



## SHRIMP U-Pb zircon dating of Pedras Grandes Suite, southern Santa Catarina State, Brazil

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*Manuscript received on January 5, 2004; accepted for publication on June 9, 2004;  
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### ABSTRACT

Two major magmatic pulses of the granitic Florianópolis Batholith in Santa Catarina State, southern Brazil, occurred between  $613 \pm 5$  Ma and  $595 \pm 5$  Ma, during the Neoproterozoic Brasiliano Cycle. These ages were obtained by U-Pb isotopic determinations with the sensitive high mass-resolution ion microprobe on igneous zircons from Pedras Grandes Suite in Santa Catarina State. Euhedral zircons remained unaltered close to a fluorite vein deposited at  $180^\circ\text{C}$  or more. These ages suggest a northern limit for the Pedras Grandes Suite, explaining the spatial relationship between the fluorite veins and the source rock.

**Key words:** SHRIMP, Pedras Grandes Suite, zircon, geochronology, fluorite.

### INTRODUCTION

The extensive Neoproterozoic granitic magmatism of the Brasiliano Cycle in the Precambrian/Cambrian shield of Santa Catarina State in southern Brazil (Fig. 1) is poorly known from a geochronological point of view. Its major significance for crustal building motivated this geochronological investigation. Granitic rocks are exposed in most of the southern part of the shield and their emplacement ages in the entire shield has been bracketed between 650 and 550 Ma by conventional U-Pb zircon dating (Basei et al. 2000) or between 640 and 590 Ma by ion microprobe data in the central part of the shield (Silva et al. 2002).

The southern part of the Florianópolis Batholith consists mostly of the Pedras Grandes Suite, which is poorly known geochronologically (Sallet et al. 2000). Only two zircon SHRIMP U-Pb ages are known for rocks exposed tens of kilometers to the north of the area studied here (Silva et al. 2002) points to the need of additional investigations to establish the timing of intrusion age of the major granitic suites. The granitic rocks in the southernmost part of the batholith have been included either in the Pedras Grandes Suite or in the Tabuleiro Suite, an issue that requires clarification.

The stability of zircon in many geological environments has been long recognized (e.g., Hanchar and Miller 1993, Vavra et al. 1996, Hartmann et al. 2000). The mineral may remain as a closed system for long periods of time, even at high temper-

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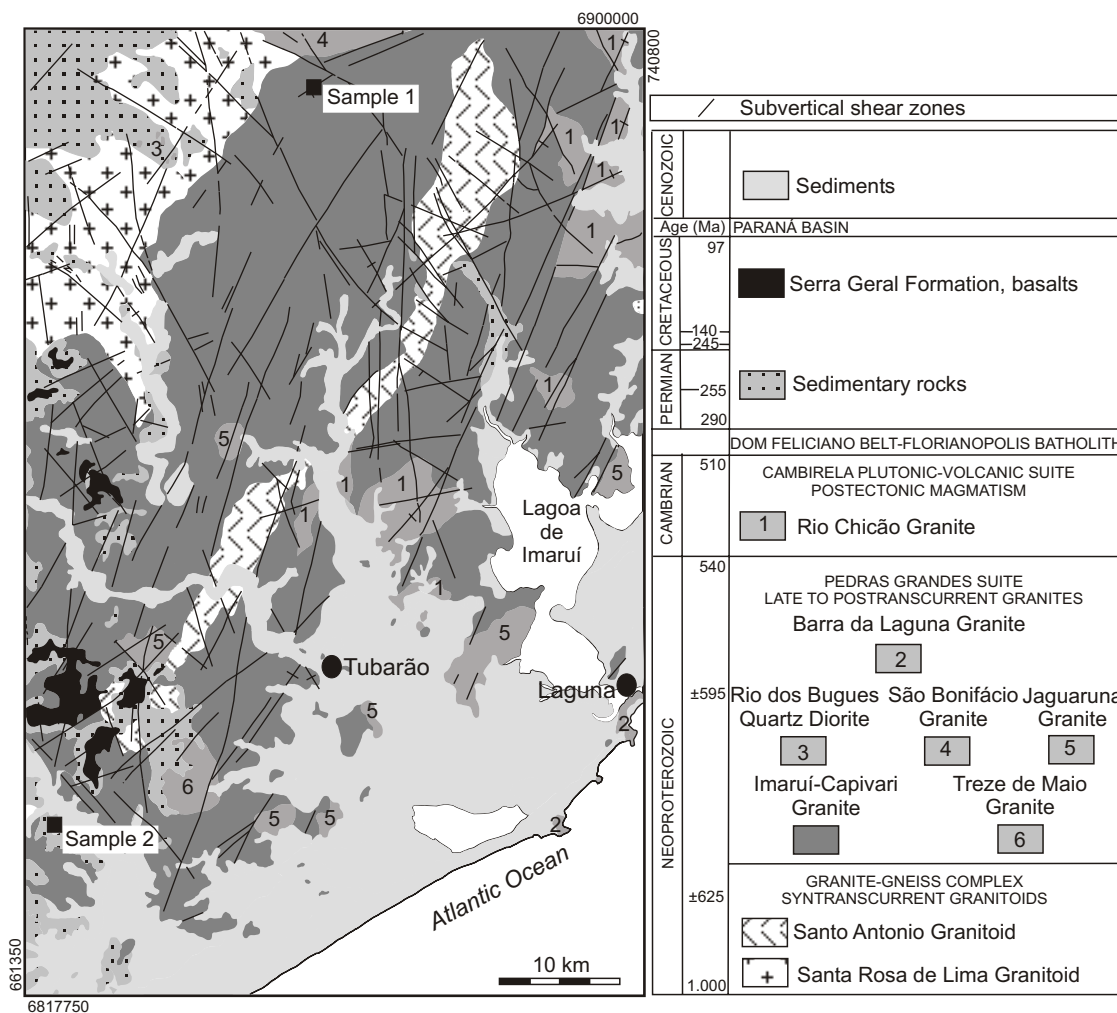


Fig. 1 – Location map. Modified after Silva et al. (2000).

atures (Cherniak et al. 1997, Lee et al. 1997), because lattice diffusion is an extremely slow process in zircon. On the other hand, defective zircons may have a much lower closure temperature and Pb diffusion may take place at temperatures as low as 210°C (Meldrum et al. 1998). Because the continued investigation of zircon stability led to the systematic decrease in the blocking temperature, our secondary goal in this study is to verify the stability of zircon under conditions of strong but low temperature alteration.

In this investigation, we determined the ages of two rock samples from the Pedras Grandes Suite

using the sensitive high-mass resolution ion microprobe (SHRIMP II). The southern portion of the Pedras Grandes Suite was altered by successive hydrothermal events: one hydrothermal event dated (apatite fission track dating – Jelinek et al. 1999) at 145 Ma, preceding the opening of the South Atlantic Ocean; and three strong fluorite mineralizing events between 130-76 Ma. This fact allows us to investigate the behavior of zircon under hydrothermal conditions with long duration in rocks simultaneously affected by fragile deformation. For this purpose, we collected two samples of the Pedras Grandes granitic suite, one in an unaffected envi-

ronment and the other strongly affected by the hydrothermal event in the immediate contact of a fluorite vein. We then determined the magmatic ages and tested the geochemical stability of zircon under low-temperature hydrothermalism of a complex evolution. As demonstrated further on, the results obtained in the altered sample show that the zircon was not affected by the hydrothermalism. The new ages combined with aerogamaespectrometry data (Hoff, unpublished data) provide new constraints for the role of the granites of Santa Catarina Fluorite District as source rocks of fluorite mineralization.

#### GEOLOGICAL SETTING

The Precambrian/Cambrian geology of southern Santa Catarina State is dominated by the large Florianópolis Batholith, with approximately 12,000 km<sup>2</sup> (Zanini et al. 1997, Basei et al. 2000, Silva et al. 2000, 2000a, Silva et al. submitted, Sallet et al. 2000), in which the Pedras Grandes Suite is the dominant plutonic body (Fig. 1). The region is commonly included in the Neoproterozoic Dom Feliciano Belt (Basei et al. 2000). Medium to coarse-grained biotite and hornblende monzogranites are the main lithologies of the Pedras Grandes Suite. This suite is dominated by K-rich granites with postcollisional geochemical characteristics. Intrusive syenogranites and a few alkaline granites, commonly ascribed to the Tabuleiro Suite, are also present (Silva et al. submitted). Remnants of Paleoproterozoic crust are found in several places and outcrop nearly continuously in the northern part of the batholith; a 3-km long remnant occurs in the southern part. Large subvertical dextral shear zones cut the batholith in a northeasterly direction (Basei et al. 2000, Bitencourt, unpublished data). The Proterozoic basement was covered by sedimentary and volcanic rocks of the Paleozoic/Mesozoic Paraná basin. Recent erosion exposed the batholith among remnants of the Phanerozoic sedimentary cover.

The Florianópolis Batholith has intrusive contacts in the north with the Brusque Group (Hartmann et al. 2000, Basei et al. 2000), composed of low to

medium grade schists of clastic derivation. Intrusive contacts are also seen with the Camboriú Complex of Paleoproterozoic age (Silva et al. 2000a). Although the chemical and petrographic compositions of the granitoids are restricted, the internal structure of the batholith is complex due to multiple intrusions of granite plutons. The granitic rocks are mostly high-K calcalkaline, such as sample 1 in this investigation. A-type granites are also present and form the Tabuleiro Suite (e.g. sample 2).

The granitic rocks were altered by fluorine-bearing hydrothermal solutions next to fluorite veins (Bastos Neto et al. 1997). The rocks were previously affected by brittle-ductile deformation, propylitic alteration and two microfracturing stages with associated alteration. Chlorite geothermometry yields temperatures around 250°C for these hydrothermal alterations. These stages were followed by several generations of microfractures with associated alterations correlated to the ore vein opening/filling processes during the Mesozoic and Tertiary, at  $\pm 200^\circ\text{C}$ ,  $\pm 160^\circ\text{C}$  and  $\pm 100^\circ\text{C}$ . High fluorine content indicates that the hydrothermal solutions had an acid character, uncommon in low temperature fluorite ore veins (Bastos Neto et al. 1997). Fission track dating of apatites next to the veins yielded ages of 144 Ma, 130-115 Ma, 98-93 Ma and 89-76 Ma (Jelinek et al. 1999).

The first phase of geological surveys at a scale of 1:50,000 carried out in the fluorite district in the 1960's and 70's by DNPM geologists led to the subdivision of district granites into large number of granite bodies and the creation of two-dozen terms to describe them. In the 1980's, geological mapping was carried out on more regional scales (Horbach and Marimon 1982, Morgental and Kirchner 1983), a consensus was reached that the district area granitoid rocks comprise one major granitic body, the Pedras Grandes Intrusive Suite (in the sense of Morgental and Kirchner 1983). The suite is exposed for approximately 150 km towards the NNE-SSW from the island of Florianópolis to the extreme south of the state where it is covered by the Paraná Basin. In this region, smaller granite intrusions were also

mapped, and were called the Tabuleiro Suite [Horbach and Marimon 1982, Sallet (unpublished data), Bastos Neto (unpublished data)] or Guabiruba Suite [Morgental and Kirchner 1983, Silva et al. 2002, Morgental (unpublished data)].

More recently, mapping by CPRM (Silva et al. 2000) subdivided the Pedras Grandes Suite into several granites (Fig. 1). In this work, (1) the designations of the Imaruí/Capivari Granites correspond to the Pedras Grande Suite (in the sense of Morgental and Kirchner 1983) whereas the Jaguaruna Granite corresponds to the Tabuleiro Suite (in the sense of Sallet, unpublished data), (2) the Jaguaruna Granite represents a variation of the Imaruí/Capivari Granite facies. In this way, the CPRM mapping corroborates the proposal of Sallet (unpublished data) and Bastos Neto (unpublished data), that the Tabuleiro Granite corresponds to a fine-grained facies of the Pedras Grandes granite. We adopt this classification of the regional granitic bodies for the present age dating investigation.

Selected previous geochronological data of the Florianópolis Batholith (Table I) established (Fig. 1) two age groups for the granitic magmatism of eastern Santa Catarina State outside of the area of interest (U-Pb in zircons; Silva et al. 2002 and unpublished data): (1)  $628 \pm 7$  to  $610 \pm 6$  Ma for the Guabiruba Granite and  $626 \pm 8$  Ma for the Paulo Lopes Granite and; (2)  $617 \pm 9$  to  $597 \pm 9$  Ma for the Tabuleiro Granite and  $593 \pm 16$  Ma for the Valungana Granite.

#### SAMPLE DESCRIPTION

##### GRANODIORITE, SAMPLE 1

Sample 1 belongs to the Pedras Grandes Suite, and was collected far from the hydrothermalized region in order to obtain the magmatic age of the central area of the batholith and the characteristics of the population of zircons in an environment not affected for the hydrothermal processes. Here the granodiorite contains plagioclase, potassic feldspar, quartz and biotite. Opaque minerals, apatite and zircon compose the magmatic accessory phases. Weak hy-

drothermal alteration is indicated by small amounts of epidote, sericite, chlorite, opaque minerals and carbonate.

The rock has a medium to coarse-grained inequigranular texture and shows synmagmatic deformation structures marked by narrow discontinuous bands of polycrystalline quartz with undulatory extinction and oriented biotite. Plagioclase is the dominant mineral, and is altered to sericite and epidote. Plagioclase also shows a myrmecitic intergrowth with quartz in the more pronounced deformation zones.

Zircon grains of this sample are elongated euhedral to subhedral prisms up to  $300 \mu\text{m}$  long, and are clear to yellow to greenish yellow in color. Prismatic to subrounded inclusions are very common, as well as rounded to nearly orthogonal fracture systems.

##### HYDROTHERMALLY ALTERED MONZOGANITE, SAMPLE 2

Sample 2 was collected in the southern portion of the Pedras Grandes Suite in the immediate contact with a fluorite vein, and was strongly affected by the hydrothermal event that produced the fluorite mineralization. This monzogranite is strongly altered, but the magmatic texture and mineralogy can still be identified. It is a medium-grained, inequigranular rock with K-feldspar as the most abundant mineral, followed by quartz, plagioclase and biotite; accessory minerals are titanite, opaque minerals, apatite and zircon. A volumetrically large alteration assemblage consists of epidote, sericite, chlorite, opaque minerals, fluorite and carbonate.

Zircon in this sample consists of long, euhedral prismatic crystals although short euhedral to subhedral prisms are also present and pyramidal terminations are common. The zircons vary from very clear to greenish yellow to reddish brown to nearly black. Fracture systems occur throughout the population. Prismatic to elipsoidal or subrounded apatite inclusions are common in the zircons.

**TABLE I**  
**Previous geochronological data of the Florianópolis Batholith. All data are U-Pb zircon.**  
**All previously analyzed samples are from the area located to the north of Figure 1.**

Granitic phase	Magmatic age (Ma)	Dating method	Source
Serra do Tabuleiro Granite	594 ± 8	SHRIMP	Silva et al. (1997)
Tabuleiro Granite	617 ± 9	SHRIMP	Silva (unpublished data)
Paulo Lopes Granite	626 ± 8	SHRIMP	Silva (unpublished data)
Guabiruba Granite	478 ± 14	Tims	Basei (unpublished data)
Ghabiruba Granite	628 ± 7	SHRIMP	Silva (unpublished data)
Valsungana Granite	647 ± 12	Tims	Basei (unpublished data)
Valsungana II Granite	593 ± 9	SHRIMP	Silva (unpublished data)
Major Gercino Suite	640	Tims	Basei et al. (1995)
Santa Luzia Granite	600 ± 7	Tims	Basei (unpublished data)
Vargem Grande	611 ± 3	SHRIMP	Silva et al. (2002)
Estr. Rancho Queimado-Forquilha	608 ± 7	SHRIMP	Silva et al. (2002)
Alto Varginha	579 ± 8	SHRIMP	Silva et al. (2002)

## MATERIALS AND METHODS

### ANALYTICAL PROCEDURES

Zircon crystals were separated by grinding crushed rock samples in a ring mill. The ground sample was passed through a 60 mesh nylon disposable sieve and washed. Zircon was then separated using heavy liquid (LST and di-iodomethane) and magnetic separation before representative grains were hand picked under a binocular microscope. Selected grains were mounted in an epoxy disc with chips of the CZ3 zircon standard (564 Ma), ground and polished until nearly half of each grain was removed, microphotographed in transmitted and reflected light, and imaged for its internal morphology using a scanning electron microscope, i.e. back-scattered electron and charge contrast imaging (Watt et al. 2000). The mount was then cleaned and gold coated in preparation for SHRIMP analyses.

The zircons were analyzed for U, Th and Pb using the sensitive high resolution ion microprobe (SHRIMP II) at Curtin University, Western Australia, using methods originally published by Compston et al. (1984) and more recently stated by Smith et al. (1998). Circular to oval areas of

20-30  $\mu\text{m}$  were analyzed from morphologically distinct areas chosen within zircon grains, together with replicate analyses of the CZ3 standard in the same epoxy mount. Corrections for common Pb were made using the measured  $^{204}\text{Pb}$  and the Pb isotopic composition of the Broken Hill galena. The level of common Pb is similar to that observed in the CZ3 standard and is considered to be largely derived from the gold coat. The uncertainty in all ages has a 95% confidence level, unless otherwise stated.

The data were plotted in the classical concordia diagram. The mean ages are weighted means at the 95% confidence level, while the single data point listed in Tables I and II are given at 2 sigma errors.

## RESULTS

Based on back-scattered electron (BSE) and charge contrast (CC) imaging of zircon crystals from sample 1 (Fig. 2), the zircon population consists of euhedrally zoned to structureless crystals with well-defined pyramidal terminations. Euhedral zoning is more prominent towards the grain rims. More rarely, some zircons show internal cores with faint oscillatory zoning which resembles the zoning derived from magmatic growth (Vavra 1994).

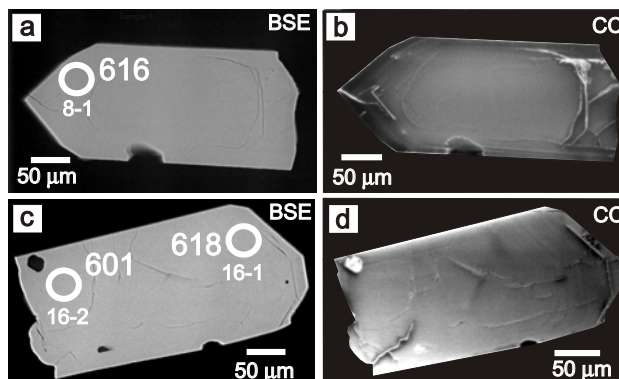


Fig. 2 – Backscattered electron (BSE) and charge contrast (CC) images of zircon grains from Sample 1. Circles indicate spot location; ages indicated in Ma. CC images were blackened with computer software.

Twenty-one SHRIMP spots were analyzed in fifteen zircon grains for this sample (Table II) and the U-Pb isotopic data plotted in a concordia diagram (Fig. 3). Most analyses are concordant at approximately 613 Ma, but two are discordant. These two (spots 21-1 and 14-1) have high common Pb content and are interpreted as affected by recent Pb loss. The remaining nineteen analyses are concordant with low common Pb and yield a mean  $^{206}\text{Pb}/^{238}\text{U}$  age of  $613 \pm 5$  Ma ( $\chi^2 = 0.90$ ; 95% confidence level). Since all these zircons have faint oscillatory zoning and pyramidal terminations, this age is considered to be the magmatic age.

BSE and CC imaging of sample 2 (Fig. 4) indicates that this population consists of homogeneous and structureless zircon grains with faint oscillatory zoning mainly near the rims. Twenty-six spots from seventeen zircon grains were analyzed for sample 2 (Table III) and U-Pb data are plotted in a concordia diagram (Fig. 5). The data form a cluster at about 600 Ma with most of the data being concordant within error limits. Four spots lying off the concordia were found; spots 10-2 and 11-1 statistically yield ages lower than the other data in the sample and more than 10% discordant; they are interpreted to have undergone Pb loss. The other two spots lying off the concordia, spots 8-1 and 2-2, have ages which are older and more comparable with the 613 Ma age

of sample 1. In both analyses, data were collected in core regions and may represent xenocrysts. All other 22 spots on zircons grains from sample 2 yield a  $^{206}\text{Pb}/^{238}\text{U}$  age of  $595 \pm 5$  Ma ( $n = 22$ ;  $\chi^2 = 1.09$ ; 95% confidence level). Based on the characteristics shown in the BSE/CC images (Fig. 4), this is interpreted to represent the magmatic age of this population.

#### DISCUSSION AND CONCLUSIONS

Two different magmatic ages were obtained in this study for the two age groups identified in previous research; the oldest (based on  $^{206}\text{Pb}/^{238}\text{U}$  ratio) is the  $613 \pm 5$  Ma, obtained for a granite sample from the central zone of the batholith. The youngest,  $595 \pm 5$  Ma, collected in a locality mapped by various authors as 'Pedras Grandes', except for the mapping by Silva et al. (2000), who used the term Imaruí/Capivari.

The results show older ages near the central region of the batholith (representing the first granitic magmatic pulses) and the lowest age is for the southwestern edge of the batholith, representing a younger pulse of magmatic activity.

On the other hand, based on aerogamaspectrometrical data (Hoff, unpublished data) it has been shown that the fluorite district is divided into two domains (Fig. 6). In the southern domain there is

TABLE II  
Zircon SHRIMP isotopic data for sample 1.

Spot	U ppm	Th/U	f 206 %	Ratios #								Age (Ma)		Conc. %
				$^{207}\text{Pb}/^{206}\text{Pb}$	$\pm$	$^{208}\text{Pb}/^{206}\text{Pb}$	$\pm$	$^{206}\text{Pb}/^{238}\text{U}$	$\pm$	$^{207}\text{Pb}/^{235}\text{U}$	$\pm$	$^{206}\text{Pb}/^{238}\text{U}$	$\pm$	
21-1	704	0.23	0.72	0.0615	0.0010	0.0499	0.0022	0.087	0.001	0.74	0.02	539	6	82
14-1	789	0.13	0.39	0.0606	0.0008	0.0351	0.0015	0.095	0.001	0.79	0.01	585	6	94
16-2	217	0.38	0.43	0.0564	0.0029	0.1153	0.0066	0.098	0.001	0.76	0.04	601	7	129
13-2	1092	0.28	0.26	0.0605	0.0008	0.0824	0.0017	0.098	0.001	0.82	0.01	602	5	97
19-1	228	0.88	0.06	0.0593	0.0013	0.2720	0.0035	0.098	0.001	0.80	0.02	603	7	104
13-3	317	0.60	0.54	0.0564	0.0022	0.1705	0.0052	0.098	0.001	0.76	0.03	604	6	129
17-1	483	0.50	0.12	0.0590	0.0014	0.1482	0.0032	0.099	0.001	0.80	0.02	608	6	107
10-1	230	0.87	0.23	0.0600	0.0012	0.2625	0.0032	0.099	0.001	0.82	0.02	611	7	101
6-1	950	0.22	0.25	0.0606	0.0006	0.0679	0.0012	0.100	0.001	0.83	0.01	612	6	98
6-2	1188	0.22	0.00	0.0610	0.0003	0.0679	0.0005	0.100	0.001	0.84	0.01	612	6	96
25-1	104	0.55	0.08	0.0590	0.0027	0.1704	0.0063	0.100	0.001	0.81	0.04	613	8	108
18-1	1106	0.35	0.03	0.0606	0.0004	0.1070	0.0009	0.100	0.001	0.84	0.01	614	6	98
2-1	375	0.47	0.02	0.0603	0.0009	0.1470	0.0021	0.100	0.001	0.83	0.02	616	7	100
8-1	923	0.28	0.02	0.0606	0.0005	0.0844	0.0008	0.100	0.001	0.84	0.01	616	6	99
20-1	1088	0.22	0.02	0.0607	0.0004	0.0674	0.0008	0.100	0.001	0.84	0.01	617	6	98
22-2	782	0.35	0.00	0.0603	0.0004	0.1087	0.0008	0.100	0.001	0.83	0.01	617	6	100
16-1	716	0.32	0.05	0.0604	0.0005	0.0975	0.0011	0.101	0.001	0.84	0.01	618	6	100
16-3	449	0.31	0.00	0.0592	0.0008	0.0951	0.0015	0.101	0.001	0.82	0.01	619	6	108
17-2	1532	0.28	0.14	0.0595	0.0007	0.0829	0.0013	0.101	0.001	0.83	0.01	619	5	106
11-1	525	0.33	0.00	0.0606	0.0006	0.1013	0.0013	0.101	0.001	0.84	0.01	620	6	99
13-1	504	0.11	0.01	0.0601	0.0007	0.0337	0.0012	0.101	0.001	0.84	0.01	622	6	102

UWA SHRIMP mount 9855. # is the ratios corrected for common Pb; conc is the concordance; f 206 is the percentage of common Pb found in  $^{206}\text{Pb}$ .

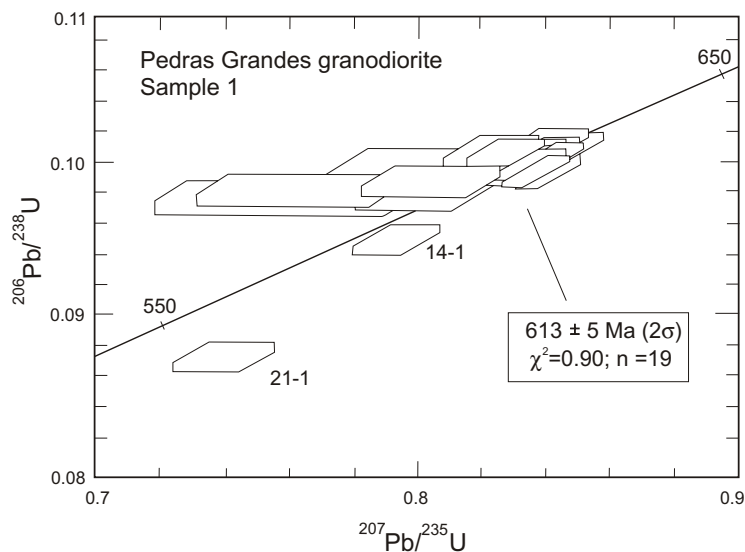


Fig. 3 – Concordia diagram for SHRIMP U-Pb data of 19 zircon grains (21 analyses). Two analyses not included in age calculation are identified (14-1 and 21-1).

an area which is elongated in the NE-SW direction characterized by a larger total potassium channel and the F-Factor count which, apparently, delineate a granite body. Based on the potassium channel count and the F-Factor, it may be deduced that around

this granite body there is a peripheral zone strongly affected by hydrothermalism. Hoff (unpublished data) named Pedras Grandes Massif the set which includes the central zone and the peripheral band. According to this interpretation, the Tabuleiro Suite

TABLE III  
Zircon SHRIMP isotopic data for sample 2.

Spot	U ppm	Th/U	f206 %	Ratios #								Age (Ma)		Conc. %
				$^{207}\text{Pb}/^{206}\text{Pb}$	±	$^{208}\text{Pb}/^{206}\text{Pb}$	±	$^{206}\text{Pb}/^{238}\text{U}$	±	$^{207}\text{Pb}/^{235}\text{U}$	±	$^{206}\text{Pb}/^{238}\text{U}$	±	
87-1	327	0.51	0.50	0.0566	0.0022	0.1563	0.0053	0.092	0.001	0.72	0.03	570	6	120
68-1	214	0.73	0.24	0.0591	0.0029	0.2172	0.0069	0.095	0.001	0.77	0.04	582	7	102
6-3	118	0.97	0.17	0.0601	0.0046	0.3040	0.0116	0.095	0.001	0.79	0.06	583	9	96
1-1	166	0.51	0.00	0.0598	0.0009	0.1595	0.0022	0.095	0.001	0.78	0.02	583	7	98
11-1	173	0.84	0.25	0.0575	0.0017	0.2601	0.0045	0.095	0.001	0.76	0.03	587	7	115
68-2	137	0.78	0.11	0.0577	0.0042	0.2408	0.0101	0.096	0.001	0.76	0.06	589	8	113
10-2	99	0.74	0.52	0.0622	0.0038	0.2385	0.0091	0.096	0.001	0.82	0.05	591	8	87
07-1	144	0.73	0.01	0.0588	0.0020	0.2285	0.0049	0.096	0.001	0.78	0.03	591	7	106
13-1	485	0.67	0.06	0.0594	0.0008	0.2056	0.0020	0.096	0.001	0.79	0.01	592	6	102
7-3	219	0.59	0.47	0.0558	0.0027	0.1802	0.0064	0.096	0.001	0.74	0.04	593	7	134
2-1	94	0.86	0.00	0.0616	0.0013	0.2632	0.0038	0.096	0.001	0.82	0.02	593	7	90
68-3	170	1.17	0.54	0.0571	0.0034	0.3435	0.0087	0.097	0.001	0.76	0.05	594	7	120
6-2	222	1.19	2.02	0.0603	0.0040	0.3625	0.0098	0.097	0.001	0.80	0.06	594	7	97
4-1	228	1.20	0.00	0.0604	0.0014	0.3666	0.0039	0.097	0.001	0.80	0.02	594	7	96
15-1	202	0.44	1.26	0.0594	0.0024	0.2190	0.0056	0.097	0.001	0.79	0.03	596	7	103
16-1	189	0.76	0.01	0.5589	0.0015	0.2363	0.0038	0.097	0.001	0.79	0.02	599	7	106
5-1	91	0.70	0.00	0.0613	0.0013	0.2224	0.0035	0.097	0.001	0.82	0.02	599	8	92
6-1	127	1.09	0.00	0.0591	0.0011	0.3398	0.0038	0.098	0.001	0.79	0.02	600	7	105
14-1	159	0.63	0.00	0.0612	0.0010	0.1944	0.0026	0.098	0.001	0.83	0.02	603	7	93
5-2	143	0.70	0.85	0.0544	0.0039	0.1957	0.0092	0.098	0.001	0.74	0.06	605	8	157
14-2	217	0.70	0.24	0.0581	0.0015	0.2139	0.0036	0.098	0.001	0.79	0.02	605	7	113
10-1	257	1.27	0.20	0.0589	0.0012	0.3831	0.0036	0.099	0.001	0.80	0.02	607	7	108
9-1	156	1.22	0.01	0.0612	0.0016	0.3744	0.0047	0.099	0.001	0.83	0.02	608	7	94
12-1	949	0.58	0.10	0.0598	0.0006	0.1829	0.0014	0.099	0.001	0.82	0.01	611	6	103
8-1	164	0.90	0.00	0.0592	0.0009	0.2880	0.0030	0.100	0.001	0.82	0.02	615	7	107
2-2	219	1.12	0.10	0.0588	0.0014	0.3406	0.0038	0.101	0.001	0.82	0.02	619	7	110

UWA-112-18-12-2A SHRIMP mount 9855. # is the ratios corrected for common Pb; conc is the concordance; f206 is the percentage of common Pb found in  $^{206}\text{Pb}$ .

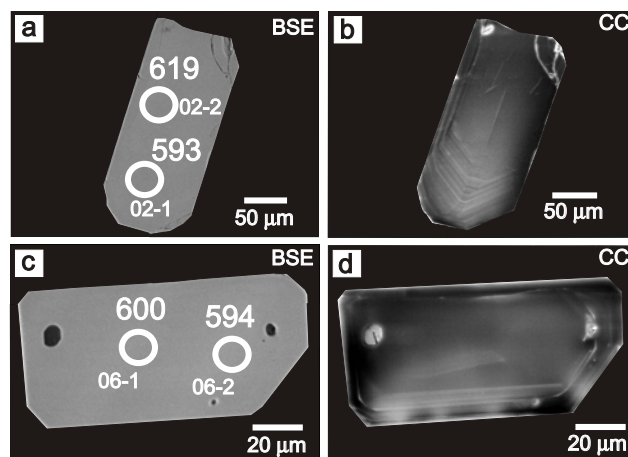


Fig. 4 – Backscattered electron (BSE) and charge contrast (CC) images of zircon grains from Sample 2. Circles indicate spot location; ages indicated in Ma. CC images were blackened with computer software.

is preferentially located along the borders of the Pedras Grandes Massif. In the northern domain there is a zone with a markedly lower total background count which characterizes a rock type distinct to the

Pedras Grandes, and within which smaller, isolated, granitic bodies which may be correlated with the Pedras Grandes Suite.

The data presented here support the above



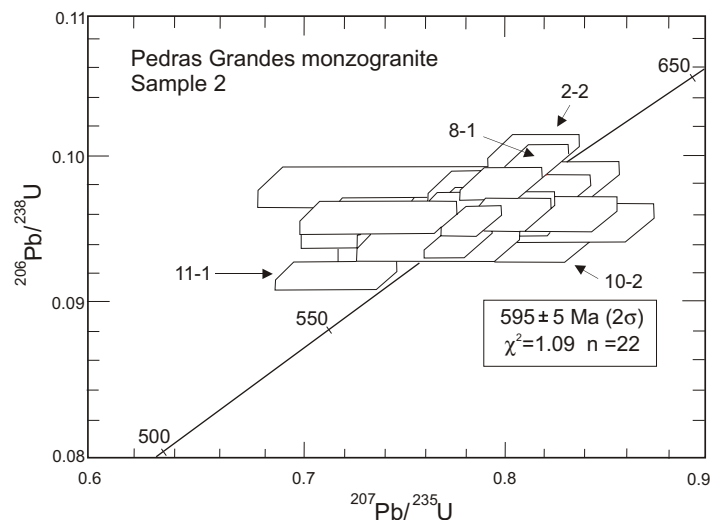


Fig. 5 – Concordia diagram for SHRIMP U-Pb data of 22 zircon grains (26 analyses). Four analyses not included in age calculation are identified (2-2, 8-1, 10-2 and 11-1).

model. The youngest age is that of the Pedras Grandes Massif, while the oldest age is that of the sample from the northern domain (in the low background count zone) which is outside the Pedras Grandes Massif. This interpretation is reinforced by the existence of an area of reduced total count to the northeast of the Pedras Grandes Massif and is older than Pedras Grandes according to Silva (unpublished data).

The delimitation of the Pedras Grandes Massif made by Hoff (unpublished data) allows visualization of the fluorite veins along the borders of this massif or in its host-rocks (Fig. 6). The border-zone is the preferential location for the fine-grained facies (the Tabuleiro Granite) and the hydrothermal processes responsible for the formation of the source rock of fluorite mineralization.

We suggest a northern limit for the Pedras Grandes Massif in this study, which supports Hoff's (unpublished data) model and clarifies an important issue (i.e. what is the relationship between the fluorite veins and the source rock) regarding the mineralization of fluorite in the fluorite district.

This investigation shows that there was no growth of new zircons during the 131-76 Ma hy-

drothermal alteration and fluorite mineralization. No corrosion of zircon or lead loss from zircons occurred during these events, because the SHRIMP analyses are consistent with the magmatic age. Zircon is therefore observed to be refractory to HF-rich fluids at 180°C.

#### ACKNOWLEDGMENTS

JADL's work in Western Australia was financed by the Brazilian Government's Project of Excellence in Metallogeny and Crustal Evolution at UFRGS and by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). Prof. David I. Groves offered his enthusiastic support. Paul Potter is thanked for the review of the text.

SHRIMP mount preparations and SEM imaging were undertaken at UWA: Marion Dahl and Brendan Griffin are acknowledged for the former and latter, respectively. Zircon analyses were carried out on a Sensitive High Resolution Ion Microprobe Mass Spectrometer (SHRIMP II) operated by a consortium consisting of Curtin University of Technology, the Geological Survey of Western Australia and the University of Western Australia with the support of the Australian Research Council.

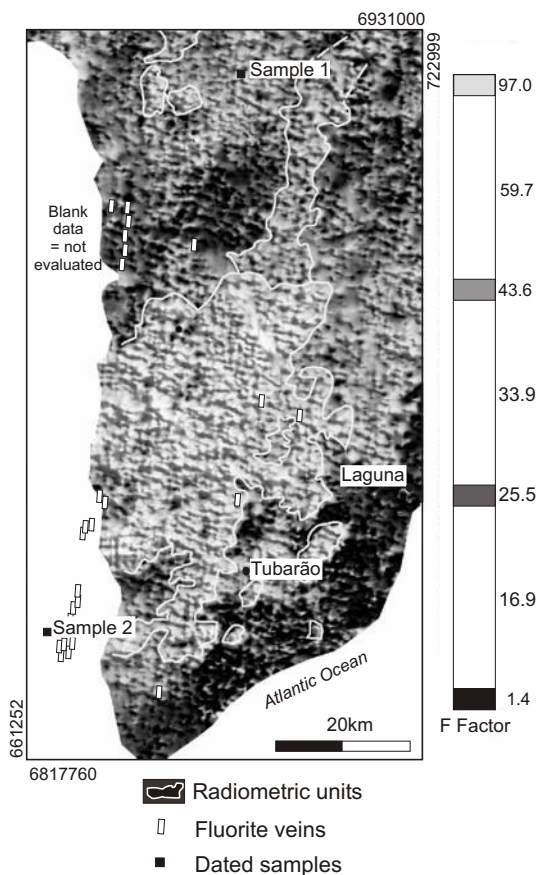


Fig. 6 – Radiometric image factor F ( $F = K \cdot U/Th$ ) counting with location of the fluorite veins. Modified after Hoff (unpublished data).

### RESUMO

Dois dos principais pulsos da atividade granítica no Batólito Florianópolis em Santa Catarina ocorreram entre  $613 \pm 5$  Ma e  $595 \pm 5$  Ma, durante o Neoproterozóico do Ciclo Brasileiro. Estas idades foram obtidas a partir de determinações isotópicas U-Pb em cristais de zircão da Suite Pedras Grandes por “*Sensitive high-resolution ion microprobe*” – SHRIMP II. Os cristais de zircão permaneceram inalterados mesmo mediante condições hidrotermais com temperaturas iguais e, até mesmo, superiores a  $180^\circ\text{C}$ . Estas idades sugerem a delimitação norte do Maciço Pedras Grandes, explicando a relação espacial existente entre os filões de fluorita e a rocha fonte destas mineralizações.

**Palavras-chave:** SHRIMP, Suite Pedras Grandes, zircão, geocronologia, fluorita.

### REFERENCES

- BASEI MAS, AHRENDT H, WEMME K AND PASSARELLI CR. 1995. Evolução Policíclica da Zona de Cisalhamento de Major Gercindo, Santa Catarina, Brasil. In: Simpósio Nacional de Estudos Tectônicos 5, Gramado, *Anais...*, SBG, p. 371–373.
- BASEI MAS, SIGA JR O, MASQUELIN H, HARARA OM, REIS NETO JM AND PRECIOZZI PORTA F. 2000. The Dom Feliciano Belt and Rio de la Plata Craton: tectonic evolution and correlation with similar provinces of southwestern Africa. In: CORDANI ET AL. (Ed.) Tectonic evolution of South America, 31<sup>st</sup> International Geological Congress, Rio de Janeiro, p. 311–334.
- BASTOS NETO AC, DARDENNE MA AND TOURAY JC. 1997. Contribuição do estudo das alterações hidrotermais de encaixante a gênese das mineralizações do distrito fluorítico de Santa Catarina. *Geochim Bras* 11: 213–229.
- CHERNIAK DJ, HANCHAR JM AND WATSON EB. 1997. Diffusion of tetravalent cations in zircon. *Contrib Mineral Petrol* 127: 383–390.
- COMPSTON W, WILLIAMS IS AND MEYER C. 1984. Geochronology of zircons from the lunar breccia 73217 using a sensitive high mass resolution ion microprobe. *Journal of Geophysical Research* 89(B): 525–534.
- HANCHAR JM AND MILLER CF. 1993. Zircon zonation patterns as revealed by cathodoluminescence and backscattered electron images: Implications for interpretation of complex crustal histories. *Chem Geol* 110: 1–13.
- HARTMANN LA, LEITE JAD, SILVA LC, REMUS MVD, MCNAUGHTON NJ, GROVES DI, FLETCHER IR, SANTOS JOS AND VASCONCELLOS MAZ. 2000. Advances in SHRIMP geochronology and their impact on understanding the tectonic and metallogenic evolution of southern Brazil. *Aust J Earth Sci* 47: 829–844.
- HORBACH R AND MARIMON RG. 1982. Contribuição ao distrito de fluorita de Santa Catarina. *Boletim Técnico – Série Geologia/Projeto Radam-Brasil*, Salvador, 1v.
- JELINEK AR, BASTOS NETO AC, LELARGE ML AND SOLIANI JR E. 1999. Apatite fission track dating of Santa Catarina State, Brazil: a complex hydrothermal evo-

- lution. *Journal of South American Earth Sciences* 12: 367–377.
- LEE JKW, WILLIAMS IS AND ELLIS DJ. 1997. Pb, U and Th diffusion in natural zircon. *Nature* 390: 159–162.
- MELDRUM A, BOATNER LA, WEBER WJ AND EWING RC. 1998. Radiation damage in zircon and monazite. *Geochim Cosmochim Acta* 62: 2509–2520.
- MORGENTAL A AND KIRCHNER CA. 1983. Síntese do mapa provisional do distrito de fluorita de Santa Catarina. In: SIMPÓSIO SUL-BRASILEIRO DE GEOLOGIA 1, Porto Alegre, *Anais...*, SBG, p. 294–306.
- SALLET R, MORITZ R AND FONTIGNIE D. 2000. Fluorite  $^{87}\text{Sr}/^{86}\text{Sr}$  and REE constraints on fluid-melt relations, crystallization time span and bulk  $D^{\text{Sr}}$  of evolved high-silica granites. *Tabuleiro granites, Santa Catarina, Brazil. Chem Geol* 164: 81–92.
- SILVA LC, McNAUGHTON NJ, HARTMANN LA, FLETCHER IR, GRESSE P AND SCHEEPERS R. 1997. U-Pb (SHRIMP) isotopic constraints for the evolution of Southern Brazilian Granitic Province, and some correlated South African, Pan-African plutons. In: INTERNATIONAL SYMPOSIUM ON GRANITES AND ASSOCIATED MINERALISATIONS 2, Salvador, *Anais...*, p. 276–277.
- SILVA LC, HARTMANN LA, McNAUGHTON NJ AND FLETCHER IR. 2000a. Zircon U/Pb SHRIMP dating of a Neoproterozoic overprint in Paleoproterozoic granitic-gneissic terranes, southern Brazil. *Am Mineral* 85: 649–668.
- SILVA LC, ARMSTRONG R, PIMENTEL MM, SCANDOLARA J, RAMGRAB G, WILDNER W, ANGELIM LAA, VASCONCELOS AM, RIZZOTO G, QUADROS MLES, SANDER A AND ROSA ALZ. 2002. Reavaliação da evolução geológica em terrenos Pré-Cambrianos brasileiros com base em novos dados U-Pb SHRIMP, Parte III: Províncias Borborema, Mantiqueira Meridional e Rio Negro-Juruena. *Rev Bras Geocienc* 32: 529–544.
- SILVA MAS, LEITES SR AND CARUSO JR F. 2000. Programa levantamentos geológicos básicos do Brasil. Criciúma, Folha SH.22-X-B. Estado de Santa Catarina. Escala 1:250.000. CPRM, Brasília.
- SMITH JB, BARLEY ME, GROVES DI, KRAPEZ B, McNAUGHTON NJ, BICKLE MJ AND CHAPMAN HJ. 1998. The Scholl shear zone, West Pilbara: Evidence for a terrane boundary structure from integrated tectonic analyses, SHRIMP U/Pb dating and isotopic and geochemical data of granitoids. *Precamb Res* 88: 143–171.
- VAVRA G. 1994. Systematics of internal zircon morphology in major Variscan granitoid types. *Contrib Mineral Petrol* 117: 331–344.
- VAVRA G, GEBAUER D, SCHMID R AND COMPSTON W. 1996. Multiple zircon growth and recrystallization during polyphase Late Carboniferous to Triassic metamorphism in granulites of the Ivrea Zone (Southern Alps); an ion microprobe (SHRIMP) study. *Contrib Mineral Petrol* 122: 337–358.
- WATT GR, GRIFFIN BJ AND KINNY PD. 2000. Charge contrast imaging of geological materials in the environmental scanning electron microscope. *Am Mineral* 85: 1784–1794.
- ZANINI LFP, BRANCO PM, CAMOZZATO E AND RAMGRAB GE. 1997. Programa levantamentos geológicos básicos do Brasil. Folhas Florianópolis (SG.22-Z-D-V) e Lagoa (SG.22-Z-D-VI), Estado de Santa Catarina. Escala 1:100.000. CPRM, Brasília, 259 p.