Continental-arc granite; CCG = Continental-collision granite. Cuíu-Cuíu suite as heavy line; Parauari field as heavy dashes; Maloquinha granitoids as dots are distinctive in their trend (which lies within the field normally occupied by the 'post-orogenic' granites), along the 1:1 ratio line.

REE and SiO_2 contents. The Nb/Zr ration values are < 1. This suite has, comparatively with Cuíu-Cuíu-type granitoid, slow Nb contents, consistent with their being largely subduction-related magmas. A widespread distribution across the various fields is seen in Pearce *et al.* (1984) and Sylvester (1989) diagrams (Figs. 12a and b).

The Maloquinha granitic suite (LPTG), apart from being distinct petrographically, are also quite easily distinguished from the others by their chemistry. On the Shand plot (Fig. 7) their analyses fall along the 1:1 ratio line, within the range of post-orogenic granites (they are dominantly peraluminous). The Sylvestry (1989) plot (Fig. 8) indicates an alkaline chemistry. They are quite fractionated: they occupy a high Rb 'within-plate' field (WPG) on the Rb-Ba-Sr diagram (Pearce *et al.*, 1984; see Fig. 9) and have mostly prominent negative Ba, Sr, Eu and Ti and positive Rb anomalies on the spidergram (Fig. 10). The Rb/Sr and Nb/Zr ratio values are very high usually > 1. REE patterns also emphasize their fractionated nature and show the 'gull-wing' pattern marked by the LREE enrichment and the HREE slight horizontal or exceptionally enriched with $(Gd/Yb)_N > 1$. The Eu negative anomalies are very strong. Nb contents of these rocks are somewhat higher than in the other suites, indicating a crustal component to the granitoids and their analyses fall in alkaline and extensional (WPG) fields according to the Pearce *et al.*, (1984) and Sylvester (1989) discriminant diagrams (Fig. 12a to d).

Geotectonic setting

Although there has been criticism of the use of 'tectonic discrimination' diagrams, many workers still consider them useful: if nothing else they highlight differences, and until a better tool is available they serve as descriptive purpose (see Table 5).

The Cuíu-Cuíu granitoids (ESTG) are not mineralogically much different from the Parauari (SLTG). A predominant mantle component to their magmas is indicated by

TABLE 5
GEOTECTONIC SETTING: TAPAJÓS MINERAL PROVINCE GRANITOIDS

Tectonic event/ granite type age	Rb-Ba-Sr	Shand/Maniar and Piccoli (1989)	Pearce et al. 1984 Rb:(Nb+Y)&Nb:Y	Sylvestry (1989) F/M&AN/C	Geotectonic Regime
Pre- Trans-Amazonian Orogeny (> 2.0 Ga) **Cuiu-Cuiu type 2.016- 2.4 Ga**	Un-evolved granitoid V.A.G. field Calc-alkaline	C.A.G.	V.A.G. to W.P.G.	S & I- to A-type	Predominant I-type granitoids Compressional regime **Volcanic-arc (continental-arc ?)**
Trans-Amazonian Orogeny 2.0-1.8 Ga) **Parauari type 1.90 Ga**	Evolved granitoid W.P.G. , COLL and V.A.G. fields Calc-alkaline	I.A.G./ C.A.G./ COLL	V.A.G. to syn W.P.G. to V.A.G.-syn	S-I & Frac. to A-type	Predominant I-type and some S-type granitoids Compressional regime and some extentional **Early subduction to collision**
Uatumã Event (1.9-1.7 Ga) **Maloquinha type 1.79 - 1.81 Ga**	Fractionated W.P.G. field Calc-alkaline to alkaline granite	Distinct P.O.G.	W.P.G./ V.A.G. syn distinct W.P.G.	S-I and A-type	Compressional to extensional **Post orogenic extensional environment (back-arc basin ?)**

Abbreviations: V.A.G.= volcanic arc granitoid; W.P.G.= within-plate granitoid; COLL= collision
P.O.G.= post-orogenic granitoid; I.A.G.= island-arc granitoid; C.A.G.= continental arc granitoid; V.A.G= volcanic arc

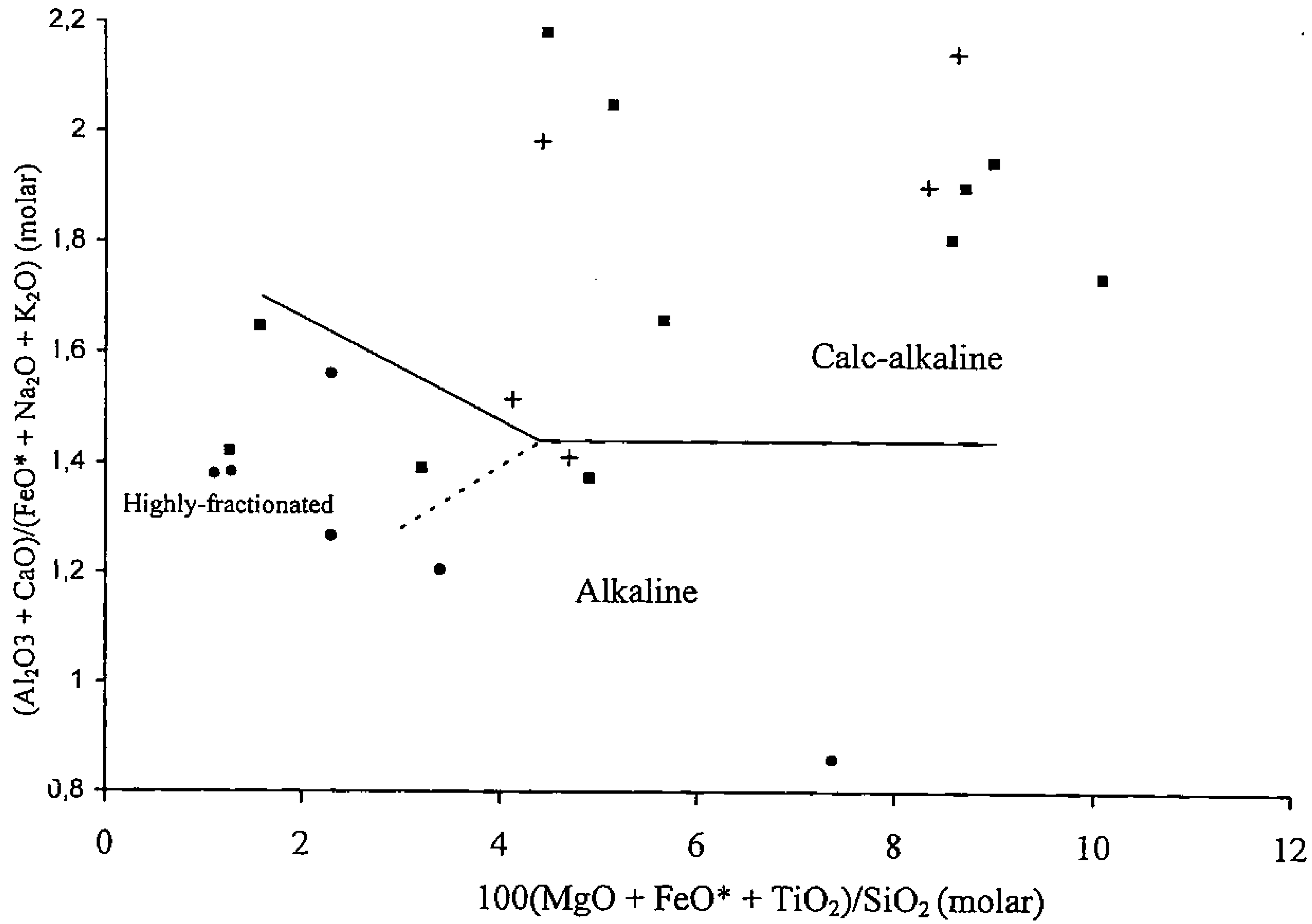

Figure 8 Sylvester (1989) type major element diagram for the three Tapajós granitoid types: Symbols are: crosses = Cuíu-Cuíu-type; squares = Parauari-type; dots = Maloquinha-type. The Maloquinha granitoids – LPTG and a few Parauari specimens – SLTG plot in the 'highly-fractionated' field of alkaline granites. (FeO* = Fe total)

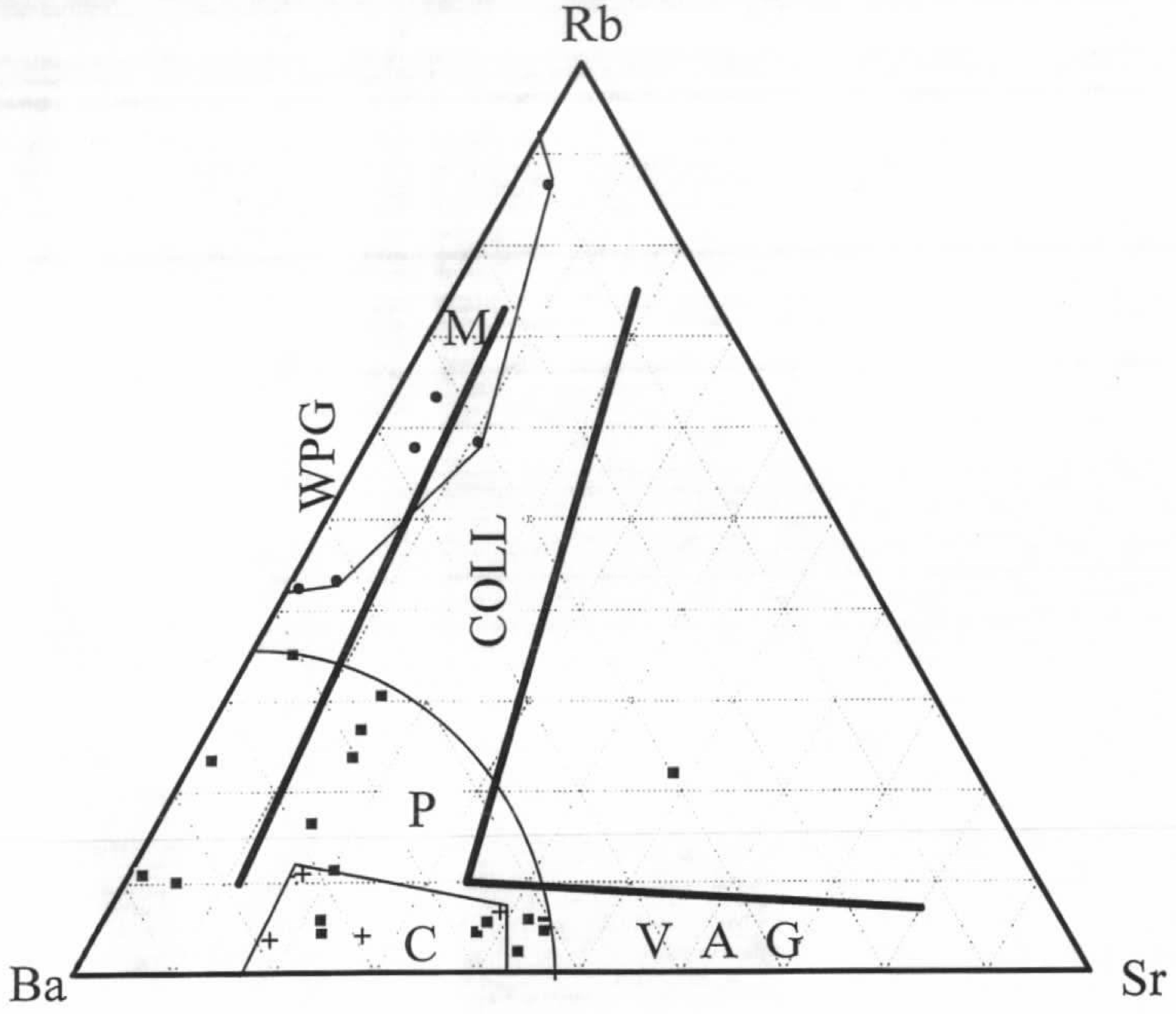

Figure 9 Rb-Ba-Sr diagram for: C = Cuíu-Cuíu-type (crosses); P = Parauari-type (squares) and M = Maloquinha-type (dots). Boundaries for tectonic discrimination after Pearce *et al.*, (1984) are: WPG = within-plate granite; COLL = collision granite; VAG = volcanic arc granite. Maloquinha are quite distinctive due to their relatively fractionated nature in the within-plate granite (WPG) field.

the chemistry. They likely represent primitive continental-arc (Cordilleran-type) intrusions.

The Parauari granitoids (SLTG) are commonly hornblende-bearing with titanite and apatite as accessories and with low amounts of pyrite as their opaque mineral and are similar to Phanerozoic Cordilleran, reduced, I-type intrusives. Specimens that are quite unaltered are metaluminous to peraluminous. Their major- and trace-element chemistry is comparable with Phanerozoic granitoids of either island- or continental-arc origin. Some of the more potassic and peraluminous granitoids may have been generated late in the orogeny as collision types and the few that are indicated as having a within-plate granite (WPG) signature may have been produced by the latest magmas in an incipient extensional environment. None of these granitoids are, highly fractionated (only one unaltered specimens gave a Rb/Sr ratio of 1.93, the remainder being <1). It is likely that these granitoids were derived in a variety of tectonic settings and possibly throughout the whole orogenic cycle. It is consistent with the geochronological study of Rb/Sr and Sm/Nd whose data indicate mantle derivation with crustal contamination (Santos *et al.*, 1997).

The Maloquinha granitoids are alkaline and probably post-orogenic, often fractionated yet are not peralkaline as obviously rift-related granites might be. They are similar to many granite suites that have late- to post-orogenic signature. The crustal origin indicated by the high $^{87}Sr/^{86}Sr$ initial ratio (0.706-0.707) and the Sm/Nd data (Santos *et al.*,1997) are consistent with this interpretation.

In addition, this suite contains more obviously oxidised facies: hematite is common (sometimes possibly pseudomorph pyrite).

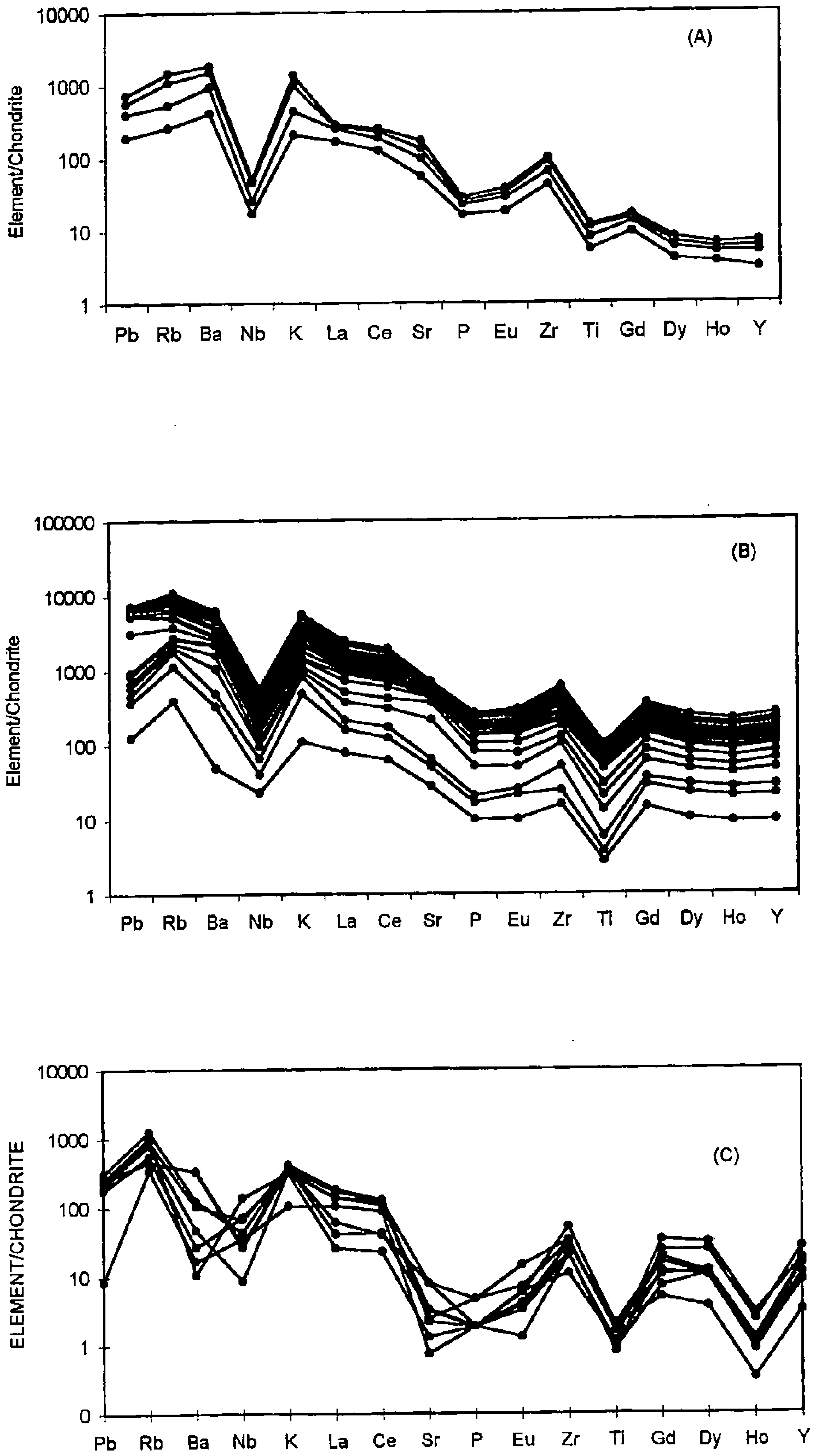

Figure 10 Spidergrams for: **(A)** Cuíu-Cuíu granitoid-type – ESTG; **(B)** Parauari granitoid-type – SLTG; **(C)** Maloquinha granitoid-type – LPTG. These are normalised to chondrite (except Rb, K, P) using the following values: Pb = 0.12; Rb = 0.35; Ba = 3.8; Nb = 0.35; K = 0.014 for %K_2O; La = 0.315; Ce = 0.813; Sr = 11; Nd = 0.597; P = 0.011 for P_2O_5%; Eu = 0.077; Zr = 5.6; Ti = 0.103 for % TiO_2; Gd = 0.275; Dy = 0.342; Ho = 0.076 and Y = 2, according to Sun (1980).

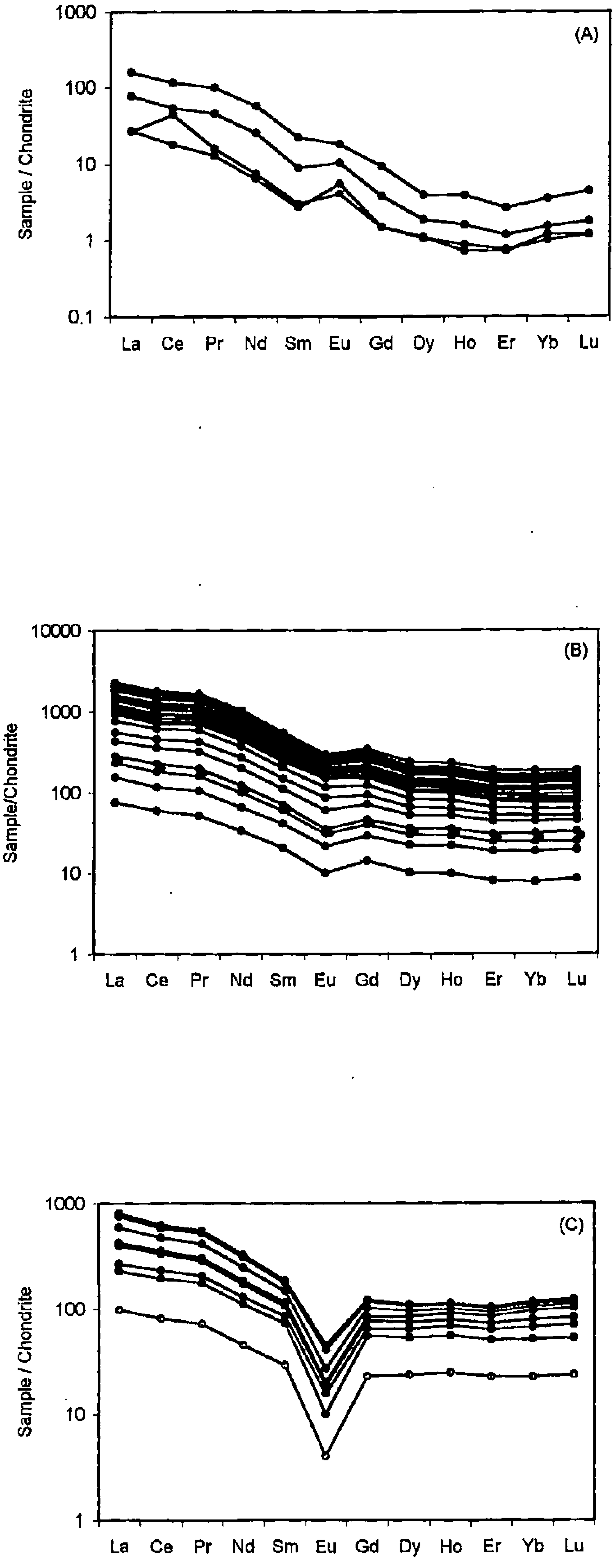

Figure 11 The rare-earth elements (REE) distribution for: (A) Cuíu-Cuíu granitoid-type – ESTG; **(B)** Parauari granitoid-type – SLTG; and (C) Maloquinha granitoid-type – LPTG. Note the different pattern of Eu anomalies showing in the three suites. Values normalised by Nakamura, 1977.

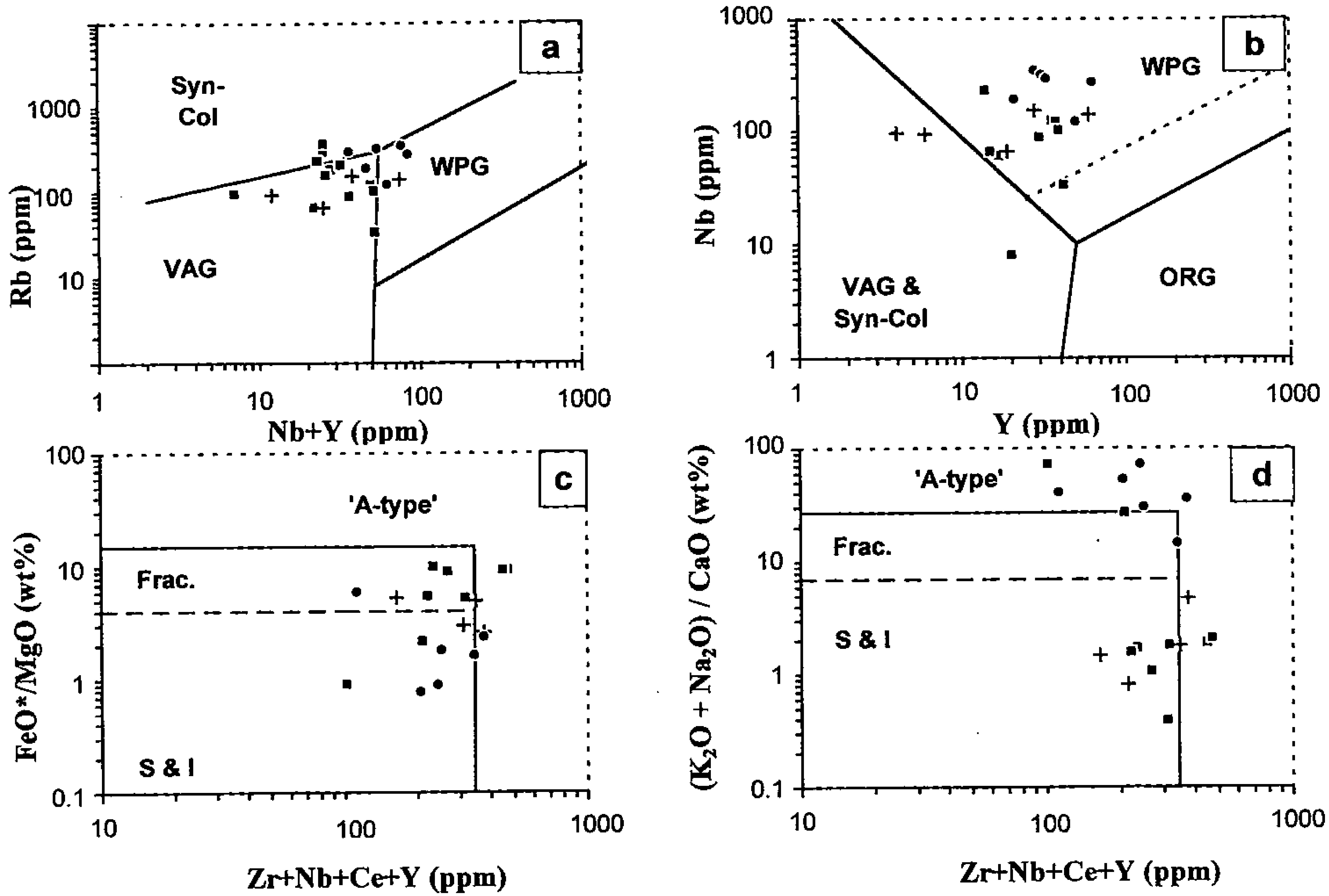

Figure 12 Tectonic discrimination diagrams of: (a) and (b) Pearce *et al.*, (1984) and (c) and (d) Sylvester (1989). Symbols are: (a) crosses: Cuíu-Cuíu granitoid-type – ESTG; (b) squares: Parauari granitoid-type – SLTG; (c) dots: Maloquinha granitoid-type – LPTG.

WALLROCK ALTERATION

Wallrock alteration is a process of irreversible chemical exchange between a hydrous solution and adjacent wallrock. Certain components are selectively leached from the wallrock and are added to the fluid, and other components (including the ore metals) are selectively taken up by wallrock and are removed from the hydrothermal fluid. The net result depends on the physical conditions at the wallrock/fluid reaction interface on the composition of the wallrock and fluid, and on the relative amounts of fluid and wallrock involved in the exchange process.

In the Tapajós Mineral Province gold associated with sulphides occurs in quartz veins or as disseminated to stockwork type, whose wallrock alterations development are quiet different. Wallrock alteration related to the three granitic suites (ESTG, SLTG and LPTG) were selected for investigation, whose areas study that provided the best examples are: (i) Cuíu-Cuíu granitoid in São José-Pepeu (Figs. 13a and b); and N.S. Conceição *garimpos;* (ii) Parauari granitoid in Bom Jesus *garimpo* (Fig. 13c); and (iii) Maloquinha granitoid in Mamoal *garimpo* (Figs. 13e and f) Enrichment/depletion diagrams from the alteration zones, normalised to the unaltered host rock and/or to the mineralised quartz vein can be seen in Figures 14a to f. Geochemical data are in Table 6 and field and mineralogical features are displayed in Table 7.

The wallrock alterations related to Cuíu-Cuíu domain are close associated with calc-alkaline granitoids (ESTG) intruded by complex dykes, whose composition varies from ultramafic/mafic to lamprophyric. The relationships between the host rock and the wallrock alteration (with penetrative fabric) suggests that the alteration zone is syn regional deformation. Gold mineralization occurs as sub-horizontal quartz veins associated with oblique transcurrent ductile-brittle shear zone (Santos, 1996a and b). Chemical analysis by electron microscopy indicates that the native gold occurs as

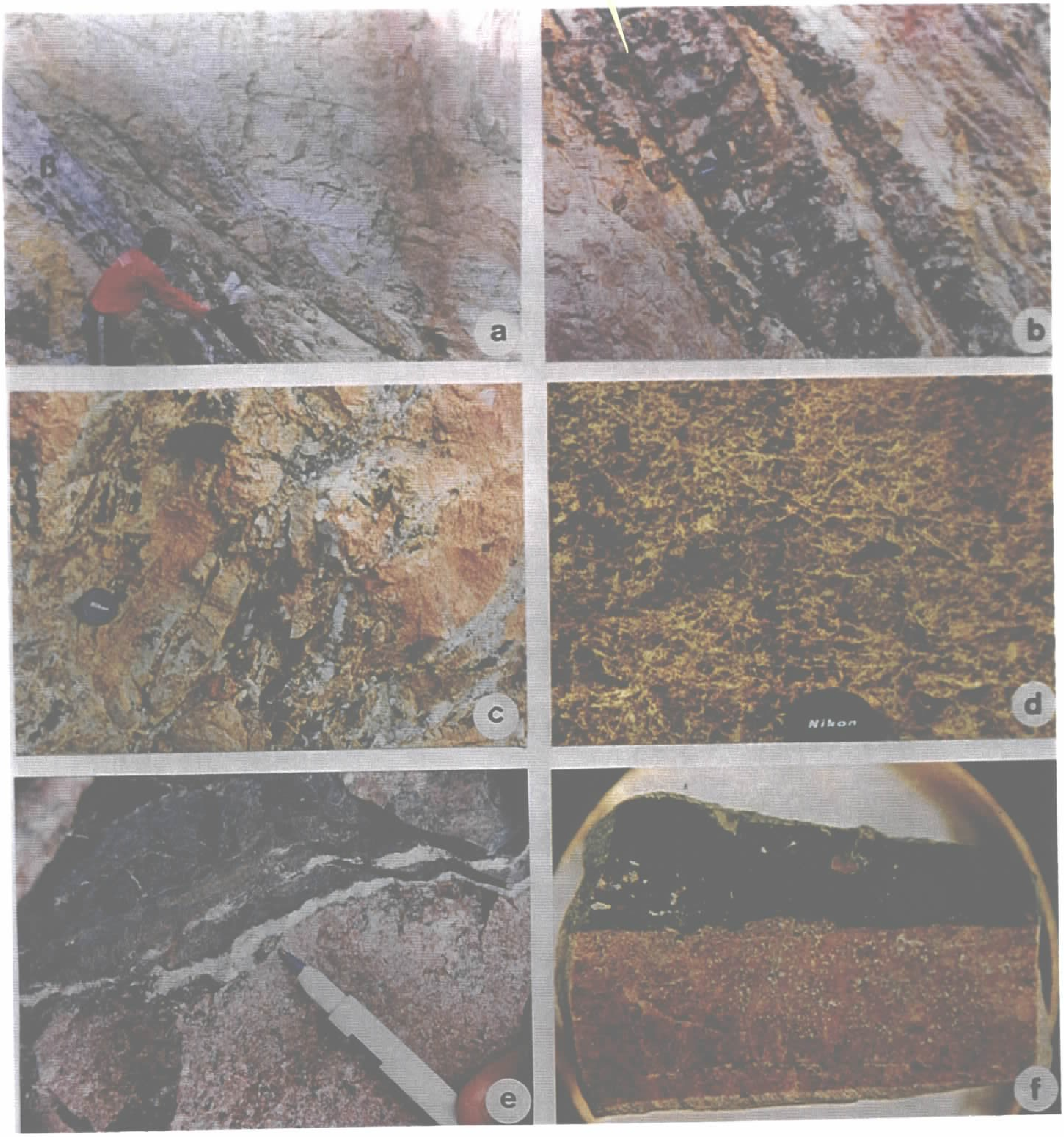

Figure 13 Gold mineralization and wallrock alteration expositions: (**a**) Lode gold deposit in Cuíu-Cuíu granitoids – ESTG cut by lamprophyre dyke - β (on the left), host rock of the mineralization. Note the ductile-brittle shear zone evidence, Pepeu-São José *garimpo* area (photomicrograph from Santos, 1996a); (**b**) Detail of the figure 13a showing the wallrock alteration and the lode gold deposit, São José-Pepeu garimpo area; (**c**) Gold-baring quartz vein in Parauari granitoid-type - SLTG, developed in ductile-brittle shear, more brittle than the Cuíu-Cuíu type, Bom Jesus *garimpo*; (**d**) stockwork gold geometries hosted by the Parauari granitoid, Carneirinho *garimpo;* (**e**) Gold-bearing quartz vein growths along the contact Maloquinha granitoid-type (on the right)/ andesitic rock (left side), Mamoal *garimpo;* (**f**) Detail of the figure 13e showig the chilled contact granitoid/andesite, Mamoal garimpo.

TABLE 6

Geochemical Data: Wallrock Alteration - Tapajós Mineral Province											
	Cuiu-Cuiu environment						**Parauari environment**			**Maloquinha environment**	
GARIMPO	São José-Pepeu			N.S. Conceição			Bom Jesus			Mamoal	
Rock-type	Quartz vein w/ Au	Wallrock alteration	Host rock	Wallrock alteration	Wallrock alteration	Host rock	Quartz vein w/ Au	Wallrock alteration	Host rock	Host rock	Host rock
Sample	MG-R- 47eIII	MG-R- 47eVII	MG-R-47 bI	MG-R-12eIII	MG-R-12eII	MG-R-15bI	MG-R -32bVIII	MG-R -32bIII	MG-R-32bIX	MG-R-52bIII	MG-R-53bI
SiO_2	77.65	69.43	71.84	63.34	62.77	42.51	94.95	66.42	73.33	51.17	78.61
Al_2O_3	3.97	17.59	13.82	15.12	14.16	11.03	3.16	17.63	14.07	17.40	11.65
Fe_2O_3	16.65	2.16	2.43	9.32	13.38	12.08	0.75	3.88	2.25	11.50	0.82
MgO	0.10	0.55	0.45	0.44	0.24	21.64	0.18	1.14	0.53	3.58	0.04
CaO	0.03	0.03	1.69	0.03	0.04	1.59	0.02	0.07	1.89	1.46	0.15
Na_2O	0.01	0.03	3.31	0.01	0.01	0.03	0.02	0.16	4.34	5.35	3.59
K_2O	0.50	3.24	4.74	0.09	0.27	0.10	0.69	5.80	3.23	1.82	4.37
TiO_2	0.03	0.32	0.32	0.35	0.75	0.68	0.05	0.40	0.27	1.59	0.09
P_2O_5	0.15	0.06	0.10	0.08	0.10	0.19	0.01	0.14	0.10	0.69	0.02
MnO	0.04	0.01	0.04	0.2	0.17	0.13	0.01	0.22	0.04	0.26	0.03
Ba	116	492	909	342	346	42	174	913	698	293	40
Co	11	2	6	57	27	47	1	30	5	21	2
Cr	157	23	6	1136	1459	3450	6	35	9	34	3
Cu	921	62	5	154	254	52	20	103	4	10	3
Li	4	10	14	24	7	11	129	32	35	36	44
Nb	1	9	14	4	9	7	0	5	7	25	48
Ni	12	12	8	106	104	643	0	11	6	35	2
Sc	13	8	5	18	16	18	2	13	6	15	1
Sr	8	18	220	2	5	11	32	37	334	205	14
V	54	33	21	74	102	143	15	113	21	94	2
Y	9	37	60	5	6	9	1	42	18	109	28
Zn	16	11	33	45	44	198	18	144	37	600	23
Zr	39	242	200	66	187	70	47	170	110	325	112
Cd	<1	<1	< 1	<1	<1	< 1	<1	<1	< 1	<1	< 1
Pb	54	7	23	60	53	74	20	2253	14	65	29
Rb	22	141	140	<2	15	<2	59	430	118	92	349
La	13.33	128.52	49.87	7.96	8.37	53.66	2.76	90.23	25.43	106.57	23.9
Ce	24.42	158.99	101.54	119.3	199.91	34.88	7.37	68.81	54.2	228.50	21.0
Pr	3.28	25.85	13.01	2.82	3.08	9.27	0.54	16.27	6.18	24.00	16.1
Nd	11.55	88.30	48.09	8.70	8.30	29.8	2.40	58.20	21.6	75.81	10.8
Sm	1.92	14.61	9.8	1.53	1.49	4.87	0.37	10.57	3.73	13.38	8.80
Eu	0.38	2.56	1.43	0.30	0.33	1.26	0.10	2.72	0.73	2.13	1.40
Gd	1.46	11.56	9.23	0.98	1.09	3.44	0.25	10.80	3.06	11.43	7.10
Dy	1.26	7.77	8.99	0.97	1.27	2.43	0.21	9.17	2.56	11.05	10.50
Ho	0.26	1.42	1.8	0.17	0.22	0.41	0.03	1.70	0.49	2.31	10.80
Er	0.71	3.19	4.73	0.37	0.45	0.90	0.07	4.37	1.28	6.39	12.50
Yb	0.69	2.88	4.32	0.65	0.89	0.78	0.14	3.78	1.25	7.15	17.40
Lu	0.12	0.45	0.61	0.1	0.14	0.12	0.03	0.58	0.19	1.10	18.20
PETROGRAPHY	Gold-bearing quartz vein w/ sulphides	Potassic (biot-rich), argillic, K-silicate	Lamprophyre (dyke)	Potassic (biot rich), argillic, K-silicate	Potassic (biot-rich), argillic, K-silicate	Tremolite-talc schist (dyke)	Gold-bearing quartz vein w/ sulphides	Potassic, K-silicate, (sericite-rich)	Monzogranite w/ biotite	Andesite (dyke)	Leuco monzogranite
Sample	MG-R- 47eIII	MG-R- 47eVII	MG-R-72bII	MG-R-12eIII	MG-R-12eII	MG-R-15bI	MG-R -32bVIII	MG-R -32bIII	MG-R-32bIX	MG-R-52bIII	MG-R-53bI

Observation: Major elements expressed in wt % and trace elements in ppm.

TABLE 7
WALLROCK ALTERATION IN GRANITOIDS:TAPAJÓS MINERAL PROVINCE

Tectonic event/ granite type-age	Structural	Host rock	Mineral Assemblage	Standard Terminology	Environment of Formation	Mineralized Site (examplo)
Pre-Trans-Amazonian Orogeny **Cuíu-Cuíu type** **2.01- 2.44 Ga**	**Ductile-brittle** strike-slip shear zone	ESTG (Cuíu-Cuíu-type)	**Biot**, clay minerals **(kaol)**, rut, qz, **mag**, sulph, iron oxide	Potassic (biot rich), K-silicate, argillic	Found in granitic-intrusion core, which gold deposit occurs in fault contact with lamprophyric intrusion	São José-Pepeu *garimpo*
Pre-Trans-Amazonian Orogeny **Cuíu-Cuíu type** **2.01- 2.44 Ga**	**Ductile-brittle** strike-slip shear zone	ESTG (Cuíu-Cuíu-type)	**Biot**, clay minerals **(kaol)**, chl, sulph, **ilm**, **hem**, epid, qz rare carb, iron oxide	Potassic (biot rich), K-silicate, argillic	Found in granitic-intrusion core, which gold deposit occurs in fault contact with ultramafic intrusion	N.S. Conceição *garimpo*
Trans-Amazonian Orogeny **Parauari type** **1.90 Ga**	Ductile-brittle strike-slip shear zone, **but more brittle**	SLTG (Parauari-type)	**K-felds**, (microcl), qz, **ser**, chlo, epid, bar, sulph, **molyb**	Potassic (ser rich) K-silicate	Found in granitic-intrusion core, structurally controlled	Bom Jesus *garimpo*
Uatumã Event **Maloquinha type** **1.79 - 1.81 Ga**	**Brittle strike-slip** shear zone	LPTG (Maloquinha-type)	**K-felds** (microcl), **ser**, chlo, mag, qz, sulph, epid, **flu**	Potassic (K-feldspar-rich), K-silicate	Found in granitic-intrusion core, which deposit occurs in fault contact of andesitic intrusion	Mamoal *garimpo*
Uatumã Event **Maloquinha type** **1.79 - 1.81 Ga**	Brittle faults **stockwork geometries**	LPTG (Maloquinha-type)	Clay minerals **(kaol)**, ser, qz, sulph	Potassic, argillic, K-silicate	Structurally controlled, associated with stock-work geometries	Carneirinho *garimpo*

Abbreviations:
Alb = albite; bt = biotite; chlo = chlorite; epid = epidote; flu = fluorite; hem = hematite ; mag = magnetite; molyb = molybdenite; microcl = microcline; pyrr = pyrrothite; sulph = sulphyde; kaol = kaolinite; K-felds = K-feldspar; qz = quartz; rut = rutile; ser = sericite

disseminated in quartz veins associated with oxidized pyrite, few base metal minerals and silver, which Au/Ag ratio = 10.

In São José-Pepeu *garimpo* the alteration zone is structural controled, aproximately 4km long by 0.5 km wide. It seems to be a dyke (strongly hydrothermal altered) hosted by the Cuíu-Cuíu monzogranite (ESTG; Fig. 13a). Quartz veins mineralized in sulphides with disseminated gold occur within the altered zone as boudins suggesting that the mineralization is syn-post shearing. The wallrock alteration consists predominantly of clay material (varies colours from violet, deep red, yellow, to white), iron oxide and silica and less biotite and sulphides (Fig. 13b). The ore study (under petrography microscope) of the mineralised quartz vein indicates the following mineral assemblage: magnetite, hematite, rutile, less sulphides (pyrite, chalcopyrite, galena), visible gold and weathering minerals (leucoxene, limonite, goethite, calcosite and covellite).

Geochemistry data of the least-altered and external boundary of the dyke (see Table 6) show high values of Cr (89 ppm), Ni (43 ppm), Sr (394 ppm), Zr (112 ppm), TiO_2 (0.62 wt%), MgO (4.78 wt %), FeO_2 (7,91 wt %), CaO (7.01 wt %), Na_2O, (4.44 wt %) and K_2O (1.26 wt %), and low contents of Nb (10 ppm) and Rb (40 ppm). These data indicate that the dyke has a composition similar to lamprophyre (see Ashley *et al.*, 1994). Enrichment/depletion diagrams from the wallrock alteration normalised to the least-altered dyke (Fig. 14a) show an enrichment in some elements such as Cu, Pb, Rb, Zr, Y, Ba, K_2O, Al_2O_3 and SiO_2 and depletion in several elements, as for example, Fe_2O_3, MgO, TiO_2, Ni and Cr (see Fig. 14b). The dyke normalised to the vein show an expressive enrichment in Cu and Pb (+ Au assumed from the ore studies) and less Cr, Fe_2O_3, and SiO_2.

In Nossa Senhora da Conceição *garimpo* the wallrock alteration is also close associated with dyke and shows similar structural relationships (strike-slip shear zone) as

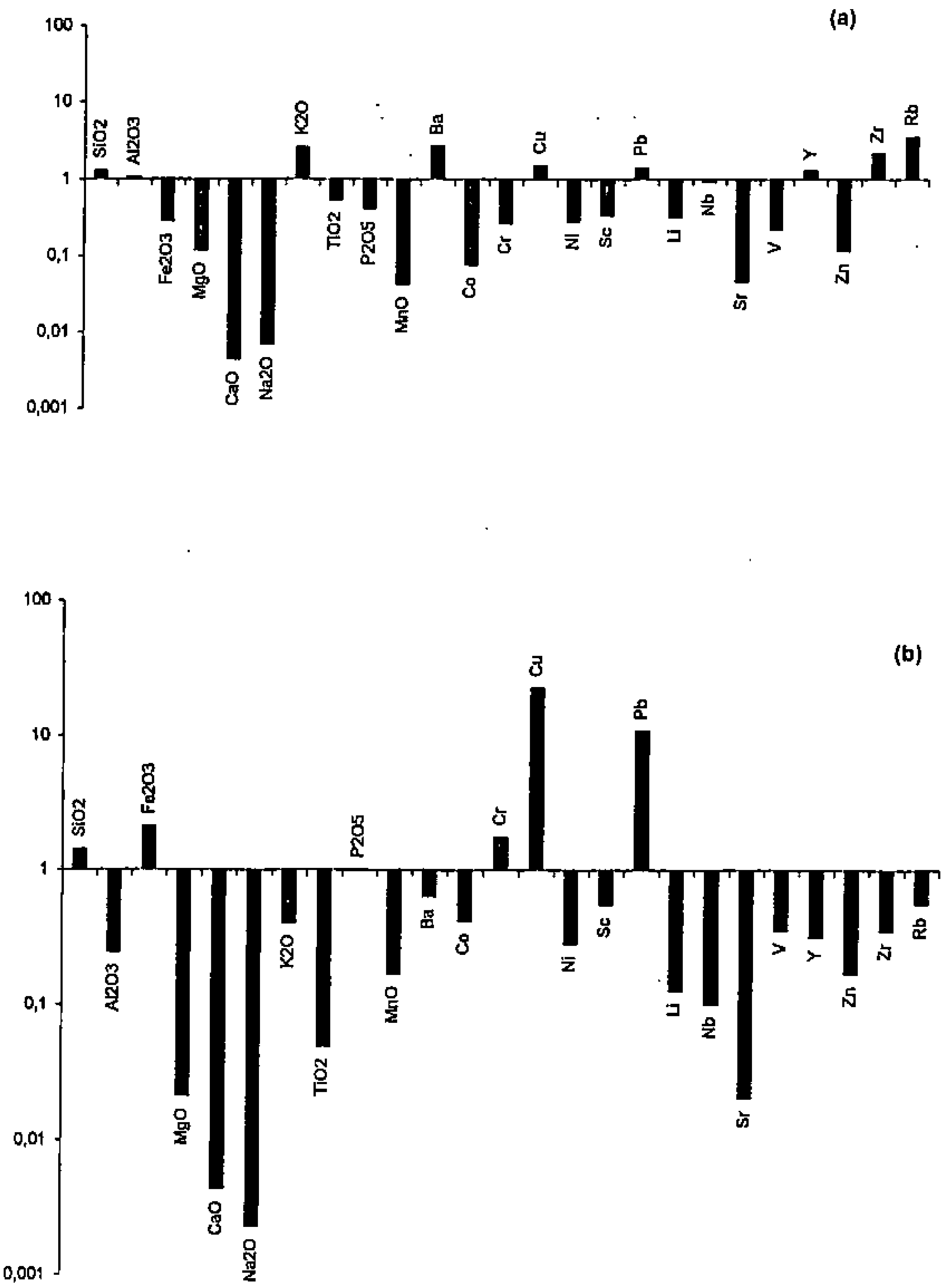

Figure 14 Enrichment/depletion diagrams for Cuíu-Cuíu granitoid – ESTG in São José-Pepeu *garimpo*: (a) alteration zone chemistry (MG-R-47eVII) compared to lamprophyric host rock (MG-R-47bI); (b) gold-bearing quartz vein chemistry (MG-R-47eIII) compared to the lamprophyre (MG-R-47bI).

São José-Pepeu area. It consists of very altered dyke cutting Cuíu-Cuíu tonalite, with high clay content, biotite, chlorite and rare carbonate. It contains boudins of gold-bearing quartz veins. However, geochemical data of the least-altered dyke (Table 6) are consistent with ultramafic rock composition with very high values of Mg (21.64 wt %), Fe_2O_3 (12.08 wt %), Cr (3450 ppm), Ni (643 ppm), V (153), TiO_2 (0.68 ppm), and less expressive CaO (1.59 wt %) and Zr (70 ppm). Enrichment/depletion diagrams from the wallrock alteration normalised to the dyke show a distribution similar to São José-Pepeu area, however, an enrichment in K_2O and TiO_2 and a depletion in Pb were detected (Figs. 14c and d). The ore mineral assemblage is quiet similar as well, but ilmenite and pyrrotite were identified in this area.

The wallrock alteration related to the Parauari granitoid environment (Bom Jesus *garimpo*) is structural controled. It consists of strike-slip shear zone, although more brittle then the Cuíu-Cuíu setting, developed during the Parauari granitoid emplacement under compressive regime (Santos, 1996b). Within the alteration zone, gold-bearing quartz vein, with én-chèlon forms, sometimes, and brecciated texture occurs suggesting active tectonic regime (e.g. Goiano garimpo). The wallrock consists, predominantly of sericite and K-feldspar, minor chlorite, barite, epidote and rare carbonate. When sericite is the dominant mineral, as function of the hydrothermalism, sigmoidal forms can be seen (e.g São Jorge *garimpo*). The mineral assemblage suggests retrograde metamorphism conditions consistent with reactivation shearing. Ore mineral study of the gold-bearing quartz vein indicated a mineral assemblage similar to the mineralization hosted by Cuíu-Cuíu granitoids, however, it shows some differences: a depletion of titanium minerals (e.g. lack of ilmenite) and enrichment in oxide such as molybdenite and some sulphides (sphalerite and bornite). Electron microscopy study indicates that the native gold occurs as disseminated in quartz veins and associated with base metal

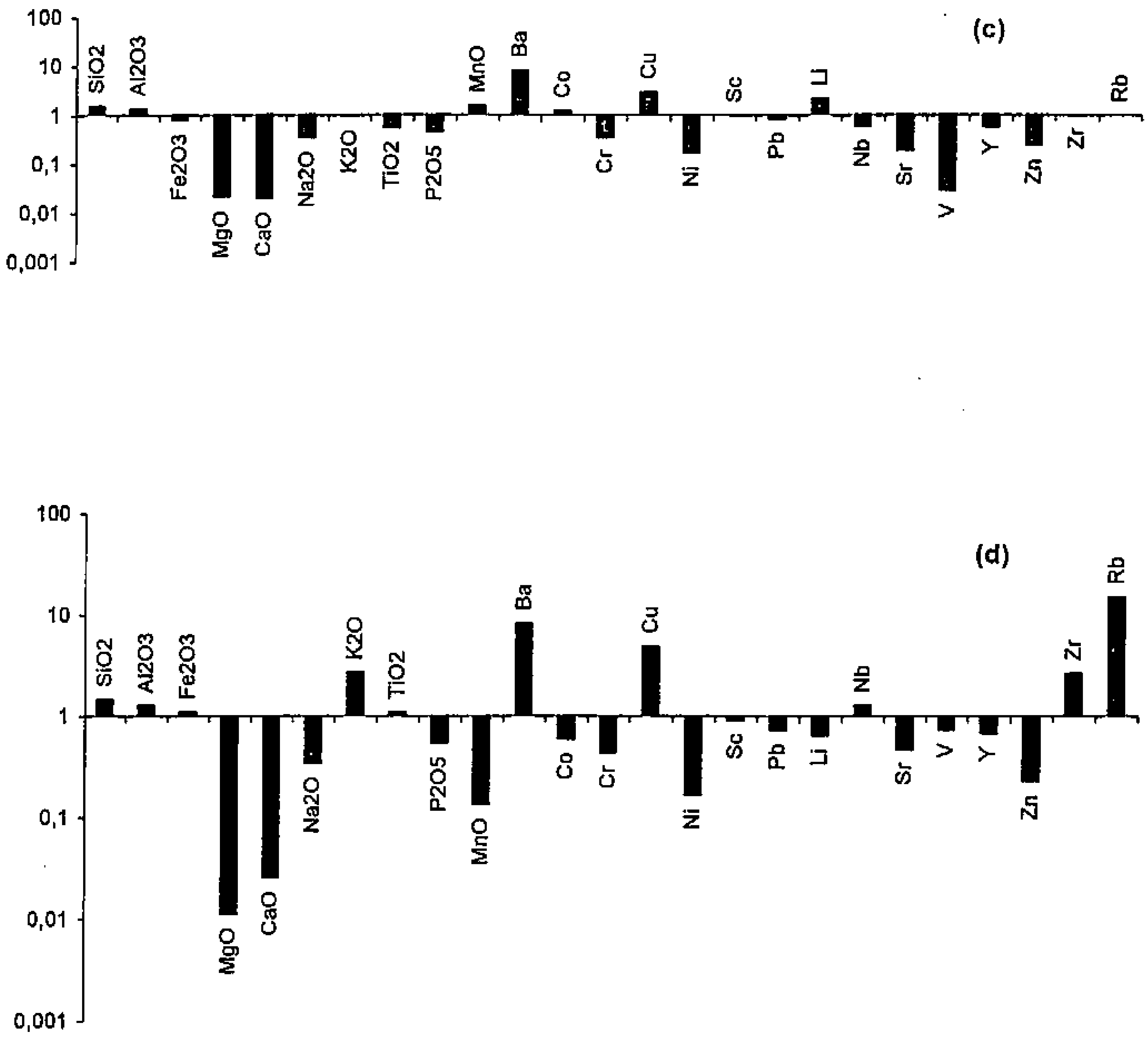

Figure 14 Enrichment/depletion diagrams for Cuíu-Cuíu granitoid – ESTG in N.S. Conceição *garimpo:* (c) alteration zone chemistry (MG-R-12eIII) compared to ultramafic (talc-tremolite schist) host rock (MG-R-15bI); (d) alteration zone chemistry (MG-R-12eII) compared to ultramafic (talc-tremolite schist) host rock (MG-R-15bI).

sulphides and silver, which Au/Ag ratio = 4 (lower than the Cuíu-Cuíu mineralization-type).

Geochemistry data of the host rock are consistent with chemistry compostion of granitic rock (e.g. Parauari-type), which major elements show high values of SiO_2 (73.33 wt %), Na_2O, (4.34 wt %) and K_2O (1.26 wt %), and low contents of FeO_2 (2.25 wt %) and MgO (0.53 wt %) and TiO_2 (0.27 wt%). Trace elements are high in Rb (118 ppm), Sr (334 ppm), Zr (110 ppm), and low in Nb (7 ppm), Cr (9 ppm), Ni (6 ppm), V (21 ppm) and Y (18 ppm). Enrichment/depletion diagrams from the alteration zone, normalised to the unaltered host rock, indicated a massive enrichment in Al_2O_3, Fe_2O_3, MgO, K_2O, TiO_2, P_2O_5, MnO, Ba, Cr, Cu, Ni, Sc, Pb, V, Y, Zn, Zr, and Rb, and depletion in SiO_2, CaO, Na_2O, Nb and Sr (Figs. 14e and f). The gold-bearing quartz vein normalised to the host rock shows enrichment in Pb, Cu and SiO_2.

The wallrock alteration in Maloquinha environment is weak developed and close associated with brittle strike-slip fault (e.g. Mamoal *garimpo;* see Santos, 1996a). The mineralization consists of dilation zone (jog-type) filled by andesitic dyke, in which chilled contact growths quartz vein with gold associated with sulphides. However, disseminated sulphides occurs either in the granitoid or in the dyke. The break of the host rock at large scale produces the hydralic fractures as a result of the fluid pressure. Dyke breccia texture with angular fragments of granite is also indicative that the intrusion was accompanied by hydrothermal processes. A new matrix is superimposed on both rocks (granitoid and the dyke), but the original textures are still preserved.

The dyke is an andesite, which major elements composition is: SiO_2 = 51.17 wt %, Al_2O_3 = 17.40 wt %, Fe_2O_3 = 11.50 wt %, MgO = 3.58 wt %, CaO = 1.46 wt %, Na_2O = 5.35 wt %, K_2O = 1.82 wt %, TiO_2 = 1.59 wt % and P_2O_3 = 0.69 wt %. Values of some trace elements are: Cr = 34 ppm, Zr = 325 ppm, Cr = 34, Ni = 35, Nb = 25, Sr = 205 ppm, Zn = 600 ppm, Pb = 65 ppm and Cu = 10 ppm.

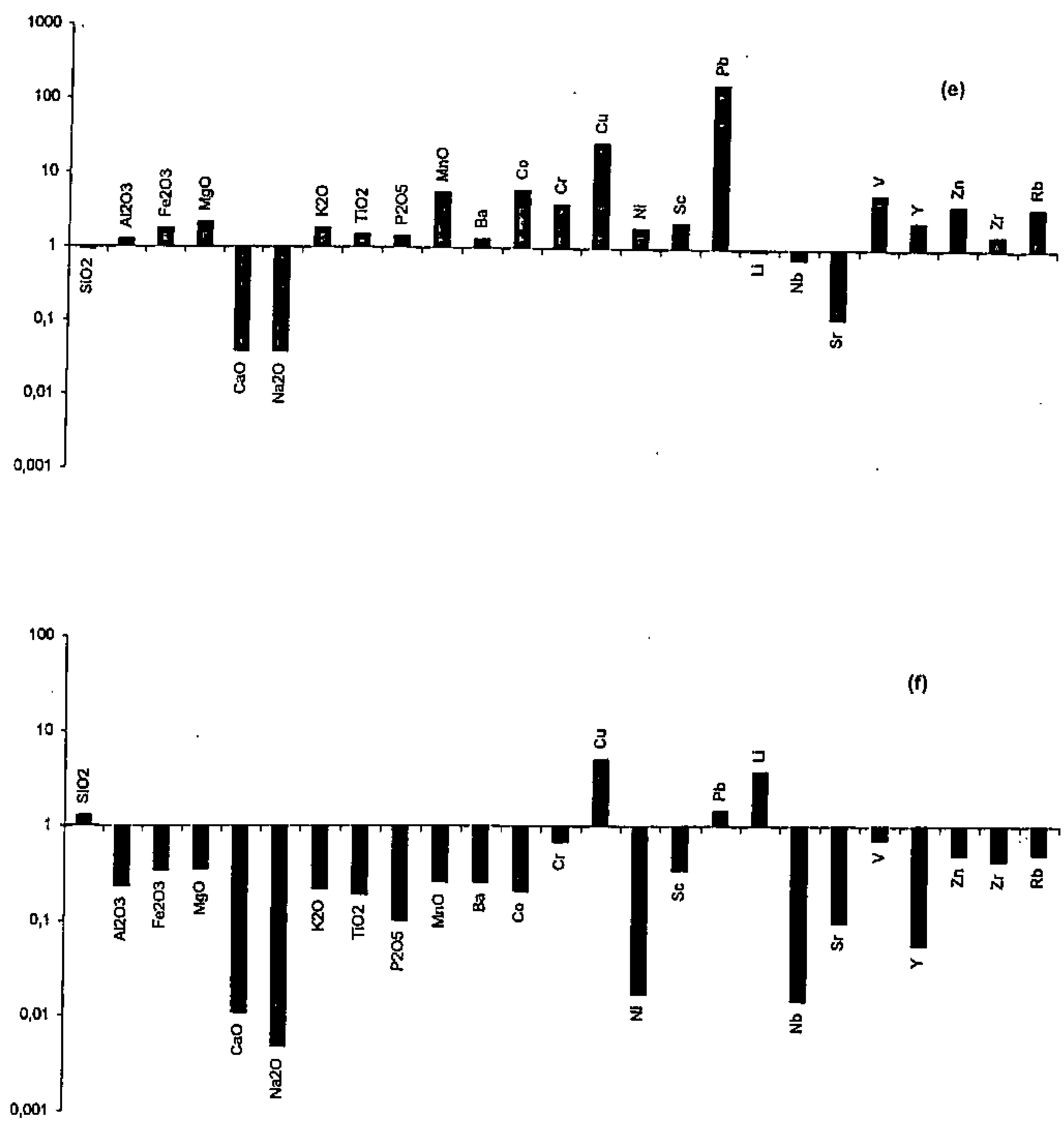

Figure 14 Enrichment/depletion diagrams for Parauari granitoid – SLTG in Bom Jesus *garimpo:* (e) wallrock alteration chemistry (MG-R-32bIII) compared to monzogranite host rock (MG-R-32bIX); (f) gold-bearing quartz vein chemistry (MG-R-32 bVIII) compared to monzogranite host rock (MG-R-32bIX).

Although the wallrock alteration occurs close associated with dyke, it looks like pervasive style and consists dominantly of potassium feldspar which origin reflect the reaction of the mineralised fluid, very rich in potassium, with the whole rock along the fractures. The K-feldspar is pink in colour and coarse grains in size. The colours is due to the presence of iron (hematite) in the crystal structure or to finely disseminated solid inclusions of hematite. Sericite also occurs and it is formed by the subsequent break of the K-feldspar. Usually, this association with sericite (lower temperature) and lower sulphidization suggests that the K-feldspar is microcline. Fluorite and chlorite (altered from biotite) associated with sericite reflect low temperature conditions. The ore mineral study indicates that the gold occurs as visible gold associated with sulphides, which paragenesis is very similar to the Parauari mineralization-type. However, molybdenite was not found, but tetrahedrite, cassiterite and fluorite occur only in this type of mineralization.

GOLD MINERALIZATION

In Tapajós Mineral Province, gold associated with sulphides is widespread and occurs in a quite large variety of host-rock, such as: gneiss basement; granitoids related to different tectonic evolution setting and volcanic and basic rocks with different ages and sediments. However, granitoids represent the most common host rock-type.

According to Coutinho *et al.* (1997), gold mineralization related to the granitoids is recognised as two types: (i) gold-bearing quartz vein-type; and (ii) disseminated to stockwork gold (Fig. 13a to f). The first type is related to Cuíu-Cuíu-granitoid-type (ESTG) such as, tonalitic gneisses (e.g. N.S. Conceição *garimpo*), granitic gneisses and deformed granites (e.g. São José-Pepeu *garimpo* area) and occurs in close association with mafic/ultramafic and lamprophyric dykes. The structural pattern suggests that the

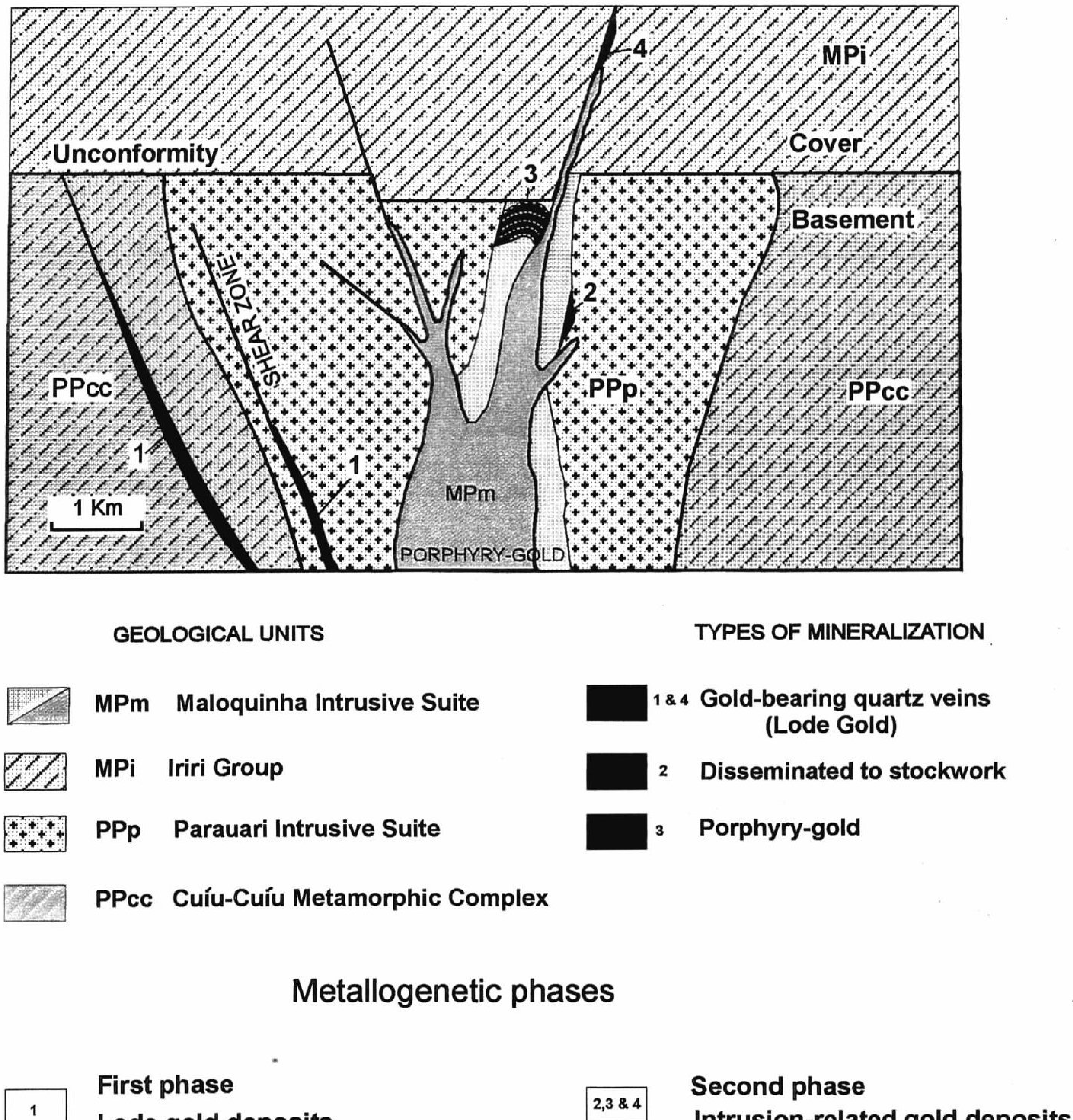

Figure 15 Schematic geological model showing the distribution of different types of mineralization in the Tapajós Mineral Province (modified from Coutinho *et al.*, 1997).

mineralization is genetically associated with ductile strike-slip shear zone development (Santos, 1996a). This type represents the lode gold deposit.

The mineralization hosted by Parauari (SLTG) granitoids is also controlled by brittle-ductile shear zone, however more brittle than the Cuíu-Cuíu mineralization-type. It consists of as quartz-filled fractures (e.g. Bom Jesus *garimpo*), which evidence (structural and mineral paragenesis) suggests it could be lode gold type as well.

The second type of mineralization occurs as quartz-filled fractures (e.g. Mamoal *garimpo*), stockwork-types vein geometries (e.g. Carneirinho *garimpo*; Fig. 13d) or disseminated in rocks (Jutaí *garimpo*) with only minor related wallrock alteration zones. The quartz veins show evidence of transitional epithermal/mesothermal-type (see Coutinho *et al.*, 1997).

According to this proposel model for the gold mineralization in Tapajós Mineral Province and shown in Figure 15, at least two metallogenetic phases are recognised: (i) the first phase represented by the mesothermal lode gold deposits (see Groves and Foster, 1991); and (ii) the second phase formed by the intrusion-related gold deposits (porphyry-gold deposits; Sillitoe, 1991). However, more works (fluid studies) and precise dating of the mineralization are in progressing to verify if the mineralizations Parauari granitoid hosted and Maloquinha type are the same large mineralization hydrothermal system, close related temporally and genetically (as occurs in Abitibi belt, Canada), or are separately.

DISCUSSION AND CONCLUSIONS

Three suites of granitoids are recognisable in the mineralized areas based on field structural, petrographic and chemical data. The REE distribution pattern in the Cuíu-Cuíu granitoids (ESTG) is typical of TTG terranes in many Archaean cratonic areas. The slight positive Eu anomalies (no plagioclase fractionation) and a concave upward pattern in the HREE probably resulted from the fractionation processes of garnet and pyroxene (cumulative HREE minerals). It suggests that these rocks have been formed at deep seat in the lower crust at a high pressure. It is consistent with the high ratios LREE/ HREE (normalised values) for the Cuíu-Cuíu suite, as for example (La/Lu)N >25, indicating a magma-origin whose melt was in equilibrium with garnet. The LILE (Rb, Ba and Sr) contents are also consistent with those values of the Archaean deep sited rocks. The Cuíu-Cuíu granitoids (ESTG) may be formed from mafic garnet granulite or gneissic-tonalitic terranes whose magma source could have been produced in a volcanic arc as continental arc (i.e. a primitive Cordillera). This granitoid-type is generally depleted mantle source enriched by a subduction fluid with a weak interation with continental crust (Pearce, 1996).

The more variable composition of the Parauari granitoids (SLTG) indicates that they may represent a complete orogenic cycle from early subduction-related magmas to collision granites with crustal component and finally later to post-tectonic extension related plutons. Based on their chemistry, a high fractionated REE pattern with (La/Yb)N values < 20 and (Gd/Yb)N ranging from 1 to 3, a systematical slight negative Eu anomalies and Rb/Sr ratios values > 1, suggest that these granitoids are more evolved than the Cuíu-Cuíu-type. The Parauari granioitds are similar to the calc-alkaline potassic granitoids of the Proterozoic terranes. The Nb/Zr ratios < 1 indicate a relationship of these rocks with the subduction zone and an emplacement probably at a medium crust level. The Parauari magmatism characterised by intermediate to acidic composition, calc-alkaline to alkaline, slightly to highly potassic and metaluminous to peraluminous, should have taken place in arc/continental collision zone (see Thièblemont et Tègyey, 1994). Generally, this magma is mantle or crustal sources augmented by melts and fluids from subducted or underthrust continental crust (Perace, 1996).

In addition, as can be seen in Figure 11b, the chondrite-normalised REE diagrams for the Parauari granitoids show two set of samples with concentration values well different. There are two points to expain the fact. First, one assumes that there is a link between REE concentration and deformation. The least-deformed specimens (e.i. Parauari granitoids MG-R-06 that occur in Davi *garimpo*) are REE depleted, while the deformed granitoids (e.i. Parauari specimens MG-R-72 b I and MG-R-72 b II in São José village, near by the Pacu river) are more enriched in REE. Secondlly, it suggests fractionation process as clearly demonstrated by petrography studies: microtonalite with REE depleted pattern, while the cataclastic monzogranite is REE enriched. This interpretation may reforce the hypothesis of a genetic link between Parauari granitoids and the Ingarana mafic/ultramafic rocks.

The Maloquinha granitoids (LPTG) have a distinct alkaline chemistry and likely were produced in a post orogenic extensional environment. The high Rb and low Sr contents with Rb/Sr ratios > 1 may be considered as a very evolved suite. The high Nb/Zr ratios and the REE 'gull-wing' pattern with very strong Eu negative anomalies, probably resulted from the plagioclase fractionation and enrichment in LREE and HREE with exceptionanally a high (Gd/Yb)N > 1, suggest extensional granitoids whose emplacement took place at a high crustal level. Quartz phenocrystals in Maloquinha granitoids and based on the experimental study of Nicholls *et al.*, (1971), it is reasonable to assume the Maloquinha magma precipitating quartz at a depth equivalent to an average of about 6 kilobars. This data have implications for the melt taking place at about 700°C correspondent to 20-30km. These conditions refletes high-level magma chamber.

On the other hand, the Maloquinha granites (LPTG) generation might represent mantle-plume activity associated with ensialic back-arc spreading, but an alternative collision origin has been suggested (F. Robert, pers. comm.), derived from the model of the Abitibi Belt, Canada. If the orogenic belt had opposing subduction zones on either side, the end-result of dual orogeny might be a central region of thick crust and particularly a lower crust with much basic underplating and elevated temperature, which could generate such extensional magmas. According to Pearce (1996) the post-collision granites are enriched mantle sources (through subduction and/or intraplate processes) with an extensive crustal interaction.

The proposed geotectonic setting model suggests that the Tapajós granitoids were generated by convergent plate margins above zones of active subduction followed by a subsequent high crustal component. The gold mineralizations are probably genetically linked to subduction-related tectonic processes in discrete volcanic arcs. This model played an important role in the different gold metallogenetic phases in the area.

The emplacement of the early syn-tectonic granitoids (Cuíu- Cuíu type), the mafic/ultramafic and lamprophyre dykes and the development of the crustal scale shear zones may be part of a genetic triangle resulting in the mesothermal lode gold deposits. This association occurs on a worldwide scale and in mining gold districts of Archaean to Mesozoic age. The mafic/ultramafic and lamprophyre dykes associated with gold mineralization related to dilational jog structures acted as conduits for dyke intrusion and, subsequently for the hydrothermal mineralised fluids (see Ashley *et al.*, 1994).

The wallrock alterations enrichment in some elements such as Cu, Pb (+ gold assumed from the ore mineral studies), Rb, Ba and K_2O suggests magmatic influence in the hydrothermal mineralized fluid (see Kerrich, 1989). The paragenetic association gold, silver, base metal minerals and the lower crust setting for the host rock are consistent with mesothermal lode gold deposits and represents the first metallogenetic gold phase in Tapajós Mineral Province.

The high values of TiO_2, Zr, Cr and Ni in the host rock suggest that the mafic/ultramafic and lamprophyre dykes could be the gold source. However, in case of unlikely that the lamprophyre dykes have been a direct source for lode gold mineralization, for the first gold metallogenetic phase, the close temporal and spatial relation of dykes, the mesothermal gold veins and the ESTG calc-alkaline intrusions are interpreted to be manifestations of the influx of mantle-derived heat and partial melts into the Tapajós Mineral Province during, at least, the Early Proterozoic time.

Evidence of active tectonic during the gold-quartz filled veins emplacement in the Parauari environment suggests that the gold mineralization is associated with strike-slip shear zone reactivation. From the early subduction-related magmas to collision granites, a broad spectrum of intrusion-related gold deposits took place followed by a extensional tectonic regime. The ore mineral paragenesis gold, base metal sulphides (Cu, Pb and Zn) and molybdenite and the wallrock alteration evidence (K-silcate alteration) suggest magmatic influence in the mineralised fluid similar to world-wide mesothermal gold-lode deposits.

The Maloquinha host-type deposits are comparable to those found in the epizonal intrusive environment (Sillitoe, 1991), and represent an intermediate position between epithermal/mesothermal gold deposits (Robert, 1996). Gold-bearing plutons-related systems contain abundant quartz veins. Usually this type of mineralization occurs peripheral to and relatively deep in an intrusion-centered hydrothermal gold system (Sillitoe, 1991).

The transitional epithermal/mesothermal style of quartz-vein mineralization and occurrence of disseminated to stockwork-type vein geometries within some of the Tapajós Mineral Province indicates that there is the possibility of hard-rock magmatic-type porphyry gold mineralization. The textures types ranges from aplitic to coarse grained porphyritic are consistent with several magmatic pulses. Structures displayed include tension fissure and longitudinal fractures, belived to be the result of magmatic doming, providing conduits for initial stockwork quartz vein development and quartz enrichment in shear zone (e.g. Carneirinho *garimp;* Fig. 13d).

Furthermore, the K-felsdpar is a major alteration and the most abundant alteration in porphyry gold deposits and it tends to be developed better in felsic rocks. In addition, the Maloquinha suite contains obviously oxidised facies: hematite is common (sometimes possibly pseudomorphing pyrite) and perhaps deserves the most attention as a potential host for pluton-hosted gold, similar to the Fort Knox type, British Columbia and Douay deposit in Abitibi Belt, Canada. In North American where porphyry gold mineralization has been found in Mesozoic Cordilleran plutons within suites of mixed calc-alkaline/extensional-type affinity related to a late-orogenic collision setting. Some of the Tapajós plutons resemble these types of porphyry, which mineralization is directly associated with specific phases of distinctive intrusive suites.

The structural control shear zone and stockwork geometries, the similarities in mineral assemblage of the gold filled quartz veins with poor sulphides (Pb, Cu, Zn) associated with molybdenite and the wallrock alteration histories (K-silicate alteration), in the gold mineralization hosted by Parauari (SLTG) and Maloquinha (LPTG) suites, suggest that large mineralizing hydrothermal systems were related temporally and genetically. It could be the same metallogenetic phase and contains the porphyry gold deposits (the second metallogentic phase) in Tapajós Mineral Province

On the other hand, the high Rb values (>120 ppm) and some HREE enrichment in Maloquinha granitoids are indicative of some metallogenetic specialization for Sn and W mineralizations. Gold associated with cassiterite has already been found in this type of granitoid (e.g. Santa Isabel *garimpo),* which area was exploited for Sn in the past.

Based on the present study, it is clear that the magmatism play an important role in the gold mineralization either in the metal source or in the fluid in the area. The relationships between the gold source and the magmatism, whose host granitoids emplacement took place at different crustal levels, may be explain in several ways: (i) magmas source depleted and/or enriched in metal (including gold); (ii) magma mixing mantle-derived and crustal contaminated; or (iii) metals (e.g. Cu, Pb, Zn, Mo and Au) added in the wallrock by hydrothermal fluids. However, it has already shown that: (i) Cuíu-Cuíu and Parauari magmatisms have a calc-alkaline nature, although some Parauari specimens are more alkaline, and Maloquinha is dominantly alkaline; (ii) Cuíu-Cuíu host granitoids contain mafic/ultramafic and lamprophyric intrusions, while Maloquinha is cut by andesitic dykes, whose intrusions with different chemical compositions have an influence in the chemistry of the wallrock alterations; (iii) Cuíu-Cuíu granitoids have a predominant mantle component, while the Parauari is a magma mix, mantle and minor crustal component and Maloquinha granitoids are predominant magma-crustal derived; and (iv) the chemical composition of mineralized fluid has a very strong plutonic influence, rich in potassium, in all different host granitoids gold deposits. Finally, it is interpreted that the gold mineralizations in Tapajós Mineral Province, for both type of deposits: (i) lode gold and (ii) porphyry gold have a link with the magmatism either in source of the gold or in the mineralised fluid. It is suggests that gold comes from mantle in the first type, while the second one has a strong crustal contamination such as is involked for classical porphyry Cu or granite-hosted Sn and W mineralizations.

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CAPTIONS

Figure 1 Tapajós Mineral Province location.

Figure 2 Geological map of the Tapajós Mineral Province. Note the mineralised study areas location.

Figure 3 Granitoid out crops: (**a**) Tonalitic gneiss, Cuíu-Cuíu-type (N.S. da Conceição *garimpo*); (**b**) Cuíu-Cuíu granitoid – ESTG showing magmatic flow evidence, where coarse and fine textures can be seen (texture banding). Note the mafic enclave, São José-Pepeu *garimpo*; (**c**) Deformed Parauari granitoid – SLTG, (São José village, near by the Pacu river); (**d**) Undeformed Parauari granitoid facies range; note the mafic enclave (on the middle), Bom Jesus *garimpo*; (**e**) Maloquinha granitoid – SLTG cut by andesitic dykes, Tapajós river, left margin; and (**f**) Maloquinha granitoid – SLTG, host of the quartz vein, which emplacement suggests extensional deformation. Note the brittle evidence, Tapajós river, left margin.

Figure 4 Airborne radiometric geophysic total count (**a**) uranium channel map and (**b**) thorium channel map. Compare to the granitic suites distribution shown in the geological map in Figure 2.

Figure 5 Granitoid hand specimens: (**a**) Cuíu-Cuíu granitoid-type – ESTG, shows a slight anastomosing fabric due to prefered orientation of mafic minerals, (Creporizão area); (**b**) Other view of (a); (**c**) Parauari granitoid-type – SLTG facies 'contact': coarse biotite monzonite (on the bottom) and fine-grained honrblende-biotite monzonite (on the top), Bom Jesus *garimpo*; (**d**) Deformed Parauari granitoid, see the oriented fabric, São José-Pepeu *garimpo*; (**e**) Maloquinha granitoid-type – LPTG, re-crystallised alkali-feldspar leucogranite, coarse grain polygonised; (**f**) Maloquinha altered porphyry – LPTG showing a few aggregate phenocrysts consisting of microcline grains (25% of the volume), Tapajós river, left margin.

Figure 6 Modal values distribution (Streckeisen, 1974) for: (**a**) crosses: Cuíu-Cuíu granitoid-type – ESTG; (**b**) squares: Parauari granitoid-type – SLTG; (**c**) dots: Maloquinha granitoid-type – LPTG.

Figure 7 Shand diagram as modified by Maniar and Piccoli (1989). Fields are: IAG = Island-arc granite; CAG = Continental-arc granite; CCG = Continental-collision granite. Cuíu-Cuíu suite as heavy line; Parauari field as heavy dashes; Maloquinha granitoids as dots are distinctive in their trend (which lies within the field normally occupied by the 'post-orogenic' granites), along the 1:1 ratio line.

Figure 8 Sylvester (1989) type major element diagram for the three Tapajós granitoid types: Symbols are: crosses = Cuíu-Cuíu-type; squares = Parauari-type; dots = Maloquinha-type. The Maloquinha granitoids – LPTG and a few Parauari specimens – SLTG plot in the 'highly-fractionated' field of alkaline granites. (FeO* = Fe total)

Figure 9 Rb-Ba-Sr diagram for: C = Cuíu-Cuíu-type (crosses); P = Parauari-type (squares) and M = Maloquinha-type (dots). Boundaries for tectonic discrimination after Pearce *et al.*, (1984) are: WPG = within-plate granite; COLL = collision granite; VAG = volcanic arc granite. Maloquinha are quite distinctive due to their relatively fractionated nature in the within-plate granite (WPG) field.

Figure 10 Spidergrams for: (**A**) Cuíu-Cuíu granitoid-type – ESTG; (**B**) Parauari granitoid-type – SLTG; (**C**) Maloquinha granitoid-type – LPTG. These are normalised to chondrite (except Rb, K, P) using the following values: Pb = 0.12; Rb = 0.35; Ba = 3.8; Nb = 0.35; K = 0.014 for %K_2O; La = 0.315; Ce = 0.813; Sr = 11; Nd = 0.597; P = 0.011 for P_2O_5%; Eu = 0.077; Zr = 5.6; Ti = 0.103 for % TiO_2; Gd = 0.275; Dy = 0.342; Ho = 0.076 and Y = 2, according to Sun (1980).

Figure 11 The rare-earth elements (REE) distribution for: (**A**) Cuíu-Cuíu granitoid-type – ESTG; (**B**) Parauari granitoid-type – SLTG; and (**C**) Maloquinha granitoid-type – LPTG. Note the different pattern of Eu anomalies showing in the three suites. Values normalised by Nakamura, 1977.

Figure 12 Tectonic discrimination diagrams of: (**a**) and (**b**) Pearce *et al.*, (1984) and (**c**) and (**d**) Sylvester (1989). Symbols are: (**a**) crosses: Cuíu-Cuíu granitoid-type – ESTG; (**b**) squares: Parauari granitoid-type – SLTG; (**c**) dots: Maloquinha granitoid-type – LPTG.

Figure 13 Gold mineralization and wallrock alteration expositions: (**a**) Lode gold deposit in Cuíu-Cuíu granitoids – ESTG cut by lamprophyre dyke - β (on the left), host rock of the mineralization. Note the ductile-brittle shear zone evidence, Pepeu-São José *garimpo* area (photomicrograph from Santos, 1996a); (**b**) Detail of the Figure 13a showing the wallrock alteration and the lode gold deposit, São José-Pepeu *garimpo* area; (**c**) Gold-baring quartz vein in Parauari granitoid-type - SLTG, developed in ductile-brittle shear, more brittle than the Cuíu-Cuíu type, Bom Jesus *garimpo*; (**d**) stockwork gold geometries hosted by the Parauari granitoid, Carneirinho *garimpo;* (**e**) Gold-bearing quartz vein growths along the contact Maloquinha granitoid-type (on the right)/ andesitic rock (left side), Mamoal *garimpo;* (**f**) Detail of the Figure 13e showig the chilled contact granitoid/andesite, Mamoal garimpo.

Figure 14 Enrichment/depletion diagrams for Cuíu-Cuíu granitoid – ESTG in São José-Pepeu *garimpo*: (**a**) alteration zone chemistry (MG-R-47eVII) compared to lamprophyric host rock (MG-R-47bI); (**b**) gold-bearing quartz vein chemistry (MG-R-47eIII) compared to the lamprophyre (MG-R-47bI).

Figure 14 Enrichment/depletion diagrams for Cuíu-Cuíu granitoid – ESTG in N.S. Conceição *garimpo:* (**c**) alteration zone chemistry (MG-R-12eIII) compared to ultramafic (talc-tremolite schist) host rock (MG-R-15bI); (**d**) alteration zone chemistry (MG-R-12eII) compared to ultramafic (talc-tremolite schist) host rock (MG-R-15bI).

Figure 14 Enrichment/depletion diagrams for Parauari granitoid – SLTG in Bom Jesus *garimpo:* (**e**) wallrock alteration chemistry (MG-R-32bIII) compared to monzogranite host rock (MG-R-32bIX); (**f**) gold-bearing quartz vein chemistry (MG-R-32 bVIII) compared to monzogranite host rock (MG-R-32bIX).

Figure 15 Schematic geological model showing the distribution of different types of mineralization in the Tapajós Mineral Province (modified from Coutinho *et al.*, 1997).

TABLES

Table 1 Geochemical data for the granitoids.

Table 2 Field, geophysical and structural features.

Table 3 Mineralogy and petrographic features.

Table 4 Geochemistry features

Table 5 Geotectonic setting

Table 6 Geochemical data of wallrock alterations

Table 7 Wallrock alteration features