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U-PB DATING OF DEFORMED MAFIC DYKE AND HOST GNEISS: IMPLICATIONS FOR UNDERSTANDING REWORKING PROCESSES ON THE WESTERN MARGIN OF THE ARCHAEAN UAUÁ BLOCK, NE SÃO FRANCISCO CRATON, BRAZIL

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ABSTRACT U-Pb ages of deformed mafic dyke and host migmatitic grey gneiss from the transition zone between the Archaean Uauá Block and the Caldeirão Belt are presented. Titanites from the metamorphic dyke's margin and zircons from the gneiss were dated at 2,039 ± 2 Ma and 2,956 ± 39 Ma, respectively. The Sm-Nd data (T_{DM}=2,965 Ma and $\varepsilon_{Nd(t)}$=1.69) on the gneiss, coupled with the U-Pb data on both dyke and gneiss, suggest that an Archaean granodioritic batholith, probably originated at an Andean-type continental margin, was intruded by mafic dykes, and subsequently was reworked during the Palaeoproterozoic collisional event associated with the development of the Salvador-Curaçá Orogen.

Keywords: U-Pb geochronology, deformation, crustal evolution

INTRODUCTION Reworking of older Archaean terrains by younger orogenic events is a common feature of Precambrian areas within several continents. Reworking processes include folding and (or) disruption of older structures, metamorphism, crustal melting, mobility of chemical elements and opening of isotope systems, sometimes also intrusion of new mantle-derived magmas. Dating reworking events has been possible by means of good field relations and the availability of syndeformational minerals suitable for isotope analysis.

On the western margin of the Archaean Uauá Block, northeastern São Francisco Craton, migmatic grey gneisses are intruded by mafic dykes. Both rock units were subsequently reworked during a collisional event associated with the development of the Palaeoproterozoic Salvador-Curaçá Orogen. As a result, the grey gneisses are refolded, and intruded by pegmatites along the new foliation plane, and the mafic dykes are boudinaged and disrupted under amphibolite facies condition. Conventional U-Pb dating of zircons from one host gneiss and syndeformational titanite from the margin of one dyke, along with whole-rock Sm-Nd data, indicate that the dyke was deformed at ca. 2,039 Ma and the gneiss (2,956 Ma) underwent little isotope disturbance. The regional implications of this study are also discussed.

GEOLOGIC SETTING Mafic dykes are a major geological component of the Uauá Block (Fig. 1), one of the several Archaean remnants exposed in the São Francisco Craton, eastern Brazil. On the basis of cross-cutting relations, two main dyke swarms (N-NE- and NW-trending groups) can be recognized. The younger one, i.e. the N-NE-trending group, was not affected by ductile deformation and is bimodal in composition (tholeiite and norite), whereas the other one comprises strongly deformed and metamorphosed basic dykes, now transformed into amphibolite. These dyke swarms intrude Archaean basement rocks (layered mafic-ultramafic complexes, banded gneisses, tonalitic to granodioritic orthogneisses), but are unconformably overlain by the Palaeoproterozoic Rio Capim Volcano-Plutonic-Sedimentary Sequence, for which Oliveira *et al*. (1998) constrained ages in the time span 2,222 Ma to 2,096 Ma.

Precise dating of the mafic dykes has been hampered by paucity of suitable minerals, such as zircon and baddeleyite. Nevertheless, whole-rock and mineral Rb/Sr isochrons presented by Bastos Leal *et al* (1994) indicate two age groups for the N-NE-trending tholeiite dyke swarm, viz. 2.38 Ga and 1.98 Ga.

The Uauá Block (Fig. 1) is bounded to the east by flat-laying Neoproterozoic metasediments of the Sergipano Orogen, or younger units, and to the west by a sequence of steeply dipping quartzites, metapelites, migmatitic gneisses, deformed granitoids and mafic rocks, collectively called Caldeirão Belt (Jordan 1972). Although less abundant, mafic dykes of the Uauá Block have also been observed in the Caldeirão Belt where they have undergone deformation and metamorphism under amphibolite facies conditions. A prominent, at least two-kilometer-wide, steeply dipping ductile deformation zone, with associated narrow shear zones, separates the Caldeirão Belt from rocks of the Uauá Block.

Although mafic dykes of the N-NE group of the Uauá Block are generally not deformed, they do are as the above referred to shear zone is approached. Thus, from east to west, they gradually change from undeformed, weakly- to non-metamorphic tholeiite to along-strike boudinaged metatholeiite and amphibolite. Intrusive field relations between dykes and country rock gneisses that are easily recognized outside the deformation zone become more difficult to be observed within it. Yet, the host gneisses are refolded and may locally display coaxial or non-coaxial fold interference patterns.

Sampling Site On outcrop UA96-2 (446812E, 8904890N – Fig. 1), at the unpaved road Uauá-Monte Santo, one mafic dyke is structurally conformable with the host migmatitic grey gneiss, both presenting a tectonic planar fabric (S_1 on dyke and S_2 on gneiss) oriented N56°W/82°NE. In spite of the strong deformation, intrusive contacts between dyke and gneiss can be inferred because of abrupt contact, folding of a previous metamorphic banding on the gneiss, local truncation of the gneissic fabric, and a fine grained texture of the dyke margin (older cooling margin). Several ductile shear zones affect the mafic dyke, the gneiss and syntectonic granitic pegmatites. They often show dextral kynematics, but sinistral E-W extensional C'bands are also common. The mafic dyke itself is boudinaged and disrupted, with measured stretching of at least 41%.

The deformed tholeiite dyke of outcrop UA96-2 has primary subophitic texture in dyke's center but is strongly foliated and recrystallized under amphibolite facies conditions at the margins. As deformation progressed the original igneous mineralogy (pyroxenes, plagioclase, pyrite, ilmenite and magnetite) was converted into a metamorphic assemblage composed of plagioclase, hornblende, titanite and a few relicts of ilmenite and Ca-pyroxene. Titanite occurs as stringlets between elongated amphibole grains and around stretched ilmenite. These textural features strongly support a syndeformational (metamorphic) origin for the titanite rather than magmatic.

The host migmatitic grey gneiss has a granodioritic composition and is dominantly composed of biotite, quartz and plagioclase, and minor K-feldspar, muscovite, zircon and calcite.

Analytical Procedures Analytical data were obtained at the Isotope Geochemistry Laboratory of the University of Kansas, USA. Abraded and non-abraded fractions of zircon single grains and titanite multigrains were spiked with a mixed ^{205}Pb-^{235}U tracer solution and dissolved in HF and HCl in microcapsules, using procedures modified after Krogh (1973). U and Pb of titanite and zircon were purified using HCl-HBr chemistry modified after Tilton (1973) and HCl chemistry after Krogh (1973), respectively. Pb and U samples were loaded together onto single rhenium filaments with phosphoric acid and silica gel, for isotopic analysis on a VG Sector multi-collector mass spectrometer equipped with a Daly detector. Mass discrimination correction of 0.1 to 0.15 % per mass unit was determined periodically by analysis of NBS SRM 982, equal-atom Pb. During these analysis, analytical blanks varied from 5 to 25 pg for Pb. PBDAT (Ludwig 1980) and ISOPLOT (Ludwig 1990) were used to reduce raw mass spectrometer data; correct for blanks; and calculate uncertainties,

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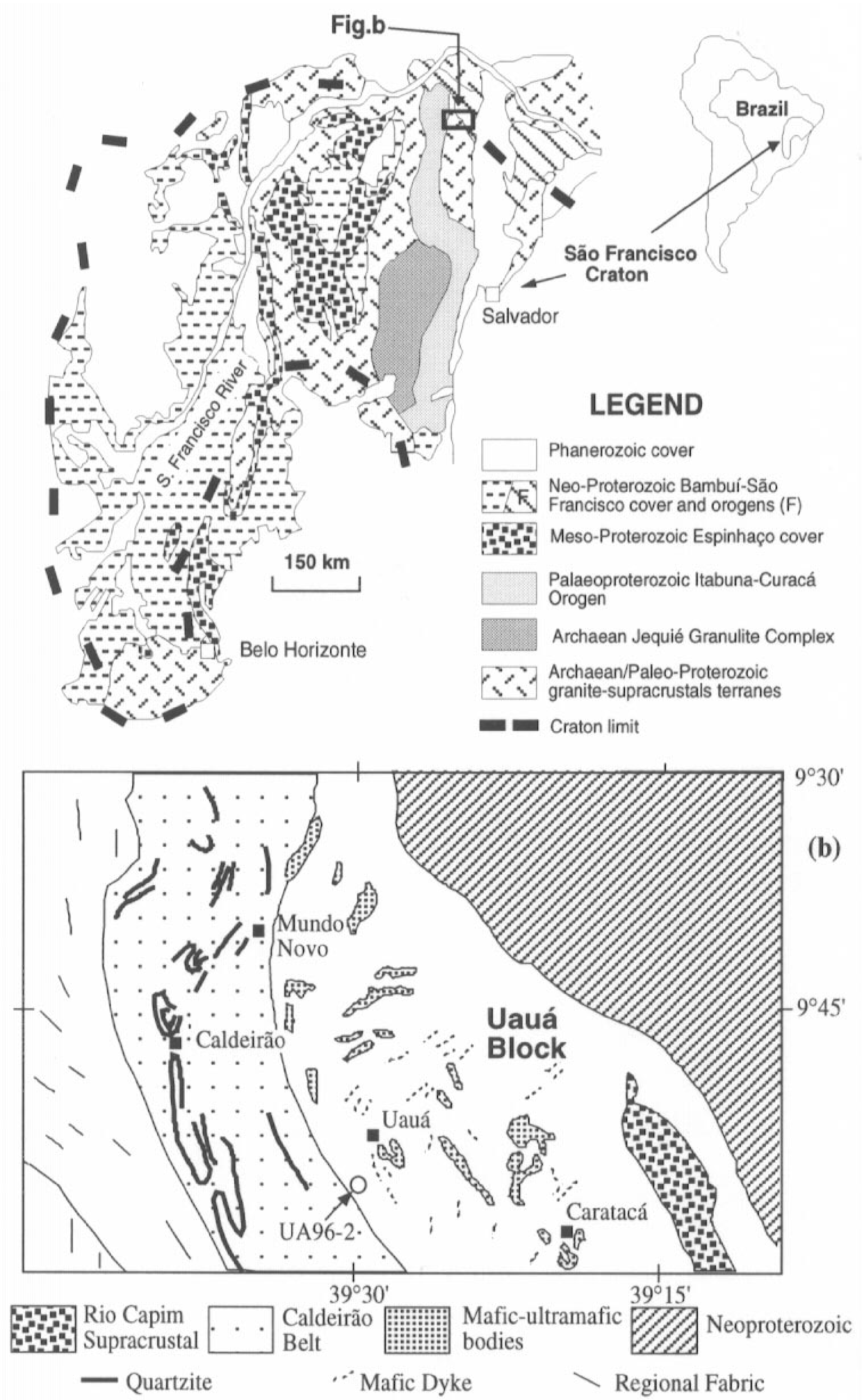

Figure 1-The São Francisco Craton (a) with location of the Uauá Block (b) and outcrop UA96-2. Modified after Inda and Barbosa (1978) and Jordan and Busch (1973).

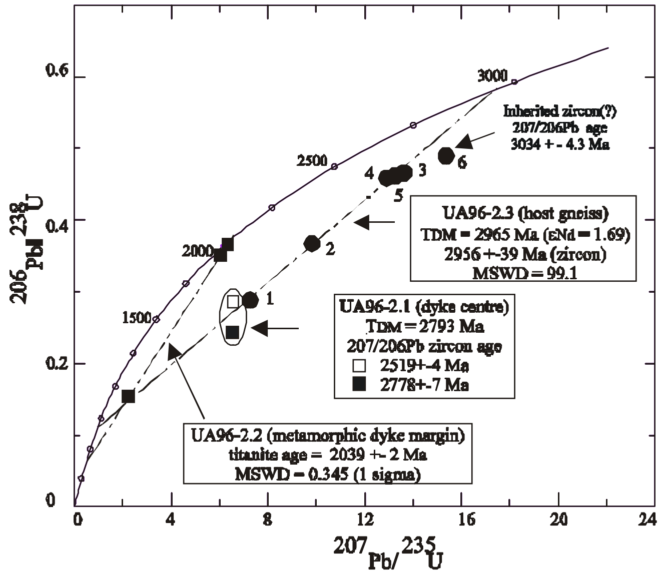

Figure 2–U-Pb ages of shear zone deformed mafic dyke (UA96-2.1, 2.2) and host gneiss (UA96-2.3), western boundary of the Uauá Block.

concordia intercepts, and weighted averages. Sm and Nd were dissolved in a HF-HNO_3 mixture and extracted using AG-50W cation and LN-spec resins ion exchange columns following the general procedures of Patchett and Ruiz (1987). Sm and Nd were loaded, respectively on Ta filament with H_3PO_4; and Re filament with H_3PO_4 and a thin coat of resin beads. Analyses are corrected for instrumental bias to a value for the La Jolla Nd standard of 0.511860. Correction for blanks was insignificant for Nd isotopic compositions and for Sm/Nd concentrations and ratios.

RESULTS AND DISCUSSION Analytical data are presented in Tables 1 and 2, whereas Fig. 2 shows a summary of our U-Pb geochronological and Nd isotope results.

Two discordia lines were obtained, one with three titanite magnetic fractions from the amphibolitic dyke margin (2,039 ± 2 Ma; sample UA96-2.2) and another with four zircons of the host grey gneiss (2,956 ± 39 Ma; sample UA96-2.3).

The titanite age is of high quality, as revealed by one nearly concordant magnetic fraction and the good fit of the regression (MSWD=0.345 at 1 sigma). This age is here interpreted as the timing of metamorphism and deformation when titanite was formed. Direct dating of deformation using the U-Pb system in titanite was also achieved by Resor *et al.* (1996) on the Proterozoic Laramie Peak shear zone, Wyoming, USA

The age found on host gneiss deserves further comments. Two additional zircons from the gneiss (zircons 3 and 6 on Fig. 2) plot to the right of the discordia and were interpreted as inherited grains from older crust. Evidence of older crust in the Uauá Block come also from U-Pb age dating of zircons from several rock units (3,161-3,050 Ma, Oliveira *et al*. 1999, Cordani *et al*. 1999) and from Nd model ages (3,256-3,368 Ma cf. Oliveira *et al*. 1999). However, the observed whole-rock Nd model age of the gneiss, viz. 2,965 Ma sets a maximum age limit for it if the Sm-Nd system has not been disturbed.

Two zircons from the central portion of the mafic dyke (sample UA96-2.1) were also analyzed. Because only three zircon crystals could be picked up from the heavy mineral concentrate we have not been able to split them into magnetic fractions, nor get any discordia. However, their apparent $^{207}Pb/^{206}Pb$ ages are 2,519 ± 4 Ma and 2,778 ± 7 Ma, and the whole-rock Nd model age is 2,793 Ma, with great uncertainty, however, because of its high $^{147}Sm/^{144}Nd$ ratio (0.18890). No firm conclusion can be drawn from these data, because the zircons have a high degree of discordance and may have come from the regional gneisses through contamination. Nevertheless, we suggest that the dyke age may be somewhere between 2,039 Ma, i.e. the age of dyke deformation, and its Nd model age of 2,793 Ma.

Finally, we would like to draw the following general conclusions from this study, with regional implications for understanding the geology of remnant Archaean nuclei in the São Francisco Craton and their subsequent reworking by younger tectonic events.

Most Archaean high-grade terrains have a complex geologic evolution, with a long history of volcanism, igneous intrusion, sedimentation, metamorphism and deformation. The reconstruction of their geology and tectonic settings are probably only possible with the help of good field relations and high-quality isotope data. From the studied gneisses and intrusive mafic dyke of the Uauá Block we can learn that Mesoarchean gneisses, possibly generated at an Andean-type

Table 1-Titanite (tit) and zircon (zr) U-Pb isotopic data from margin and center of mafic dyke and host gneiss.

				Concentrations			Corrected values		
Sample	Rock	Mineral Fraction	Weight (mg)	U ppm	Total Pb ppm	Com Pb ppm	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
UA96-2.3	gneiss	1-zr-m(1)	0.003	767.75	270.57	31.4	0.289998	7.2759	0.181965
UA96-2.3	gneiss	2-zr-m(0)	0.009	624.68	2697.1	6.33	0.368455	9.8091	0.193083
UA96-2.3	gneiss	3-zr-nm(-1)	0.01	467.65	243.23	3.41	0.466012	13.6348	0.212202
UA96-2.3	gneiss	4-zr-nm(-1)ab	0.003	342.8	173.73	3	0.458181	13.0217	0.206124
UA96-2.3	gneiss	5-zr-nm(-1)ab	0.003	473.44	241.68	4.61	0.460827	13.2600	0.208692
UA96-2.3	gneiss	6-zr-nm(-1)ab	0.002	207.42	137.94	20.9	0.49008	15.3702	0.227464
UA96-2.2	dyke	tit-m(8)ab	0.342	48.20	27.55	2.53	0.352048	6.0656	0.124961
UA96-2.2	dyke	tit-m(6)	0.351	28.74	17.52	1.21	0.365173	6.3211	0.125544
UA96-2.2	dyke	tit-m(4)	0.308	103.99	23.26	3.02	0.15267	2.2356	0.106205
UA96-2.1	dyke	zr-nm(0.6)ab1	0.002	392	124.45	6.4	0.285795	6.5464	0.166129
UA96-2.1	dyke	zr-nm(0.6)ab2	0.002	595.6	169.78	10.6	0.244233	6,5404	0.194222

Table 2-Sm-Nd isotopic data from mafic dyke's center and host gneiss

	Rock	Age	Sm	Nd	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	T_{DM}	$\varepsilon_{Nd(0)}$	$\varepsilon_{Nd(t)}$
UA96-2.3	gneiss	2956(?)	0.799	5.135	0.09405	0.510720	2965	-37,41	1.69
UA96-2.1	mafic dyke	?	1.881	6.019	0.18890	0.512600	2793	-0,75	

continental margin (zircon age=2,956 Ma, T_{DM}=2,965 Ma and $\varepsilon_{Nd(t)=}$1.69), were deformed and later intruded by mafic dykes, which to some extent remained relatively undisturbed in low strain regions within the Uauá Block. During the Paleoproterozoic part of these dykes and their host gneisses have been deformed by the continent-continent collisional event that originated the Itabuna-Salvador-Curaçá orogen, as evidenced by the 2039 Ma age on syndeformational titanites from the amphibolite margin of a mafic dyke found within a highly deformed zone that separates the Uauá Block from the Caldeirão Belt. The main N-NW-trending deformation and associated high temperature amphibolite facies metamorphism observed in the latter is thus very likely to be of similar age, perhaps somewhat older owing to the possible lower closure temperature of the U-Pb system in titanites than in zircons; Indeed, detrital zircons from quartzites of the Caldeirão Belt yield a metamorphic age of 2,076 ± Ma (Mello *et al.* 1999). Despite the strong deformation and high-grade metamorphism during the Paleoproterozoic reworking event, zircons from the dyke's host gneiss allowed us to unravel part of the gneiss petrogenesis.

Similar studies are currently being carried out in other areas of the Salvador-Curaçá orogen, especially in mineral deposit districts, in order to understand their metallogenesis and provide geological models for exploration.

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References

Bastos Leal L.R., Teixeira W., Piccirillo E.M., Menezes Leal A.B., Girardi V.A.V. 1994. Geocronologia Rb/Sr e K/Ar do enxame de diques máficos de Uauá, Bahia (Brasil). *Geochimica Brasiliensis*, **8**:99-114.

Cordani U.G., Sato K., Nutman, A. 1999. Single zircon SHRIMP determinations from Archean tonalitic rocks near Uauá, Bahia, Brazil. In: South American Symposium on Isotope Geology, 2, Córdoba, Argentina, *Actas*, 27-30.

Inda H.A.V. & Barbosa J.F. 1978. *Mapa geológico do Estado da Bahia (Escala 1:1.000.000)*. Secretaria de Minas e Energia da Bahia.

Jordan H. 1972. Die Minas Gruppe in Nordost-Bahia, Brasilien. *Geologisches Rundschau*, **61**:441-469.

Jordan, H. & Busch, K. 1973. *Mapa geológico da região de Uauá-Bedengó 1:100,000*. Bundesanstalt für Bodenforschung (Hannover, Germany) & SUDENE (Recife, Brazil).

Krogh T.E. 1973. A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determination. *Geochimica et Cosmochimica Acta*, **37**:485-494.

Ludwig K.R. 1980. Calculation of uncertainties of U-Pb isotopic data. *Earth and Planetary Science Letters*, **46:**212-220.

Ludwig K.R. 1990. *Isoplot: a plotting and regression program for radiogenic isotope data, for IBM-PC compatible computers*, Version 2.02. U.S. Geol. Surv. Open File Rep., 88-557, revision of Feb. 13, 44 pp. Plus program disk.

Mello E., Oliveira E.P., McNaughton N. 1999. SHRIMP U-Pb geochronology of detrital zircons from Early Precambrian quartzite of the Caldeirao Belt, NE São Francisco Craton, Bahia-Brazil. In: South American Symposium on Isotope Geology, 2, Córdoba, Argentina, *Actas*, 78-81.

Oliveira E.P., Lafon J-M., Souza Z.S. 1998. A Paleoproterozoic age for the Rio Capim volcano-plutonic sequence, Bahia, Brazil: whole-rock Pb-Pb, Pb-evaporation and U-Pb constraints. In: SBG, Congresso Brasileiro de Geologia, 15, Belo Horizonte, *Anais* , 14.

Oliveira E.P., Lafon J-M., Souza Z.S. 1999. Archaean-Proterozoic transition in the Uauá Block, NE São Francisco Craton, Brazil: U-Pb, Pb-Pb and Nd isotope constraints. In: SBG, International Symposium on Tectonics, 1, Lençois, *Proceedings*, Section 1, 38-40.

Patchett P.J. & Ruiz J. 1987. Nd isotopic ages of crust formation and metamorphism in the Precambrian of eastern ands southern Mexico. *Contribuition to Mineralogy and Petrology*, **96**:523-528.

Resor P.G., Chamberlain K.R., Frost C.D., Snoke A.W., Frost B.R. 1996. Direct dating of deformation: U-Pb age of syndeformational sphene growth in the Proterozoic Laramie Peak shear zone. *Geology*, **24**:623-626.

Tilton G.R. 1973. Isotopic lead ages of chondritic meteorites. *Earth and Planetary Science Letters*, **19**:321-329.

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