GEOCHRONOLOGY OF THE GRANITOID HOSTED SALAMANGONE GOLD DEPOSIT, LOURENÇO DISTRICT, AMAPÁ, BRAZIL.

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ABSTRACT The Salamangone deposit occurs in the Lourenço Gold District, Amapá. It is associated to Paleoproterozoic metamorphosed supracrustal rocks and a calc-alkaline complex. The deposit lies within a metaluminous to weakly peraluminous, calc-alkaline tonalitic-granodioritic pluton. The Au-mineralization consists of an epigenetic quartz-vein system, enriched in Au and As, and structurally controlled by a ductile-brittle shear zone. U-Pb zircon analyses of tonalite gave a crystallization age of 2.16 ± 0.13Ga, whereas Sm-Nd T_{DM} model ages of tonalite and granodiorite range from 2.24 and 2.34Ga. e_{Nd}(T) vary from +2.88 to +3.02. Additional whole rock Rb-Sr isochron ages on granitoids yielded values in the range of 2.17 to 2.28Ga, with $^{87}Sr/^{86}Sr$ initial ratio of 0.702. The isotopic data and geochemical signature of granitoids suggest that the Lourenço region, as well as the neighboring areas in French Guyana, represents a vast area largely floored by accreted juvenile arc terranes without evidence of Archean crust contamination, being related to the development of a calc-alkaline magmatic arc, which was produced within the Maroni-Itacaíunas Province, during a major Paleoproterozoic orogenic event.

Keywords: Amazonian Craton, Paleoproterozoic, tonalite-trondhjemite-granodiorite(TTG), gold mineralization.

INTRODUCTION The Salamangone Au-deposit is the most important among the several Au-deposits and prospects which have been mined in the Lourenço Gold District-Amapá. Here the Au-quartz-vein system is contained within a calc-alkaline granitoid complex (tonalite-granodiorite), and the ore is enclosed within a shear zone. This association is not much different from what has been reported in comparable Canadian Archean terranes (Callan and Spooner 1989, 1998), Australia (Cassidy *et al*. 1998), Paleoproterozoic terranes of French Guyana (Milési *et al*. 1995) and West Africa (Milési *et al*. 1992, Oberthür *et al*. 1998).

The geochronology of the State of Amapá is poorly documented and up to the present the Lourenço region has received little attention. In this paper emphasis is placed on the geochronological data on the granitoids hosted Salamangone Gold Deposit, which constitute part of the ongoing Ph.D. thesis of S.A.A. Nogueira, at the Instituto of Geociências of the University of São Paulo.

GEOLOGICAL SETTING The Lourenço Au-District is located in the central portion of the State of Amapá, within the Maroni-Itacaiúnas Province, 2.2-1.95Ga (Teixeira *et al*. 1989), of the Amazonian Craton (Almeida 1978). According to Terraconsult (1986) and Lima *et al*. (1991) the Lourenço region is included in the Lourenço Metamorphic Suite which consists of high-grade partially migmatized metamorphic supracrustal rocks and calc-alkaline (TTG-type) complexes. All these rocks are cross-cut by a ductile-brittle shear zone, to which the Salamangone and a variety of mineralized au-quartz-vein are associated (Fig. 1). The Lourenço Metamorphic Suite together with the Vila Nova Group (Lima *et al.* 1974) mostly recognized in the southern part of the State of Amapá, Paramaca Group (Paramaca Series of Choubert 1974) comprised within the boundary of Amapá and French Guyana, could represent Paleoproterozoic supracrustal sequences.

THE SALAMANGONE GOLD DEPOSIT The deposit is contained within a ductile-brittle shear zone striking N50-60°W and dipping 55 to 70°NE, which is over 350m long and has an average thickness of about 50m (Fig.1). It lies within a calc-alkaline, metaluminous to slightly peraluminous tonalite to granodiorite pluton. It is characterized by high contents of incompatible trace elements and LREE, showing a geochemical signature of volcanic arc granites-VAG (Pearce *et al*. 1984). The primary mineralization consists of ribbon-quartz veins enriched in Au and As, exhibiting relatively low enrichment of Ag, Pb, Cu Bi, and Au-quartz infilling in microfractures. Au is associated with sulfides, mainly arsenopyrite. The deposit is epigenetic in character and structurally controlled by a ductile-brittle shear zone, very similar to analogous epigenetic Au-deposits discussed by Cassidy *et al*. (1998).

ANALYTICAL TECHNIQUES AND SAMPLING Sm-Nd, Rb-Sr and K-Ar isotopic analyses were carried out at the Geochronological Research Center of São Paulo University (CPGeO-USP), whereas U-Pb and Pb-Pb at the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences (IPGG-RAS), St-Petersburg, Russia.

Rb and Sr contents were determined by X-ray fluorescence, and Sm and Nd values by isotopic dilution. The spectrometric readings were done on a VG-354 mass-spectrometer. K contents were determined by a flame spectrometer and Ar values by a gaseous source mass-spectrometer, Reynolds MS-1, according to the standard analytical procedures described by Amaral *et al*. (1966). Pb-Pb analyses were undertaken on a IPGG-RAS Finnigan MAT 2618 collector mass spectrometer. Zircon analyses and air-abrasion treatment followed the method of Krogh (1973, 1982). All samples were spiked with a ^{235}U-^{208}Pb mixed tracer and the total blanks were 0.05-0.1ng Pb and 0.005ng U. The Rb-Sr, U-Pb and Pb-Pb isotopic data were regressed using the program of Ludwig (1999). Isochrons with a large MSWD value, had these age calculations based on Model 3. The ages were calculated with $l_{Rb} = 1.42 \times 10^{-1}$ anos^{-1}, proposed by Steiger and Jäger (1977). Sm-Nd model ages (T_{DM}) were calculated using the depleted mantle model of De Paolo (1988).

The sampling sites for this study are illustrated in Fig. 1. The samples consist dominantly of a hornblende-biotite- tonalite, with biotite-granodiorite and aplite.

RESULTS AND DISCUSSION Pb isotope analyses and Pb, Th and U contents of samples of the granodiorite and tonalite of the Salamangone area are presented in Tables 1 and 2. Zircons extracted from the tonalite were analyzed by the U-Pb method, and analytical points are plotted on a Concordia Diagram defining a discordia line (Fig. 2), with upper and lower intercepts of 2.16 ± 0.13 Ga and 0.48 ± 0.13 Ga respectively. The first age is interpreted as the crystallization age of the plutonism, while the second one has no geological meaning due to extreme Pb loss by continuous-diffusion processes. Furthermore the same granitoid define a Pb-Pb whole-rock isochron (Fig. 3), which yields an age of 1995 ± 260 Ma with a m_1 value = 8.4 (MSWD=0.7).

Sm-Nd depleted mantle model ages calculated for both tonalite and granodiorite gave ages of 2.24 and 2.34 Ga respectively (Fig. 4). ε_{Nd} values calculated to 2.1 Ga range from +2.88 to +3.02 (Table 3), which indicate that magmatic precursors are significantly older (by 100-200Ma) than tonalite and granodiorite U-Pb age estimates. It is also suggested that the Lourenço region represents a vast area of juvenile continental crust with no contamination with Archean crust. In this way the isotopic data, along with the U-Pb age estimates, reinforce previous interpretation that consider the Lourenço area as part of the Maroni-Itacaiunas Geochronological Province, whose crustal evolution took place during a major Paleoproterozoic accretion event between 2.25 and 1.95 Ga.

The U-Pb and Pb-Pb study has been complemented by Rb-Sr analyses. The analytical results are listed in Table 4. Six whole-rock samples from the granodiorite gave a Rb-Sr isochronic age of 2169 ± 89 Ma , an $^{87}Sr/^{86}Sr$ initial ratio of 0.7023 ± 0.0004 and a MSWD value of 1.3 (Fig. 5), while five whole-rock samples from the tonalite yield a Rb-Sr age of 2278 ± 240 Ma with $^{87}Sr/^{86}Sr$ initial ratio of

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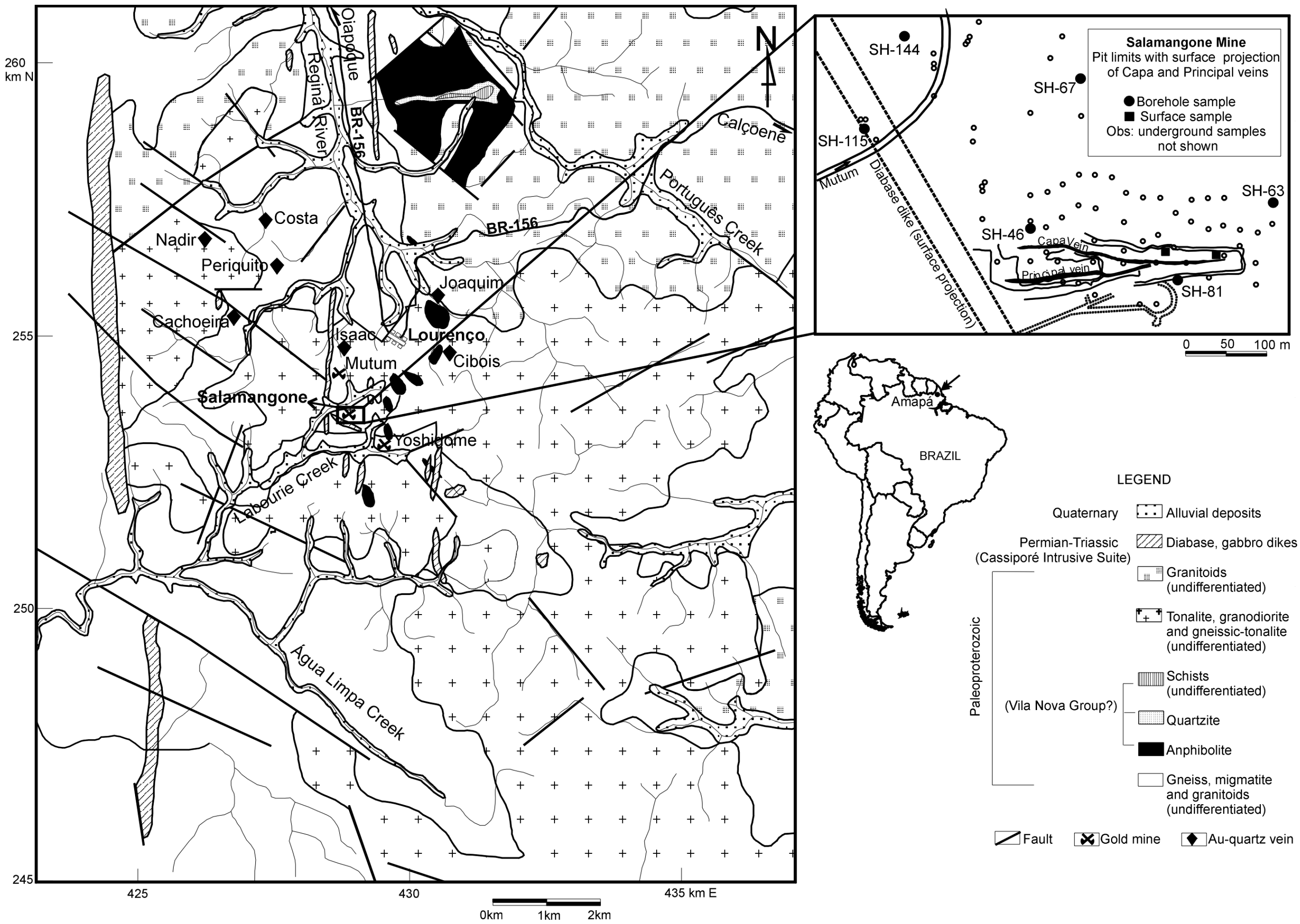

Figure 1-Geological sketch map of the Lourenço Gold District, modified and complemented after Terraconsult (1986).

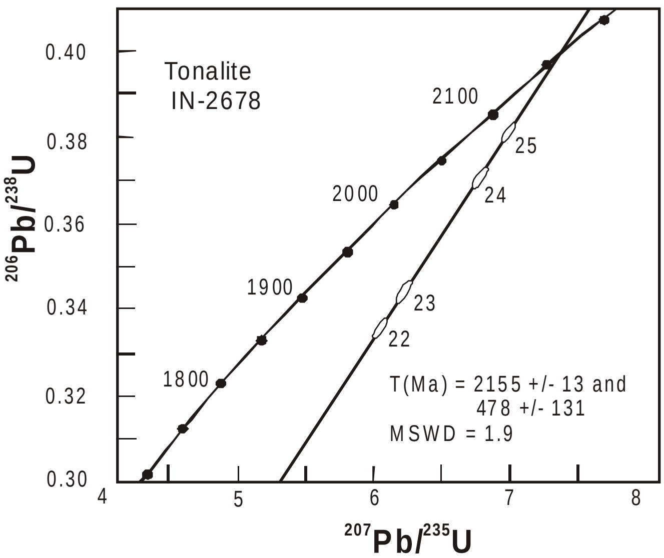

Figure 2-U-Pb concordia diagram for tonalite (host rock of the Salamangone mineralization).

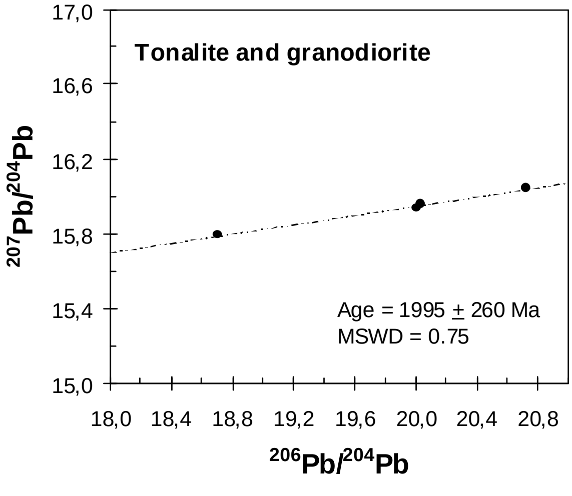

Figure 3-Pb-Pb whole rock isochron for tonalite and granodiorite (host rocks of the Salamangone mineralization).

0.7019 ± 0.0012 and MSWD=0.58 (Fig. 6). The low initial $^{87}Sr/^{86}Sr$ ratios obtained for both contemporaneous granodiorite and tonalite are in close agreement, suggesting that their parental magmas were derived from similar source.

Younger magmatic activities in the Lourenço region are represented by aplitic-veins which cross-cut the 2.1 Ga granitoids. Samples from the aplites yield a Rb-Sr whole-rock isochronic age of 1976 ± 200 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.708 ± 0.021 and MSWD = 0.13 (Fig. 7). The high error of the Sr initial ratio, due to the lack of analytical points close to the origin, is responsible for the high uncertainty of the age.

Samples from the altered tonalite were chosen to try to date the mineralization episode. The analytical points, plotted in the Rb-Sr isochronic diagram, yield a slope age of 1830 ± 270 Ma and $^{87}Sr/^{86}Sr$ initial ratio of 0.7045 ± 0.0029 and MSWD = 5.4 (Fig. 8). The scattering of some of the points about the isochron may have been caused by uncompleted Sr isotope homogenization during the

Table 1-U-Pb analytical data on zircon fraction of tonalite.

N/Sample fraction size (μm)	Concentrations (ppm)		$^{206}Pb/^{204}Pb^{a}$	Isotopic ratios corrected for blank and common Pb[b]				Rho[c]	Age (Ma)		
	Pb	U		$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$		$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
22/IN-2678, <100	61.6	167.0	1736	0.1308±1	0.11581±1	6.0444±187	0.3353±10	0.99	1982±6.1	1864±5.8	2108±0.8
23/IN-2678, >100	60.6	160.0	2266	0.1316±1	0.13115±2	6.2513±200	0.3445±11	0.98	2012±6.4	1908±5.9	2120±1.0
24/IN-2678, >100, A 70%	43.7	99.8	566.9	0.1329±1	0.14863±1	6.7957±224	0.3707±12	0.95	2085±6.9	2033±6.5	2137±1.9
25/IN-2678, <100, A 90%	31.0	70.1	646.9	0.1335±1	0.13207±3	7.0171±253	0.3813±13	0.96	2114±7.6	2082±7.3	2144±1.9

Notes: [a] measured ratio; [b] uncertainties (95% confidence level) refer to last digits of corresponding ratios; [c] correlation coefficients of $^{207}Pb/^{235}U$ vs. $^{206}Pb/^{238}U$ ratios, A50%-amount of zircon removed after air-abrasion; U/Pb* ratios for unweighed fractions were determined by the calculations of U and Pb concentrations for symbolic weight.

Table 2-Pb-Pb analytical data on tonalite and granodiorite.

Sample	Rock	Pb (ppm)	U (ppm)	Th (ppm)	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$
IH-26	Tonalite	12.2	2.46	13.2	20.010	15.936	38.702	0.7964
C-01	Granodiorite	18.2	2.75	9.37	18.700	15.793	36.227	0.8445
SL-37	Granodiorite	19.8	4.43	14.2	20.031	15.957	36.589	0.7966
SL-64	Granodiorite	18.2	3.64	12.9	20.720	16.044	36989	0.7743

Table 3-Sm-Nd analytical data on tonalite and granodiorite.

Sample	Rock	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	Error	$^{143}Nd/^{144}Nd$	Error	T_{dm}(GA) (DePaolo)	$\varepsilon_{Nd}(0)$	$\varepsilon_{Nd}(T)$
IH-26	Tonalite	4.809	25.417	0.1144	0.0001	0.511587	0.000044	2.242±0.063	-20.50	+3.02
C-01	Granodiorite	0.937	6.992	0.0810	0.0001	0.511010	0.000036	2.344±0.039	-31.76	+2.84

Table 4-Rb-Sr analytical data on tonalite, granodiorite aplite and tonalite (altered tonalite).*

Sample	Rock	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	±Error	$^{87}Sr/^{86}Sr$	±Error
SL-02	Tonalite	41.4	447.0	0.2679	0.0038	0.71086	0.00020
SL-20	Tonalite	67.8	625.3	0.3139	0.0046	0.71208	0.00005
SL-44	Tonalite	67.6	544.6	0.3590	0.0100	0.71364	0.00007
S-20	Tonalite	96.7	486.2	0.5760	0.0160	0.72096	0.00009
SL-30	Granodiorite	86.7	449.5	0.5590	0.0160	0.72028	0.00014
SL-37	Granodiorite	108.3	235.7	1.3350	0.0380	0.74500	0.00012
SL-64	Granodiorite	78.4	617.2	0.3680	0.0051	0.71366	0.00018
C-01	Granodiorite	58.3	951.1	0.1774	0.0015	0.70788	0.00009
C-02	Granodiorite	86.6	535.8	0.4680	0.0130	0.71619	0.00008
SHN-04	Granodiorite	62.4	612.2	0.2950	0.0080	0.71158	0.00007
SLAP-01	Aplite	165.9	73.3	6.673	0.1850	0.89812	0.00015
SLAP-02	Aplite	227.4	57.6	11.801	0.3230	1.04073	0.00010
SLAP-05	Aplite	236.0	72.4	9.693	0.2670	0.98650	0.00250
SLAPL-01	Aplite	143.5	74.4	5.671	0.1580	0.86859	0.00008
SLFC-06	Tonalite*	81.5	315.0	0.7500	0.0210	0.724880	0.000070
SLFL-07	Tonalite*	101.0	528.4	0.5537	0.0077	0.718590	0.000200
SLFC-09	Tonalite*	185.8	416.3	1.2952	0.0183	0.738260	0.000280
SLFL-14	Tonalite*	67.6	612.1	0.3198	0.0046	0.712390	0.000100

mineralization event or by subsequent disturbance of the isotope system associated with mineralization overprint and/or shear episodes. The altered tonalite exhibit a more radiogenic initial $^{87}Sr/^{86}Sr$ ratio than the fresh tonalite. The higher initial $^{87}Sr/^{86}Sr$ ratio of altered tonalite in relation to the expected low Sr isotopic composition of fresh tonalite, can be related to the overall effect of mineralizing fluid/rock interaction and Sr fractionation processes. K-Ar age determinations on biotite from the altered tonalite yield values ranging from 1794 to 1758 Ma (Table 5) comparable in time to those of the Maroni-Itacaiunas orogen, Rb-Sr and K-Ar mineral ages between 2,08 Ga and 1,76 Ga, reported by Montalvão and Tassinari 1984 and Tassinari 1996. Considering that the estimated temperature of mineralizing solutions was at least 300°C (Nogueira 2000), the K-Ar results might reflect the cooling age of the hydrothermal event. Alternatively, based on regional geochronological information, it is possible to interpret the results as regional cooling ages or as apparent ages reflecting subsequent

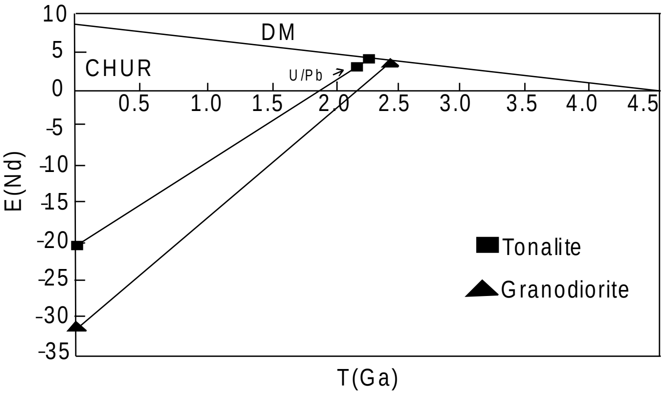

Figure 4-Nd vs. age diagram showing evolution lines for tonalite and granodiorite of the mine site.

Table 5-K-Ar biotite analytical data on altered tonalite.

Sample	Rock	Mineral	%K	±Error	$Ar^{40}Rad.10^{-6}$ (ccSTP/g)	Ar Atm (%)	Idade (Ma)
SLFL-01	Tonalite	Biotite	7.3898	0.5482	863.73	0.53	1770.4
SLFP-21	Tonalite	Biotite	7.4669	0.5000	891.25	0.38	1794.1
SLFP-22	Tonalite	Biotite	7.3699	0.9054	852.39	2.09	1758.6

isotopic disturbance during younger tectono-metamorphic activity (remobilization within the mineralized zone) related to the neighboring 1.76Ga felsic and alkaline bodies of the Falsino and Mapari suites (Tassinari *et al.* 1984).

FINAL CONSIDERATIONS The data obtained on granitoids of the Lourenço region are indistinguishable from previous geochronological results on similar rocks in other areas of the Maroni-Itacaiúnas Province. In the French Guyana, syntectonic granitoids and gneissic-migmatitic terranes of "Série Ille de Cayenne" yielded ages of 2.1–1.95 Ga, with Sr initial ratios around 0.7018–0.7024, μ_1 value of 8.2 and positive ε_{Nd} values (Teixeira *et al*. 1985, Milési *et al*. 1995). U-Pb ages on detrital zircon zircons from metagraywackes and conglomerates from greenstone belt sequences gave ages between 2.25 and 2.1 Ga (Gibbs 1980, Milési *et al*. 1995, Gibbs and Olszewski 1982). In addition Vanderhaeghe *et al*. (1998) constrained an episode of trondhjemitic magmatism at 2.17 Ga followed by the emplacement of calc-alkaline intrusions at 2.14–2.11 Ga and a late high-K magmatism at 2.09–2.08 Ga. Moreover the volcanism of the Vila Nova Group in northeast Pará and the Paramaca Group in French Guyana, both related to the greenstone belt sequences, yield Sm-Nd isochronic ages of 2.26 and 2.1 Ga respectively (McReath and Faraco 1997, Gruau *et al*. 1985).

The isotopic data available for the Lourenço Au-District and neighboring regions in Amapá and French Guyana, strongly suggest a geodynamic crustal evolution model, based on the development of a calc-alkaline magmatic arc in the time interval (2.25-2.0). This can be explained by subduction of oceanic lithosphere in the beginning of the collision between a continental mass, composed at that time by the Central Amazonian Province - Carajás-Iricoumé Block (Tassinari 1996) and the West African craton (Tassinari and Macambira 1999). Therefore the most plausible tectonic setting which necessarily includes the Salamangone gold deposit was genetically related to convergent tectonics associated to plate movement and supercontinental aggregation during the Paleoproterozoic.

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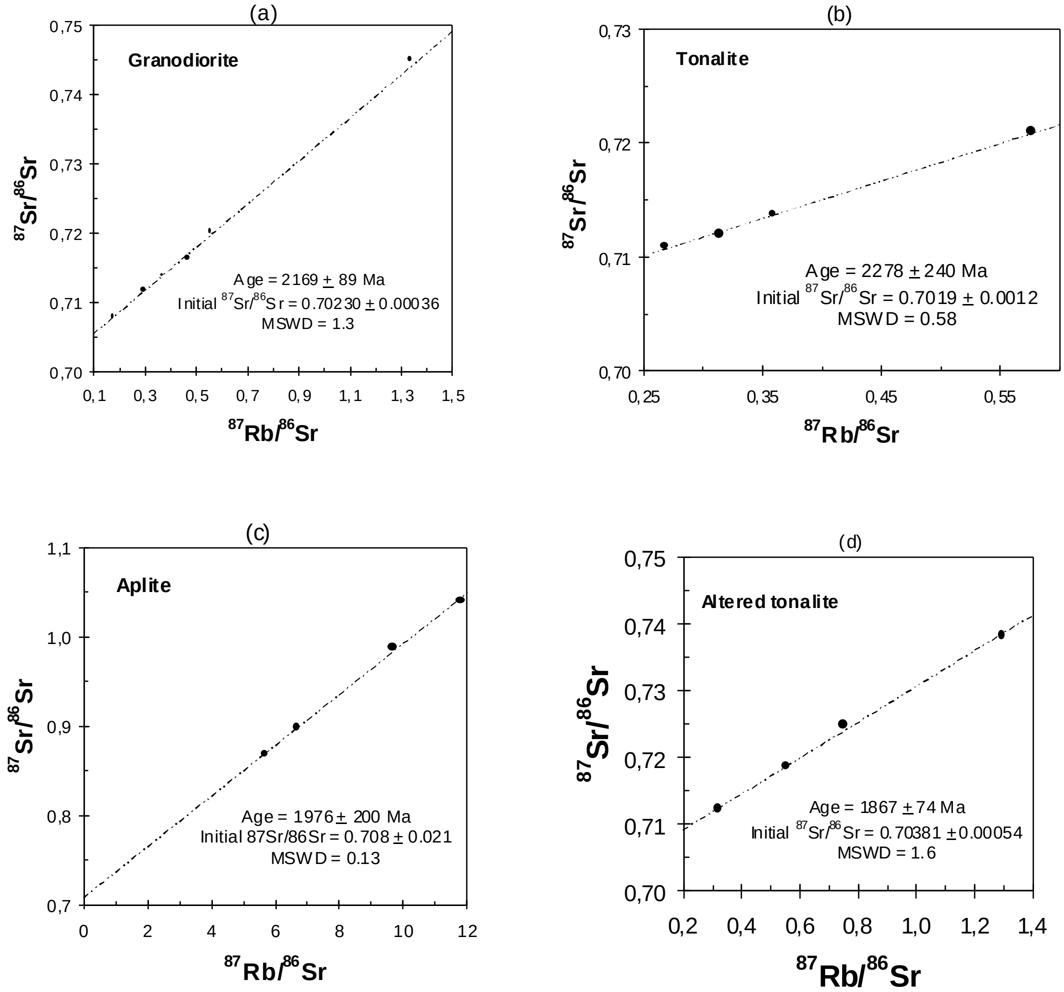

Figure 5-Rb-Sr whole rock isochron for: (a) granodiorite, (b) tonalite, (c) aplite and (d) altered tonalite (host rocks of the Salamangone mineralization).

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