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RESERVORIOS POTENCIALES DE FLUIDOS DE LOS DEPOSITOS DE ORO MESOTERMALES DEL "GREENSTONE BELT" RIO ITAPICURU, BAHIA, BRASIL

POTENTIAL FLUID RESERVOIRS FOR MESOTHERMAL GOLD DEPOSITS IN THE RIO ITAPICURU GREENSTONE BELT, BAHIA, BRAZIL

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INTRODUCTION

The lower Proterozoic Rio Itapicuru greenstone belt has long been an important gold province in the north-eastern portion of the São Francisco craton, State of Bahia, Brazil. This geotectonic unit consists of a highly folded sequence of mafic volcanics, andesitic-dacitic lavas/pyroclastics and volcanically-derived turbidities, which surround syn-tectonic granite-gneiss domes (Fig. 1; Kishida, 1979). The supracrustals are metamorphosed mainly to the greenschist facies, but show a gradation to amphibolite facies towards the borders of the domes (Silva and Netto, 1993). From petrological and geochemical data, Silva (1987) proposed that the development of the greenstone sequence took place in a

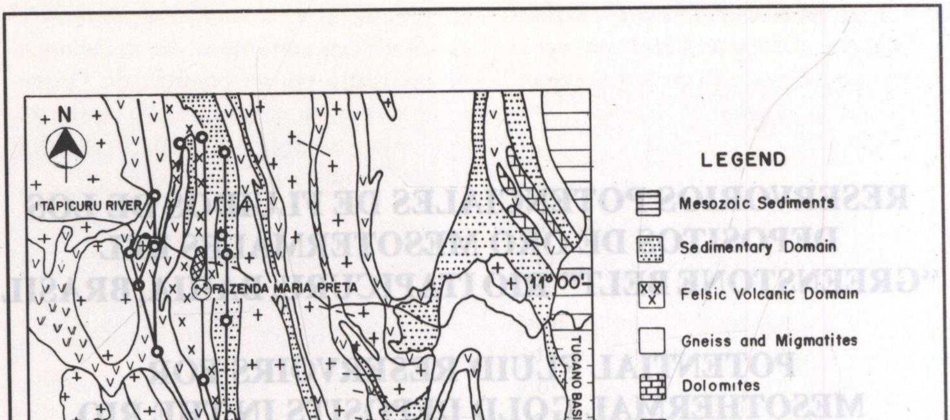

Fig. 1: Geology of the Rio Itapicuru greenstone belt and the location of the Fazenda Brasileiro and Fazenda Preta gold deposits (from Kishida et al., 1991)

back-arc environment, related to a plate collision, during the transition between the Archaean and Proterozoic in the São Francisco craton. Important auriferous districts in the north and southern sectors of this greenstone belt contain a series of small to medium size mesothermal gold deposits, which are closely associated with N-S and E-W regional scale shear zones (Fig. 1; Kishida et al., 1991).

This work aims to contribute to the understanding of the genesis of the mesothermal gold deposits of the Rio Itapicuru greenstone belt, by placing particular emphasis on the nature, evolution and possible sources of the ore-bearing fluids, through an integrated study of fluid inclusions and stable isotopes on the Fazenda Brasileiro (FB) and Fazenda Maria Preta (FMP) gold deposits.

GOLD MINERALIZATION AT FAZENDA BRASILEIRO (FB) AND FAZENDA MARIA PRETA (FMP) DEPOSITS

The major orebodies of the FB deposit, in the southern sector of the greenstone, consist of networks of sulphide-rich, quartz carbonate-albite veins and veinlets confined in a hydrothermally-altered magnetite-quartz-chlorite schist (¨xisto magnético¨), possibly a mafic intrusion of gabbroic composition (Teixeira et al., 1990). At the FMP deposit, north sector of the greenstone, the gold mineralization occurs in metre-wide quartz-ankerite veins hosted by carbonaceous sediments, also in quartz-ankerite breccia and stockworks hosted by rhyodacites and diorites. In both deposits, gold (Ag/Au= 0.08-0.1) occurs in its native state finely disseminated in the quartz veins and veinlets or closely associated with arsenopyrite, pyrite, muscovite-phengite white mica and Fe-rich chlorite. Replacement textures and microstructural observations have suggested that gold deposition in both deposits probably took place during late to post-peak metamorphism and deformational events (Teixeira et al., 1990; Xavier, 1991). This is corroborated by a preliminary investigation using the $^{40}Ar/^{39}Ar$ systematics, which has shown that the hydrothermal alteration and the gold deposition at the FB deposit occurred between 2083 and 2031 M.a. (Vasconcelos and Becker, 1992).

CHEMISTRY AND REDOX STATE OF THE FLUIDS

Fluid inclusion studies by microthermometry and micro-Raman spectroscopy in gold-bearing quartz veins showed that the ore-bearing fluids are compositionally similar for both FB and FMP deposits. They were defined as low-salinity (< 5 wt% eq. NaCl) aqueous solutions, with 11.5-45 mol% CO_2, minor amounts of N_2 (0-7.7 mol%) and CH_4 (0-0.7 mol%). Additionally, fluid inclusion volatile analysis by gas chromatography systematics yielded trace amounts of C_2 - C_4 hydrocarbons, such as C_2H_4 (1-16 ppm), C_2H_6 (0.01-87 ppm), C_3H_4 (0-2 ppm), C_3H_6 (0-0.03 ppm), C_3H_8 (0-21 ppm), C_4H_{10} (0-29 ppm), and COS (0.02-44 ppm). Based on the bulk-density isochores of the fluid inclusions, combined with the arsenopyrite and chlorite geothermometers, the P-T regime of these fluids was estimated at 390° - 455°C/2.7 - 4.8 kb and 360° - 420°C/2 - 4.1 kb for the FB and FMP gold deposits, respectively. The calculated fO_2 of the mineralizing fluids yielded values in the range 10^{-25} - 10^{-31} bar, based on the fluid inclusion compositions and the estimated P-T conditions. These values are concentrated slightly below and slightly above the QFM and Ni-NiO buffers, revealing the reducing nature of the mineralizing fluids (Fig. 2).

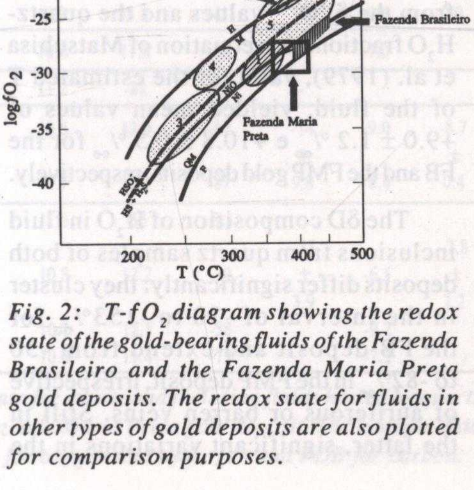

Fig. 2: T-fO_2 diagram showing the redox state of the gold-bearing fluids of the Fazenda Brasileiro and the Fazenda Maria Preta gold deposits. The redox state for fluids in other types of gold deposits are also plotted for comparison purposes.

THE ISOTOPIC COMPOSITION OF THE MINERALIZING FLUIDS

The $\delta^{18}O$ compositions of quartz, the δD of H_2O and the $\delta^{13}C$ of CO_2 in inclusion fluids, were obtained in mineralized and barren veins from the FB and FMP gold deposits and the data are organized in Tables 1 and 2. The $\delta^{18}O$ composition of auriferous vein quartz varies from +11.5 to +14.4°/$_{oo}$ (mean of +13.3±1 °'$_{oo}$) in the FB deposit, whereas the range for veins from the FMP deposit is confined to +14.3 - +17.2°/$_{oo}$ (mean of +15.4 ± 0.7 °/$_{oo}$). In the latter deposit, $\delta^{18}O$ of quartz in barren veins ranges from +15.1 to +15.9°/$_{oo}$, with a mean of +15.5 ± 0.3 °/$_{oo}$. The narrow range shown by the $\delta^{18}O_{qtz}$ data suggests that the bulk of the quartz veins in individual deposits, irrespective of the type or gold content, have precipitated from hydrothermal fluids of uniform isotopic compositions, with no drastic change in the temperature (Kerrich, 1989). The lower $\delta^{18}O$ values shown by the vein quartz of the FB deposit, compared to the FMP deposit, may be accounted for the higher temperature range estimated for the fluid regime in this deposit. The $\delta^{18}O$ composition of the fluid calculated from the $\delta^{18}O_{qtz}$ values and the quartz-H_2O fractionation equation of Matsuhisa et al. (1979), valid for the estimated T of the fluid, yielded mean values of +9.0 ± 1.2 °/$_{oo}$ e +10.8 ± 0.5 °/$_{oo}$ for the FB and the FMP gold deposits, respectively.

The δD composition of H_2O in fluid inclusions from quartz samples of both deposits differ significantly: they cluster in the interval of -70 to -153°/$_{oo}$ for the FB deposit and extend from -30 to -82°/$_{oo}$ in the FMP deposit, irrespective of auriferous or barren veins. Still in the latter, significant variations in the δD are also shown by some individual gold-bearing veins (Table 1). The low δDH_2O values for the FB gold deposit are interpreted as the result of mixing of H_2O released from early-formed H_2O-CO_2 inclusions and isotopically lighter H_2O extracted from later generations of aqueous fluid inclusions (Goldfarb et al., 1991). Fluid inclusion studies carried out by Xavier (1988) and Coelho et al. (1991) demonstrated that the occurrence of trails of secondary low-salinity aqueous inclusions is ubiquitous in mineralized quartz veins of this deposit. The variation of δDH_2O for the FMP is attributed to hydrogen isotope fractionation between liquid H_2O and CH_4, formed during the interaction of the fluids with the carbon present in the host carbonaceous matter-rich lithologies, via reaction:

$$2C+2H_2O=CO_2+CH_4$$

In this process, the δD is partitioned preferentially into the residual liquid phase. It is very unlikely that the magnitude of the dispersion in δDH_2O values in both deposits was due to the mixing of depleted and enriched reservoirs. Any such mixing would reflect in shifts of both δDH_2O and $\delta^{18}O_{fluid}$, but the uniformity of the quartz $\delta^{18}O$ values eliminates this possibility.

The $\delta^{13}C$ composition of the fluid inclusion CO_2 for the FB deposit is tightly constrained between -5.6 and -10.4°/$_{oo}$, with a mean at -7.6 ± 1.7°/$_{oo}$ (Table 1), whereas for the FMP the $\delta^{13}CCO_2$ values vary from -6.0 to -10.2°/$_{oo}$ and show a mean at -7.9 ± 1.3°/$_{oo}$ (Table 2). Additionally, the values of $\delta^{13}CCO_2$ for barren veins of the FMP deposit do not seem to vary substantially from the values attributed to the mineralized veins: they range from -6.5 to -9.2°/$_{oo}$ and show a mean at -7.8±1.2°/$_{oo}$ (Table 2). Collectively, all these $\delta^{13}CCO_2$ values overlap, suggesting a common carbon reservoir for the fluids in both deposits. Nevertheless,

TABLE 1

VEIN	$\delta18O_{qtz}$	$\delta^{18}O_{H2O}$		δD_{H2O}	$\delta^{13}C_{CO2}$
SAMPLES		390°C	455°C		
FB-54	12.3	8.0	9.3	-153	-7.2
FB-56	11.5	7.2	8.5	-92	-7.4
FB-58	13.9	9.6	10.9	-	-8.7
FB-61	14.4	10.1	11.4	-90	-6.4
FB-62	13.8	9.5	10.8	-106	-5.6
FB-63	13.4	9.1	10.4	-70	-10.4
MEAN	13.3 ± 1.0			-102 ± 31	-7.6 ± 1.7

Table 1: Oxygen, hydrogen and carbon isotope data for quartz and inclusion fluids hosted by quartz in D_2 auriferous veins from the Fazenda Brasileiro gold deposit. The isotopic data are reported in per mil ($^o/_{oo}$) relative to SMOW for oxygen and hydrogen and PDB for carbon.

TABLE 2

VEIN	SAMPLES	$\delta^{18}O_{qtz}$	mean	$\delta^{18}O_{H2O}$		δD_{H20}	mean	$\delta^{13}C_{CO2}$	mean
SYSTEM				360°C	420°C				
NE-SW vein	TRI02/50E	15.4		10.3	11.7	-77	-		
			15.0			-78		-8.0	
	TRI02/55E	15.0	±	9.9	11.3	-78	±	-77	±
			0.3				1.0		0.3
	TRI14/495E	14.7		9.6	11.4	-79		-8.3	
NE-SW vein	FRAI41/57,40m	15.1	10.0	11.4		-37	-6.5	-	
N-S vein	TRII27/TRII40	16.2	16.7	11.1	12.5	-65	-62	-6.0	-6.4
			±				±		±
	TRII40/303E	17.2	0.7	12.1	13.5	-59	4.2	-6.7	0.4
N-S vein	FRAII12/181,95m	14.3	14.9	9.2	10.6	-65	-51	-10.2	-8.6
			±				±		±
	FRAII12/184,25m	15.5	0.8	10.4	11.8	-37	19.8	-7.11	2.2
N-S vein	FRAII15/53,50m	15.5	15.4	10.4	11.8	-51	-46	-9.5	-9.6
			±				±		±
	FRAII15/57,00m	15.4	0.0	10.3	11.7	-41	7.0	-9.6	0.0
N-S vein	TRIII78	15.5		10.4	11.8	-68		-7.0	-
N-S vein	TRIII07/898E	14.9	9.8	11.2	-82	-6.7	-		
E-W vein	TRII27/327E	15.7	15.7	10.6	12.0	-67	-74	-9.0	-8.7
			±				±		±
	TRII27/335E	15.8	0.0	10.7	12.1	-81	9.8	-8.4	0.4
barren veins	FRAI18/92,53m	15.3	10.2	11.6	-53	-8.3			
			15.5				-55		-7.8
	FRAII12/178,00m	15.9	±	10.8	12.2	-30	±	-6.5	±
			0.3				3.9		1.2
	FRAII12/80,90m	15.8		10.7	12.1	-58		-9.2	
	TRIII07/898E	15.1		10.0	11.4	-79		-7.2	

Table 2. Oxygen, hydrogen and carbon isotope data for quartz and inclusion fluids hosted by quartz in auriferous veins and barren veins from the Fazenda Maria Preta gold deposit. The isotopic data are reported in per mil ($^o/_{oo}$) relative to SMOW for oxygen and hydrogen and PDB for carbon.

no major differences in the $\delta^{13}CCO_2$ values were recognized during release of CO_2 in stepped heating runs (300 to 700°C) carried out in some quartz samples, indicating that even if different generations of CO_2-rich fluids are present, they show uniform $\delta^{13}C$ composition, probably evidencing a common fluid reservoir. The variation of the isotopic values observed in these deposits may reflect changes in the redox state of the fluids due to the interaction with the carbonaceous lithologies. In such a context, buffering of the redox state of the fluids to lower levels, would cause a depletion of the $\Sigma\, \delta^{13}C_{fluid}$ (Kerrich, 1989).

The $\delta^{34}S$ data obtained from arsenopyrite and pyrite in mineralized samples of the FB and FMP gold deposits are grouped in the interval of +0.1 to +1.3‰ (mean at +0.62 ± 0.45‰) and +0.5 to +6.6‰ (mean at +2.5 ± 0. 4‰), respectively (Fig. 3). Sulphides from barren samples of the FPM deposit show a much broader range of values than the gold-related sulphides, varying from -9.6 to +15‰ (Fig. 3). The $\delta^{34}S$ value of a mineral species precipitated from a hydrothermal fluid is the result of several interactive physico-chemical factors, including the original $\delta^{34}S$ value of the fluid reservoir, temperature, pH, and the redox state of the fluid. The first parameter can be regarded as a source characteristic, whereas the latter three are particularly governed by conditions at the site of the ore deposition (Ohmoto and Rye, 1979). Consequently, the narrow range and the close mean values obtained for the mineralized samples imply a homogenous $\delta^{34}S$ composition in the fluid reservoir, as well as constant physico-chemical conditions at the gold deposition sites in both deposits. Considering that the gold-bearing sulphide assemblage is dominated by arsenopyrite-pyrite-pyrrhotite, and noting the calculated fO_2 of the fluids, the absence of sulphate minerals and the ubiquitous presence of carbonaceous matter in the host rocks, the major sulphur species in the fluid is assumed to be H_2S rather than SO_2. Under such conditions, the $\delta^{34}S_{mineral}$ is insensitive to redox shifts and only minor enrichments (~1‰) relative to the fluid occurs (Ohmoto and Rye, 1979). In other words, $\delta^{34}S$ will show a restricted range of values, consistent with the reported data for the mineralized samples, and thus the $\delta^{34}S_{mineral}$ is a good approximation of the $\delta^{34}S_{fluid}$. Conversely, the scattering of the $\delta^{34}S$ values for several barren samples from the FMP deposit may indicate different sources of sulphur or large fractionation between $\delta^{34}S_{mineral}$ and $\delta^{34}S_{fluid}$ due to changes in the physico-chemical conditions in the environment of sulphide deposition.

DISCUSSION

The low-salinity, CO_2-rich fluids defined for the FB and FMP gold deposits, in the Rio Itapicuru greenstone belt, are typical of fluids associated with Precambrian greenstone gold deposits in other cratonic areas (*e.g.* Australia, Canada, South Africa, Zimbabwe, etc.; Groves and Foster, 1991). However, the reservoir for the major components of these fluids, as well as the ultimate processes responsible for the generation of high volumes of such fluids, remain debatable.

In the case of the FB gold deposit, the $\delta^{18}OH_2O$ values may support either metamorphic or magmatic/mantle sources, whereas the δD data are similar to the isotopic signature of evolved meteoric waters, as proposed by Nesbitt et al., 1986, for the Mesozoic mesothermal precious metal mineralization of the

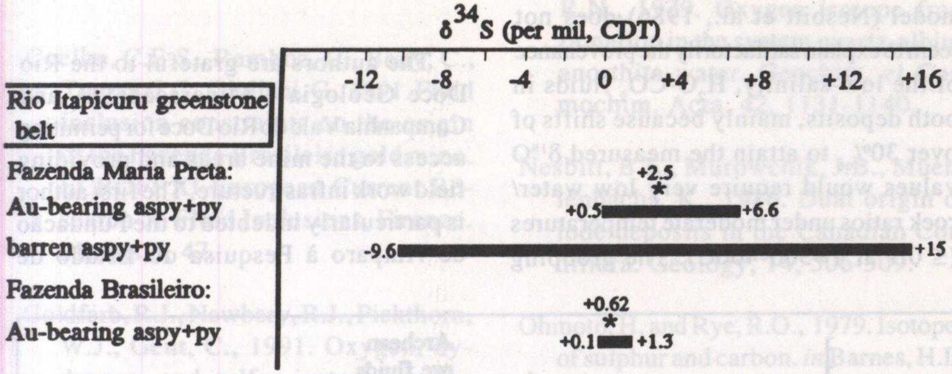

Fig. 3: Range of $\delta^{34}S$ values from sulphides of the Fazenda Brasileiro and Fazenda Maria Preta gold deposits. Also shown is the range of $\delta^{34}S$ values sulphides in barren samples of the Fazenda Maria Preta gold deposit.

Canadian Cordillera (Fig. 4). However, as mentioned in the previous section, the δD data are interpreted as the result of mixing of inclusion fluids of different generations and, consequently, they do not correspond to the original δDH_2O composition of the auriferous fluids. Collectively, the $\delta^{18}OH_2O$ and the δDH_2O compositions for the FMP gold deposit seem to be consistent with a metamorphic origin for the fluids (Fig. 4). However, the values of -30 to -82 $^{\circ}/_{oo}$ possibly represent inclusion fluids that have interacted with carbonaceous matter. The range of -37 to -59 $^{\circ}/_{oo}$ probably better defines the δDH_2O composition of the ore-bearing solutions, since these values were obtained from vein samples dominated by H_2O-CO_2 inclusions which represent homogenous fluids which did not take part in reaction with carbonaceous matter.

The $\delta^{13}C$ compositional range of inclusion CO_2 obtained for the FB and FMP gold deposits indicate that the bulk of the carbon was not derived from a reduced carbon reservoir ($\delta^{13}C$= -23.2 to -30.8 $^{\circ}/_{oo}$; Xavier, 1991) or from marine carbonates ($\delta^{13}C$= -2 to +4$^{\circ}/_{oo}$). On the basis of these $\delta^{13}C$ values, it is not possible to differentiate between a magmatic/mantle sources and a crustal source for the carbon of the fluids.

In both deposits, the mean $\delta^{34}S$ values close to 0$^{\circ}/_{oo}$ of the gold-related sulphides point to a magmatic source for the sulphur, indicating some contribution from magmatic fluids.

In summary, the stable isotope data reveal that the major components of the FB and FMP gold-bearing fluids could have been derived from different reservoirs during metamorphic and mantle/magmatic processes. Indeed, available geochronological data (Silva, 1992) have indicated that the emplacement of the granitic domes took place concomitantly with the regional metamorphism of the supracrustals and, in this context, both metamorphic and magmatic fluids (either derived from the mantle or from the melting of portions of the lower crust) could have contributed to the bulk of the auriferous fluids. The meteoric water model (Nesbitt et al., 1986) does not seem to explain satifactorily the provenance of the low-salinity, H_2O-CO_2 fluids in both deposits, mainly because shifts of over 30$^o/_{oo}$ to attain the measured $\delta^{18}O$ values would require very low water/rock ratios under moderate temperatures ($\leq$ 0.1 at T=300-400C). The grouping of the $\delta^{18}O_{quartz}$, $\delta^{13}CCO_2$, $\delta^{34}S_{sulphide}$ within a narrow range of values and the pervasive hydrothermal alteration in the shear zone domains, favour a fluid-dominated hydrothermal system and, consequently, high water/rock ratios. However, this model cannot be thoroughly assessed since the δD values of the meteoric water in the area and its latitude during the lower Proterozoic are not known.

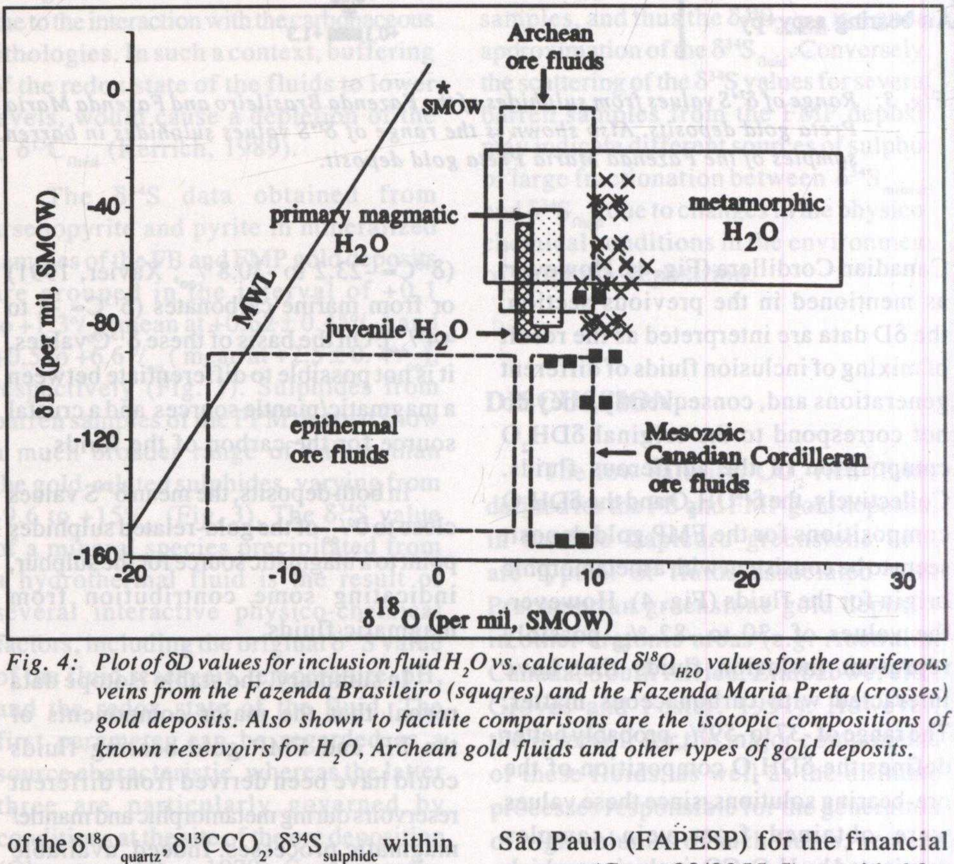

Fig. 4: Plot of δD values for inclusion fluid H_2O vs. calculated $\delta^{18}O_{H2O}$ values for the auriferous veins from the Fazenda Brasileiro (squqres) and the Fazenda Maria Preta (crosses) gold deposits. Also shown to facilite comparisons are the isotopic compositions of known reservoirs for H_2O, Archean gold fluids and other types of gold deposits.

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