Chapter V

SHRIMP U-Pb ZIRCON GEOCHRONOLOGY OF ARCHEAN GNEISSES AND CONTENDAS-MIRANTE CONGLOMERATES, SÃO FRANCISCO CRATON

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WHY SHRIMP ZIRCON GEOCHRONOLOGY?

U-Pb zircon geochronology using SHRIMP (sensitive high resolution ion microprobe) involves isotopic analysis of ca. 30 μm deep pits within sectioned zircons mounted in polished epoxy-resin discs (see Compston et al., 1984; Williams & Claesson, 1987; Kinny et al., 1990 for a description of the analytical technique). Under normal operating conditions a SHRIMP analysis of a zircon takes twenty minutes, with preliminary results available instantly. This method of analysis lends itself to the investigation of the complex, commonly isotopically-disturbed, zircon populations that are found in many Precambrian rocks, particularly gneisses and detrital sediments. Multiple analyses within a given group of zircons gives rise to accurate and precise age determinations, commonly with uncertainties in the $^{207}Pb/^{206}Pb$ age of less than ±10 Ma (2δ). Also of great importance is that migmatites can be investigated almost as easily as a simple rock, allowing accurate age determinations of the two or more components within them. Because of the small size of the domains in zircons analysed by SHRIMP, the age of younger overgrowths on, or older inherited cores within grains can be determined. Overgrowths may indicate the age of a high grade metamorphic event (e.g. Williams & Claesson, 1987). Inherited zircon cores may be restite which has survived the anatexis of the source of the granitic rock, or may be derived from wall rocks sampled during the ascent of the granitic magma. Thus inherited zircons can be used to define the age of rocks at a deeper level in the crust, and hence provide deep structural information. On the other hand, the conventional isotope-dilution thermal-ionisation analysis method for either single or multiple zircons yields average U-Pb ages, which are typically U-concentration weighted. These weighted average zircon ages for rocks with a complex zircon populations and multiple Pb-loss history may not necessarily accurately date any real event.

SHRIMP ZIRCON GEOCHRONOLOGY RESULTS

A brief resumé of SHRIMP U-Pb zircon geochronology on four samples of Archean granitoids and gneisses and a Proterozoic Contendas-Mirante metaconglomerate from the São Francisco Craton of Bahia State (Fig. V.1) is given here together with summary concordia diagrams (Figs. V.1, V.2 and V.3). Detailed interpretation of the zircon populations are included below. A tonalite (#AC-2B) and a granite (#AC-1E) from the Sete Voltas and Boa Vista "basement" domes in the Early Proterozoic Contendas-Mirante supracrustal belt yielded concordant ages of 3403±5 Ma and 3353±5 Ma, respectively. These domes have been interpreted as basement rocks that were uplifted into their cover during the Middle Proterozoic Transamazonian orogeny. To the west of the Contendas-Mirante belt, there is an Archean granite-greenstone terrane, which from previous Rb/Sr geochronology is believed to have cratonized approximately 2700 Ma ago. Two samples of granodioritic gneisses from the Lagoa do Morro area, belonging to the granite-greenstone terrane, have been dated. One gneiss (#AC-4E) yielded a concordant age of 3184±6 Ma. In the other sample (#AC-4G), the zircons are discordant with $^{207}Pb/^{206}Pb$ ages between 2823 and 2446 Ma, apart from one zircon which is concordant at 2845±14 Ma, which is taken as the best estimate of the age of this sample. These results show that the gneisses and granites in the granite-greenstone terrane contain more than one age component, and include rocks which predate the main evolution of this terrane at ca. 2700 Ma by as much as 500 Ma.

A metaconglomerate sample (CGM-004) from the Contas River, southeast of Santana town in the Contendas-Mirante supracrustal belt (Fig. V.1), yielded many detrital zircons. The majority of the isotopic determinations on the detrital zircons yield U-Pb ages that are concordant within uncertainty (Fig. V.4). The conglomerate must have been deposited between ca. 2150 Ma (the youngest detrital zircons) and ca. 1900 Ma, when the Contendas-Mirante supracrustal belt was intruded by granites. Discussion of zircon ages has only used analyses with U-Pb ages that are concordant within 2δ uncertainty. The smoothed $^{207}Pb/^{206}Pb$ frequency distribution plot

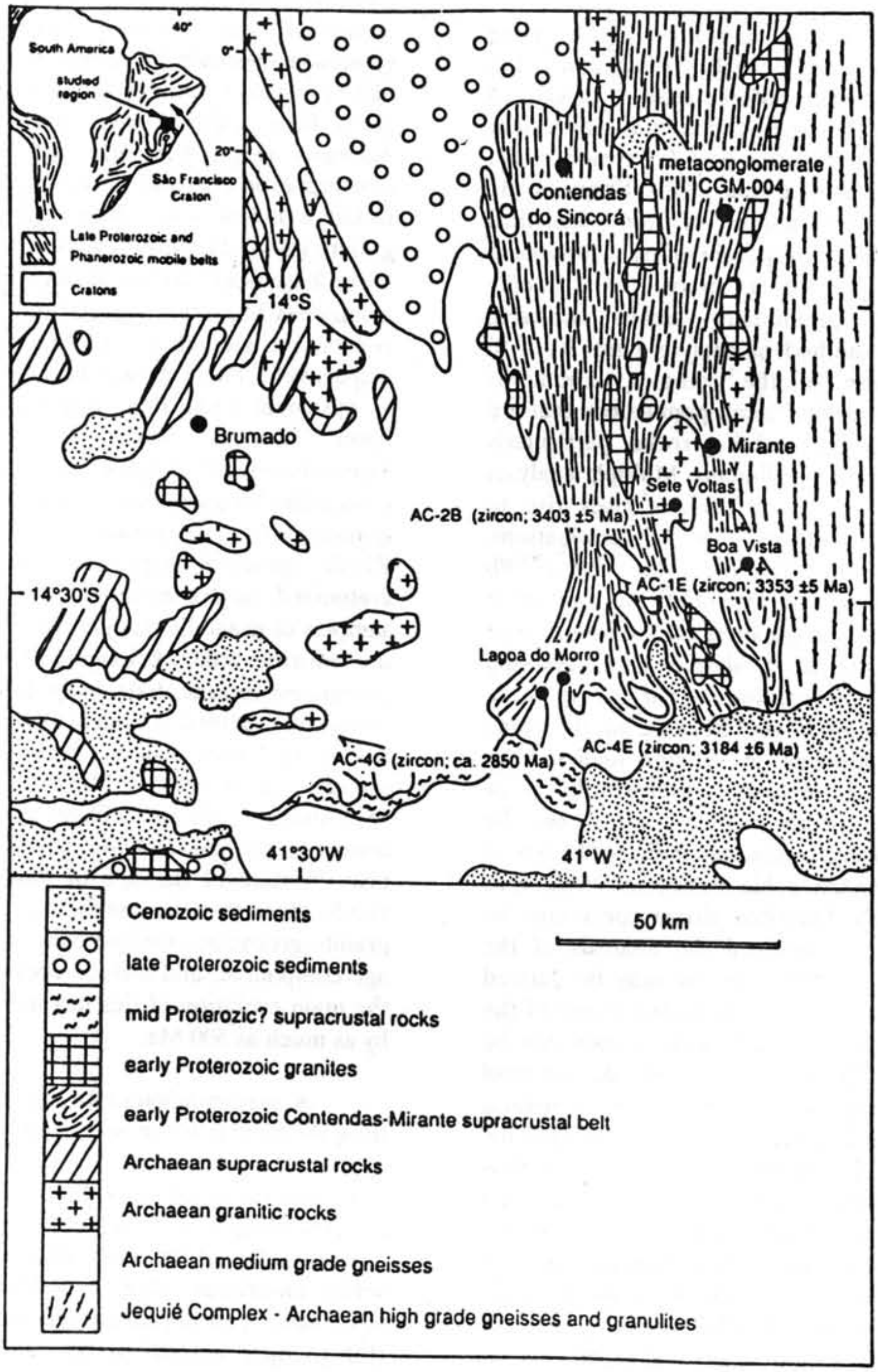

Figure V.1 - Geological map of the studied part of the São Francisco Craton, Bahia State, Brazil (adapted from Fig. 2 of Cordani et al., 1985).

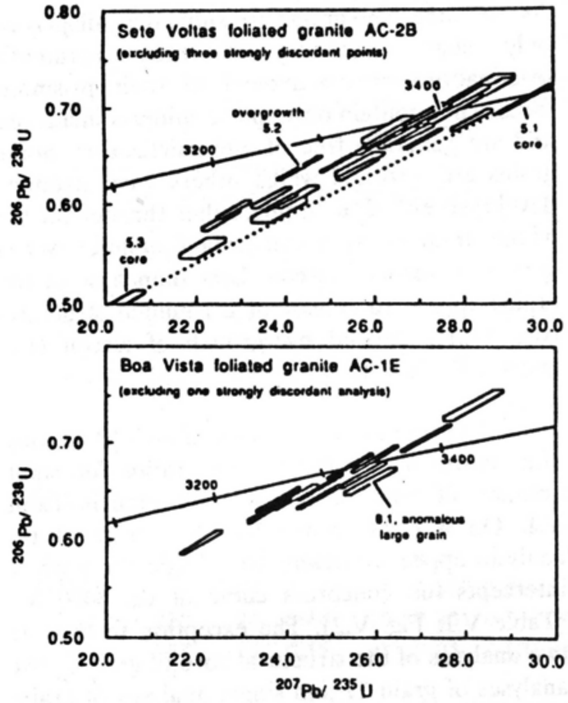

Figure V.2 - U-Pb concordia diagram, Sete Voltas AC-2B and Boa Vista/Mata Verde granitoid AC-1E (1σ uncertainty boxes).

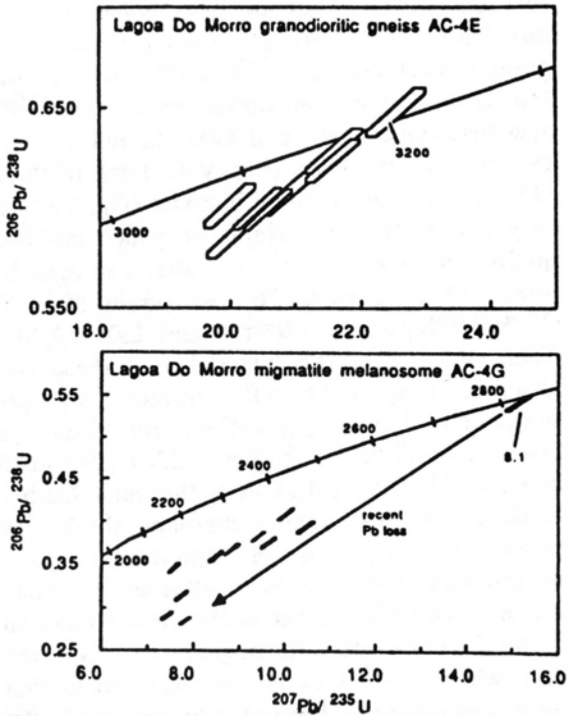

Figure V.3 - U-Pb concordia diagram. Lagoa do Morro granodiorites AC-4E and AC-4G (1σ uncertainty boxes).

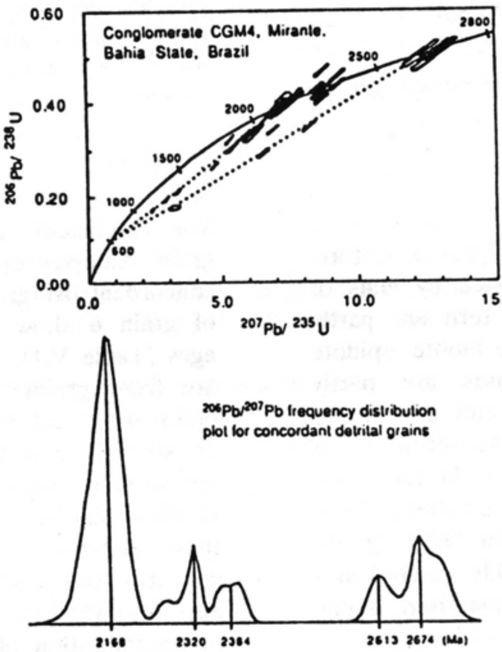

Figure V.4 - U-Pb concordia diagram and smoothed $^{207}Pb/^{206}Pb$ frequency plot for detrital zircons in metaconglomerate CGM-004.

for concordant grains shows a polymodal age distribution (Fig. V.4). The most prominent age group is centered on a $^{207}Pb/^{206}Pb$ age of 2168 Ma. Less abundant are grains with $^{207}Pb/^{206}Pb$ ages between ca. 2300 and 2400 Ma and between ca. 2600 and 2710 Ma (Fig. V.4). Each of these older groups appear to be bimodal (Fig. V.4). In only one of the four grains on which multiple analyses were made, can this spread in ages be attributed to ancient Pb loss (grain 39 with $^{207}Pb/^{206}Pb$ ages of 2389±28 and 2305±12 Ma; Table V.2). Thus the bimodality of these two groups is interpreted to reflect further complexity in the detrital zircon population; with sub-groups centered on $^{207}Pb/^{206}Pb$ ages of 2320, 2384, 2613 and 2674 Ma (Fig. V.4). 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. The most probable source of the detrital material in the conglomerate is the Jequié Complex to the east, which consists of late Archean rocks that were migmatised and intruded by granites in the Early Proterozoic.

DETAILED DESCRIPTION

SETE VOLTAS TONALITE AC-2B, DOME IN THE CONTENDAS-MIRANTE BELT

Sample AC-2B from Sete Voltas is an equigranular, medium to coarse grained biotite tonalite, which still retains its igneous texture. Large biotites are pseudomorphed by mats of finer-grained biotite, which in turn are partly replaced by intergrowths of pale biotite, epidote and alkali feldspar. Plagioclases are partly replaced by phengite, epidote and albite, and their margins are commonly broken-down into a mosaic of subgrains, interpreted to be the result of cataclasis. Thus the sample shows little evidence of deformation under high grade conditions, but it has been weakly sheared and partly recrystallised and metasomatised under greenschist facies conditions.

Most of the zircons are prismatic in habit, reddish-brown to pale yellow in colour and up to 300 μm long. The grains are subhedral, displaying only slight rounding of their pyramidal terminations or embayment of their prismatic faces. They contain only sparse mineral inclusions and are generally free of metamictization. Some grains are unzoned whilst others have strongly-developed euhedral zoning either throughout the whole grain or as a concordant mantle over a kernel of unzoned zircon. Less than 5 % of the grains appear to consist of a rounded structural core with a second overgrowth of zircon (e.g. grain 5, Table V.1).

Representative analyses of AC-2B zircons, after correction of the isotopic ratios for small amounts of common Pb, are presented in Table V.1. On a U-Pb concordia plot, most of the analyses appear to belong to a single array which intercepts the concordia curve at ca. 3400 Ma (Table V.1; Fig. V.2). The exception to this are two analyses of the structural core of grain 5, two analyses of grain 17 and single analyses of grains 18 and a structural core in grain 12, which yield older ages. Grains 18 and 12 are strongly discordant with some of the highest common Pb contents measured in AC-2B zircons (Table V.1), and are not discussed further. The analyses of grains 5 and 17 are less disturbed both in terms of discordancy and common Pb content. Of these, analysis 5.1 is concordant within uncertainty, with a $^{207}Pb/^{206}Pb$ age of 3466±8 Ma (2δ). Analysis 5.2 of the overgrowth on this grain is slightly discordant, with a $^{207}Pb/^{206}Pb$ age of 3345±10 Ma, significantly younger than the core of the grain. Analyses of the structureless "core" and concordant overgrowth of strongly zoned zircon of grain 6 show indistinguishable $^{207}Pb/^{206}Pb$ ages (Table V.1). The rest of the analysed sites are from grains devoid of internal structural boundaries, and regardless of whether unzoned or strongly zoned zircon was analysed, they appear to belong to a single population in terms of their similar isotopic systematics. Many of these analyses are within the uncertainty of the concordia and yield a weighted mean $^{207}Pb/^{206}Pb$ age of 3403±5 Ma, which is interpreted as the age of crystallisation of the tonalite. The structural core of grain 5, grain 17 and possibly grainss 18 and 21 are interpreted as inherited zircons derived from older rocks. The concordant

Table V.1 - Representative SHRIMP zircon data for orthogneisses.

site	U (µg/g)	Th (µg/g)	Th/U	^{204}Pb (ng/g)	com. ^{206}Pb(%)	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{208}Pb/^{206}Pb	^{207}Pb/^{206}Pb	207/206 age (Ma)	disc (%)
Sete Voltas tonalite AC-2B, dome in the Contendas-Mirante belt											
21.1	427	217	0.51	162	2.29	0.336 ±5	14.41 ±0.24	0.2858 ±35	0.3115 ±16	3528 ±8	-53
18.1	248	149	0.60	71	1.65	0.355 ±6	14.86 ±0.27	0.2964 ±46	0.3032 ±22	3486 ±11	-56
5.1	425	350	0.82	<1	<0.01	0.707 ±15	29.37 ±0.62	0.2145 ±10	0.3006 ±8	3466 ±4	-1
17.1	216	104	0.48	5	0.07	0.687 ±11	28.19 ±0.47	0.1176 ±11	0.2975 ±9	3426 ±16	-2
17.2	389	159	0.41	3	0.02	0.668 ±11	27.11 ±0.45	0.1050 ±9	0.2944 ±9	3441 ±5	-4
5.3	565	572	1.01	1228	8.21	0.505 ±9	20.45 ±0.43	0.2833 ±60	0.2939 ±27	3438 ±14	-23
9.1	88	49	0.56	1	0.02	0.607 ±12	24.24 ±0.51	0.1441 ±27	0.2896 ±19	3415 ±10	-10
16.1	73	46	0.62	<1	<0.01	0.717 ±14	28.52 ±0.60	0.1617 ±20	0.2885 ±16	3410 ±9	2
1.1	140	101	0.72	<1	<0.01	0.700 ±15	27.84 ±0.63	0.1844 ±17	0.2886 ±13	3410 ±7	0
6.1	155	59	0.38	5	0.10	0.672 ±12	26.70 ±0.52	0.0940 ±15	0.2882 ±13	3408 ±7	-3
11.2	150	88	0.59	7	0.15	0.669 ±11	26.55 ±0.46	0.1512 ±17	0.2877 ±12	3405 ±6	-3
10.1	40	25	0.63	3	0.25	0.718 ±16	28.41 ±0.74	0.1548 ±51	0.2869 ±31	3401 ±17	3
14.1	177	208	1.17	1	0.01	0.710 ±13	28.07 ±0.55	0.2902 ±23	0.2866 ±13	3399 ±7	2
6.2	220	96	0.44	19	0.30	0.607 ±11	23.71 ±0.45	0.0374 ±17	0.2833 ±13	3381 ±7	-10
5.2	367	49	0.13	<1	<0.01	0.637 ±13	24.33 ±0.51	0.0369 ±4	0.2769 ±8	3345 ±5	-5
Boa Vista granite AC-1E, dome in the Contendas-Mirante belt											
8.1	113	95	0.84	<1	<0.01	0.661 ±14	25.86 ±0.59	0.2196 ±21	0.2839 ±15	3384 ±8	-3
3.1	188	248	1.32	5	0.08	0.666 ±14	25.68 ±0.56	0.3559 ±21	0.2796 ±10	3361 ±6	-2
5.1	200	182	0.91	<1	<0.01	0.644 ±13	24.73 ±0.53	0.2408 ±14	0.2785 ±9	3355 ±5	-4
7.1	339	226	0.67	12	0.11	0.684 ±14	25.98 ±0.55	0.1698 ±13	0.2756 ±9	3338 ±5	1
1.1	645	73	0.11	32	0.17	0.628 ±13	23.61 ±0.49	0.0295 ±7	0.2725 ±6	3321 ±4	-5
12.1	248	116	0.47	21	0.29	0.596 ±12	22.06 ±0.47	0.1270 ±14	0.2683 ±10	3296 ±6	-9
9.1	1243	590	0.47	2710	1.19	0.169 ±4	4.98 ±0.16	1.1050 ±130	0.2134 ±48	2932 ±36	-66
Lagoa do Morro granodioritic gneiss AC-4E											
5.1	86	100	1.17	2	0.06	0.648 ±12	22.55 ±0.46	0.3011 ±29	0.2524 ±15	3200 ±9	1
8.1	193	304	1.58	7	0.12	0.623 ±11	21.58 ±0.41	0.4091 ±25	0.2511 ±11	3191 ±7	-2
2.1	93	118	1.28	3	0.10	0.606 ±11	20.87 ±0.43	0.3267 ±32	0.2497 ±15	3183 ±10	-4
6.1	268	419	1.56	6	0.08	0.598 ±11	20.57 ±0.38	0.4006 ±19	0.2495 ±8	3182 ±5	-5
3.1	248	234	0.94	<1	<0.01	0.598 ±11	20.41 ±0.38	0.2313 ±14	0.2474 ±9	3168 ±6	-5
4.1	154	80	0.52	5	0.11	0.600 ±11	19.97 ±0.39	0.1352 ±18	0.2414 ±12	3129 ±8	-3
Lagoa do Morro granodioritic melanosome in migmatite AC-4G											
8.1	321	518	1.61	1	0.01	0.543 ±10	15.15 ±0.28	0.4267 ±23	0.2024 ±9	2845 ±7	-2
12.1	534	875	1.64	3	0.04	0.284 ±4	7.81 ±0.13	0.4589 ±20	0.1996 ±7	2823 ±6	-43
10.1	582	259	0.45	11	0.13	0.290 ±44	7.43 ±0.12	0.1240 ±11	0.1858 ±7	2705 ±6	-39
6.1	486	183	0.38	13	0.16	0.366 ±64	8.83 ±0.16	0.1199 ±13	0.1751 ±8	2607 ±7	-23
S2 (sphene)					0.71			0.5826 ±63	0.2018 ±22	2841 ±18	
S1 (sphene)					1.06			0.1076 ±63	0.1247 ±29	2025 ±41	
S5 (sphene)					1.68			0.1676 ±71	0.1220 ±31	1985 ±45	
S3 (sphene)					12.71			0.0720 ±700	0.1101 ±293	1801 ±584	
S4 (sphene)					8.26			0.0440 ±342	0.1034 ±144	1687 ±216	

Table V.2 - Representative SHRIMP zircon data for metaconglomerate CGM-004.

site	type	U (µg/g)	Th (µg/g)	Th/U	^{204}Pb (ng/g)	com. ^{206}Pb(%)	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{208}Pb/^{206}Pb	^{207}Pb/^{206}Pb	207/206 age (Ma)	disc (%)
38.2	*Ia*	71	46	0.65	<1	<0.01	0.483 ±15	12.41 ±0.43	0.1721 ±30	0.1863 ±19	2710 ±17	-6
22.1	*Ib*	139	96	0.69	<1	<0.01	0.503 ±16	12.92 ±0.42	0.1837 ±19	0.1862 ±12	2708 ±10	-3
38.1	*Ia*	62	39	0.63	<1	<0.01	0.511 ±17	13.09 ±0.46	0.1659 ±32	0.1858 ±20	2705 ±18	-2
38.3	*Ia*	66	44	0.67	1	0.06	0.521 ±17	13.22 ±0.46	0.1668 ±31	0.1839 ±19	2688 ±17	1
37.1	*Ia*	178	105	0.59	1	0.01	0.500 ±15	12.64 ±0.41	0.1380 ±17	0.1831 ±12	2682 ±11	-2
16.1	*Ib*	208	167	0.80	1	0.03	0.519 ±16	13.05 ±0.42	0.2164 ±20	0.1825 ±11	2675 ±10	1
19.1	*Ia*	218	158	0.72	20	0.36	0.515 ±16	12.58 ±0.41	0.1856 ±26	0.1772 ±13	2627 ±12	2
5.1	*Ia*	242	150	0.62	8	0.14	0.502 ±16	12.17 ±0.42	0.1598 ±21	0.1758 ±12	2613 ±11	0
6.1	*Ia*	212	391	1.84	20	0.29	0.660 ±22	15.90 ±0.57	0.4129 ±46	0.1746 ±17	2603 ±17	26
17.1	*Ib*	506	362	0.72	43	0.60	0.293 ±89	6.55 ±0.21	0.1888 ±29	0.1622 ±13	2479 ±14	-33
39.2	*Ib*	201	90	0.45	13	0.30	0.438 ±13	9.30 ±0.31	0.1143 ±24	0.1539 ±13	2389 ±14	-2
15.1	*Ib*	176	104	0.59	<1	<0.01	0.428 ±13	8.71 ±0.28	0.1595 ±19	0.1477 ±11	2319 ±13	-1
4.1	*Ib*	234	105	0.45	33	0.64	0.457 ±15	9.28 ±0.33	0.1137 ±31	0.1471 ±15	2313 ±18	5
39.1	*Ib*	994	259	0.26	<1	<0.01	0.342 ±10	6.91 ±0.21	0.0696 ±6	0.1465 ±5	2305 ±6	-18
10.1	*Ib*	230	197	0.86	8	0.17	0.432 ±13	8.56 ±0.28	0.2142 ±28	0.1436 ±13	2271 ±15	2
49.1	*Ib*	219	91	0.42	<1	<0.01	0.403 ±12	7.61 ±0.25	0.1111 ±17	0.1372 ±11	2192 ±14	0
3.1	*II*	531	410	0.77	<0	<0.01	0.400 ±13	7.56 ±0.25	0.2224 ±15	0.1372 ±7	2192 ±8	-1
26.1	*II*	156	122	0.78	8	0.29	0.382 ±12	7.21 ±0.24	0.2318 ±34	0.1368 ±15	2187 ±19	-5
21.1	*II*	134	69	0.51	4	0.17	0.392 ±12	7.35 ±0.24	0.1387 ±24	0.1359 ±13	2176 ±16	-2
52.1	*II*	154	47	0.31	6	0.20	0.392 ±12	7.35 ±0.27	0.0494 ±44	0.1359 ±22	2176 ±28	-2
29.1	*II*	372	151	0.41	2	0.02	0.406 ±12	7.60 ±0.24	0.1064 ±12	0.1359 ±8	2175 ±10	1
31.1	*Ia*	198	59	0.30	8	0.21	0.406 ±12	7.59 ±0.25	0.0768 ±24	0.1357 ±13	2173 ±17	1
30.1	*Ib*	441	233	0.53	7	0.09	0.387 ±12	7.22 ±0.23	0.1443 ±15	0.1354 ±8	2169 ±10	-3
44.1	*III*	322	125	0.39	40	0.75	0.343 ±10	6.40 ±0.21	0.0983 ±30	0.1353 ±14	2168 ±18	-12
23.1	*II*	360	136	0.38	10	0.13	0.469 ±14	8.74 ±0.28	0.0883 ±16	0.1352 ±10	2166 ±12	14
20.1	*II*	254	44	0.17	33	0.83	0.325 ±10	6.03 ±0.22	0.0433 ±44	0.1346 ±22	2158 ±29	-16
7.1	*Ib*	389	177	0.45	44	0.56	0.417 ±14	7.74 ±0.27	0.1203 ±24	0.1345 ±11	2158 ±15	4
25.1	*II*	275	190	0.69	3	0.05	0.396 ±12	7.35 ±0.23	0.1858 ±16	0.1345 ±8	2157 ±10	0
42.1	*III*	89	74	0.84	1	0.06	0.404 ±13	7.47 ±0.27	0.2190 ±44	0.1339 ±19	2149 ±25	2
24.1	*II*	376	196	0.52	43	0.60	0.388 ±12	7.15 ±0.23	0.1302 ±25	0.1336 ±12	2146 ±15	2
27.1	*II*	348	188	0.54	<1	<0.01	0.389 ±12	7.16 ±0.23	0.1438 ±13	0.1335 ±8	2144 ±10	-1
50.1	*II*	217	103	0.48	45	1.08	0.397 ±12	7.29 ±0.26	0.0862 ±42	0.1333 ±19	2142 ±26	1
45.1	*Ib*	421	173	0.41	6	0.08	0.356 ±11	6.49 ±0.21	0.1120 ±14	0.1321 ±8	2126 ±11	-8
46.1	*II*	210	138	0.66	<1	<0.01	0.389 ±12	7.08 ±0.23	0.1750 ±19	0.1320 ±10	2125 ±13	0
35.1	*II*	251	171	0.68	<1	<0.01	0.399 ±12	7.19 ±0.23	0.1770 ±19	0.1306 ±10	2106 ±13	3
2.1	*Ia*	164	110	0.67	4	0.12	0.382 ±13	6.87 ±0.25	0.1848 ±31	0.1305 ±14	2104 ±19	-1
1.1	*III*	105	36	0.35	15	0.74	0.409 ±14	7.31 ±0.30	0.0837 ±52	0.1297 ±24	2094 ±33	6
41.1	*Ib*	506	299	0.59	20	0.24	0.333 ±10	5.91 ±0.19	0.1389 ±18	0.1286 ±9	2079 ±12	-11
14.1	*II*	457	252	0.55	<1	<0.01	0.307 ±9	5.45 ±0.17	0.1472 ±11	0.1285 ±6	2078 ±8	-17
32.1	*Ib*	405	231	0.57	<1	<0.01	0.267 ±8	4.73 ±0.15	0.1476 ±15	0.1285 ±8	2077 ±11	-27
9.1	*II*	412	332	0.81	16	0.25	0.322 ±10	5.70 ±0.18	0.2025 ±22	0.1281 ±10	2072 ±13	-13
8.1	*III*	312	105	0.34	4	0.09	0.321 ±10	5.32 ±0.18	0.0909 ±17	0.1201 ±9	1957 ±14	-8
18.1	*Ib*	715	429	0.60	37	0.51	0.212 ±6	3.32 ±0.11	0.1756 ±25	0.1139 ±11	1863 ±17	-34
51.1	*Ib*	1044	212	0.20•	31	0.32	0.195 ±6	2.92 ±0.09	0.0597 ±17	0.1086 ±9	1776 ±15	-35
12.1	*Ib*	886	75	0.08	42	0.58	0.169 ±5	2.39 ±0.08	0.0860 ±23	0.1025 ±10	1670 ±19	-40

analysis for 5.1 $^{207}Pb/^{206}Pb$ age of 3473±8 Ma) gives the minimum, probably approaching the true age, of this inherited component. The SHRIMP age of 3403±5 Ma is marginally older than the single zircon thermal evaporation U-Pb age of 3394±5Ma obtained on a Sete Voltas tonalite by Martin et al. (1991).

BOA VISTA GRANITE AC-1E, DOME IN THE CONTENDAS-MIRANTE BELT

Texturally, apart from less cataclasis, the Boa Vista granite AC-1E is very similar to the Sete Voltas tonalite, suggesting they have experienced a similar history. The zircons in AC-1E are prismatic apart from a few that are bi-pyramidal in habit. They are commonly between 200 and 300 μm long and pale yellow/pink or more rarely reddish brown in colour. None of the grains contain either structural cores or overgrowths, and the exteriors of the grains are euhredral to slightly subhedral. Most of the grains are structureless or have only weakly-developed euhedral zoning. Nearly all the grains contain a few apatite needle inclusions, and more rarely inclusions of quartz or feldspar. Morphologically, all the zircons seem to belong to the same population, and have characters typical of zircon grown during crystallisation of granitic magma.

Representative analyses of AC-1E zircons, after correction of the isotopic ratios for common Pb, are presented in Table V.1. Apart from high U, high common Pb analysis 9.1, the other analyses are concordant to only slightly discordant (Fig. V.2). The analyses that are concordant within uncertainty generally have slightly older $^{207}Pb/^{206}Pb$ ages than the slightly discordant analyses, suggesting the zircons have suffered variable degrees of ancient Pb-loss. A single analysis of grain 8 yielded the oldest $^{207}Pb/^{206}Pb$ ages of 3384±16 Ma (2δ). Apart from being slightly larger, this grain has no distinguishing characters. However, erratic variation in the measured $^{206}Pb^+$ compared with $^{207}Pb^+$ ion counts on successive mass-scans might have led to a slight over-estimation of the age of this grain. The most concordant analyses yield a weighted mean $^{207}Pb/^{206}Pb$ age of 3353±5 Ma, which is interpreted as the time of crystallisation of the granitic protolith.

LAGOA DO MORRO GRANODIORITIC MIGMATITE AC-4E, GREENSTONE-GRANITE COMPLEX

The sample is a medium grained and granodioritic in composition. It displays a very weak compositional banding on the scale of a few mm. This compositional banding, accentuated by a weak biotite fabric, is discordant to the main biotite foliation. The plagioclases are locally replaced by albite, epidote and phengite, indicating that a small amount of recrystallisation under greenschist facies conditions has taken place.

Zircons in AC-4E are prismatic, euhedral and up to 300 μm long. Most of the grains are clear to pale yellow in colour, but the centers of some grains are blackened and metamict. Excluding metamict centers, the grains are devoid of obvious internal structure apart from weak euhedral zoning developed in some grains.

Representative analyses of AC-4E zircons, after correction of the isotopic ratios for small amounts of common Pb, are presented in Table V.1. All of the analyses, apart from 4.1 which has a somewhat lower $^{207}Pb/^{206}Pb$ ratio, form a single array. This array intercepts concordia at ca. 3200 Ma (Fig. V.3), but with slightly younger $^{207}Pb/^{206}Pb$ ages for the most discordant analyses (Fig. V.3). However, with the exception of two analyses, they all have indistinguishable $^{207}Pb/^{206}Pb$ ratios, and yield a weighted mean age of 3184±6 Ma, which is interpreted as the time of crystallisation of the granodioritic protolith of AC-4E.

LAGOA DO MORRO GRANODIORITIC MIGMATITE MELANOSOME AC-4G, GRANITE-GREENSTONE COMPLEX

AC-4G is a biotite granodiorite. Like sample AC-4E from the same area, a weak compositional banding has been overprinted by a biotite foliation, and these is evidence of very slight retrogression under greenschist facies conditions.

The sample gave a low yield of zircon, but abundant sphene. The zircons are prismatic, up to 200 μm long and pale yellow in colour. Their prismatic terminations are markedly rounded and the prismatic faces of some grains are strongly embayed, which is interpreted to indicate the corrosion of the grains by a metamorphic fluid or possibly by a silicate melt. Many of the grains contain small, disseminated quartz and feldspar inclusions and also metamict domains. These further restricted the already limited choice of sites for analysis. The interiors of the grains are devoid of structure, apart from weakly-developed euhedral zoning in some grains.

Despite care in choosing analysis sites, all those chosen with the exception of 8.1 are strongly discordant (Table V.1, Fig. V.3). Concordant grain 8.1 has a $^{207}Pb/^{206}Pb$ age of 2845±14 Ma (2δ), whilst the strongly discordant analyses have $^{207}Pb/^{206}Pb$ ages between 2823±12 and 2607±14 Ma (Table V.1). Thus it is clear that these zircons have suffered not only considerable recent Pb loss, but also significant variable amounts of ancient Pb loss. The data does not permit determination of a precise accurate zircon age for the sample. However, the concordant grain 8.1 with the highest $^{207}Pb/^{206}Pb$ age suggests an age of circa 2850 Ma for the sample.

$^{207}Pb/^{206}Pb$ ages of five sphene grains were also determined (Table V.1). Pb-U isotopic ratios are not reported because the sphenes were run with a zircon standard, for which the Pb-U calibration cannot be used. A site on sphene grain 2 with low common Pb content yielded a $^{207}Pb/^{206}Pb$ age of 2841±36 Ma (2δ), which within its rather large uncertainty agrees with the age of the "oldest" concordant zircon 8.1. The other four sphene analyses yielded Middle Proterozoic ages (Table V.1). Of these, two analyses (grains 1 and 5) with the lowest common Pb content yielded indistinguishable $^{207}Pb/^{206}Pb$ ages of 2025±81 and 1985±90 Ma. On the other hand, low-U (judging from low $^{238}U^+$ and $^{238}U^{16}O^+$ ion count rates, for want of a sphene Pb-U calibration during analysis), high common Pb analyses of grains 3 and 4 yielded slightly lower ages, but with very large uncertainties. Although the sphene determinations are not very precise, they do indicate that AC-4G underwent some recrystallisation in the Middle Proterozoic, during the Transamazonian orogeny. The already mentioned ancient Pb loss of many zircons may well have been related to this recrystallisation event.

METACONGLOMERATE CGM-004

Sample CGM-004 (Fig. V.1) comes from the Mirante schist of the Contendas-Mirante belt on the Contas River, southeast of Santana town. The metasedimentary unit to which it belongs is composed of mica schists and meta-sandstones, with interbedded feldspathic meta-sandstones and metaconglomerates. The micashists include some nodular varieties (with andalusite ± cordierite), and some magnesian varieties which could be weathered mafic volcanic rocks. The outcrop of CGM-004 is a monogenic metaconglomerate, with pebbles and cobbles of quartzites. The matrix is schistose, with increase in quartz content together with pebble concentration. The quartzitic cobbles up to 10 cm across and the schists clasts are only up to a few centimeters long. The matrix, cobbles and clasts have the same mica foliation. The cobbles are too strained to ascertain if they already had a foliation or gneissosity prior to being incorporated into the sediment.

Sample CGM-004 yielded abundant zircons. Most of the zircons have a prismatic habit, and range from almost euhedral to distinctly rounded. Some of them have pitted surfaces, suggestive of abrasion during sedimentary transport, and indicating their detrital nature. However, the grains may be divided into several groups on the basis of size, colour 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 strongly rounded. 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 have homogeneous centres surrounded by 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 colour and commonly showing distinct fine-scale euhedral zoning. These grains range from almost euhedral to distinctly rounded. Type III forms approximately 10 % of the population and consists of small (< 150 μm), clear, euhedral grains which commonly display fine-scale euhedral zoning.

Isotopic data and U and Th elemental abundances for representative analyses are presented in Table V.2, ranked according to decreasing ^{207}Pb/^{206}Pb age. 58 analyses were performed on 52 grains (representative analyses, Table V.2). The majority of the analysed sites yield U-Pb ages that are concordant within 2δ uncertainty, with ages between circa 2150 and 2710 Ma (Fig. V.4). With one exception, all the remaining analyses fall between 2150-600 Ma and 2710-600 Ma discordia (Fig. V.4). This suggests that the zircons underwent variable, generally small, amounts of Pb-loss possibly at ca. 600 Ma, perhaps associated with the Brasiliano orogeny, as recorded by K-Ar ages in parts of the region (Cordani et al., 1985). In order to avoid blurring of age distribution patterns of the zircons by any ancient Pb loss, discussion of zircon ages only uses analyses with U-Pb ages that are concordant within 2δ uncertainty. The smoothed ^{207}Pb/^{206}Pb frequency distribution plot for concordant grains shows a polymodal age distribution (Fig. V.4). The most prominent age group is centered on a ^{207}Pb/^{206}Pb age of 2168 Ma. Less abundant are grains with ^{207}Pb/^{206}Pb ages between ca. 2300 and 2400 Ma and between ca. 2600 and 2710 Ma (Fig. V.4). Each of these older groups appear to be bimodal (Fig. V.4). Thus the bimodality of these two groups is interpreted to reflect further complexity in the detrital zircon population; with sub-groups centered on ^{207}Pb/^{206}Pb ages of 2320, 2384, 2613 and 2674 Ma (Fig. V.4). 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. 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 V.2). Type II and III grains belong exclusively to the 2100-2200 Ma group.

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