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SHRIMP U-Pb ages of detrital zircons from the early Proterozoic Contendas-Mirante supracrustal belt, São Francisco Craton, Bahia, Brazil

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Abstract—SHRIMP U-Pb geochronology has been undertaken on detrital zircons in a orthoconglomerate from the metamorphosed Contendas-Mirante supracrustal belt, São Francisco Craton, Bahia, Brazil. The majority of the U-Pb age determinations on the detrital zircons are concordant within uncertainty, and display three principal age groups; 2710-2600 Ma, 2400-2300 Ma and most abundant, 2200-2150 Ma. The conglomerate must have been deposited between ca. 2150 Ma (the youngest detrital zircons) and 2000-1900 Ma, when the Contendas-Mirante supracrustal belt was intruded by peraluminous granites. 3100-3400 Ma gneisses and granitoids crop out as domes within the Contendas-Mirante supracrustal belt, which have been interpreted as reactivated basement to the belt. These gneisses have not contributed a significant amount of detrital material to the conglomerate because the oldest detrital zircons have an age of only ca. 2700 Ma. Instead, the source of the detrital material in the conglomerate might be represented by the Jequié Complex to the east, which consists of late Archaean rocks that were migmatized and intruded by granites in the early Proterozoic.

Resumen—Circones detricos in un conglomerado metamorfico del cinturon supracortical Contendas-Mirante, Sao Francisco Craton, Bahia, Brazil, fueron datados por U-Pb usando SHRIMP. La mayoria de las edades determinadas por U-Pb son acordes y se pueden agrupar en tres grupos; 2710-2600 Ma, 2400-2300 Ma y 2200-2150 Ma, la poblacion mas abundante. La depositacion del conglomerado debio ocurrir entre 2150 Ma (la edad del circon detritico más joven) y el emplazamiento de granitos peraluminicos entre 2000-1900 Ma en el cinturon supracortical. Gneises y granitos en forma de domos con edades de 3100-3400 Ma afloran en el cinturon supracortical Contendas-Mirante y han sido interpretados previamente como reactivaciones del zocalo. Estos gneises no han contribuido significativamente a la materia detritica que forma el conglomerado porque el circon detritico mas joven solo tiene una edad de 2700 Ma. En vez, la provenencia del material detritico en el conglomerado pudo ser representado por el complejo Jequié al este el cual consiste de rocas que fuerón migmatizadas en el Arcaico tardio y intruidas por granitos en el Proterozoico temprano.

INTRODUCTION

THE SÃO FRANCISCO CRATON of Bahia State, Brazil, has been shown by Rb-Sr whole rock geochronology to contain early Archaean to early Proterozoic gneisses and granitoids (Cordani and Iyer, 1978; Cordani *et al.*, 1985), and include the oldest-known rocks in South America. Single zircon age determinations for gneisses and granitoids confirmed that the oldest of these rocks (3200-3400 Ma) occur in domes within the early Proterozoic Contendas-Mirante supracrustal belt (Martin *et al.*, 1991; Nutman and Cordani, in press). The Contendas-Mirante supracrustal belt contains abundant detrital sediments. By dating detrital zircons from these sediments, it would be possible to assess whether the granitoid and gneiss domes were the source of the sediments, and, if so, whether they contain even older (≥ 3400 Ma) rocks. The results of dating of detrital zircons from a conglomerate in the Contendas-Mirante supracrustal belt are reported in this paper.

GEOLOGICAL SETTING

The region contains the northern boundary of the Ribeira orogenic belt with the São Francisco Craton. The Ribeira belt developed during the late Proterozoic to early Paleozoic Brasiliano orogenic cycle. In the south and west of the region the Brasiliano cycle is marked by heating and some deformation, but without the emplacement of new granitic rocks. K-Ar apparent ages in this part of the region indicate complete argon loss ca. 600 Ma ago (Cordani *et al.*, 1985). In the north and eastern parts of the region K-Ar biotite and hornblende ages are between 1700 and 1800 Ma which are interpreted as cooling ages marking the termination of the early Proterozoic Transamazonian orogeny (Cordani *et al.*, 1985).

The western segment of the region consists of granitic-migmatitic-gneissic rocks with which are associated several units of supracrustal rocks. All these rocks have greenschist to amphibolite facies metamorphic assem-

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blages and have been subjected to polyphase deformation. In most cases, Rb-Sr geochronology of the associated granites have yielded ages of ca. 2700 Ma, but gneisses from the Lagoa do Morro area (Fig. 1) have yielded SHRIMP U-Pb zircon ages of 3184 ± 6 Ma and 2845 ± 14 Ma (Nutman and Cordani, in press). This western segment of the region has been interpreted as a late Archaean granite-greenstone complex that contains remnants of somewhat older rocks (Cordani *et al.*, 1985).

The central segment of the region is dominated by the early Proterozoic Contendas-Mirante supracrustal belt (Marinho *et al.*, 1979, 1980; Cordani *et al.*, 1985). The Contendas-Mirante belt crops out in an area approximately 40 km wide and 160 km long, and has been intensely deformed giving rise to N-S trending folds and tectonic breaks (Sabaté *et al.*, 1980). The belt consists of a lower ultramafic-mafic-felsic and immature sediment unit which is overlain by a unit of phyllites and sandstones. The lower unit contains nearly all of the volcanogenic components. These are found intercalated with detrital and chemical sediments. The belt has been metamorphosed under greenschist facies conditions and intruded by late- to syn-tectonic granites, which have yielded Rb-Sr whole-rock isochron ages of 2000-1900 Ma (Cordani *et al.*, 1985; Sabaté *et al.*, 1990; Marinho, 1991). These events form part of the early Proterozoic Transamazonian orogeny, also recorded by early Proterozoic K-Ar ages throughout the north and eastern parts of the region. Within the Contendas-Mirante belt there are several gneiss and granitoid domes, up to 80 km long (Fig. 1), which pre-date the early Proterozoic granites described above and have yielded late to mid Archaean ages by several methods (Marinho, 1991; Martin *et al.*, 1991; Nutman *et al.*, in press). Sabaté and Gomes (1984) and Sabaté *et al.* (1988) show that they represent allochthonous segments of basement, uplifted by early thrusting during the Transamazonian orogeny.

The eastern segment of the region is occupied by high grade granulite-amphibolite facies gneisses which belong to the Jequié Complex (Cordani and Iyer, 1978; Barbosa, 1986). Rb-Sr whole rock geochronological studies suggest that gneisses with ages of 2600-2700 Ma are important in the Jequié Complex (Cordani and Iyer, 1978; Cordani *et al.*, 1985; Barbosa, 1986), and that subsequently migmatization and granite emplacement took place in one or more events between 2400 and 2200 Ma, followed by further metamorphism during the Transamazonian orogeny between 2000 and 1800 Ma (Cordani *et al.*, 1985; Wilson, 1987; Wilson *et al.*, 1988).

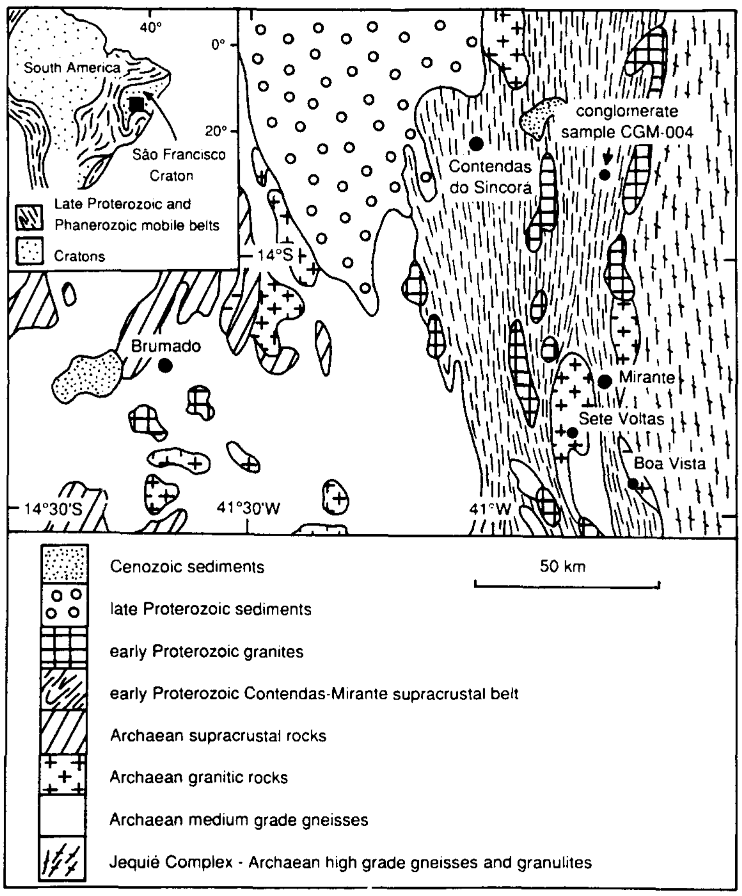

Fig. 1. Geological map of the studied part of the São Francisco Craton, Bahia State, Brazil (adapted from Fig. 2 of Cordani *et al.*, 1985).

SHRIMP WITHIN-GRAIN U-Pb ZIRCON GEOCHRONOLOGY

Analytical Method And Calculation Of Ages

U-Th-Pb isotopic ratios and elemental abundances in ca. 30 μm diameter areas of zircons were analyzed using the ion microprobe SHRIMP, and were referenced to the Australian National University standard zircon SL13 ($^{206}Pb/^{238}U$ = 0.0928; 572 Ma). Further details of the analytical procedure are given by Compston *et al.* (1984), with refinements to calibration of the data given by Williams and Claesson (1987) and Kinny *et al.* (1990). Zircon ages quoted in this paper, unless stated otherwise, are derived from $^{207}Pb/^{206}Pb$ ratios of analyses selected as being of the least isotopically-disturbed sites, and are quoted in the text with 2σ uncertainties. The criteria used for the recognition of the least disturbed sites are low common Pb contents (expressed as comm. ^{206}Pb%; the percent of total ^{206}Pb which is non-radiogenic, based on measured ^{204}Pb) and low degrees of discordancy (expressed here as [$^{206}Pb/^{238}U$age /$207_{Pb}/206_{Pb}$age-1] × 100). Analyzed sites have very low common Pb contents (with the exception of an analysis of grain #7), thus the ages quoted here are insensitive to the choice of common Pb composition (see caption to Table 1) used in calculating the radiogenic isotopic ratios. Ages have been calculated using the values for decay constants and present-day $^{238}U/^{235}U$ recommended by the IUGS Subcommission on Geochronology (Steiger and Jäger, 1978).

Conglomerate CGM-004

Sample CGM-004 (Fig. 1) comes from 13°49'58" S 40°46'06" W near the Contas River, southeast of Santana town. The sedimentary unit to which it belongs is composed of mica schists and meta-sandstones, with interbedded feldspathic meta-sandstones and meta-conglomerates, forming a tectonic slice considered to belong to the clastic sediments of the Mirante subunit in the upper part of the volcano-sedimentary sequence (e.g., Marinho, 1991). The mica schists include some nodular varieties (with andalusite ± cordierite), and some magnesian varieties which could be weathered mafic volcanic rocks. The outcrop of CGM-004 is an orthoconglomerate, with quartz-rich pebbles and schist clasts. The matrix is schistose, with increase in quartz content together with pebble concentration. The pebbles are up to 10 cm long and the schist clasts are up to a few centimeters long. The matrix, pebbles and clasts have the same mica foliation. The pebbles are too strained and recrystallized to ascertain if they already had a foliation or gneissosity prior to being incorporated into the sediment.

CGM-004 was a whole-rock sample consisting of matrix, pebbles and clasts, and yielded abundant zircons. Most of the zircons have a prismatic habit, and range from almost euhedral to distinctly rounded (Fig. 2). Some of them have pitted surfaces, suggestive of abrasion during sedimentary transport, and indicating their detrital nature. The grains may be divided into several groups on the basis of size, color and degree of rounding. Type I forms approximately 10% of the population and are mostly large (up to 300 μm long) dark brown to pink stubby prismatic grains. The shape of these grains ranges from subhedral to

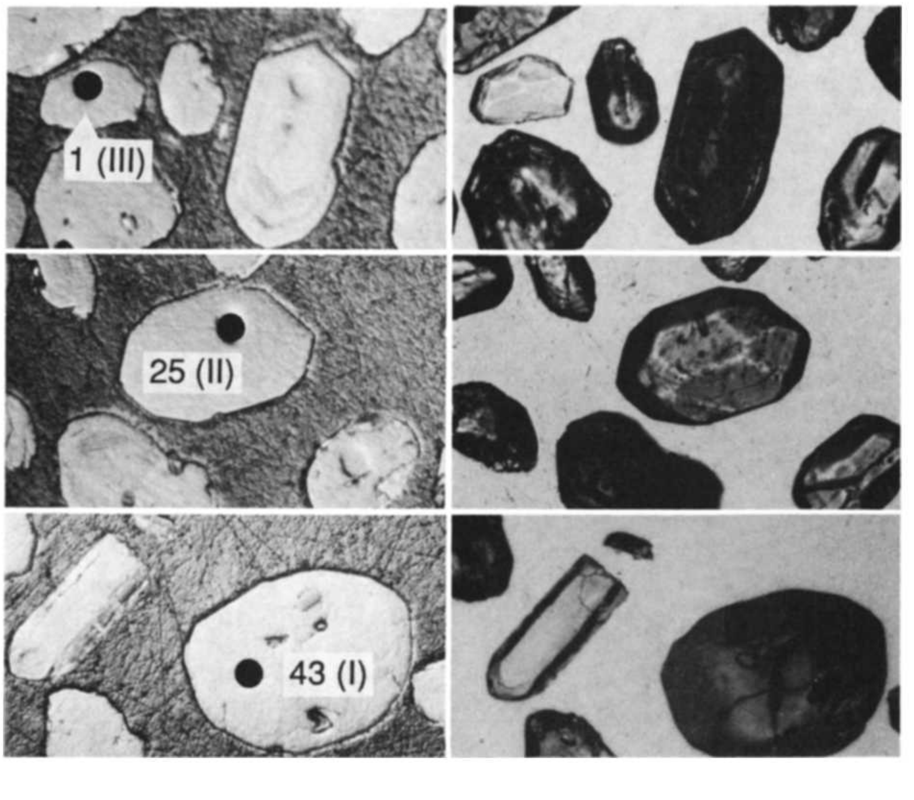

Fig. 2. Representative analyzed zircons, viewed in reflected light (left) and in transmitted light (right).

Table 1. SHRIMP U-Pb zircon data

Site, type	U (ppm)	Th	Th/U	^{204}Pb (ppb)	Comm. ^{206}Pb (%)	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Age (Ma)	disc.
38.2, *Ia*	71	46	0.65	<1	<0.01	0.483±15	12.41±0.43	0.1863±19	2710±17	-6
22.1, *Ib*	139	96	0.69	<1	<0.01	0.503±16	12.92±0.42	0.1862±12	2708±10	-3
38.1, *Ia*	62	39	0.63	<1	<0.01	0.511±17	13.09±0.46	0.1858±20	2705±18	-2
38.3, *Ia*	66	44	0.67	1	0.06	0.521±17	13.22±0.46	0.1839±19	2688±17	1
37.1, *Ia*	178	105	0.59	1	0.01	0.500±15	12.64±0.41	0.1831±12	2682±11	-2
16.1, *Ib*	208	167	0.80	1	0.03	0.519±16	13.05±0.42	0.1825±11	2675±10	1
43.1, *Ia*	176	224	1.27	46	1.04	0.520±16	13.07±0.44	0.1823±18	2674±17	1
34.1, *Ia*	169	95	0.56	29	0.73	0.491±15	12.09±0.41	0.1786±18	2640±17	-2
19.1, *Ia*	218	158	0.72	20	0.36	0.515±16	12.58±0.41	0.1772±13	2627±12	2
5.1, *Ia*	242	150	0.62	8	0.14	0.502±16	12.17±0.42	0.1758±12	2613±11	0
6.1, *Ia*	212	391	1.84	20	0.29	0.660±22	15.90±0.57	0.1746±17	2603±17	26
11.1, *Ib*	457	165	0.36	18	0.23	0.350±11	8.25±0.26	0.1708±09	2566±09	-25
17.1, *Ib*	506	362	0.72	43	0.60	0.293±89	6.55±0.21	0.1622±13	2479±14	-33
40.1, *Ib*	337	239	0.71	6	0.09	0.407±12	8.72±0.28	0.1554±10	2406±11	-8
39.2, *Ib*	201	90	0.45	13	0.30	0.438±13	9.30±0.31	0.1539±13	2389±14	-2
40.2, *Ib*	412	288	0.70	12	0.14	0.417±13	8.74±0.28	0.1521±11	2370±12	-5
39.3, *Ib*	528	165	0.31	<1	<0.01	0.420±13	8.59±0.27	0.1484±07	2327±08	-3
15.1, *Ib*	176	104	0.59	<1	<0.01	0.428±13	8.71±0.28	0.1477±11	2319±13	-1
4.1, *Ib*	234	105	0.45	33	0.64	0.457±15	9.28±0.33	0.1471±15	2313±18	5
39.1, *Ib*	994	259	0.26	<1	<0.01	0.342±10	6.91±0.21	0.1465±05	2305±06	-18
10.1, *Ib*	230	197	0.86	8	0.17	0.432±13	8.56±0.28	0.1436±13	2271±15	2
36.1, *II*	288	217	0.75	22	0.38	0.413±13	7.84±0.26	0.1379±12	2200±15	1
49.1, *Ib*	219	91	0.42	<1	<0.01	0.403±12	7.61±0.25	0.1372±11	2192±14	0
3.1, *II*	531	410	0.77	<0	<0.01	0.400±13	7.56±0.25	0.1372±07	2192±08	-1
26.1, *II*	156	122	0.78	8	0.29	0.382±12	7.21±0.24	0.1368±15	2187±19	-5
13.1, *II*	200	132	0.66	7	0.18	0.392±12	7.39±0.24	0.1367±13	2186±16	-2
21.1, *II*	134	69	0.51	4	0.17	0.392±12	7.35±0.24	0.1359±13	2176±16	-2
52.1, *II*	154	47	0.31	6	0.20	0.392±12	7.35±0.27	0.1359±22	2176±28	-2
29.1, *II*	372	151	0.41	2	0.02	0.406±12	7.60±0.24	0.1359±08	2175±10	1
31.1, *Ia*	198	59	0.30	8	0.21	0.406±12	7.59±0.25	0.1357±13	2173±17	1
30.1, *Ib*	441	233	0.53	7	0.09	0.387±12	7.22±0.23	0.1354±08	2169±10	-3
44.1, *III*	322	125	0.39	40	0.75	0.343±10	6.40±0.21	0.1353±14	2168±18	-12
23.1, *II*	360	136	0.38	10	0.13	0.469±14	8.74±0.28	0.1352±10	2166±12	14
48.1, *Ia*	424	268	0.63	1	0.01	0.377±11	7.03±0.22	0.1352±08	2166±10	-5
20.1, *II*	254	44	0.17	33	0.83	0.325±10	6.03±0.22	0.1346±22	2158±29	-16
7.1, *Ib*	389	177	0.45	44	0.56	0.417±14	7.74±0.27	0.1345±11	2158±15	4
25.1, *II*	275	190	0.69	3	0.05	0.396±12	7.35±0.23	0.1345±08	2157±10	0
7.2, *Ib*	1157	814	0.70	3520	26.68	0.174±6	3.20±0.20	0.1339±65	2150±12	-52
42.1, *III*	89	74	0.84	1	0.06	0.404±13	7.47±0.27	0.1339±19	2149±25	2
24.1, *II*	376	196	0.52	43	0.60	0.388±12	7.15±0.23	0.1336±12	2146±15	2
28.1, *II*	473	368	0.78	6	0.07	0.378±11	6.97±0.22	0.1335±07	2145±09	4
27.1, *II*	348	188	0.54	<1	<0.01	0.389±12	7.16±0.23	0.1335±08	2144±10	-1
50.1, *II*	217	103	0.48	45	1.08	0.397±12	7.29±0.26	0.1333±19	2142±26	1
45.1, *Ib*	421	173	0.41	6	0.08	0.356±11	6.49±0.21	0.1321±08	2126±11	-8
46.1, *II*	210	138	0.66	<1	<0.01	0.389±12	7.08±0.23	0.1320±10	2125±13	0
47.1, *III*	395	205	0.52	36	0.55	0.340±10	6.12±0.20	0.1308±14	2109±18	-11
35.1, *II*	251	171	0.68	<1	<0.01	0.399±12	7.19±0.23	0.1306±10	2106±13	3
2.1, *Ia*	164	110	0.67	4	0.12	0.382±13	6.87±0.25	0.1305±14	2104±19	-1
1.1, *III*	105	36	0.35	15	0.74	0.409±14	7.31±0.30	0.1297±24	2094±33	6
41.1, *Ib*	506	299	0.59	20	0.24	0.333±10	5.91±0.19	0.1286±09	2079±12	-11
14.1, *II*	457	252	0.55	<1	<0.01	0.307±9	5.45±0.17	0.1285±06	2078±08	-17
32.1, *Ib*	405	231	0.57	<1	<0.01	0.267±8	4.73±0.15	0.1285±08	2077±11	-27
33.1, *II*	433	382	0.88	26	0.41	0.303±9	5.38±0.18	0.1285±13	2077±18	-18
9.1, *II*	412	332	0.81	16	0.25	0.322±10	5.70±0.18	0.1281±10	2072±13	-13
8.1, *III*	312	105	0.34	4	0.09	0.321±10	5.32±0.18	0.1201±09	1957±14	-8
18.1, *Ib*	715	429	0.60	37	0.51	0.212±6	3.32±0.11	0.1139±11	1863±17	-34
51.1, *Ib*	1044	212	0.20	31	0.32	0.195±6	2.92±0.09	0.1086±09	1776±15	-35
12.1, *Ib*	886	75	0.08	42	0.58	0.169±5	2.39±0.08	0.1025±10	1670±19	-40

Data are listed according to decreasing $^{207}Pb/^{206}Pb$ age. U-Pb isotopic ratios are given with 1σ uncertainties, after correction for common lead using the ^{204}Pb correction method. Comm. ^{206}Pb(%) is the percent of total ^{206}Pb which is non-radiogenic, based on measured ^{204}Pb. As some of the zircons are interpreted to have undergone Pb-loss and hence open system behavior at ca. 600 Ma, we have taken Cumming and Richards (1975) linear model III 600 Ma Pb as the common Pb composition. Disc. is the discordancy in percent.

strongly rounded (e.g. grain #43, Fig. 2). Variety Ia consists of the largest, most rounded grains which are largely free of internal zoning, and Ib consists of somewhat more euhedral grains which commonly consist of homogeneous centers around which there is a conformable mantle of finely-zoned zircon. Type II forms approximately 80% of the population and consists of medium to small grains (100 to 200 μm long), pale orange to pink in color and commonly showing distinct fine-scale euhedral zoning. These grains range from almost euhedral to distinctly rounded (e.g. grain #25, Fig. 2). Type III forms approximately 10% of the population and consists of small (≤150 μm), clear, euhedral grains which commonly display fine-scale euhedral zoning (e.g. grain #1, Fig. 2).

Isotopic data and U and Th elemental abundances are presented in Table 1, ranked according to decreasing $^{207}Pb/^{206}Pb$ age. 58 analyses were performed on 52 grains. The majority of the analyzed sites yielded U-Pb ages that are concordant within 2σ uncertainty and have ages between ca. 2150 and 2710 Ma (Fig. 3). Multiple analyses were made on grains #7, 38, 39 and 40. Of these, only #39 showed intra-grain variation in $^{207}Pb/^{206}Pb$ age (ages of 2389 ± 28 Ma 2% discordant, 2327 ± 16 Ma 3% discordant and 2305 ± 12 Ma 18% discordant; Table 1). With the exception of #8.1 all discordant analyses fall between 2150-600 Ma and 2710-600 Ma discordia (Fig. 3). From the isotopic systematics alone this could be interpreted in two ways; variable, generally small amounts of Pb-loss from some of the zircons at ca. 600 Ma; or zircon recrystallization or growth of new zircon at 600 Ma. The grains which gave rise to the most discordant analyses have neither overgrowths of younger zircon which could have been included in analysis sites nor evidence (from variable optical reflectivity and truncation of zoning within grains) for patchy recrystallization. Therefore, the discordant grains are interpreted to have undergone variable, generally small, amounts of Pb-loss, perhaps at predominantly ca. 600 Ma. In order to reduce blurring of age distribution patterns of the zircons by ancient Pb-loss, the following discussion is based on those analyses with U-Pb ages that are concordant within 2σ uncertainty. The smoothed $^{206}Pb/^{207}Pb$ age frequency distribution plot for concordant grains shows a polymodal age distribution (Fig. 3). The most prominent age group is centered on 2168 Ma. Less abundant are grains with ages between ca. 2300 and 2400 Ma and between ca. 2600 and 2710 Ma (Fig. 3). These older groups appear to be bimodal (Fig. 3), which is interpreted to reflect further complexity in the detrital zircon population; with sub-groups centered on ages of 2320, 2384, 2613 and 2674 Ma (Fig. 3). Due to the small number of data in each of these subgroups, these ages should be regarded as approximate, and uncertainties have not been attached to them.

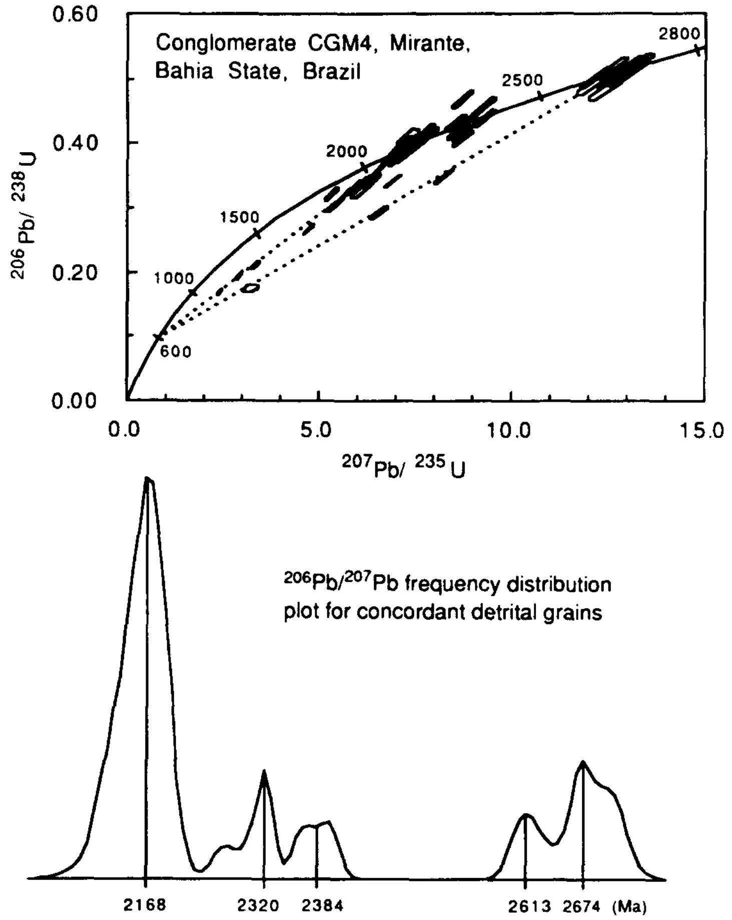

Fig. 3. U-Pb concordia (1σ uncertainty boxes) and $^{207}Pb/^{206}Pb$ age smoothed frequency distribution diagrams, conglomerate CGM-004.

Nearly all type I grains belong to the ca. 2600-2710 Ma and 2300-2400 Ma groups, with all of the type Ia grains belonging to the 2300-2400 Ma group (Table 1). Type II and III grains belong exclusively to the 2100-2200 Ma group. U abundances mostly range between 100 and 500 ppm, with Th/U ratios between 0.25 and 0.85. However, most of the type Ia grains (>2600 Ma) have U abundances of less than 200 ppm (but with Th/U ratios within the range of the other grain types), and thus have the lowest U abundances of all the grain types (Table 1).

DISCUSSION

The zircon results presented in this paper combined with isotopic data on granites that intrude the Contendas-Mirante belt (Cordani *et al.*, 1985; Sabaté *et al.*, 1990; Marinho, 1991) indicate that the sedimentary unit represented by CGM004 was deposited between ca. 2150 and 1900 Ma. The zircon age data permit identification of different age components within the metaconglomerate sample. All the older grains (≥ 2600 Ma) are distinctly rounded, but the younger grains show variable degrees of rounding and some are almost euhedral. This suggests the older grains either underwent farther transport or that they experienced more cycles of erosion and deposition than the younger ones.

The SHRIMP U-Pb zircon results provide evidence on the source of detrital material in Contendas-Mirante supracrustal belt metasediments. All the 52 grains analyzed have $^{207}Pb/^{206}Pb$ ages of ≤ 2710 Ma. This means that we can be 95% confident that any older (undetected) detrital zircons form less than 10% of the population. At this confidence level, it is highly unlikely that the studied conglomerate sample received detrital material from the mid to early Archaean gneisses and granitoids exposed in domes such as at Boa Vista and Sete Voltas, which crop out in the tract occupied by the Contendas-Mirante supracrustal belt. On the other hand, the detrital zircon ages match the Rb-Sr ages (within their large uncertainties), for the Jequié Complex to the east, in which 2600-2700 Ma gneisses and 2200-2400 Ma migmatite components and granites have been recognized (Cordani *et al.*, 1985). Therefore, the Jequié Complex or maybe the Itabuna complex further to the east are considered to be a likely source of the detrital material in the conglomerate. However, on the basis of a single sample, it is not possible to state whether CGM004 is representative of the provenance of the detrital material for all the sediments in the Contendas-Mirante belt.

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