SHORT NOTE

# Gold processing residue from Jacobina Basin: chemical and physical properties

***Luiz Rogério Pinho de Andrade Lima*[1], *Letícia Alonso Bernardez*[2] *& Luis Alberto Dantas Barbosa*[2]**

**Abstract** Gold processing residues or tailings are found in several areas in the Itapicuru River region (Bahia, Brazil), and previous studies indicated significant heavy metals content in the river sediments. The present work focused on an artisanal gold processing residue found in a site from this region. Samples were taken from the processing residue heaps and used to perform a physical and chemical characterization study using X-ray diffraction, scanning electron microscopy, neutron activation, X-ray fluorescence, induced coupled plasma-mass spectrometry, among others analytical methods. The results indicate that the material is composed mainly by quartz and goethite. The average size of the processing residue particles is about 150 microns, and the density is close to that of quartz. The main elementary constituents are silicon, iron, aluminum, magnesium, and potassium. Among the trace elements, it can be highlighted: sodium, titanium, chromium, zirconium, calcium, sulfur, manganese, copper, mercury, and gold. A remarkable feature of these gold processing residue is that the gold and mercury are both concentrated in the fine and coarse particles. The processing residue gold content is of about 1.8 mg/kg and the mecury content is of about 10 mg/kg. The gold content of this residue has the same order of magnitude of gold ores treated by a cyanidation plant in this region.

*Keywords:* gold ore, Jacobina Basin, São Francisco Province, tailings, artisanal gold mining.

**Resumo** *Rejeitos da produção artesanal de ouro da região do Grupo Jacobina: propriedades químicas e físicas.* Rejeitos da extração de ouro são encontrados em varias áreas da bacia do Rio Itapicuru (Bahia, Brasil) e estudos precedentes indicaram valores significantes para as concentrações de metais pesados nos sedimentos transportados pelas águas destes rios. Neste estudo, amostras foram coletadas nas pilhas de resíduos da produção artesanal de ouro (garimpos) e usadas para a sua caracterização física e química usando difração de raios x, microscopia eletrônica de varredura, ativação de nêutrons, fluorescência de raios x, espectrometria de massa com fonte de plasma induzido, dentre outros métodos analíticos. Os resultados indicaram que o material é composto basicamente por quartzo e goetita. O tamanho médio das partículas do rejeito mineral é de cerca de 150 microns e a densidade é próxima do valor do quartzo. Os principais elementos encontrados no rejeito mineral são: silício, ferro, alumínio, magnésio e potássio. Dentre os elementos traços os principais são: sódio, titânio cromo, zircônio, cálcio, enxofre, manganês, cobre, mercúrio, e ouro. Uma característica interessante deste resíduo mineral é o fato que tanto o ouro quanto o mercúrio estão concentrados tanto nas partículas finas quanto nas grossas, mas não nas partículas de dimensão intermediaria. O rejeito mineral estudado apresenta uma concentração de ouro de cerca de 1.8 mg/kg e de mercúrio de cerca de 10 mg/kg. A concentração de ouro deste rejeito tem a mesma ordem de grandeza encontrada em minérios de ouro tratados por uma usina localizada nesta região.

*Palavras-chave*: Minério Aurífero, Grupo Jacobina, Cráton do São Francisco, Rejeitos, Garimpos.

**INTRODUCTION** Environment degradation due to artisanal gold mining has been widely reported (Hinton *et al.*, 2003), and a survey performed at the Itapicuru River hydrographic basin, located at a semi-arid region of the Northeast of the State of Bahia (Brazil), indicated the presence of high content of heavy metals (de Andrade Lima, 1995; Queiroz *et al.*, 1998).

The characterization of gold processing residues is relevant because it can aid the development of specific clean up or immobilization techniques to minimize this major environmental problem (Hinton *et al.*, 2003). The specific gold processing residue discussed in this work is located at a semi-arid region that is vulnerable because it is relatively close to drink water sources. This residue is found in the Serra de Santa Cruz, at 10°45'13"S, 40° 23'04"W, in the city of Pindobaçu (Bahia), which is 414 km far from the state capital, Salvador.

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1 - Departamento de Ciência e Tecnologia dos Materiais,Universidade Federal da Bahia, Salvador (BA), Brazil. E-mail: lelo@ufba.br

2 - Departamento de Ciência e Tecnologia dos Materiais, Univ. Federal da Bahia, Salvador (BA), Brazil. E-mails: leticiab@ufba.br e ladantas@ufba.br.

The gold processing residue characterized in this work is provenient from a site that is located in the Jacobina basin, which is part of the São Francisco province of Bahia, and containing gold-bearing conglomeratic units (Barbosa and Dominguez, 1996; Milesi et al, 2002). Gold is industrially mined in the Jacobina basin from gold-pyrite-bearing conglomerates and artisanaly mined from both quartz veins and gold-pyrite-bearing conglomerates. There are also in the Jacobina basin disseminated gold-bearing mineralization, such as discordant in quartz veins, at the contact basic-ultrabasic rocks, and subconcordant at different statigaphic levels in quartzite and conglomerate. The Serra de Santa Cruz site is located close to a gold mine, where the mineralization is contained in a system of Au-As subvertical veins and extension fissures modified by deformation, and the veins are composed of quartz with free gold, pyrite, rare arsenopyrite, tourmaline, chlorite, and white mica surrounded by a halo of disseminated pyrite within the quartzite (Milesi et al, 2002).

In this study, the physical and chemical properties of the residue from artisanal gold mining sites from the Pindobaçu region are described, including the mineralogy, size distribution, density, and chemical composition.

## MATERIALS AND METHODS

**Tailings sampling** Previous sampling campaign were performed at the gold processing residue (tailings) heap of the Pindobaçu artisanal gold mining area to provided information about the site, the extraction and processing method and the extension of the environmental degradation (de Andrade Lima, 1995). In January 2002, the gold processing residue heaps was sampled in several points and the solid material dried, homogenized, resampled and used for the granulometric, chemical and mineralogical studies presented in this work.

**Physical characterization** The X-ray diffraction analysis (Fig. 1), which is used to identify the main mineralogical composition of the residue, were performed on a Philips PW1710 diffratometer with CuKα radiation at the Department of Mining, Metals and Materials Engineering of McGill University (Canada). The diffractogram interpretation was made with the assistance of the X'Pert Quantify search match software by PANalytical.

The scanning electron microscope JEOL 840-A equipped with a X-ray dispersion energy spectrometry system (EDS) from the Department of Mining, Metals and Materials Engineering of McGill University (Canada) was used to evaluate the composition and the texture of the particles of the tailings. The samples were directly mounted in glass lames with an epoxy resin and carefully polished. These lames were than coated with either carbon or a gold-palladium alloy. The backscattered electron images and the correspondent EDS analyses were evaluated to infer about the phases.

The size distribution of the gold processing residue was evaluated using the conventional screening test with a ro-tap and a set of screens from 20 to 400 mesh Tyler (Wills and Napier-Munn, 2006).The density of this material was measured using the a pycnometer of 100 mL (Klein, 2002).

**Chemical characterization** Several analytical methods were used to determine the gold processing residue elements content in order to produce representative results. These methods included induced coupled plasma (ICP-AES), X-ray fluorescence (XRF), induced coupled plasma and mass spectrometry (ICP-MS), neutron activation analysis (INAA), fire-assay, infrared, ion selective electrode, atomic absorption with cold vapor generation (Vértes *et al.*, 1998).The neutron activation analyses were performed at the Department of Physical Engineering of the Polytechnic School (University of Montreal, Canada), and the other analyses were performed at the Activation Laboratories Ltd, (Canada).

## RESULTS AND DISCUSSION

**Physical characterization** The diffratogram scan for the gold processing residue sample shows that it is predominantly composed by quartz ($SiO_2$) with small amount of goethite (FeO(OH)), which is in agreement with the site geology (Milesi *et al.*, 2002; Barbosa and Dominguez, 1996; Klein, 2002).

Some backscattering scanning electron microscope images of the samples are presented in figure 2,

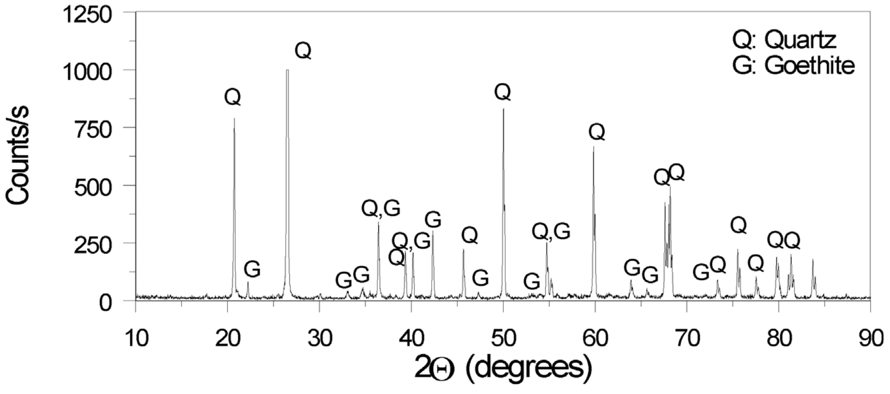

*Figure 1 - X-ray diffractogram for the gold processing residue.*

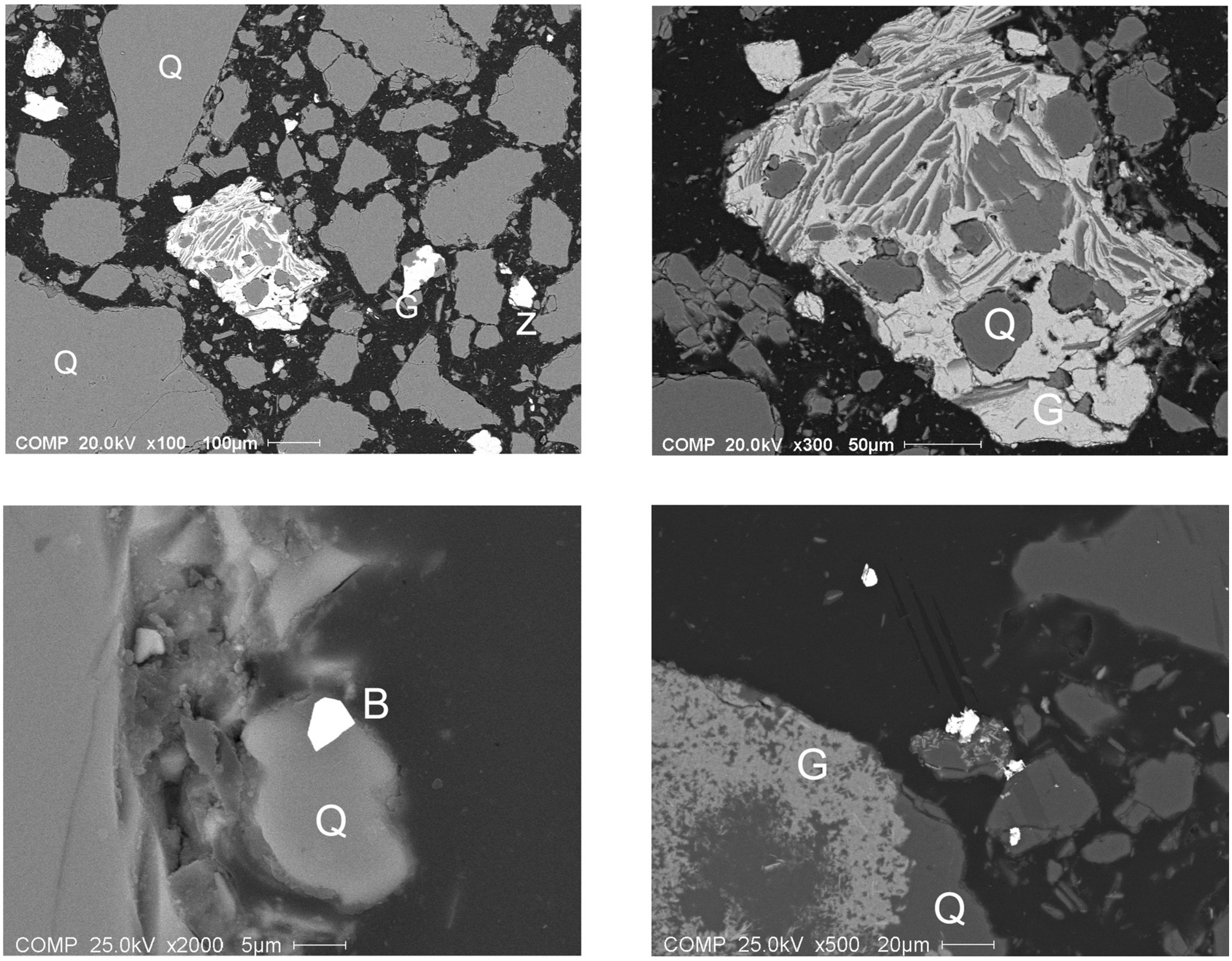

*Figure 2 - Backscattering scanning electron microscope images of the gold processing residue particles. B stands for bismuth (Bi), Q for quartz ($SiO_2$), G for goethite ($FeO(OH)$), and Z for zircon ($ZrSiO_4$).*

which show the predominance of quartz and the presence of several goethite regions. The SEM images also shows the presence of some scarce elements, such as titanium, zirconium, cerium, bismuth, and lanthanum that are originated in the granites of the Jacobina geologic region (Milesi *et al.*, 2002; Barbosa and Dominguez, 1996).The liberated gold particle found in this sample is about 3 microns.

The density of the gold processing residue is 2.76 g/cm$^3$ that is close to the quartz density (2.65 g/cm$^3$), the major mineralogical constituent of the tailings (Klein, 2002).The enhancement in this value is clearly due to the presence of goethite.

The size distribution of the particles of the Pindobaçu artisanal gold mining residue is presented in figure 3. Note that the characteristic diameter that retains half of the particles population ($d_{50}$) is about 150 microns, which characterizes a relatively coarse tailings for a gold ore (Marsden and House, 2006). It is high likely that the gold particles were not completely liberated due to the inadequate grinding procedure used in this artisanal gold mining operation (Wills and Napier-Munn, 2006; Marsden and House, 2006).

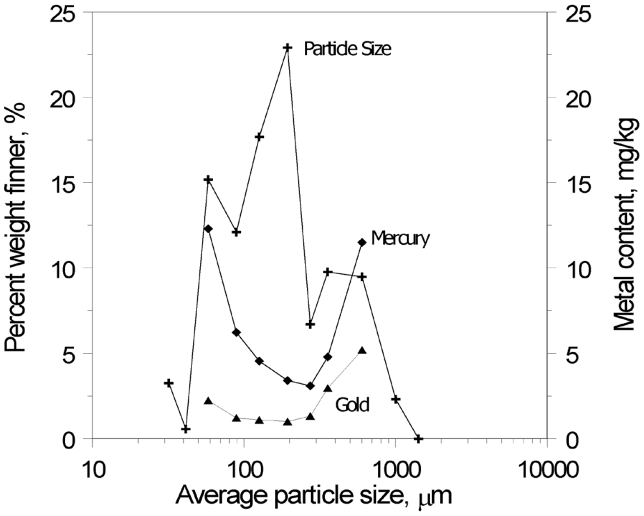

*Figure 3 - Size distribution and gold and mercury content in the particles of the gold processing residue.*

**Elementary chemical analysis** Figure 3 also shows the gold and mercury content and distribution in the particles. Gold is concentrated in the coarse particles, and a large amount of mercury is found in both finer and coarse particles. Mercury occurs associated with gold, which seems indicate the formation of an amalgam with this metal. The gold and mercury distribution shows that gold is more heterogeneously distributed in the particles due to the concentration of particles with intermediate size and the gold location of this metal in the coarse particles (Hinton *et al.* 2003).

Table 1 presents the concentration of the major constituents of the gold processing residue and table 2 the concentration of the trace elements. The analytical method used for the determination of each element is also presented in these tables, and in several cases an element was analyzed using distinct sample and more than one method. This procedure is useful to confirm the results, evaluate the detection limit of the analytical method, and to give an idea about the sample homogeneity of the samples. As indicated by the mineralogical characterization, the main constituents of the residue are silica and iron oxide that account for about 95% of the weight. The sample also has some aluminum, magnesium, and potassium. Among the trace elements, the most abundant are: arsenic, barium, cerium, chromium, copper, lead, manganese nickel, titanium, tungsten, vanadium, zinc, and zirconium. Several of these elements came from the granites of the Jacobina geologic region (Milesi *et al.*, 2002, Barbosa and Dominguez, 1996; Klein, 2002).

The residue gold content is about 1.8 mg/kg and the mercury content is about 10 mg/kg, which are in agreement with the results of metal content in each size fraction, shown in figure 3. Note that the gold content of the residue is high and has the same order of magnitude of the gold ore treated by a cyanidation plant in this region (Marsden and House, 2006).

*Table 1 - Concentration of the major constituents in the gold processing residue (in %).*

| Element | INAA | ICP-MS | ICP [a] | Miscellaneous |
|---|---|---|---|---|
| $SiO_2$ | 84 | - | - | - |
| $Fe_2O_3$ | 9.4 | 11.4 | 10.5 | - |
| $Al_2O_3$ | 2.5 | 2.36 | 1.28 | - |
| MgO | 0.46 | 0.3 | 0.40 | - |
| $K_2O$ | 0.18 | 0.18 | 0.22 | - |
| $P_2O_5$ | - | - | 0.165 | - |
| $Na_2O$ | 0.0930 | 0.0364 | 0.108 | - |
| $TiO_2$ | 0.164 | - | 0.0834 | - |
| $Cr_2O_3$ | 0.0354 | 0.0300 | - | - |
| CaO | 0.0157 | 0.0140 | 0.0280 | - |
| C | - | - | - | 0.1020 [b] |
| S | <0.300 | - | 0.017 | 0.020 [b] |

a: With total digestion; b: Infrared

*Table 2 - Trace element contents in the gold processing residue (in mg/kg).*

| Element | INAA | ICP-MS | ICP [a] | XRF [b] | Miscellaneous |
|---|---|---|---|---|---|
| Ag | <0.2 | 1.02 | <0.3 | - | - |
| As | 71 | 77.9 | - | - | - |
| Au | 1.7 | - | - | - | 1.876 [c] |
| B | - | <1 | - | - | - |
| Ba | 85 | 102 | - | - | - |
| Be | - | 0.8 | 1 | - | - |
| Bi | - | 13.7 | 21 | - | - |
| Br | 1.4 | - | - | - | - |
| Cd | <0.6 | 0.2 | 0.7 | - | - |
| Ce | 36 | 43.8 | - | - | - |
| Cl | 20 | - | - | - | - |
| Co | 5.4 | 6.6 | 7 | - | - |
| Cs | 0.11 | 1.77 | - | - | - |
| Cu | 51 | 66.2 | 87 | - | - |
| Dy | 2.5 | 2.0 | - | - | - |
| Er | - | 1.1 | - | - | - |
| Eu | 0.84 | 0.75 | - | - | - |
| F | - | - | - | - | 400 [d] |
| Ga | <15 | 6.1 | - | 9 | - |
| Gd | <15 | 3.0 | - | - | - |
| Ge | <7 | 0.1 | - | - | - |
| Hf | 5.5 | 0.6 | - | - | - |
| Hg | 8.8 | - | - | - | 9.927 [e] |
| Ho | - | 0.4 | - | - | - |
| I | 3.6 | - | - | - | - |
| In | 0.054 | <0.1 | - | - | - |
| Ir | <0.005 | - | - | - | - |
| La | 24 | 28.5 | - | - | - |
| Li | - | 1 | 1 | - | - |
| Lu | 0.27 | 0.2 | - | - | - |
| Mn | 68 | 119 | 101 | - | - |
| Mo | 1.1 | 1.6 | <1 | - | - |
| Nb | - | 1.3 | - | <1 | - |
| Nd | 17.9 | 22.4 | - | - | - |
| Ni | 67 | 70.3 | 76 | - | - |
| Os | <0.07 | - | - | - | - |
| Pb | - | 41.8 | 21 | - | - |
| Pd | <1 | - | - | - | - |
| Pr | <10 | 6.5 | - | - | - |
| Pt | <1 | - | - | - | - |
| Rb | - | 4.3 | - | 6 | - |
| Re | <0.1 | <0.001 | - | - | - |
| Ru | <0.5 | - | - | - | - |
| Sb | 1.7 | 1.7 | - | - | - |
| Sc | 5.4 | - | - | - | - |
| Se | <3 | 3.2 | - | - | - |
| Sm | 3.5 | 3.7 | - | - | - |
| Sn | <5 | <1 | - | - | - |
| Sr | <12 | 8.0 | 11 | 10 | - |
| Ta | 0.33 | <0.1 | - | - | - |
| Tb | 0.49 | 0.4 | - | - | - |
| Te | <10 | 1.5 | - | - | - |
| Th | 4.2 | 3.6 | - | - | - |
| Tl | - | 0.09 | - | - | - |
| Tm | <1 | 0.2 | - | - | - |
| U | 2.9 | 2.8 | - | - | - |
| V | 49 | 46 | 58 | - | - |
| W | 62 | 7.4 | - | - | - |
| Y | - | 8.6 | 9 | 16 | - |
| Yb | 1.6 | 1.0 | - | - | - |
| Zn | 41 | 80.4 | 55 | - | - |
| Zr | - | 32 | - | 187 | - |

a: With total digestion; b: With pressed pellet; c: Fire assay; d: Ion selective electrode; e: Cold vapor with flow injection mercury system (FIMS)

**CONCLUSIONS** The XRD results show that the studied gold processing residue is mainly composed by quartz and goethite, which is confirmed by SEM images and EDS spectra. The elementary analysis of the residue, performed with different methods, such as ICP-MS, INAA, XRF, ICP, and AAS, confirms the mineralogical results and reveals the presence of several less common elements, associated with the granite of the Jacobina geologic region. The residue gold content is about 1.8 while the mercury content is about 10 mg/kg, which is very high. The gold and mercury distribution in the size fractions indicates that these metals are closely associated.

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