ARCHEAN AND EARLY PROTEROZOIC COMPLEXES OF SANTA CATARINA, PARANÁ AND SÃO PAULO STATES, SOUTH-SOUTHEASTERN BRAZIL: AN OUTLINE OF THEIR GEOLOGICAL EVOLUTION

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ABSTRACT The Luís Alves, Serra Negra and Itatins complexes are Archean to early Proterozoic metamorphic units in the Brazilian States of Santa Catarina, Paraná and São Paulo, south of the 24°S parallel. This paper summarizes their geological evolution based on petrographic, chemical, and mainly geochronological data. The three complexes consist of metamorphic rocks of the granulite facies, dominantly: norites, enderbites, charnoenderbites, ultramafites of granulite facies, kinzigites, quartzites, biotite-hornblende gneisses, meta-quartz diorites, metadiorites, metagabbros, serpentinites and talcites. Petrographic and chemical data support an igneous origin for most of these rocks. The radiometric age determinations made by the Rb-Sr and the K-Ar methods on different materials gave results related, for the most part, to the Pre-Jequié (about 3,100 m.y.), Jequié (2,600 ± 200 m.y.) and Transamazônico (2,000 ± 200 m.y.) events. Geochronological data suggest that the three complexes were formed predominantly by crustal accretion-differentiation processes.

INTRODUCTION The Luís Alves, Serra Negra and Itatins complexes are lithostratigraphic units of Precambrian metamorphic rocks in the south-southeastern region of Brazil (Fig. 1). These metamorphic complexes are considered to be cratonic fragments situated between two late Proterozoic fold belts, the Apiaí and Tijucas. A reworked and rejuvenated basement in the late Proterozoic separates the three complexes, from each other and from the Apiaí Fold Belt.

According to Hasui, Carneiro and Coimbra (1975), the Precambrian terrains between these two fold belts belong to a median massif, the Joinville Median Massif. Geochronological, structural and petrographic evidences, however, have been presented in recent years favouring a close correlation between these terrains and those of Southwest Angola and Northwest Namibia (Hasui, Almeida and Brito Neves, 1978; Kaul, 1979, 1980). For the latter, a great part of the Precambrian terrains between the Apiaí and Tijucas fold belts corresponds to the Luís Alves Craton (Fig. 2), which is the Southwestern prolongation of the Congo Craton of Africa in south-southeastern Brazil.

Several contributions have been made to the geological knowledge of these three complexes and their surrounding terrains. Such contributions mainly emphasize the aspects of regional geology, geotectonics, geochronology, petrology, petrography, geochemistry and correlations with Africa. Besides these works, the following contributions are worth mentioning: Fuck, Trein and Marini (1967); Basumallick *et al.* (1969); Minióli (1972); Fyfe and Leonardos Junior (1974); Cordani (1974); Girardi *et al.* (1974); Almeida, Hasui and Brito Neves (1976); Silva *et al.* (1977); Kaul, Issler and Bonow (1978); Hartmann, Nardi and Cupertino (1979); Hartmann, Silva and Orlandi Filho (1979); Moreira and Marimon (1980); Silva and Dias (1981); Moreira and Marimon (1982).

The main purpose of this paper is synthesize the geological evolution of three complexes. Luís Alves, Serra Negra and Itatins, based on petrographic, chemical, mainly geochronological data, obtained principally through the program of geological mapping of the Radambrasil Project.

PETROGRAPHY These complexes are made up almost exclusively of metamorphic rocks of the granulite facies. Rocks of the amphibolite facies appear rarely and rarer still of the greenschist facies.

Various authors have contributed to the petrography of such complexes, notable among them Basumallick *et al.* (1969); Hartmann, Silva and Orlandi Filho (1979); Silva *et al.* (1977); Silva and Dias (1981); and Moreira and Marimon (1980, 1982).

During the execution of the Radambrasil Project geological mapping program, several samples from these complexes were collected and analysed petrographically, mainly from Luís Alves Complex as plotted in Fig. 3. The results are summarized as follows.

Metamorphic rocks of the granulite facies

Norites Among all the rock types of the Luís Alves Complex, the norites are apparently predominant. They are of a dark grey colour, medium to coarse grained and of banded structure. Under the microscope, they show granoblastic (rarely ophitic, cataclastic or nematoblastic) texture. They consist essentially of plagioclase, hypersthene and diopside. Plagioclase (An 30-50) is antiperthitic, sometimes myrmekitic. Zoned plagioclase is rather rare. Sericitization is the most common kind of alteration in this feldspar. Hypersthene occurs partially altered to bastite, as well as hornblende, due to retrogressive metamorphism. Diopside also shows some alteration to hornblende. Other mineral components of these rocks are: biotite, chlorite, quartz and garnet. Biotite is intensely pleochroic and shows alteration to chlorite. Quartz is related to the cataclasis that affected the rock.

Enderbites These rocks occur rather frequently and are very similar to the norites. They differ from the latter basically by containing larger proportions of quartz and very little diopside. Samples from the Itatins Complex have only a small percentage of orthoclase.

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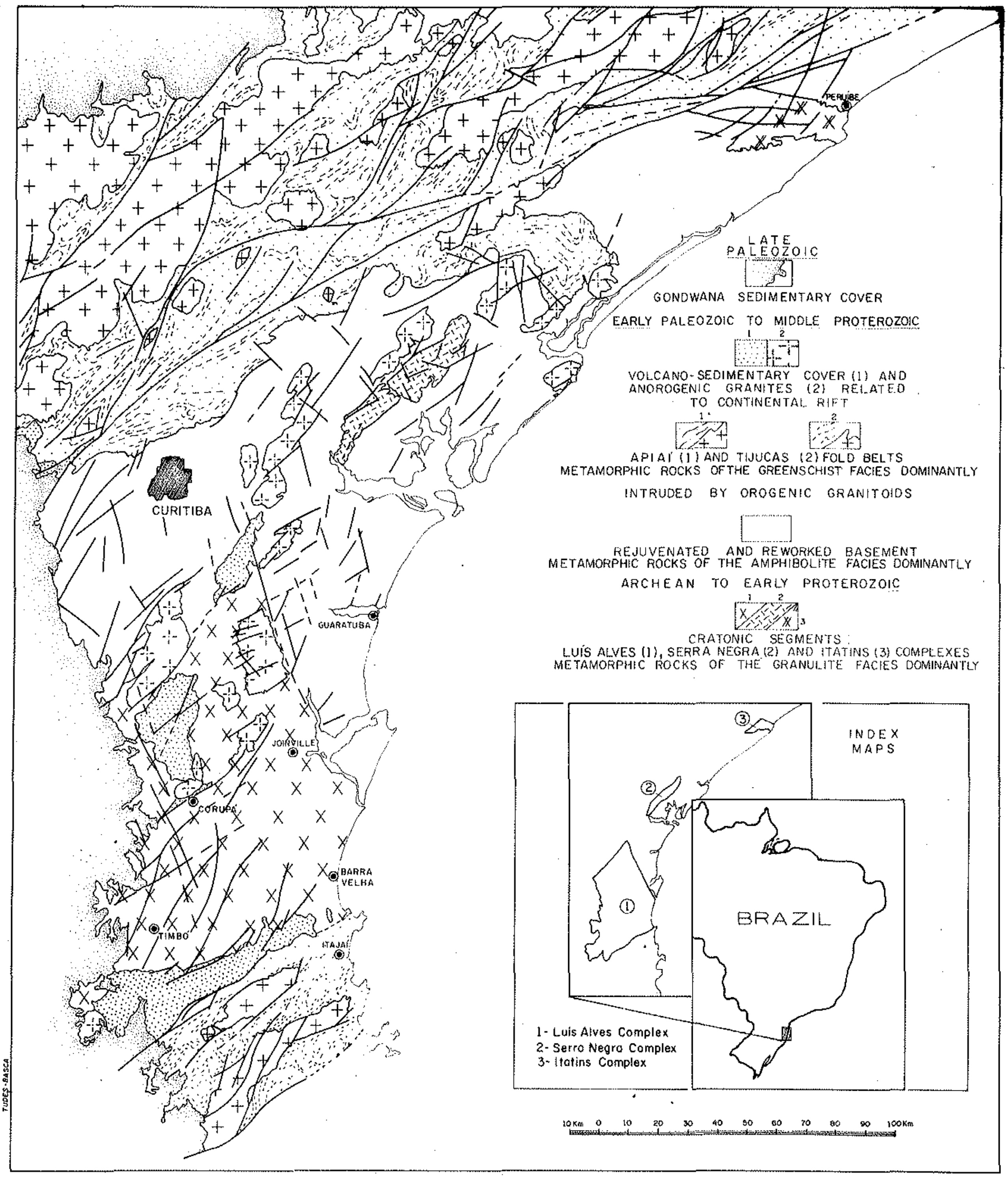

Figure 1 – Simplified Geological Map of South-Southeastern Brazil. Quaternary Cover, Diabase Dikes and Alkaline massifs are not represented.

Charnoenderbites These rocks are of a bright grey colour, banded structure, granoblastic texture, basically made up of plagioclase (andesine), quartz, orthoclase, biotite, hypersthene, diopside, and amphiboles. Less than 1% of the total composition of the rocks corresponds to apatite, zircon, carbonates, clay minerals, sericite and chlorite. The amphiboles (hornblende, actinolite and cummingtonite) are derived from the transformation of the pyroxenes.

Ultramafites These rocks occur only in the Luís Alves Complex in the form of boudins of various sizes included in norites and enderbites. In general, they correspond to pyroxenites, essentially formed of hypersthene and diopside, rarely containing olivine. Among these pyroxenites, the websterites are common. Hornblende pyroxenites sometimes occur. More common types of textures in these rocks are: granular hypidiomorphic, granoblastic, cataclastic se-

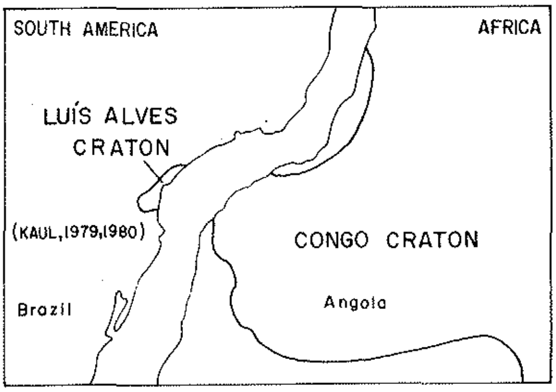

Figure 2 – The Luís Alves and Congo cratons

riate, as well as textures produced by the crystallization of cumulus to intercumulus materials.

Kinzigites In the Luís Alves and Itatins complexes, kinzigites can be found in rare outcrops as lenses and beds inserted in norites and enderbites. They commonly present banded structure and granoblastic texture, being composed of sillimanite, biotite, garnet, orthoclase, antiperthitic plagioclase and quartz.

Quartzites These rocks occur only in some outcrops of the Luís Alves Complex, forming beds inserted in different host rocks. They are finegrained, frequently quite fractured, with granoblastic texture and essentially composed of quartz. Opaque minerals, hypersthene and garnet appear in very small proportions. These rocks grade in some cases to iron formations, which are composed of quartz, magnetite, hematite and very rare pyroxene.

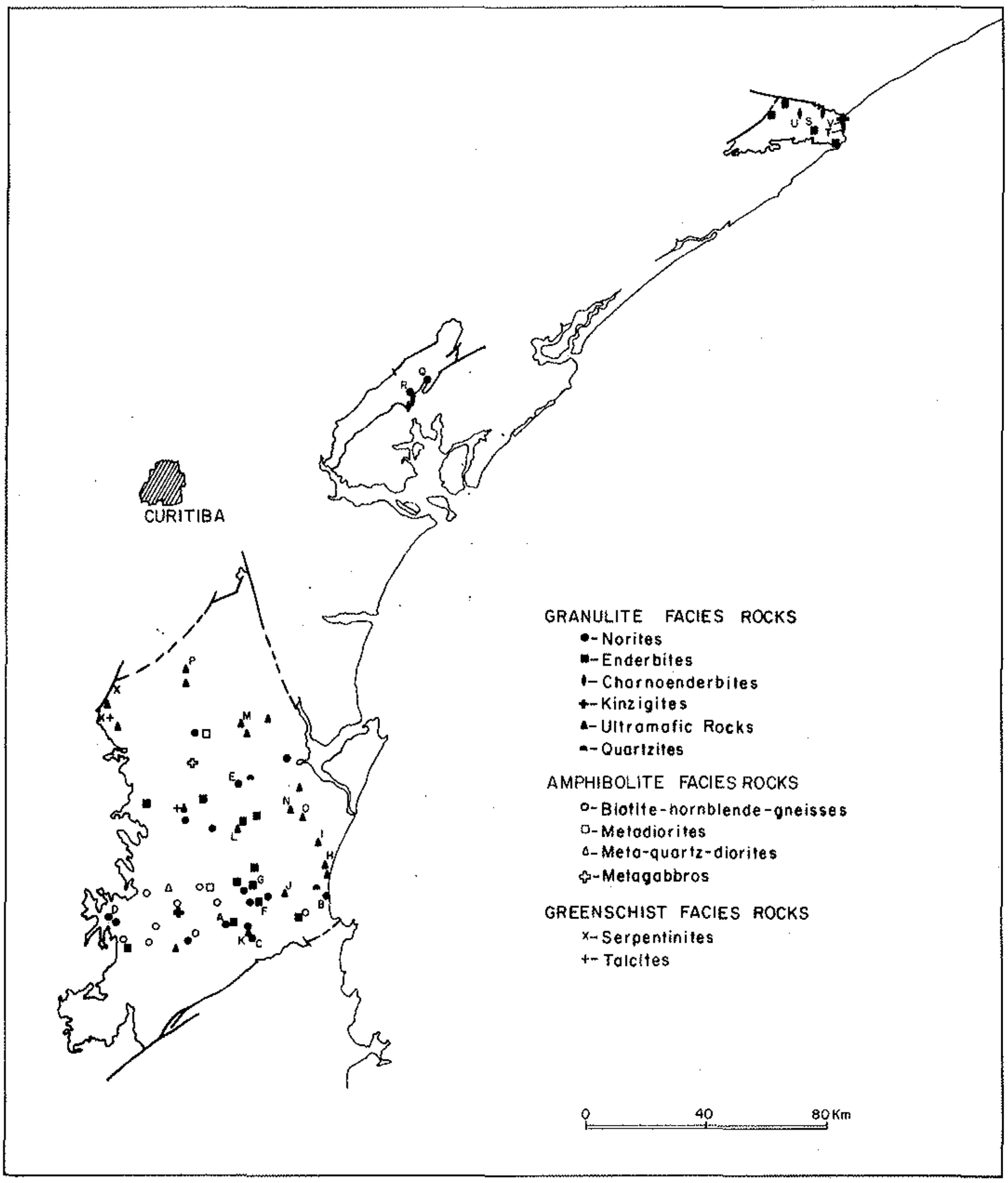

Figure 3 – Location map of samples from Luís Alves, Serra Negra and Itatins complexes. Symbols and letters for petrographic and chemical analyses respectively. See Tables 1 and 2

Metamorphic rocks of the amphibolite facies

Biotite hornblende gneisses These rocks apparently occur only in the Luís Alves Complex, notably in the Southern and Southeastern parts of this unit. They show typical gneissic banding and usually have a granular hypidioblastic, somewhat cataclastic, texture. They have in general a tonalitic composition, essentially formed of plagioclase, quartz, biotite and hornblende.

Meta-quartz diorites, metadiorites and metagabbros These rocks, which composition varies from intermediate to basic, can be found in some outcrops of the Luís Alves Complex. They have a massive to gneissic structure and are composed essentially of plagioclase and hornblende with variable proportions of quartz and pyroxenes (diopside-augite). The plagioclase varies from sodic andesine to labradorite.

Metamorphic rocks of the greenschist facies

Serpentinites These rocks occur only in the Northwest part of the Luís Alves Complex, near Piên, associated with ultramafites of the granulite facies. They are commonly strongly magnetic, having a banded structure, granoblastic texture and composition formed essentially of antigorite. Opaque minerals, plagioclase, olivine, brucite and chrysotile may be present in small percentages.

Talcites Like the serpentinites, the talcites occur only in the northwest part of the Luís Alves Complex, as small bodies generally associated with ultramafites. They have a slight massive structure, granoblastic texture and are composed essentially of talc, with very small proportions of serpentine, tremolite and opaque minerals.

MINERAL ASSEMBLAGES The more commonly observed mineral assemblages, in the above described rocks, are the following:

In the metamorphic rocks of the granulite facies:

- hypersthene + diopside ± quartz ± plagioclase
- hypersthene + diopside + garnet + quartz + plagioclase
- hypersthene + garnet + quartz
- hypersthene + diopside ± plagioclase
- hypersthene + diopside ± biotite ± hornblend ± plagiclase ± quartz

In the metamorphic rocks of the amphibolite facies:

- quartz + plagioclase + biotite + hornblende ± garnet
- hornblende + plagioclase ± biotite ± quartz

In the metamorphic rocks of the greenschist facies:

- antigorite ± plagioclase ± olivine
- talc + tremolite

PETROGRAPHIC CONSIDERATIONS ON THE ORIGIN OF THE ROCKS

According to Moreira and Marimon (1980), the ophitic texture observed in the norites and enderbites as well as textures resulting from the crystallization of cumulus/intercumulus materials in the ultramafites are typical igneous textures preserved in all these rocks. The presence of olivine crystals in ultramafites (districts of Barra Velha and Piên) and the zoned plagioclase in norites (Timbó region) suggests igneous origin.

ANALYSIS OF MAJOR AND TRACE ELEMENTS

The results of chemical analyses of major and trace elements of metamorphic rocks samples of the granulite facies from the three complexes, Luís Alves, Serra Negra and Itatins are shown in Tables 1 and 2.

These analyses were carried out for the Radambrasil Project by the laboratories of Paulo Abib Engenharia S.A. (major elements) and Geologia e Sondagens Ltda. (Geosol) (trace elements).

Moreira and Marimon (1980, 1982) have already discussed these analytical results in detail and also made comparisons with data of rocks of Archean complexes from other continents. The principal conclusions were: a) analytical data suggest that there is a preponderance of rocks of igneous origin (orthometamorphic rocks; b) these rocks exhibit similarities to those from calc-alkaline igneous suites (Tarney, 1975); c) High-grade metamorphism caused alkali depletion, mainly of Potassium.

Table 1 – Major element abundances in granulite facies rocks of the Luís Alves, Serra Negra and Itatins complexes*

	Luís Alves**																S. Negra***			Itatins***		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
SiO_2	44.14	50.70	43.49	49.01	45.06	59.64	47.26	48.90	96.30	45.15	35.90	39.58	50.13	50.19	48.23	48.25	67.47	44.82	71.38	69.60	63.80	61.58
Al_2O_3	13.14	21.05	12.86	14.28	14.88	17.85	20.99	3.94	2.97	5.43	2.87	19.24	2.27	1.85	4.21	4.46	14.98	12.61	14.44	15.35	15.93	10.70
Fe_2O_3	4.28	4.13	11.46	4.28	3.98	3.35	5.06	2.74	6.16	5.22	22.92	8.48	2.84	2.18	3.12	4.39	0.34	4.85	0.90	1.15	1.92	3.62
FeO	13.40	4.26	8.28	8.53	9.62	3.17	5.48	8.28	11.69	21.87	12.66	7.18	13.65	9.74	9.74	9.62	4.90	10.80	1.59	1.28	3.54	6.67
MnO	0.31	0.10	0.21	0.18	0.19	0.10	0.10	0.19	0.30	0.68	0.74	0.10	0.39	0.28	0.26	0.21	0.13	0.22	<0.10	<0.10	<0.10	<0.10
MgO	4.91	2.93	4.97	6.24	6.96	1.38	3.35	16.29	15.47	9.42	6.97	4.79	16.04	16.93	15.60	15.62	1.42	8.84	0.63	0.57	2.03	2.61
CaO	12.14	7.90	9.46	7.61	10.36	5.71	7.11	13.00	11.48	5.71	11.76	10.64	7.60	13.39	12.34	11.07	1.04	11.94	2.58	2.57	4.21	2.54
Na_2O	2.53	4.92	3.50	3.33	2.23	4.51	5.00	1.34	0.96	0.70	1.10	2.89	0.77	1.08	0.93	0.85	4.11	1.90	4.05	4.93	3.47	3.29
K_2O	0.41	0.19	0.32	0.85	0.30	0.97	1.68	0.10	0.10	0.10	0.10	0.85	0.12	0.10	0.10	0.10	3.58	0.45	3.29	3.42	1.57	4.29
TiO_2	1.88	0.57	2.12	1.47	1.08	0.57	1.02	0.31	0.71	0.82	0.40	1.47	0.21	0.23	0.50	0.46	0.46	0.80	0.32	0.41	0.48	0.91
P_2O_5	0.15	0.29	0.24	1.05	0.25	0.23	0.41	0.10	0.10	0.21	0.10	0.31	0.10	0.10	0.10	0.10	0.21	0.13	<0.10	<0.10	<0.17	<0.10
H_2O	0.11	0.23	0.12	0.10	0.15	0.17	0.10	0.18	0.22	0.34	0.76	0.33	0.16	0.13	0.18	0.33	—	—	—	—	—	—
PF	0.10	1.36	0.95	0.33	0.40	0.67	0.75	1.19	0.18	0.10	0.40	1.80	0.42	0.48	0.83	1.16	0.19	0.10	0.41	0.39	0.41	0.67
Total	**97.50**	**98.63**	**97.98**	**97.26**	**95.46**	**98.32**	**98.31**	**96.56**	**96.64**	**95.75**	**96.68**	**97.66**	**94.70**	**96.68**	**96.14**	**96.62**	—	—	—	—	—	—

* Values in % ** Data from Moreira and Marimon (1980) *** Data from Moreira and Marimon (1982)
A-E, Q, R: Norites; F, G, S: Enderbites; H-P: Ultramafites; T, U: Charnoenderbites; V: Kinzigite (see Fig. 3)

Table 2 – Trace element abundances in granulite facies rocks of the Luís Alves, Serra Negra and Itatins complexes*

	Luís Alves**																S. Negra***			Itatins**		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
Ag	N	N	N	N	N	N	N	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B	—	—	—	—	—	—	—	N	N	N	N	N	N	N	N	N	—	—	—	—	—	—
Ba	80	400	184	860	220	10,60	660	52	400	254	50	254	158	15	42	72	320	168	860	510	800	900
Cd	—	—	—	—	—	—	—	N	N	N	N	N	N	N	N	N	—	—	—	—	—	—
Ce	N	N	N	N	N	N	246	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Co	64	18	88	46	60	6	<5	66	90	72	<5	68	66	74	76	92	—	—	—	—	—	—
Cr	62	18	189	387	250	20	<5	1420	1030	730	32	336	655	1000	1100	540	80	330	8	14	44	124
Cu	50	30	254	78	56	16	16	14	<5	96	<5	70	176	120	112	6	18	120	<5	<5	<5	31
La	N	N	N	120	N	N	110	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nb	N	N	N	N	N	N	26	N	N	N	N	N	N	N	N	N	27	46	<10	<10	<10	<10
Ni	98	18	156	140	120	18	8	280	234	260	18	234	274	240	260	208	40	168	10	5	12	77
Pb	14	208	10	14	14	N	18	N	N	N	34	38	102	20	30	N	—	—	—	—	—	—
Rb	<10	<10	<10	32	12	30	44	10	<10	<10	<10	<10	14	<10	11	14	—	—	159	132	116	122
Sr	194	690	192	550	460	580	740	128	88	134	N	204	78	40	56	60	540	540	134	96	280	112
ThO_2	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
V	318	144	296	180	222	98	66	—	—	—	—	—	—	—	—	—	212	510	21	15	57	132
Zn	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	224	380	<200	<200	<200	<200
Zr	260	120	132	184	84	172	164	—	—	—	—	—	—	—	—	—	152	210	38	98	52	210
Y	96	20	68	54	40	38	18	22	24	60	84	42	56	22	26	28	—	—	—	—	—	—
Yb	12	1	8	5	4	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

*Values em ppm **Data from Moreira and Marimon (1980) ***Data from Moreira and Marimon (1982)
A-E,Q,R: Norites; F,G,S: Enderbites; H-P: Ultramafites; T,U: Charnoenderbites; V: Kinzigite (see Fig. 3)

GEOCHRONOLOGY Dated rocks are plotted as illustrated in Fig. 4. All the geochronological results were obtained at the Centro de Pesquisa Geocronológica (CPGeo) of the Universidade de São Paulo. These results were recalculated using the decay constants suggested by Steiger and Jager (1978). The Rubidium-Strontium and Potassium--Argon methods of dating used by GPGeo are detailed in Kawashita (1972) and Amaral *et al.* (1967), respectively.

Discussion of the results Up to the present time, a significant number of ages have been determined in the Luís Alves Complex by the whole-rock Rb-Sr and the K-Ar methods. Several of these age determinations have already been published (Bartorelli, Minioli and Kawashita, 1969; Minioli, 1972; Girardi *et al.* 1974; Hartmann, Silva and Orlandi Filho, 1979). Those age determinations done for the Radambrasil Project remained until now unpublished. Fig. 5 shows the Rb-Sr references isochronic pattern for rocks of the Luís Alves Complex. The dated samples are rocks of the granulite (granulites, ultramafites) and amphibolite (gneisses, granitic rock) facies.

In spite of relatively low Rb^{87}/Sr^{86} ratios (Fig. 5), there is, in this complex, evidence of at least three important events of isotopic homogenization of Sr. The oldest alignment of about 3,100 m.y. appears to have geological significance from plot PLA 4 which is situated at a favorable analytical position on the diagram. However, some additional Rb-Sr age determinations are necessary to confirm the presence of early Archean rocks formed during the Pre-Jequié Event in the region under study (Luís Alves district).

The Rb-Sr reference isochron with 2,663 ± 60 m.y. ($R_0 = 0.704$) was constructed from the results of six measurements (MSWD = 0.71). This isochronic age is considered here as the age in which the analysed rocks were formed (Jequié Event). The location of the dated samples in the areas of Ibirama, Cedro, Corupá and Luís Alves agrees with the fact that Archean crust was already relatively extensive by that time.

On the other hand, the isochron with 2,224 ± 46 m.y. ($R_0 = 0.704$) confirms the regional importance of the Transamazônico Event which should have developed, in part, over an already existing sialic crust. Two plots (JC-446 and JC-DT-32) positioned a little below this isochron seem to indicate the presence of this event not later than about 1,850 m.y. ago. It is worth noting that a Rb-Sr isochron of Transamazônico age (about 2,000 m.y.) has already been constructed for metamorphic rocks of granulite facies from the Piên region (Girardi *et al.* 1974), confirming that high-grade metamorphic rocks were formed during that time. The four determinations reported by Girardi *et al.* (1974) are shown in Table 3 (VG 46,67,62,214).

The existing K-Ar radiometric results for the Luís Alves Complex are listed in Table 4. The age grouping refers mainly to samples from the regions of Barra Velha and Piên. The apparent ages measured on several materials (biotite, amphiboles, K-feldspars, plagioclases and whole--rocks) are distributed over a wide range of time, from the Archean to the late Proterozoic/early Paleozoic.

Up to now, the oldest ages (around 3.5 b.y.) were found only in the coastal area near Barra Velha. In the same way, the apparent results between 2.8-2.5 b.y. and 2.4-2.2 b.y. were found in rock samples from the coast between Joinville and Barra Velha. All these radiometric groupings confirm quite clearly the archean character of this part of the Luís Alves Complex. Moreover, all the K-Ar data suggest partial Argon losses.

The K-Ar apparent ages typical of the Transamazônico Event (2.1-1.7 b.y.) comprise a large part of the geochronological data. Geographically, these ages are extensively distributed throughout the Luís Alves Complex (regions of Piên, Corupá, Cedro, Ibirama, Luís Alves and Barra Velha) and confirm outstandingly the regional tectonic stabilization at the end of the Transamazônico Event.

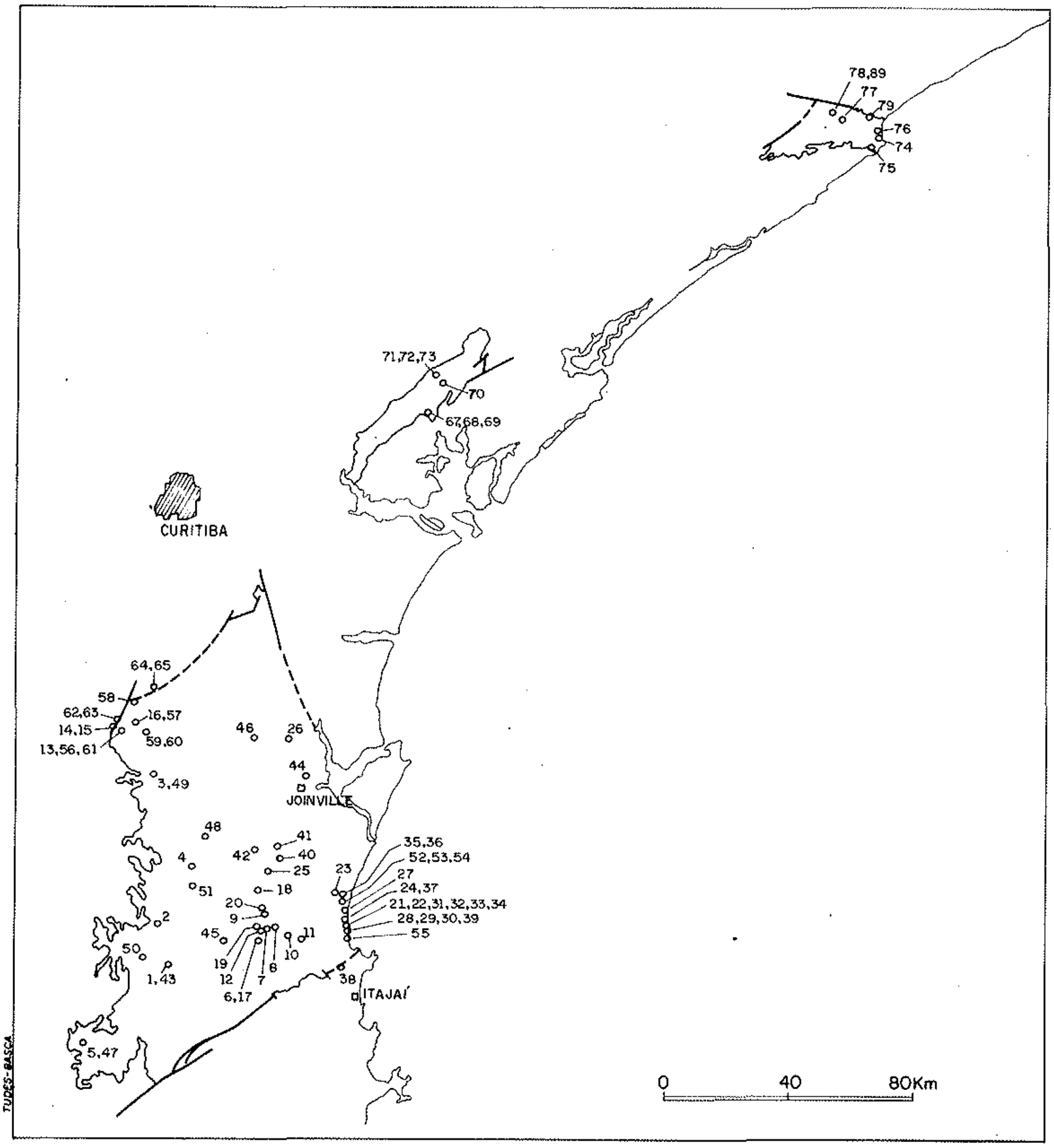

Figure 4 – Location map of dated rocks. The numbers indicate samples dated by K-AR and/or Rb-Sr methods (see tables 3, 4, 5, 6, 7A and 7B)

Table 3 – Rb-Sr analytic data on sampled rocks of Luis Alves complex

Fig. 4/n.°	Lab/n.°	Sample	Rock	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}	Ref.
1	4632-4631	851 JCDT 32	Gneiss	0.382	0.7144	1
2	4616	851 JCDT 50	Gneiss	1.05	0.7380	1
3	5157	919 JC 410	Gneiss	0.39	0.7184	1
4	5159	919 JC 446	Catacl. Granite	0.39	0.7140	1
5	4637	881 PKCW 45	Quartz Monzonite	0.558	0.7212	1
6	3657	PLA-02	Granulite	0.59	0.7237	2
7	3635	PLA-16B	Granulite	1.82	0.7737	2
8	3658	PLA-04	Granulite	1.32	0.7631	2
9	3659	PLA-05	Ultramafic rock	0.10	0.7073	2
10	3660	PLA-08	Ultramafic rock	0.035	0.7062	2
11	3661	PLA-12	Granulite	0.41	0.7200	2
12	3662	PLA-15	Granulite	0.05	0.7051	2
13	515	VG-46	Granulite	0.062	0.7044	3
14	516	VG-67	Granulite	0.064	0.7053	3
15	529	VG-62	Granulite	1.032	0.7335	3
16	539	VG-214	Granulite	0.192	0.7077	3

References: 1 – Radambrasil; 2 – Hartmann *et al.* (1979); 3 – Girardi *et al.* (1974)

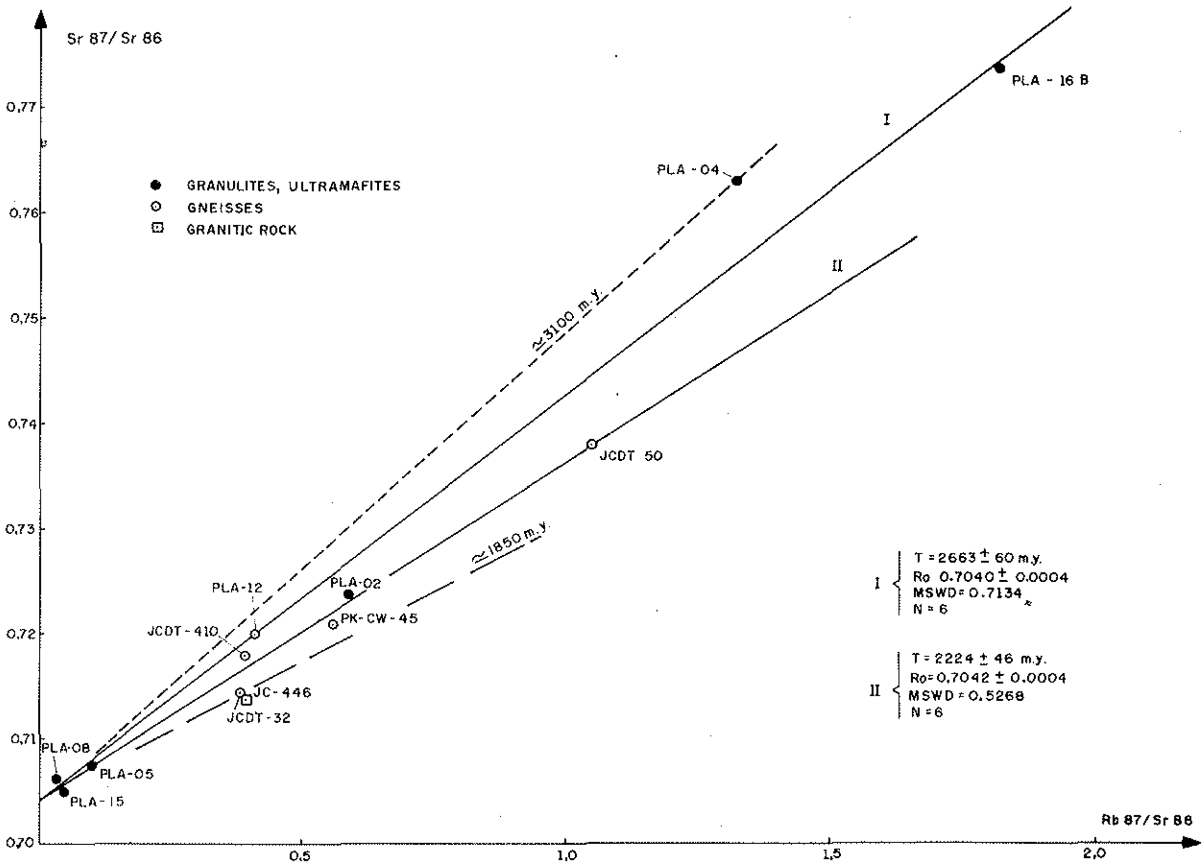

Figure 5 – Rb-Sr isochron diagram on sampled rocks of Luís Alves complex

K-Ar ages younger than those related to this event are found only on the borders of the Luís Alves Complex, as for example in metabasites at Piên (VG 79, 194; Table 4) and in trachytes at Barra Velha (BM 13,58; Table 4). This whole group, which shows a minimum age dated from the end of the late Proterozoic/early Paleozoic, can be regarded as related to the marginal development of the Apiaí and Tijucas fold belts (Brasiliano Event) or to an anorogenic episode connected with the formation of continental rifts.

The Serra Negra and Itatins complex (Fig. 1) are far less extensive than the Luís Alves Complex.

There are eight available radiometric results for the Serra Negra Complex (Tables 5 and 6) made on metamorphic rocks of the granulite facies.

The whole-rock Rb-Sr determinations plotted on an isochronic diagram (Fig. 6) reveal an age of 2,210 ± 120 m.y. ($R_0 = 0.708$) which corresponds to the Transamazônico Event. This radiometric value is interpreted here as corresponding to the time of formation of the selected group of samples. Some dispersion of the plots can be explained by the fact that dated rock materials were not rigorously cogenetic.

It is noteworthy that high initial ratio ($R_0 = 0.708$) of the isochronic diagram is uncommon for high-grade Transamazônico rocks, suggesting a magma contamination during a crustal accretion-differentiation process or previous crustal existence of the dated materials. The existence of very old K-Ar ages, that is, Archean ages (Table 6), appears to favour the latter hypothesis. On the other hand, the apparent age of 1,030 m.y. for sample AA 114 shows a significant Argon loss for feldspar.

As has been shown, rocks of the Serra Negra Complex can be very old. The apparent K-Ar age determinations (Table 6) appear to draw a geochronological correlation with the Luís Alves Complex. The Rb-Sr isochron (Fig. 6) reflects the importance of the overprint of the Transamazônico Event on the dated rocks, in a manner analogous to that found for the Luís Alves Complex.

For the Itatins Complex, there are fifteen Rb-Sr whole rock analyses (Table 7*A*) and one biotite Rb-Sr analyses (Table 7*B*) carried out on samples of metamorphic rocks of the granulite facies. The geochronological picture presented by the rocks of this complex is shown by the Rb-Sr reference isochron in Fig. 7. The significance of the group of results is connected to the major events of isotopic homogenization of Strontium.

The isochron which corresponds to the oldest age, 2,614 ± ± 68 m.y. ($R_0 = 0.703$), was drawn from four plots (MSWD = 0.38). In spite of the small number of samples, this age is provisionally interpreted as an important rock-forming event related to the formation of the granulite facies rocks of the complex under consideration. Two samples (PE-20A and PE-24A) are clearly older than the isochronic age, probably reflecting isotopic disturbance, and are not therefore taken into consideration in this work.

A little below the isochron of the Archean age six plots probably indicate the influence of the Transamazônico Event on the partial isotopic rejuvenation of Strontium. The

Table 4 – K-Ar analytic data on sampled rocks of Luis Alves complex

Fig. 4/n.°	Lab/n.°	Sample	Rock	Mat.	%K	$Ar^{40} \times 10^{-5}$(CCSTP)/g	$\%Ar^{40}_{atm}$	Age(m.y.)	Ref.
17	4692	PLA-02	Granulite	Biot.	6.326	78.84	0.6	1,850 ± 130	1
18	4101	PLA-14	Basanite	WR	0.262	3.44	4.2	1,903 ± 27	1
19	4100	PLA-09	Basanite	WR	0.994	4.69	3.6	930 ± 27	1
20	4089	PLA-07	Granulite	Biot.	6.018	70.60	0.6	1,780 ± 55	1
21	1857	BM-15	Amphibolite	Amph.	0.706	15.80	5.4	2,605 ± 69	2
22	2430	BM-15	Amphibolite	Amph.	0.716	17.50	2.3	2,727 ± 23	2
23	1862	BV-A	Amphibolite	Amph.	0.277	7.13	4.3	2,804 ± 73	2
24	1866	BM-11	Pyroxenite	Pyrox.	0.405	10.20	3.4	2,777 ± 76	2
25	1976	BM-20	Gneiss	Biot.	5.533	57.80	1.0	1,642 ± 13	2
26	1983	BM-19	Gneiss	Biot.	6.139	68.20	1.0	1,712 ± 55	2
27	2129	BM-10	Gneiss	Amph.	0.853	12.70	9.2	2,059 ± 63	2
28	1984	BM-23	Pyroxenite	Pyrox.	0.053	2.11	7.7	3,417 ± 20	2
29	2317	BM-46	Migmatite	K-Feld.	8.470	32.20	1.2	771 ± 30	2
30	2094	BM-46	Migmatite	Amph.	2.061	14.50	6.5	1,242 ± 14	2
31	2318	BM-49	Amphibolite	Amph.	0.038	1.37	22.0	3,444 ± 535	2
32	2319	BM-49R	Amphibolite	Amph.	0.022	0.83	82.6	3,415 ± 197	2
33	1038	VL-16/2/67	Pyroxenite	WR	0.045	1.69	9.5	3,400 ± 600	2/3
34	1292	VL-6/7/67	Amphibolite	Hornbl.	0.262	4.87	3.7	2,350 ± 100	2/3
35	1302	4C-2/68	Websterite	WR	2.450	49.20	1.4	2,450 ± 100	2/3
36	1337	4C-2/68R	Websterite	WR	2.540	4.43	2.0	2,260 ± 100	2/3
37	1353	4-11/67	Pyroxenite	Pyrox.	0.120	2.38	3.7	2,430 ± 100	2/3
38	2096	BV-16	Gneiss	Orthocl.	4.252	40.80	16.9	1,552 ± 60	2
39	2097	BV-07B	Migmatite	Orthocl.	8.509	35.00	3.8	824 ± 9	2
40	2098	BM-16	Migmatite	K-Feld.	7.108	30.50	3.9	852 ± 11	2
41	2106	BM-18	Pyroxenite	Pyrox.	0.123	1.51	58.6	1,826 ± 77	2
42	4406	851 JCDT 42A	Noritic Gabbro	Plag.	0.359	5.52	4.5	2,097 ± 39	4
43	4409	851 JCDT 32	Gneiss	Biot.	6.802	87.22	9.4	1,878 ± 48	4
44	4410	851 JCDT 96	Quartz Norite	Amph.	1.256	26.96	1.4	2,530 ± 52	4
45	4411	851 JCDT 27	Gneiss	Biot.	5.788	72.58	0.4	1,851 ± 25	4
46	4495	851 JCDT 79	Hyperst. Gabbro	Plag.	0.596	4.24	14.2	1,264 ± 19	4
47	4397	881 PKCW 45	Quartz Monzonite	Biot.	6.651	72.54	0.8	1,693 ± 21	4
48	4691	948 PK 212.1	Pyroxenite	Amph.	0,450	7.79	2.1	2,247 ± 80	4
49	4588	919 JC 410	Gneiss	Biot.	6.272	73.42	2.2	1,773 ± 38	4
50	4582	919 JCEF 455	Diatexite	Biot.	0.902	9.80	4.4	1,680 ± 32	4
51	4575	851 JC 49A	Paragneiss	Biot.	6.618	109.0	0.8	2,182 ± 49	4
52	1856	BM-13	Trachyte	WR	1.74	35.0	4.9	446 ± 29	2
53	2101	BM-32	Trachyte	WR	4.223	471.0	1.9	1,715 ± 68	2
54	1858	BM-56	Trachyte	WR	3.414	118.0	3.7	714 ± 29	2
55	2100	BM-58	Trachyte	WR	4.517	126.0	18.2	596 ± 8	2
56	2813	VG-46	Granulite	Plag.	0.222	2.18	19.7	1,570 ± 23	1
57	2817	VG-255A	Granulite	Plag.	0.798	7.03	16.9	1,454 ± 36	1
58	2818	VG-97	Granulite	Plag.	0.133	1.83	18.4	1,955 ± 31	1
59	2815	VG-263	Migmatite	Amph.	1.000	0.12	3.3	1,787 ± 25	1
60	2816	VG-263	Migmatite	Plag.	0.836	11.54	13.8	1,961 ± 56	1
61	2814	VG-79	Metanorite	Plag.	0.279	0.59	68.2	456 ± 42	1
62	2656	VG-24	Metagabbro	Amph.	1.193	15.34	32.1	1,866 ± 56	1
63	2698	VG-24	Metagabbro	Plag.	0.474	2.58	41.3	1,018 ± 23	1
64	2636	VG-194	Metagabbro	Biot.	7.763	21.35	13.3	583 ± 37	1
65	2786	VG-194	Metagabbro	Plag.	0.501	1.15	15.2	503 ± 12	1

References: 1 – Hartmann *et al.* (1979); 2 – Minioli (1972); 3 – Bartorelli *et al.* (1969); 4 – Radambrasil

Table 5 – Rb-Sr analytic data on sampled rocks of Serra Negra complex

Fig. 4/n.°	Lab/n.°	Sample	Rock	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}	Ref.
66	4566	AT 598B	Enderbite	0.01	0.7074	1
67	3689	SN 3	Charnockite	0.92	0.7376	2
68	3789	SN 5	Charnockite	0.02	0.7091	2
69	3795	SN 6	Charnockite	0.107	0.7126	2

References: 1 – CPRM; 2 – Basei CPGeo

Table 6 – K-Ar analytic data on sampled rocks of Serra Negra complex

Fig. 4/n.°	Lab/n.°	Sample	Rock	Mat.	%K	Ar^{40}rad × 10^{-5}(CC STP/g)	%Ar^{40}atm	Age(m.y.)	Ref.
70	4463	848 LK 22A	Norite	Plag.	0.517	17.64	0.8	3,192 ± 37	1
71	3468	AA-107	Charnockite	Feld.	0.759	18.39	5.9	2,713 ± 115	2
72	3470	AA-104	Charnockite	Feld.	0.467	9.91	28.9	2,530 ± 36	2
73	3488	AA-114	Charnockite	Feld.	3.493	19.07	3.2	1,030 ± 12	2

References: 1 – Radambrasil; 2 – Batolla Jr. *et al.* (1977)

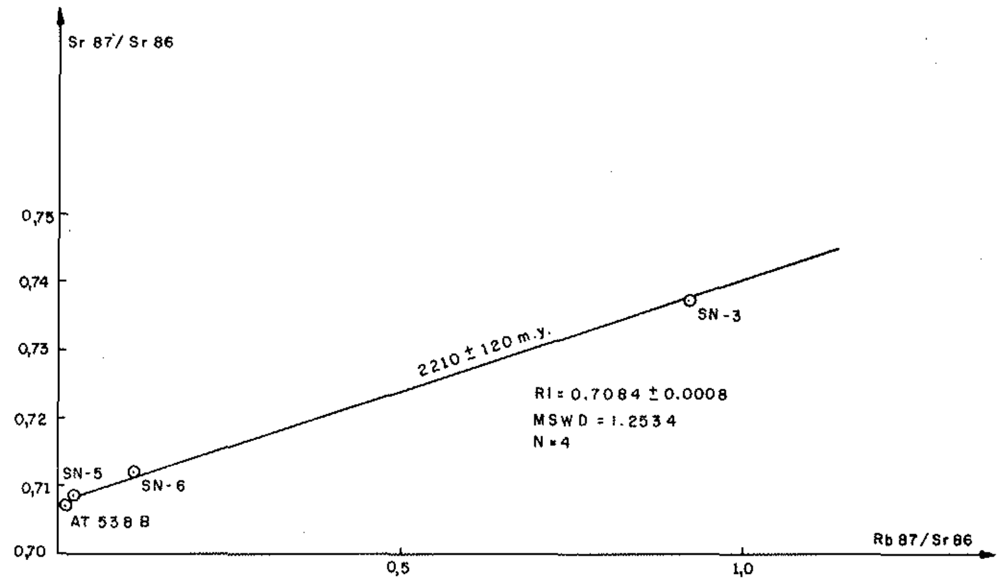

Figure 6 – Rb-Sr isochron diagram on sampled rocks of Serra Negra complex

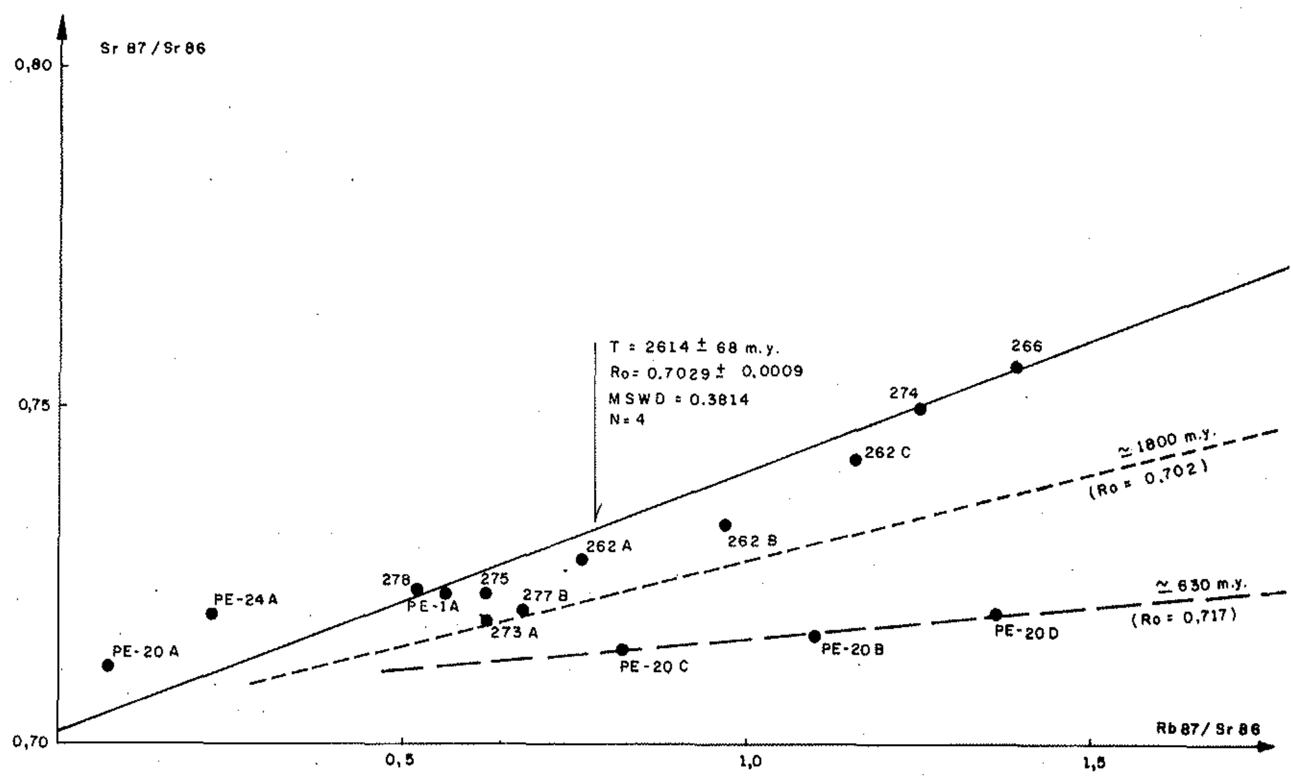

Figure 7 – Rb-Sr isochron diagram on sampled rocks of Itatins complex

Table 7A — Rb-Sr analytic data on sampled rocks of Itatins complex

Fig. 4/n.°	Lab/n.°	Sample	Rock	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}	Ref.
74	5020	892 JC 266	Opdalite	1.39	0.7557	1
75	5021	892 JC 273A	Granulite	0.62	0.7180	1
76	5022	892 JC 274	Gneiss	1.25	0.7496	1
77	5023	892 JC 275	Opdalite	0.62	0.7223	1
78	5024	892 JC 278	Enderbite	0.52	0.7228	1
79	5025	892 JC 277B	Opdalite	0.67	0.7198	1
80	4563	AT 262A**	Enderbite	0.76	0.7275	2
81	4564 ≡ 4448	AT 262B**	Enderbite	0.97	0.7324	2
82	4565	AT 262C**	Enderbite	1.16	0.7422	2
83	2413 ≡ 2318	PE 20A**	Granulite	0.07	0.7117	3
84	2319	PE 20B**	Granulite	1.10	0.7160	3
85	2321	PE 20D**	Granulite	1.36	0.7194	3
86	2320	PE 20C**	Granulite	0.82	0.7144	3
87	2412	PE 1A**	Granulite	0.56	0.7224	3
88	2415	PE 24A**	Granulite	0.23	0.7194	3

**Samples without localization plot in Fig. 4

References: 1 – Radambrasil; 2 – CPRM; 3 – IYER/CPGeo

Table 7B — K-Ar analytic data for the enderbite of Itatins complex

Fig. 4/n.°	Lab/n.°	Sample	Material	%K	$Ar^{40}rad \times 10^{-5}$ (CC STP/g)	$\%Ar^{40}atm$	Age(m.y.)	Ref.
89	4494	892 JC 278	Biotite	6.842	18.55	2.26	590 ± 10	1

Reference: 1 – Radambrasil

hypothetical alignment (shown dashed) in this part of the diagram corresponds to 1.8 b.y.

Finally, the three remaining analytical results (points PE-20B, C,D), clearly cogenetic, show the presence of the Brasiliano Event on the Itatins Complex.

Summing up, the Itatins Complex, in the light of the radiometric results, is a crustal fragment which originated in the Archean and was afterwards subjected to important Proterozoic tectono-thermal processes. The polycyclic character of this complex is in agreement with its geographical position close to the Apiaí Fold Belt.

CONCLUSIONS In South-Southeastern Brazil, the complexes of Luís Alves, Serra Negra and Itatins are lithostratigraphic units made up of metamorphic rocks of the granulite, amphibolite and greenschist facies. Rocks of the granulite facies largely dominate.

Petrographic and chemical analysis data suggest that there is a predominance of orthometamorphites among all these rocks.

With reference to geochronological information, it can be said initially that a significant number of radiometric age determinations by the Rb-Sr and K-Ar methods exist for the three complexes, but mainly for that of Luís Alves. The Rb-Sr age determinations for this complex show evidence of at least three important events of isotopic homogenization of Strontium: Pre-Jequié Event (3,100 ± 129 m.y.; $R_0 = 0.7035 \pm 0.0007$), Jequié (2,663 ± 60 m.y.; $R_0 = 0.7040 \pm 0.0004$) and Transamazônico (2,224 ± 46 m.y.; $R_0 = 0.7042 \pm 0.0004$). These low initial Sr^{87}/Sr^{86} ratios suggest that the rocks formed in these three events are mantle-derived materials. On the other hand, the K-Ar age determinations for this complex are distributed over a wide interval of time, from the Archean to the early Paleozoic.

The ages typical of the Transamazônico Event (2.1-1.7 b.y.) are widely distributed throughout the complex and confirm notably the regional tectonic stabilization of this crustal fragment at the end of this event. The more recent ages, that are post-transamazonian, can be regarded as related to the marginal development of fold belts (Brasiliano Event) or to transformations connected with the formation of continental rifts.

The Rb-Sr age determinations for the Serra Negra Complex revealed a transamazonian age (2,210 ± 120 m.y.; $R_0 = 0.708$). This high initial ratio suggests that there was a certain contamination of the primary magma during a crustal accretion-differentiation process or previous crustal existence of the dated materials relative to the Transamazônico Event. The very old K-Ar ages, that is Archean, seem to favour this latter hypothesis.

The Itatins Complex Rb-Sr age determinations revealed a Jequié isochronic age (2,614 ± 68 m.y.; $R_0 = 0.703$), as well as influences of the Transamazônico (approximately 1,800 m.y.) and Brasiliano (approximately 630 m.y.) events. The Jequié age is provisionally interpreted as corresponding to an important rock-forming event (formation of the granulite facies rocks of this complex). The ages related to the Brasiliano Event are interpreted as the result of the proximity of the Apiaí Fold Beld — an active belt during the Brasiliano Event.

To summarize, the complexes of Luís Alves, Serra Negra and Itatins, in South-Southeastern Brazil, are lithostratigraphic units of metamorphic rocks, principally of the granulite facies, formed in Archean and early Proterozoic times predominantly by crustal accretion-differentiation processes. Regional tectonic stabilization was attained, at least in the Luís Alves Complex, by the end of the Transamazônico Event, about 1.8 b.y. ago.

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