THE LAGOA DA VACA COMPLEX: AN ARCHAEOAN LAYERED ANORTHOSITE BODY ON THE WESTERN EDGE OF THE UAUÁ BLOCK, BAHIA, BRAZIL

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RESUMO O COMPLEXO LAGOA DA VACA: UM CORPO ANORTOSÍTICO ACAMADADO ARQUEANO DO LIMITE OESTE DO BLOCO UAUÁ, BAHIA O Complexo Anortosítico de Lagoa da Vaca é um corpo ígneo metamorfizado e composto por bandas ricas em plagioclásio e anfíbolio. Dados de química mineral indicam que anortositos e peridotitos associados não são geneticamente relacionados. Um isocrona Pb-Pb em rocha total forneceu uma idade de $3,160 \pm 65$ Ma, implicando que este e o complexo anortosítico mais antigo já encontrado no Craton do São Francisco. Como o complexo apresenta um valor modelo $\mu=8.8 \pm 0.62$, compatível com derivação de seu magma progenitor do manto litosférico ou do manto empobrecido seguido de contaminação crustal, e aflora na margem ocidental do Bloco Arqueano de Uauá, próximo a uma possante zona de cisalhamento que separa o Bloco Uauá da Faixa Caldeirão (migmatito-quartzito-ortogneiss), a sua intrusão deve ter ocorrido em um ambiente continental, possivelmente semelhante a uma margem continental passiva atual.

Palavras-chaves: Arqueano, anortosito

ABSTRACT The Lagoa da Vaca Anorthosite Complex is a metamorphosed layered igneous body composed of plagioclase and amphibole-rich bands. Mineral chemical data indicate that anorthosites and associated peridotites are genetically unrelated. A whole-rock Pb-Pb isochron yielded an age of $3,160 \pm 65$ Ma, implying that this anorthosite complex is the oldest one ever found in the São Francisco Craton. Since the complex presents a model μ value of 8.8 ± 0.62 , compatible with its derivation from the subcontinental lithospheric upper mantle or from the depleted mantle, in both cases followed by crustal contamination, and crops out on the western edge of the Archaean Uaua Block, close to a major ductile shear zone that separates the Uaua Block from the Caldeirão migmatite-quartzite-orthogneiss belt, its emplacement is likely to have occurred in a continental setting, most possibly similar to present-day passive continental margin.

Keywords: Archaean, anorthosite

INTRODUCTION Remnants of layered bodies of basic and/or ultrabasic composition are common in Archaean high-grade gneiss terranes worldwide. They have been divided into two types by Windley *et al.* (1981): (i) those composed mostly of anorthosite and leucogabbro such as the Fiskeneasset (West Greenland), Messina (South Africa) and Sittampundi (India), and (ii) another group dominated by ultramafic and mafic rocks with examples described in Scotland (Sills *et al.* 1982), South Africa (Anhaeusser 1985) and Canada (Sutcliffe *et al.* 1989, Bruegmann *et al.* 1997). In Brazil, similar complexes have been reported in the states of Bahia (Oliveira *et al.* 1982, Cruz 1989) and Para (Machado *et al.* 1991, Suita & Strieder 1996).

The Archaean Uaua Block, on the northeastern portion of the São Francisco Craton, contains several mafic to ultramafic intrusives (Fig. 1). One of which, the Lagoa da Vaca anorthosite-leucogabbro layered complex, has been unsuccessfully explored for chromite and Platinum group elements during the last two decades. In spite of the economic interest, its geology is still poorly known. Here we summarize new field relations, age dating, mineral- and whole-rock chemical data and speculate on its possible tectonic setting.

GEOLOGICAL BACKGROUND The Uauá Block (Fig. 1) is one of the several Archaean remnant exposed in the São Francisco Craton, a geologic entity stable since the Paleoproterozoic. It is bounded to the East by flat-lying Neoproterozoic metasediments of the Sergipano Orogen or younger units, and to the West by a sequence of steeply dipping quartzites, metapelites, migmatites, deformed granitoids and mafic rocks, collectively called Caldeirão Belt (Jordan, 1972). A two-kilometre-wide shear zone separates this belt from rocks of the Uaua Block (Jordan, 1972).

The Uaua Block consists mainly of banded gneisses intruded by tonalitic bodies and mafic-ultramafic complexes, most of them metamorphosed in granulite facies conditions and later retrogressed to amphibolite grade. Intruding or

overlying this Archaean basement there occurs a bimodal norite-tholeiite mafic dyke swarm (Oliveira 1993), pegmatites, a few granitic bodies and the Rio Capim volcano-sedimentary sequence. Tholeiitic and noritic dykes have been observed also in the Caldeirão Belt where they have undergone deformation and metamorphism under amphibolite facies conditions. This raises the possibility that the Caldeirão Belt formerly also belonged to the Uaua Block.

Earlier geochronological studies on the Uaua Block have indicated Rb-Sr isochronous ages on gneisses in the range 3.1-2.7 Ga (Teixeira 1993 and references therein, Leal *et al.* 1994). For a tonalite close to the Rio Capim sequence, Mascarenhas and Sa (1982) obtained a Rb-Sr age of 3.12 Ga, whereas whole-rock Sm-Nd model ages and SHRIMP U-Pb on zircons yielded ages in the time span 3.7 to 3.2 Ga (U. Cordani, personal communication, 1996). Tonalitic orthogneisses from the Lagoa da Vaca area had their zircons analysed by the Pb evaporation technique (cf. Koeber 1986) - the results indicated a minimum age of 3,072 Ma for the granulite facies metamorphism (Paixão *et al.* 1995). Unpublished Nd isotope data for these orthogneisses (Oliveira *et al.*, in prep) yielded a TDM age of circa 3,278 Ma with an epsilon Nd of about -0.57, suggesting the presence of older continental crust in the area. The mafic dyke swarms intrusive in the Archaean basement have been dated by Leal *et al.* (1994) who encountered two age groups, namely 2.4 Ga and 2.0 Ga.

Ages for the Caldeirão Belt are not available. However, farther to the South this belt is overlain by Paleoproterozoic metasupracrustal rocks of the Rio Itapicuru Greenstone Belt (Davison *et al.*, 1988, Rocha Neto, 1994, Silva, 1997) which constrain a minimum Paleoproterozoic age for it.

THE LAGOA DA VACA COMPLEX Field Relations The Lagoa da Vaca complex (LVC) crops out on the northwestern edge of the Uaua Block very close to the boundary with the Caldeirão Belt (Fig. 1). Its areal distribution is

Figure 1 - Geological outline of Uauá area in relation to the São Francisco Craton. Adapted of Jordan (1973) and Inda and Barbosa (1978).

Figura 1 - Esboço geológico da região de Uauá em relação ao Craton do São Francisco. Adaptado de Jordan (1973) e Inda e Barbosa (1978).

not fully known owing to poor outcrops, deformation and lack of regional geological mapping. In the type area of Lagoa da Vaca farm (Fig. 2), the complex is exposed continuously for 3-4 km in the east-west direction and 7-8 km in the north-south direction. Its eastern and southern limits are made with granulite facies tonalitic orthogneisses interleaved with fine-banded amphibolites, probably representing an older metavolcanic sequence into which both tonalite and layered complex might have intruded. To the west it is conformable with sheared gneisses and migmatites of the Caldeirão Belt. Scattered outcrops of the complex have been observed as far as 30 km northwards.

According to Paixão (1996) the complex consists mostly of layered anorthosite and leucogabbro with minor hornblende and amphibolite. Earlier studies (Carvalho Filho *et al.* 1981) have included spinel-bearing peridotites in LVC, but mineral chemical data coupled with widespread occurrence of peridotites in the Uaua Block with no associated anorthosite indicate that peridotites might not necessarily belong to LVC, as will be recalled later. Centimetre-thick, amphibole-rich bands intercalated with thicker, plagioclase-rich bands typically give igneous layering in LVC. Modal grading and slump

structures indicate that the igneous stratigraphic top lies to the West. However, because the complex has undergone at least two major ductile deformation events, one with foliation planes parallel to the N-S-trending igneous banding and another at approximately right angles to the first, any attempt to reconstruct the primary igneous stratigraphy must be very cautious. A third deformation episode, at shallow crustal depths, was responsible for faults and the local development of mylonites.

Petrography and Mineral Chemistry In this section both anorthositic and peridotitic rocks will be dealt with to show that the two rock groups might not be genetically related. Mineral compositions were obtained on a Cameca microprobe at Instituto de Geociências of Universidade de Brasília.

The anorthositic rocks display granoblastic texture and are composed mostly of plagioclase (An=58-64) and green-brownish edenite amphibole. Calcic pyroxene (En=35-39, Wo=41-48) is a minor constituent along with the accessories apatite, zircon and opaques. Because the amphibole is oriented parallel to the rock foliation, we interpret its occurrence as resulting mostly from amphibolite facies metamorphism. On

Figure 2 - Geological map of Lagoa da Vaca area (after Paixão 1996).

Figura 2 - Mapa geológico da área de Lagoa da Vaca (segundo Paixão, 1996)

the other hand, colorless tremolite was also recorded as a replacement product after calcic pyroxene; its origin may be either late magmatic or metamorphic. Carbonate, epidote and chlorite are fault-related low-grade metamorphic minerals. Though amphibole is widespread in both felsic and mafic portions of the banded anorthosites, it is mostly concentrated in the latter. In one of these bands (sample EO-98.1, Table 1), edenitic amphibole has been partially substituted by a symplectitic intergrowth of hypersthene (En=51-52), diopside (En=36, Wo=47) and plagioclase (An=81-84), indicating that the anorthositic complex has to some extent also undergone granulite facies metamorphism. Alternatively, the above re-

ferred to symplectites could have formed after high pressure garnet through decompression associated with regional tectonic uplift. In general, plagioclase shows normal compositional zoning or no variation from core to rim. It is more calcic in the mafic bands than in the felsic ones. Unlike other Archaean anorthosites with plagioclase megacrysts (An=80-90 cf. Ashwal 1993), the Lagoa da Vaca plagioclases are less calcic (An=58-64). Representative mineral analyses of plagioclase, amphibole and pyroxenes of the anorthositic rocks are shown in Table 1.

The peridotites are mostly composed of serpentine, olivine (Fo=85-87), orthopyroxene (En=83-87), calcic pyroxene

Table 1 - Representative mineral compositions of Lagoa da Vaca anorthosites. Plag-plagioclase; Px-pyroxene; c-core; r-rim.
Tabela 1 - Composições minerais representativas de anortositos do Complexo Lagoa da Vaca. Plag-plagioclásio; Px-piroxênios; c-centro; r-margem.

	EO1 Plag2-c	EO1 Plag2-r	EO2 Plag1-c	EO2 Plag1-r	EO3 Plag1-r	EO3 Plag1-c	EO4 Plag1-c	EO4 Plag1-r
SiO ₂	52,588	52,463	54,571	55,873	53,396	54,1	52,191	52,168
Al ₂ O ₃	30,581	30,315	29,251	28,827	30,346	29,72	30,755	31,166
CaO	13,448	12,845	11,765	10,415	12,776	12,341	13,66	13,448
FeO	0,208	0,068	0,252	0,173	0,078	0,07	0,115	0,246
Na ₂ O	3,795	3,913	4,574	5,107	4,027	4,203	3,762	3,577
K ₂ O	0,109	0,086	0,133	0,046	0,108	0,084	0,051	0,077
Total	100,729	99,69	100,546	100,441	100,731	100,518	100,534	100,682
Si	2,369	2,382	2,45	2,496	2,397	2,429	2,357	2,35
Al	1,624	1,622	1,548	1,518	1,605	1,573	1,637	1,654
Ca	0,649	0,625	0,566	0,499	0,615	0,594	0,661	0,649
Fe	0,008	0,003	0,009	0,006	0,003	0,003	0,004	0,009
Na	0,332	0,344	0,398	0,442	0,35	0,366	0,329	0,312
K	0,006	0,005	0,008	0,003	0,006	0,005	0,003	0,004
Total	4,988	4,981	4,979	4,964	4,976	4,97	4,991	4,978
An	65,77	64,14	58,24	52,83	63,28	61,56	66,54	67,20
	EO2 Px1-c	EO2 Px1-r	EO2 Px2-c	EO98.1 Px1-c	EO98.1 Px1-r	EO98.1 Px2-r	EO98.1 Px2-c	EO98.1 Px5-r
SiO ₂	52,284	52,88	52,591	51,87	51,373	52,241	51,609	51,964
TiO ₂	0,105	0,079	0,144	0,156	0,161	0,138	0,302	0,148
Al ₂ O ₃	1,92	1,191	1,669	1,866	2,043	1,644	3,351	1,889
FeO	10,091	10,159	10,556	10,256	10,063	10,558	11,813	10,39
MnO	0,388	0,358	0,332	0,155	0,29	0,215	0,16	0,223
MgO	11,976	12,488	12,136	12,195	12,093	12,554	12,771	12,208
CaO	22,608	22,728	22,468	22,006	21,876	21,96	18,762	22,266
Na ₂ O	0,393	0,303	0,369	0,303	0,354	0,282	0,441	0,295
Cr ₂ O ₃	0,098	0,039	0,059	0,095	0,072	0,081	0,079	0
Total	99,863	100,225	100,324	98,902	98,325	99,673	99,288	99,383
Si	1,958	1,98	1,97	1,968	1,939	1,966	1,944	1,958
Ti	0,003	0,002	0,004	0,004	0,005	0,004	0,009	0,004
Al	0,085	0,053	0,074	0,083	0,091	0,073	0,149	0,084
Fe	0,316	0,318	0,331	0,325	0,318	0,332	0,372	0,327
Mn	0,012	0,011	0,011	0,005	0,009	0,007	0,005	0,007
Mg	0,669	0,697	0,677	0,69	0,68	0,704	0,717	0,686
Ca	0,907	0,912	0,901	0,895	0,884	0,886	0,757	0,899
Na	0,028	0,022	0,027	0,022	0,026	0,021	0,032	0,022
Cr	0,003	0,001	0,002	0,003	0,002	0,002	0,002	0
Total	3,981	3,996	3,997	3,995	3,954	3,995	3,987	3,987
En	35,36	36,17	35,46	36,13	36,13	36,63	38,84	35,88
Fs	16,70	16,50	17,34	17,02	16,90	17,27	20,15	17,10
Wo	47,94	47,33	47,20	46,86	46,97	46,10	41,01	47,02

Table 2 - Representative mineral compositions of peridotites. LV- Lagoa da Vaca area; U B- outside the Lagoa da Vaca area; Oliv-olivine; Plag-plagioclase; Cpx-calcic pyroxene; Opx-orthopyroxene; Itc-intercumulus.

Tabela 2 - Composições minerais representativas de peridotitos. LV- área de Lagoa da Vaca; U B- fora da área de Lagoa da Vaca; Oliv-olivina; Plag-plagioclásio; Cpx-piroxênio calcico; Opx-ortopiroxênio; Itc-intercumulus.

	MP30.1 Cpx1 LV	MP30.1 Cpx3-ltc LV	MP30.1 Opx4 LV	MP28 Opx6 LV	MP99.1 Opx2 LV	MP99.1 Opx3 LV	MP99.1 Cpx1 LV	MP99.1 Cpx3-ltc LV	EO144A Cpx9 UB	EO144A Cpx7-ltc UB	EO144A Opx3 UB	EO144A Opx2 UB	EO68.4 Cpx2-ltc UB	EO68.4 Cpx3 UB
SiO ₂	53,549	51,415	56,003	56,53	56,275	55,863	51,897	53,246	54,394	52,324	55,344	56,818	53,231	51,082
TiO ₂	0,181	0,246	0,083	0,052	0,062	0,049	1,207	0,266	0,149	0,247	0,092	0,161	0,546	0,636
Al ₂ O ₃	4,476	7,281	3,08	2,136	2,891	3,237	5,593	5,155	2,859	5,386	4,317	2,553	4,229	6,802
FeO	4,498	1,455	8,22	9,355	8,239	8,066	2,717	4,523	3,249	3,631	8,21	8,156	3,128	2,766
MnO	0,077	0	0,152	0,222	0,181	0,164	0,006	0,093	0,096	0,238	0,159	0,172	0,105	0,093
MgO	21,233	16,685	30,118	32,101	31,042	30,425	16,201	20,776	19,313	19,108	30,007	31,45	17,5	15,477
CaO	14,446	21,11	2,168	0,209	1,618	1,87	20,281	14,765	18,973	16,936	2,29	1,524	20,258	20,98
Na ₂ O	0,705	0,747	0,125	0,037	0,066	0,069	1,184	0,677	0,669	0,682	0,129	0,06	0,732	0,934
Cr ₂ O ₃	0,872	0,643	0,935	0,06	1,069	0,892	0,474	0,577	0,95	1,762	0,873	0,522	0,865	1,521
Total	100,037	99,582	100,884	100,702	101,443	100,635	99,56	100,078	100,652	100,314	101,421	101,416	100,594	100,291
Si	1,903	1,833	1,942	1,959	1,939	1,939	1,883	1,902	1,936	1,868	1,911	1,953	1,913	1,842
Ti	0,005	0,007	0,002	0,001	0,002	0,001	0,033	0,007	0,004	0,007	0,002	0,004	0,015	0,017
Al	0,187	0,306	0,126	0,087	0,117	0,132	0,239	0,217	0,12	0,227	0,176	0,103	0,179	0,289
Fe	0,134	0,043	0,238	0,271	0,237	0,234	0,082	0,135	0,097	0,108	0,237	0,234	0,094	0,083
Mn	0,002	0	0,004	0,007	0,005	0,005	0	0,003	0,003	0,007	0,005	0,005	0,003	0,003
Mg	1,125	0,887	1,557	1,658	1,594	1,574	0,876	1,106	1,025	1,017	1,544	1,611	0,937	0,832
Ca	0,55	0,807	0,081	0,008	0,06	0,07	0,788	0,565	0,724	0,648	0,085	0,056	0,78	0,811
Na	0,049	0,052	0,008	0,003	0,004	0,005	0,083	0,047	0,046	0,047	0,009	0,004	0,051	0,065
Cr	0,025	0,018	0,026	0,002	0,029	0,024	0,014	0,016	0,027	0,05	0,024	0,014	0,025	0,043
Total	3,980	3,953	3,984	3,996	3,987	3,984	3,998	3,998	3,982	3,979	3,993	3,984	3,997	3,985
En	62,19	51,07	83,00	85,60	84,29	83,81	50,17	61,24	55,53	57,36	82,74	84,74	51,74	48,20
Fs	7,41	2,48	12,69	13,99	12,53	12,46	4,70	7,48	5,25	6,09	12,70	12,31	5,19	4,81
Wo	30,40	46,46	4,32	0,41	3,17	3,73	45,13	31,28	39,22	36,55	4,56	2,95	43,07	46,99
	MP107	MP107	MP28	MP28	MP99.1	MP99.1	EO68.4	EO68.4	EO144A	EO144A			EO144A	EO144A
	Oliv2	Oliv3	Oliv1	Oliv2	Oliv1	Oliv3	Oliv1	Oliv2	Oliv2	Oliv5			EO144A	EO144A
	LV	LV	LV	LV	LV	LV	UB	UB	UB	UB			Plag1a	Plag1b
													UB	UB
SiO ₂	40,678	40,474	40,067	40,152	40,378	40,542	40,908	40,277	40,995	40,55		SiO ₂	57,764	57,927
Cr ₂ O ₃	0,033	0,007	0,05	0,026	0,079	0,029	0,091	0,002	0,036	0		Al ₂ O ₃	27,741	28,182
MgO	46,395	46,504	45,143	45,717	46,365	46,468	46,813	46,451	46,616	46,078		CaO	8,693	8,586
FeO	13,517	13,426	13,902	14,559	13,068	12,865	13,128	12,482	12,909	13,397		Na ₂ O	6,037	6,067
NiO	0,45	0,374	0,485	0,329	0,486	0,449	0,527	0,424	0,494	0,413		K ₂ O	0,31	0,21
Total	101,073	100,785	99,647	100,783	100,376	100,353	101,467	99,636	101,05	100,438		Total	100,545	100,992
Si	1,002	0,999	1,004	0,998	1	1,003	1,002	1,002	1,006	1,004		Si	2,588	2,580
Cr	0,001	0	0,001	0,001	0,002	0,001	0,002	0	0,001	0		Al	1,419	1,433
Mg	1,703	1,711	1,686	1,693	1,711	1,714	1,709	1,723	1,706	1,701		Ca	0,417	0,410
Fe	0,278	0,277	0,291	0,303	0,271	0,266	0,269	0,26	0,265	0,277		Na	0,525	0,526
Ni	0,009	0,007	0,01	0,007	0,01	0,009	0,01	0,008	0,01	0,008		K	0,018	0,012
Total	2,993	2,994	2,992	3,002	2,994	2,993	2,992	2,993	2,988	2,99		Total	4,968	4,962
Fo	85,97	86,07	85,28	84,82	86,33	86,57	86,40	86,89	86,56	86,00		An	43,46	43,22

(En=47-62; Wo=30-47), spinels and rare plagioclase (An=44), in that order of abundance. Olivine is clearly a cumulus phase either occurring as isolated grains in a ground-mass of serpentine or as inclusions in orthopyroxene megacrysts. Calcic pyroxene is typically the intercumulus phase along with plagioclase. Brown to red chromium spinels occur as disseminated grains and are relatively more abundant in calcic pyroxene-bearing rocks than elsewhere. Green hercynite spinels are also common - Because they are restricted to metaperidotites with metamorphic green amphibole, their occurrence along with that of amphibole has been used as a criterion to distinguish between metamorphic and non-metamorphic (or weakly metamorphosed) peridotites.

Representative mineral analyses of peridotites are given in Table 2 and compositions of minerals from both peridotites and anorthosites from the Lagoa da Vaca area are shown in Fig.3 for comparison. Because peridotites similar to those at Lagoa da Vaca occur elsewhere in the Uauá Block, where they are not associated with anorthosites, compositions of their minerals are also given in Table 2 and plotted in Fig. 3.

As shown in figure 3, pyroxenes from peridotites are very similar in composition no matter if they are associated or not with anorthosites. Their intercumulus calcic pyroxenes are also compositionally very close to their cumulus counterparts. Olivine and orthopyroxenes have similar forsterite and enstatite values, respectively.

When a comparison is made between corresponding minerals from peridotites and anorthosites, a significant compositional gap is observed (Fig. 3). Indeed, calcic pyroxenes from anorthosites are more evolved than those from peridotites, whereas the opposite holds for plagioclase. Since the observed gaps in mineral compositions and contrasting anorthite contents of plagioclase are not compatible with the anorthositic rocks being derived from the peridotites by fractional crystallization, we suggest that the two rock types are not consanguineous. Although we do not completely discard the possibility that at Lagoa da Vaca they might have an origin in common, as for instance by derivation from different magma types, the occurrence of peridotites elsewhere in the Uauá Block, with no associated anorthosite but very similar in composition to those from Lagoa da Vaca area, strongly

indicates that anorthosite and peridotite might not be genetically linked.

Geochemistry Representative whole-rock analyses of anorthosites from the LVC are shown in Table 3, and their

Table 3 - Chemical compositions of Lagoa da Vaca anorthosites. Major elements in wt%; trace and rare earth elements in ppm; Flag-total normative plagioclase (An+Ab+Or); Eu/Eu-Europium anomaly.*

Tabela 3 - Composições químicas de anortositos do Complexo Lagoa da Vaca. Elementos maiores em peso %; elementos traço e terras raras em ppm; Plag-plagioclásio normativo total (An+Ab+Or); Eu/Eu*-anomalia de Európio.

	EO1	EO2	EO3	EO4	MP62	MP103
SiO ₂	51,60	50,29	49,95	49,24	51,18	50,99
TiO ₂	0,16	0,34	0,24	0,34	0,14	0,53
Al ₂ O ₃	27,96	23,65	25,81	25,67	27,82	20,97
Fe ₂ O ₃ tot.	2,66	5,39	4,08	4,87	2,66	5,54
MnO	0,03	0,07	0,05	0,06	0,03	0,09
MgO	1,01	3,42	2,18	1,63	1,20	4,11
CaO	12,55	12,51	13,27	13,73	12,32	8,61
Na ₂ O	3,71	4,18	4,26	4,04	3,31	4,62
K ₂ O	0,18	0,26	0,27	0,19	0,75	1,73
P ₂ O ₅	0,03	0,02	0,01	0,10	0,05	0,26
L.O.I	0,37	0,47	0,40	0,04	0,84	1,95
Total	100,26	100,60	100,51	99,91	100,30	99,40
Plag	91,66	73,05	76,29	75,73	91,28	72,40
Cpx	2,47	13,91	12,61	13,52	1,62	7,87
Opx	4,69				5,09	
Oliv		6,27	3,25	2,55	0,4	9,62
Cr	53	324	88	85	55	107
Ga	21	19	21	19	21	20
Nb	<4	<4	<4	<4	<4	<4
Ni	23	53	37	26	18	68
Rb	<3	<3	<3	<3	9	30
Sr	254	221	263	234	296	433
V	42	115	66	80	37	97
Y	3	8	5	7	5	7
Zn	23	41	35	39	29	75
Zr	14	20	14	28	16	27
La	1,64	2,54		3,07		
Ce	3,02	4,96		6,3		
Pr						
Nd	1,41	1,93		2,36		
Sm	0,34	0,91		0,93		
Eu	0,46	0,62		0,6		
Gd						
Tb	0,07	0,09		0,19		
Dy						
Er						
Yb	0,21	0,6		0,72		
Lu	0,031	0,083		0,099		
Eu/Eu*	3,95	2,96		1,89		
(La/Yb) _n	5,28	2,86		2,88		

Table 4 - Lead isotope data for anorthositic rocks from the Lagoa da Vaca Complex.

Tabela 4 - Dados de isótopos de Chumbo para rochas anortosíticas do Complexo Lagoa da Vaca.

Sample No	²⁰⁶ Pb/ ²⁰⁴ Pb	1 sigma	²⁰⁷ Pb/ ²⁰⁴ Pb	1 sigma
EO98	13.4170	0.0085	14.6630	0.0138
EO97	13.8470	0.0140	14.7623	0.0185
EO14	14.3860	0.0117	14.9311	0.0254
EO98.1	15.1020	0.0120	15.0743	0.0158
Age: 3,161 ± 65 Ma simple μ: 8.8 ± 0.62 MSWD: 0.91				

normative compositions along with rare earth elements (REE) patterns are plotted in Figs. 4 and 5. Major and trace elements were analysed by X-ray fluorescence at Institute de Geociências of UNICAMP, whereas data for REE were obtained by Neutron activation analysis at IPEN-USP.

On Streckeisen's classification for anorthositic rocks (Streckeisen 1976), the Lagoa da Vaca rocks vary from olivine leucogabbro through gabbroic anorthosite to pure anorthosite (Fig. 4). Their REE compositions are characteristic of rocks with accumulated plagioclase, with moderate (Eu/Eu* -1.89-3.95) but prominent positive Eu anomalies on chondrite-nor-

Figure 3 - Pyroxenes, olivine and plagioclase compositions of Lagoa da Vaca anorthosites and peridotites.

Figura 3 - Composições de piroxênios, olivina e plagioclásio de anortositos de Lagoa da Vaca e peridotitos.

Figure 4 - Normative compositions of Lagoa da Vaca Complex anorthositic rocks plotted on classification diagram for anorthositic rocks (Streckeisen, 1976).

Figura 4 - Composições normativas de rochas anortosíticas do Complexo Lagoa da Vaca plotadas no diagrama de classificação para rochas anortosíticas (Streckeisen, 1976).

Figure 5 - Rare earth element plots for Lagoa da Vaca and other Archean anorthosites. Normalizing values from Evensen *et al.* (1978); Data for Fiskenaesset, Sittampundi and Bad Vermilion Lake complexes after Ashwal (1993). Figura 5 - Plotes de elementos Terras Raras para anortositos arqueanos e de Lagoa da Vaca. Valores de normalização de Evensen *et al.* (1978); Dados para Fiskenaesset, Sittampundi e Bad Vermilion extraídos de Ashwal (1993).

malised diagram (Fig. 5). They also display enrichment of light REE relative to the heavy REE ($La_n/Yb_n = 2.86-5.28$) and are comparable to other Archean anorthosites (Fig. 5).

Geochronology The Lagoa da Vaca anorthositic rocks were dated by the whole rock Pb-Pb isochron technique following the procedures of Lafon *et al.* (1993). The analytical work and mass spectrometer data acquisition were all carried out in the isotope laboratory at Centre de Geociências of Universidade Federal do Para, northern Brazil. Preliminary results were summarised in Paixão *et al.* (1995).

Table 4 and Fig. 6 illustrate the results which yielded an age of 3.161 ± 65 Ma (MSWD=0.91) with a single-stage model μ ($^{238}\text{U}/^{204}\text{Pb}$) of 8.8 ± 0.62 . As far as we are aware this is the oldest anorthosite complex in the São Francisco Craton and perhaps in the whole South American Platform.

Tectonic Setting Reconstitution of the tectonic setting of older, multiply deformed and metamorphosed igneous complexes is generally very difficult, if not impossible, owing to uncertainties in field relations and to whether or not present-day tectonic settings are fully applicable to ancient rocks. Nonetheless, several attempts have been made and the majority takes into account the associated rocks, geochemistry and isotope geology. Thus, for Archean anorthosites two likely environments have been put forward, namely oceanic and continental (Ashwal 1993 and references therein). Accordingly, typical Archean megacrystic anorthosites are generally associated with greenstone belts suggesting an oceanic environment, whereas other complexes, such as the Messina (South Africa) and Sittampundi (India), are spatially associated with marbles, quartzites, amphibolites and quartzofeldspathic gneisses, which in turn indicate that they originally might have formed within a cratonic or continental shelf environment.

In the Lagoa da Vaca area, observation of field relations with associated rock is hampered by paucity of exposures and

Figure 6 - Pb-Pb isochron for Lagoa da Vaca anorthosites. Figura 6 - Isocrona Pb-Pb para anortositos de Lagoa da Vaca.

weathering. Therefore, only indirect indications can be discussed here on the basis of isotope geochemistry and a few field relations.

According to Moorbath and Taylor (1981) the Archean mantle typically has a single-stage model μ of 7.5. to 8.0. In the plumbotectonics model of Zartman and Doe (1981) the subcontinental upper mantle has μ values of about 8.3, the upper continental crust ~ 13.3 or higher and the lower crust ~ 6.3 or lower. Allegre *et al.* (1988) argued that magmas derived from the depleted mantle have μ values in the range 4.7-5.9. The calculated μ value for the Lagoa da Vaca anorthosites (8.8) is slightly higher than the postulated mantle values of Moorbath and Taylor (1981) but closer to that of Zartman and Doe (1981).

To explain the petrogenesis of mantle derived magmas, such as that from which the Lagoa da Vaca rocks crystallised, with μ higher than the assumed mantle values, it is usually proposed that crustal contamination may have played a role. Therefore, two possibilities may be advanced here regarding the studied rocks, viz. derivation of the primary magma either from the subcontinental lithospheric mantle or from the depleted mantle, both requiring varying amounts of crustal contamination, the latter much more.

Independent evidence in favour of crustal contamination of the LVC primary magma comes from the country rocks. The anorthositic rocks are generally conformable with quartzofeldspathic gneisses, but on their eastern boundary a finely banded metasupracrustal sequence separates them from tonalitic orthogneisses that apparently are intrusive into the supracrustal rocks. Unpublished Nd isotope data for these 3.0 Ga-old orthogneisses (Oliveira *et al.*, in prep) yielded a TDM age of 3,278 Ma with an epsilon Nd of -0.57, indicating the presence of older continental basement in the area.

If this reasoning proves to be true, though additional field- and isotope work is necessary, the most likely tectonic setting for emplacement of the Lagoa da Vaca layered anorthosite complex is the continental one.

CONCLUSIONS The Lagoa da Vaca Anorthosite Complex is a metamorphosed layered igneous body composed of plagioclase- and amphibole-rich bands. In the type area of Lagoa da Vaca farm, it crops out continuously for about 3-4 kilometres in width and over 10 kilometres in length. Modal grading and slump structures indicate that the primary igneous top lies to the west though it is uncertain whether this was the

original position owing to the deformation that the complex experienced.

Earlier studies had suggested that peridotites could be part of the complex. Although we cannot totally discard this possibility for those peridotites cropping out in the Lagoa da Vaca area, the similarity between the chemistry of their minerals and those from peridotites from outside the Lagoa da Vaca area, where they are not associated with anorthosites, indicates otherwise. Indeed, calcic pyroxenes from anorthosites are more evolved than those from peridotites, whereas the opposite holds for plagioclase. Since the observed gaps in mineral compositions and contrasting anorthite contents of plagioclase are not compatible with the anorthositic rocks being derived from the peridotites by fractional crystallization, we suggest that the two rock types are unrelated.

On the basis of a whole-rock Pb-Pb isochron, the Lagoa da Vaca anorthosites have an Archaean age of about 3,160 Ma,

and are, thus, the oldest anorthosite complex ever found in Brazil.

Since the complex presents a model μ value of 8.8 ± 0.62 , compatible with its derivation from the subcontinental lithospheric upper mantle or from the depleted mantle followed by crustal contamination, and crops out on the western edge of the Archaean Uauá Block, close to a major ductile shear zone that separates the Uauá Block from the Caldeirão migmatite-quartzite-orthogneiss belt, its emplacement is likely to have occurred in a continental setting, most probably similar to present-day passive continental margin.

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