AGES OF GRANITES OF THE SERRINHA NUCLEUS, BAHIA (BRAZIL): AN OVERVIEW

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ABSTRACT The ages of granites of the Serrinha Nucleus (SN), in the eastern part of Bahia State, Brazil are poorly constrained and radiometric dating is mainly by the Rb-Sr whole rock isochron method, indicating a complex intrusive history. New Pb-Pb and U-Pb zircon for plutons widely distributed within the SN terrains range from Archean (>3070 Ma) to Paleoproterozoic (2067 Ma) and generally support the interpretation that at least three plutonic events affect these terrains. The range of ages evidently constitutes a large interval of regional granitic emplacement which can be divided into three principal domains: pre, syn and late/post tectonic. The new Archean ages (2.7 to 3.1 Ga.) by the U-Pb zircon method indicate reworking of an older crust during the Paleoproterozoic plutonic event in the SN region and clearly point to the existence of an Archean basement prior to 2.7 Ga. (Jequié Cycle). The younger ages (table 1) help to further constrain the extension and age of Archean components of the São Francisco Craton which is important for a complete understanding of the Precambrian geology of that part of Brazil.

*Keywords***:** Serrinha Nucleus, Paleoproterozoic, Geochronology

INTRODUCTION AND GEOLOGICAL BACKGROUND The Serrinha Nucleus (SN), located in the São Francisco Craton, Bahia, Brazil, covers an area of approximately 21,000km^2. Its consists of two major basement domains (migmatitic gneisses): Uauá block in the north and Santa Luz Complex in the south. However, the relationship between them has not been studied and remains debatable. In the west they are entirely surrounded by the Salvador-Curaçá Mobile Belt (SCMB) and in the eastern part they are covered by Tercio-Quaternary sediments of Tucano-Recôncavo basins (Fig. 1).

Volcano-sedimentary sequences of the Itapicuru River Greenstone Belt (IRGB) and Capim Group (CG) overlie these basement terrains. The IRGB is interpreted as being formed in a back-arc basin related to plate collision (Silva 1992). Almost all lithostratigraphic units of the SN were metamorphosed under greenschist facies conditions during the Transamazonic tectono-thermal event, with amphibolite facies developed only in the contact aureoles around granitic intrusions. From the sparse geochronological data available for the volcanic rocks, the mafic basal (2.2Ga) and felsic intermediate (2.1Ga) units are separated by roughly 100 Ma (Silva 1992). This greenstone belt is probably associated with the supracrustal rocks of the CG (Winge and Danni 1980) and it presents characteristics analogous to Archean/ Paleoproterozoic granite-greenstone complexes found in shield regions around the world.

The plutonic rocks are the focus of the present study. Recent field mapping and associated petrological studies (Matos and Conceição 1993, Alves da Silva 1994, Nascimento 1996, Rios 1998, Rios *et al.* 1998) have led to the recognition of two principal plutonic groups in this area (Fig. 1), established on the basis of lithological similarities. A pre/syn-tectonic plutonic group involves three types of granites (G1, G2, G3), with ages varying from 2.6Ga to 1.9Ga (Rios *et al.* 1998), which are thought to have intruded during regional deformation (Alves da Silva 1994). The oldest type (G1) is made up of TTGs that form dome/oval shaped structures, elongated north-south, with a widespread distribution within the SN gneissic-migmatitic Archean basement. These granites have low to high-K calc-alkaline compositions. Pervasive shear bands developed in G2 and G3 granites suggest syn-magmatic deformation (Alves da Silva 1994) and they intrude into IRGB rocks (Fig. 1). Within G3 type, magmatic structures are still preserved and their shapes are slightly elongated when compared with G2.

In the late/post tectonic group, the plutons are fresh, undeformed (only igneous foliations), discordant to regional fabrics and invade highly foliated gneissic and migmatitic basement, in some cases displaying narrow contact metamorphic aureoles (Nascimento 1996, Rios 1998). Their emplacement does not seem to be separated by a large time gap from the syn-tectonic group. The G4 group is composed of potassic to ultrapotassic rocks enriched in LREE with porphyritic to coarse-grained textures, while G5 is basically an isotropic, equigranular, fine to medium grained, homogeneous, gray granite/ granodiorite of alkaline composition.

Various studies on this granite-greenstone terrain have been carried out in the last decade. However geochemical and isotopic data are still quite scarce. This paper presents some new zircon ages and briefly discusses their significance to the evolution of the region. In a broader sense, this study contributes to increase the analytical database for the area helping to better understand its tectonic setting.

ANALYTICAL TECHNIQUES **Sample Preparation** Each sample was prepared using standard techniques of crushing and mineral separation. Only the very least paramagnetic fractions of zircons were used in the manual picking under a binocular microscope.

$^{207}Pb/^{206}Pb$ by Köber Method Single zircon evaporation studies were carried out at the Isotopic Laboratory of Pará (PARA-ISO), at the Federal University of Pará (Bélem/Brazil). Faraday and Daly cups were both used. Errors on zircon ages are taken as 2s (±95% of precision). The analyses were run using both Finnigan (MAT 262) and VG (isomass 54-E) mass spectrometers. On Finnigan we used the classic methodology (Köber 1987) with a double rhenium filament and when possible, each grain was analyzed at three different temperature steps (1450^{o}C; 1500^{o}C and 1550^{o}C). The method was also adapted to be used on a VG isomass 54-E spectrometer (Gaudette et al., 1998), using a single rhenium filament and its less flexible character introduces a larger error to the analyses. On the VG, samples are heated continuously and completely evaporated while the lead isotopic ratios are measured.

U/Pb zircon dissolution technique All grains selected for U-Pb dissolution measurements were abraded with pyrite prior to analyses (Krogh 1982). A combination of single grains and multigrain analyses of a single grain type was used, with single grains tending to give more concordant results. Miniaturized Teflon exchange anion columns were used for the extraction of U and Pb on grains over 0.005 mg. Small zircon solutions (< 0.005 mg) were loaded on filaments without ion-exchange separation. Samples were spiked with a mixed ^{205}Pb-^{235}U spike. Pb and U are loaded together onto outgassed single Re-filaments using silica gel and phosphoric acid. All U-Pb isotopic analyses for the SN rocks were performed at the Jack Satterly Geochronological Laboratory of the Royal Ontario Museum (Toronto-Canada). Isotopic ratios were measured using a VG-354 spectrometer in a temperature ranging from 1350^o to 1600^{o}C usually using a Daly multiplier detector. Uncertainties in the ages are at 95% confidence level.

AGE DATA AND INTERPRETATION Sample location, data and descriptions are presented in figure 1 and table 1. Each sample was collected from a single outcrop.

SN Basement One sample (NS 1543) from the granodiorite-gneisses of the Santa Luz Complex was analyzed by the Pb/Pb

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evaporation technique. This sample might be a paragneiss. Individual results vary and the mean age is estimated to be 2050 ± 51Ma (Tab 01). This age is not considered to be of geological significance for the basement, but probably marks the late event that affected the SN rocks.

G1 Type - Curral pluton Rios *et al.* (1998) suggest that the G1 type could be associated with arc crust formation. In this case, they should be pre-tectonic and emplaced before the greenstone/basin had been originated. This group consist of leucocratic, medium to coarse-grained rocks, varying from tonalites to granodiorites and monzogranites, with low potassium calc-alkaline affinities and locally exhibiting migmatitic textures. For the Curral Granite (NS 1346) the results show two levels of Pb-Pb minimum ages, the first one resulting in 2076 ± 19Ma and the second, 2468 ± 3Ma. One zircon shows the age of 2862 ± 5Ma, which probably represens inheritance (Table 1).

G2 Type - Ambrósio Dome Ambrósio is the largest granitoid body inside the greenstone belt (45km x 10km). Its character has been discussed by some authors who concluded that is not a basement uplift but rather an intrusive body, syntectonically intruded as a diapir (Alves da Silva 1994), with banded tonalitic/granodioritic gneisses on its borders and isotropic granites/granodiorites in the centre. It has a very young Pb/Pb evaporation age (1948 ± 28Ma; Table 1). The Archean ages obtained by U/Pb (Table 1; fig 2) are considered a reliable proof of the existence of an Archean crust in this area, preceding granite emplacement, while the pluton age is show to be Paleoproterozoic.

G3 Type - Nordestina Pluton This body is a concordant ovoid/ elongated north-south intrusion (360km^2; fig 1). The rock is foliated and inequigranular, with gneissic borders containing schlieren and pegmatites and a porphyritic core, suggesting a zoned intrusion. This pluton has been previously dated between 2.0-2.1 Ga. (see Rios *et al.* 1998). Sample NS 1333 is a fine/medium grained isotropic biotite-tonalite. The large error associated with the Pb/Pb age could be attributed to the methodology (use of VG adaptation) and alteration of the zircon samples (Table 1). Sample NS 1642, selected for U-Pb studies, is a hornblende-granite and its zircons show evidence of inherited cores and lead loss that may also have affected the analyses of sample NS 1333 (fig 2). The ages obtained by both methods are around 2.07Ga (Table 1). On sample NS1642 we used step-wise HF leaching experiments trying to isolate the least damaged and more concordant crystals, but this procedure do not seem to improve the quality of results in this sample.

G4 Type - Morro do Afonso Massif, Agulhas and Bananas Massif, Cansanção Pluton The Morro do Afonso Syenitic Pluton (MASP - 12km^2) consists mostly of syenites with subordinate monzonites. The rocks are alkaline, potassic and porphyritic and occur associated with ultrapotassic lamprophyric dykes (voguesites and minnetes) with lamproitic characteristics (Rios 1998). Two samples from different facies were dated by the Pb/Pb method (Table 1). One grain of 2641±4Ma is considered to be inherited, indicating some crustal contribution during emplacement of this body.

The Agulhas and Bananas Massif (30km^2) consists of homogeneous alkaline/potassic syenitic rocks whose textures are distinguished from the MASP and could be compared with the syenites of SCMB. Two samples were dated and their ages (Table 1) confirm its late/post tectonic character.

The Cansanção Pluton intrudes the Nordestina Pluton (G3) to the west (fig 1) and has monzonites and monzodioritic rocks instead of the common syenitic composition of G4. These rocks are associated with mafic lenses and dykes and contain abundant enclaves with monzosyenitic to plagioclasic compositions. The Pb/Pb zircon age (2105Ma; Table 1) is older than the 2025 ± 47 Ma age (Pb/Pb rock; Nascimento 1996) previously reported in the literature.

The ages obtained for the G4 type during this work range between 2067± 22 Ma (Bananas) and 2105± 3 Ma (Cansanção). They are the first ages for this group and point to a north-south trend (fig 1) that seems also to control the geochemistry and emplacement characteristic of the massifs in this type (Rios *et al.* 1998).

G5 Type - Morro do Lopes Massifs Thirty-five small (<8km^2) circular plutons characterize this group. The rock is well exposed and fresh. Sample NS 1440 was analyzed by Pb/Pb and shows

Table 1 -Pb/Pb and U/Pb isotopic data for the Serrinha Nucleus Granites.

PLUTON	SAMPLE	DESCRIPTION OF GRAINS (USED TO CALCULATE THE MEAN AGE)	MEAN AGE (MA)	REMARKS AND METHOD
Santa Luz (Basement)	NS1543 Granodiorite-Gneiss	4 Zr; pale br to br; some op and met; brok; incl; rounded borders; c; z	2050 ± 51	Large individual discrepances; 1 xcr = 2108 ± 4Ma; $^{204}Pb/^{207}Pb < 0.0010$. Pb evap. Finnigam
Curral (G1)	NS 1346 Granodiorite	4 Zr; el l to short pr; tr; pale br to colourless; incl; Euh; rounded borders	2076 ± 19	1 xcr = 2468± 3Ma; 1 xnc = 2862± 5Ma; $^{204}Pb/^{207}Pb < 0.0004$. Pb evap. Finnigam
Ambrósio (G2)	NS 1378 Tonalite	1 Zr; Fragment of gr; brok; tr; pale br; rounded borders	1948 ± 28	$^{204}Pb/^{207}Pb < 0.0010$; just one evaporation step. Pb evap. Finnigam
	NS 1351 Tonalite	4 Ab Zr; common lead < 6pg; rounded; clr; colourless to pale pink; brok.	>3070	Probably inherited grains; tips and cores measured separately. U/Pb
Nordestina (G3)	NS 1333 Tonalite-Trondjhemite	4 Zr; Euh; pale br to br; tr; fratures; maybe c; incl.	2004 ± 103	$^{204}Pb/^{207}Pb < 0.0010$; Pb evap. VG 54-E
	NS 1642 Hornblende Granite	10 Ab Zr; rounded to Euh; clr; pale br to pink; irregular shapes; tr; c	2069 ± 1	common lead 0.5 to 5pg; 2 Zr fractions and 1frag HF washed. U/Pb
Morro do Afonso (G4)	MA 949 Leucocratic Syenite	5 Zr and Zr frag; tr; pale br; fratures; z; c;	2097 ± 16	$^{204}Pb/^{207}Pb < 0.0010$; One Zr with c dated as 2641± 4Ma (xenocryst). Pb evap. Finnigam
	MA 932 Mesocratic Syenite	3 Zr; pale br; tr; Euh; fratures; ell; incl;	2081 ± 27	$^{204}Pb/^{207}Pb < 0.0010$; Pb evap. VG 54-E
Agulhas and Banana (G4)	NS 1439 Agulhas Syenite	5 Zr; ell; tr; pale br; incl; Euh; rounded borders; maybe c; z;	2067 ± 22	$^{204}Pb/^{207}Pb < 0.0004$; Pb evap. VG 54-E
	NS 1415 Bananas Syenite	3 Zr; ell; pale br to br; tr; fratures; rounded borders; incl; z; Euh.	2087 ± 17	$^{204}Pb/^{207}Pb < 0.0004$; Pb evap. VG (1gr)+ Finnigam (2gr)
Cansanção (G4)	NS 1331 Monzonite	4 Zr; Euh; pale br to br; op c; tr ov; incl;	2105 ± 3	$^{204}Pb/^{207}Pb < 0.0004$; Pb evap. VG (2gr)+ Finnigam (2 gr)
Morro do Lopes (G5)	NS 1436 Granite-Granodiorite	4 Ab Zr; ell; z; clr; br to pale pink; irregular shapes to Euh	2072 ± 1	common lead 0.8 to 2pg; U/Pb
	NS 1440 Granodiorite	3 Zr, tr; pale br; Euh; ell; incl; rounded borders;	2003 ± 2	1 xcr = 3002± 1Ma; $^{204}Pb/^{207}Pb < 0.0004$. Pb evap. Finnigam

Zr = Zircon; Ab = Abraded; brok = broken; incl = inclusions; c=cores; ov = overgrowth; z = zones; met = metamitic; tr = transparent; op = opaque; xcr = xenocryst; gr = grain; ell = ellongated; pr = prismatic; Euh = euhedral; br = brown; frag = fragment.

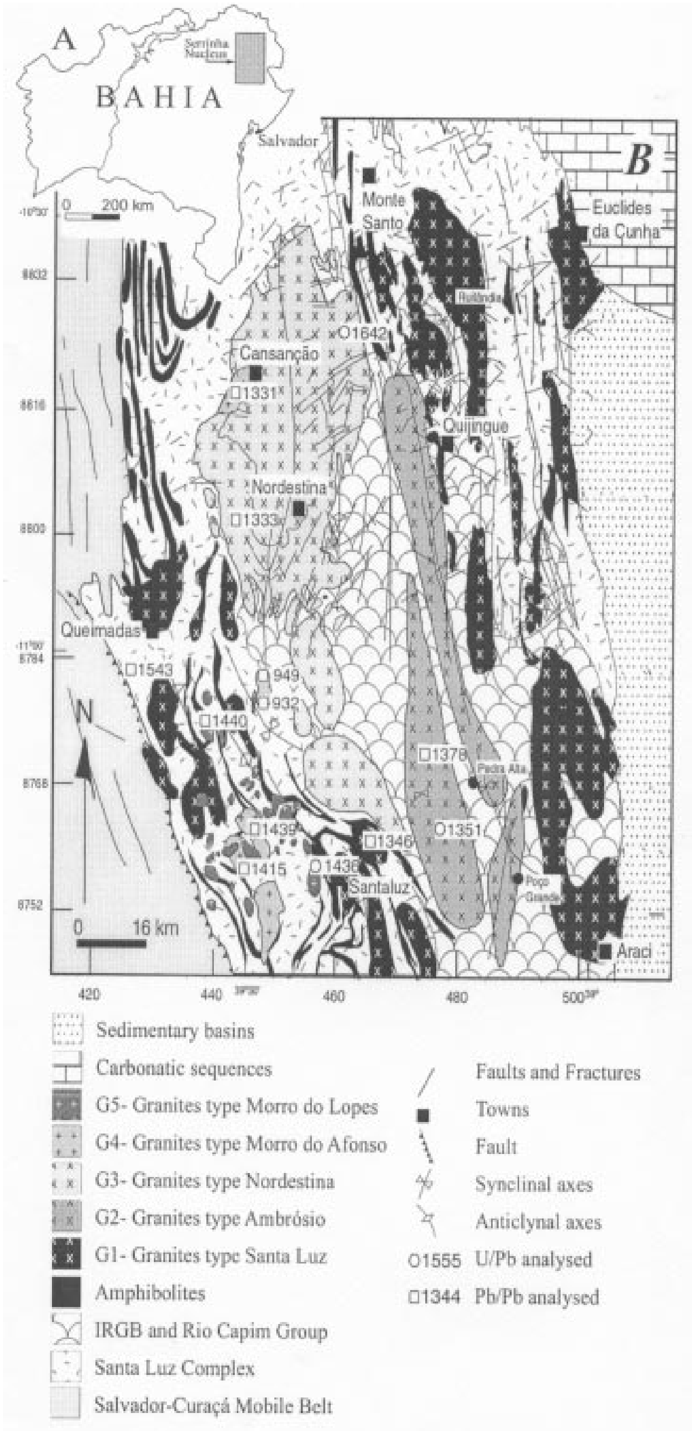

Figure 1 - (A) Location map of Bahia State in Brazil. (B) Simplified geological map of the Serrinha Nucleus, Bahia (Brazil)

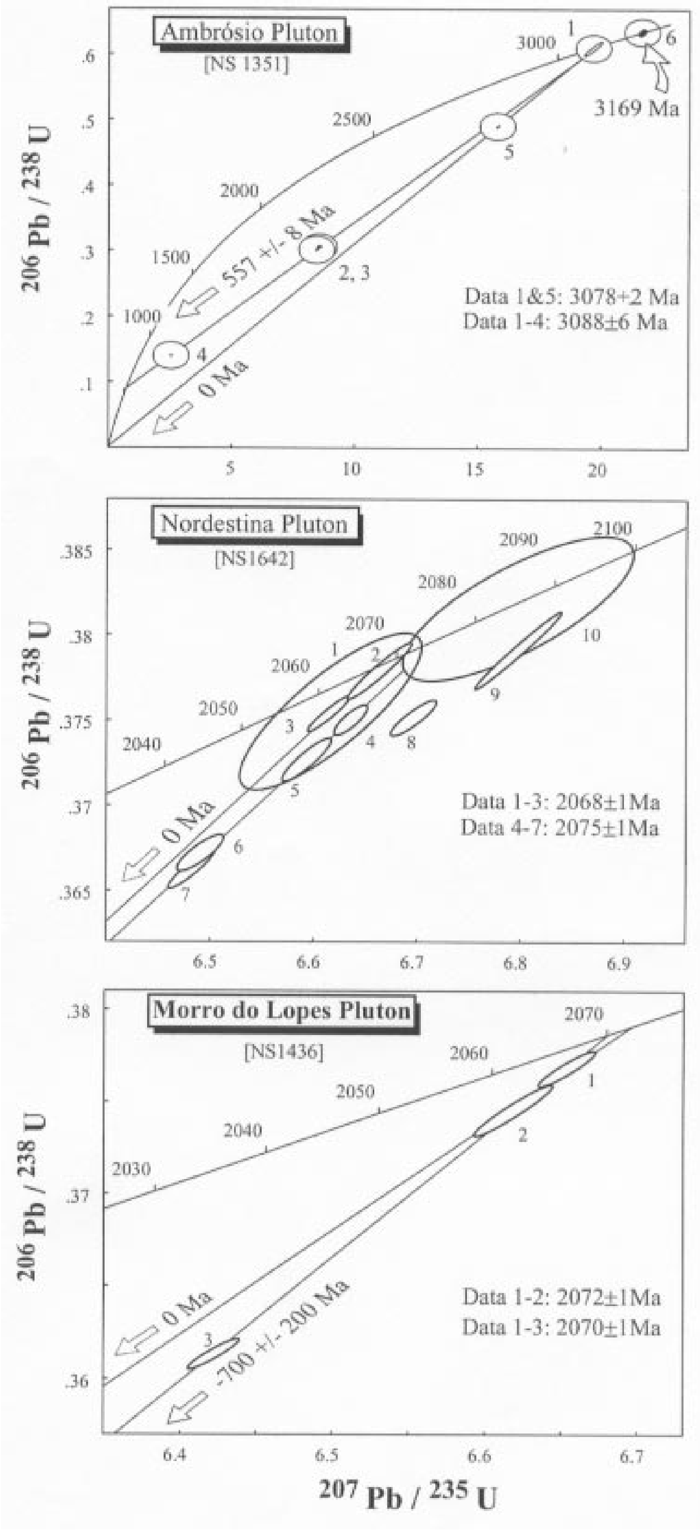

Figure 2 - Concordia diagrams showing U-Pb zircon data obtained for the Serrinha Nucleus Granites

one zircon of Archean age (3002±3 Ma). This is probably a reliquiar xenocryst and suggests a crustal contribution for the origin of these rocks. The crystallization age of G5 granites is at least 2070Ma (Table 1; fig 2), which is slightly older than what was expected for this magmatism (Rios *et al.* 1998).

CORRELATIONS AND DISCUSSION

The SN plutons are important as evolutionary markers, providing means of constraining the time of regional tectonism in Bahia State. In West Africa, the major granitoids are divided into two groups: the “belt-type, now interpreted as sin/pre-orogenic bodies (±2170 Ma) and the “basin-type”, which is younger, with ages ranging of 2090-2120 Ma (Hirdes *et al.* 1992, Davis *et al.* 1994). This orogenic classification is related to the Eburnean Orogeny which, in this region, was preceded by two major events called Leonian (ca. 3.0 Ga.) and Liberian (ca. 2.7 Ga.), the last one being the most important event in the West Africa Craton.

In South America, the Omai intrusion, described by Norcross (1997) in the Guyana Shield is dated at 2094±1 Ma. This undeformed pluton may be correlated with the basin-type granites of West Africa. It intruded during the post deformational stages of the Transamazonian Orogeny and the time difference between Omai intrusion and the metavolcanic rocks of Guiana is only 26 M.y. The authors limit the final stages of deformation and metamorphism of the Transamazonian in this region within the range 2120-2094 Ma. This time gap seems similar to that in the SN. In Bahia, Brazil, isotopic studies on syenites limits their ages between 2.1Ga (SCMB-East) and 2.05Ga (Urandi-Paratinga Mobile Belt-West; Rosa *et al.* 1999).

Remnant of late Archean crust are largely preserved within granite-greenstone terrains worldwide, with ages ranging between 3.0-2.7 Ga. The current data suggest that the oldest rocks in the SN, the G1 granites, could be correlated with a magmatic event before the extension at 2.6-2.7 Ga., perhaps related to the Liberian Orogeny (Jequié Cycle). G2 and G3 Types are probably separated by only a few million of years in emplacement and up to now it has been impossible to make geochronological distinctions between them. The results for the late-post/tectonic group (G4 and G5) of SN are interpreted as good estimates for their crystallization ages. Some of these ages are the first available for these groups of granites and make possible a more realistic and reliable comparison between them. Many authors make correlations between the Transamazonian event and the Eburnean Orogeny (Hirdes *et al.* 1996, Bertrand and Sá 1990), suggesting an accretionary east-west process forming these two orogenies and involving significant post/late tectonic intrusive activity around 2.1Ga.

With the new data we can differentiate between the pre-tectonic granites of G1 (probably Archean) and the syn-tectonic Paleoproterozoic groups (G2 and G3). These latter rocks show evidence of an Archean sialic precursor. Within the Transamazonian period of igneous activity there were two major stages of intrusion. The first stage produced the G2 and G3 granites, related to the greenstone belt volcanism and following the final stages of deformation, but a short time later, a second phase of intrusive activity created more potassic granitic rocks and other intrusions ranging from quartz syenites to diorites and lamprophyres which do not show the deformational characteristics of their host. However, the results presented here will become more valuable as new geochronological data are acquired.

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