INTRODUCTION Fluid inclusions are tiny samples of fluids trapped in minerals either during or after their crystallization. For them, information about several physico-chemical parameters such as composition, salinity, density, temperature, and pressure of formation may be determined.

Fluid inclusion studies carried out in greenstone belt gold deposits have shown that gold is deposited by low salinity (< 5 eq. wt% NaCl), H₂O-CO₂ solutions with temperatures varying from 280° to 500°C and pressures between 0.8 and 5.0 kb (Phillips & Groves 1983, Smith et al. 1984, Brown & Lamb 1986, Groves & Phillips 1987).

The purpose of this work is to determine the physico-chemical characteristics, evolution, and nature of the gold-bearing fluids, through a systematic fluid inclusion investigation in several mineralized samples from the Fazenda Brasileiro Gold Mine, in the southern portion of the Rio Itapicuru greenstone belt, one of the main primary gold producing areas in Brazil. Despite the difficulty to correlate the inclusion fluids studied to the actual gold-depositing fluids, this word, also attempts to provide valuable data to the understanding of the processes by which the gold content of the fluids was deposited.

GEOLOGICAL SETTING In the northern portion of the São Francisco Craton in the State of Bahia, a group of supracrustal rocks occurring as in-folds and surrounding oval-granite–gneiss domes was defined and later known as the Rio Itapicuru greenstone belt, of Archean or Lower Proterozoic age (Fig. 1) (Kishida 1979, Teixeira 1984).

According to Kishida (op. cit.) and Kishida & Riccio

CHARACTERIZATION AND EVOLUTION OF ORE-FORMING FLUIDS AT FAZENDA BRASILEIRO GOLD MINE, RIO ITAPICURU GREENSTONE BELT, BA

ROBERTO PEREZ XAVIER

ABSTRACT Fluid inclusion studies by microthermometry and Raman spectroscopy carried out on the main hosts of the gold mineralizations at Fazenda Brasileiro Mine, southern portion of Rio Itapicuru greenstone belt define the mineralizing fluids as relatively dense (0.85-0.95 g/cm³) and hot (> 400°C) solutions composed essentially of CO₂ (89-7-85.3 mole%) and minor amounts of CH₄ and N₂, which gradually evolved to more aqueous fluids (40 to 62.5 mole% H₂O) of low salinity (< 10 eq. wt% NaCl) at lower temperatures (250-300°C). The isochores of the carbonic and H₂O-CO₂ fluids and the temperature of total homogenization combined with geothermometric data on the ore paragenesis, point to at least two periods of gold deposition: 1.380-419°C and 2.2-3.2 kb in the quartz-feldspathic and arsenopyrite-pyrite quartz veins at 2.700-300°C and 1.2-1.4 kb in the massive quartz vein. Based on experimental work on the solubility of gold complexes, chemical characteristics of mineralizing fluids, ore paragenesis and Au/Ag ratio, it was possible to speculate that the transport of gold occurred mainly by reducing (high ΣH₂S/ΣSO₄) stages, as Au-complexes, the so-called “Au(II) Au(III)”, and as Au3+ or Au5+ (H₂S)²⁻. In the earliest stage of mineralization conditions of gold deposition were probably attained due to fluid/rock reactions which led to a decrease in the activity of S²⁻ by precipitating sulphides (arsenopyrite, pyrite, pyrrhotite, etc). The predominance of the H₂O regime over the CO₂ regime in the latest stage might have been the cause of CO₂ dilution, decrease in pH and oxidizing conditions as a consequence, the precipitation of gold. The fluid inclusion data also suggest a metamorphic origin for the mineralizing fluids, most likely through the devolatilization of the basal sequences of the volcano-sedimentary pile. The devolatilization process would be able produce low salinity, H₂O-CO₂ fluids which would later migrate through favourable structural sites and deposit their metal content.

RESUMO CARACTERIZAÇÃO E EVOLUÇÃO DOS FLUIDOS MINERALIZANTES NA MINA DE OURO FAZENDA BRASILEIRO, GREENSTONE BELT DO RIO ITAPICURU, BA, BRASIL. Os estudos de inclusões fluidas por microtermometria e espectroscopia Raman nas hospedeiras das mineralizações auríferas da Fazenda Brasileiro, localizada na parte sul do greenstone belt do Rio Itapicuru, permitiram definir os fluidos mineralizantes como soluções quentes (> 400°C), de densidade relativamente alta (0,85-0,90 g/cm³), inicialmente compostas por CO₂ (89,7-85,3 mole%) e pequenas quantidades de CH₄ e N₂, que gradualmente evoluem para soluções que se tornam gradativamente mais aquosas (de 40 a 62,5 mole% de H₂O) e de baixa salinidade (< 10 eq. % em peso NaCl). As isocôrnes dos fluidos carboníferos e aquacarboníferos e as temperaturas de homogenização total, combinadas com dados de geothermometria fornecidos pela paragenese mineral, sugerem a existência de pelo menos dois períodos de deposição do ouro: 1. 380-419°C e 2.2-3.2 kb na brecha quartz-feldspática e veio de quartz com arsenopirita e pirita a 2.700-300°C e 1.2-1.4 kb no veio de quartz moção. Baseando-se em estudos experimentais da solubilidade de complexos sulfídicos, nas características químicas dos fluidos mineralizantes, e na razão Au/Ag, pode-se presumir que o ouro foi transportado como iocomplexos do tipo Au(H₂S)₂(H₂S)₄, H₂Au (H₂S)₄ ou Au₄(H₂S)₈S⁻₂ em soluções redutoras (razão ΣH₂S/ΣSO₄ alta) e com PH em torno da neutralidade ou levemente alcalina. Nos estágios mineralizantes iniciais, condições de elevada atividade de sulfeto e baixa atividade de CO₂ levaram ao decréscimo na atividade de S²⁻ com a precipitação dos sulfetos metálicos (arsenopirita, pirita, pirrotita etc). Nos estágios de colocação dos veios de quartz tardios acredita-se que a deposição do ouro tenha ocorrido por introdução de H₂O no sistema, causando a diluição de CO₂, diminuição do pH, oxidação e consiguiente devolatilização dos complexos transportadores deste metal. A origem metamórfica desses fluidos mineralizantes é também indicada pelo estudo de inclusões fluidas, entendendo-se que possam ser derivados a partir de processos de devolatilização das sequências mais baiais do greenstone belt, capazes de produzir fluidos carboníferos e auca carboníferos de baixa salinidade, que posteriormente migram através de âmbitos estruturais favoráveis, causam fraturamento hidráulico e depositam seu conteúdo metálico.

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Figure 1 – Simplified geology of the northern portion of Bahia State and location of the Rio Itapicuru greenstone belt (inner rectangle): 1. Cenozoic cover; 2. phanerzoic sediments; 3. São Francisco Supergroup; 4. Nordeste Fold Belt; 5. Espinhaço Supergroup; 6. Jacobina Group; 7. granulite complex; 8. greenstone belts; 9. gneiss migmatite complex (Teixeira et al. 1982)

(1980), these supracrustal rocks may be divided into three distinct domains: 1. Mafic Volcanic Domain (MVD), 2. Felsic Volcanic Domain (FVD), and 3. Sedimentary Domain (SD) (Fig. 2).

The MVD is dominant throughout the area, comprising massive and pillowed metabasalts of tholeiitic affinity and minor interlayered chemical sediments (iron formation and cherts).

In contrast with these mafic sequences, the FVD is more restricted in area and consists of a rock assemblage of calc-alkalic composition with predominance of pyroclastics (tuffs and agglomerates), andesitic-dacitic lavas, fragmentary epiclastics (sandstones, siltstones, and shales), and chemical sedimentary interlayerings.

The SD forms thick individualized horizons in the upper part of this volcano-sedimentary sequence and is mainly composed of arkoses, conglomerates, greywackes, and pelites.

The intrusive rock suites include: 1. the granite-gneiss domes with granites and granodiorites in their central portion and tonalites at their margins; 2. late-tectonic subvolcanic bodies of quartz feldspathic porphyritic rocks, and 3. gabbroic dykes and sills which occur as interfacing within the MVD and SD, or traverse the granite-gneiss domes (Kishida 1979, Teixeira et al. 1982).

Silva (1983) recognized three distinct metamorphic events within the supracrustal sequence. The M 1 event was interpreted as seafloor metasomatism on part of the volcanic rocks, producing spilites and keratophyres. The M 2 event was related to intrusions of granite-gneiss domes which resulted in a metamorphic zoning within the supracrustal rocks, grading from greenschist facies to amphibolite facies. The effect of the M 3 event is restricted to contact aureoles around late-tectonic intrusives.

Based on mineral parageneses and mineral chemistry, Silva (op. cit.) estimated the P-T values from the metamorphic events as follows: $M_1 = 0.2$ kbar/$<400^\circ$C; $M_2 = 2$-4kbar/400-600$^\circ$C, and $M_3 = <2$kbar/500-600$^\circ$C.

The structural pattern shown by the supracrustal sequence is very complex and the knowledge of the styles of deformation is not homogeneous throughout the greenstone belt. In the southern portion, Teixeira (1984) defined four phases of ductile deformation and one corresponding to a brittle tectonic regime whereas in the western part; studies are still in progress, with emphasis on shear zones (Silva & Matos 1987).

THE GEOLOGY OF THE FAIXA WEBER AND THE GOLD MINERALIZATION AT FAZENDA BRASILEIRO MINE Since 1974, prospecting for gold carried out by Rio Doce Geologia e Mineração S.A.
(Docegeo) has shown several anomalies associated with basalts of the MVD, andesites of the FVD, subvolcanic bodies, and gabbroic sills. One of the most important discoveries has been the Faixa Weber orebodies located at the extreme south of the Rio Itapicuru greenstone belt.

The local stratigraphy is considered to be composed from the bottom to the top of the following lithological associations (Fig. 3) (Teixeira et al. 1988):

1. The Fazenda Canto unit turbidite sequence, composed mainly of fine-grained carbonaceous metasediments, with alternating well laminated metargillite, metasiltstone, and interlayers of black metachert and metagreywacke.

2. The Fazenda Brasileiro unit consisting of gabbroic rocks associated with a magnetite-bearing quartz-chlorite schist ("magnetic schist") and discontinuous and strongly deformed lenticular shaped quartz-feldspathic bodies which are referred as "quartz-feldspathic" breccia. Based on major and trace element geochemistry, Montes Lopes (1982) suggested a calc-alkaline affiliation for the gabbroic rocks and a carbonate facies iron formation nature for the "magnetic schist". In the light of new geochemical, petrological, and structural data, Teixeira (op. cit.) reinterpreted the Fazenda Brasileiro unit as representing a metamorphosed and folded differentiated sill which consists of a basal gabbro which grades upwards to an iron-rich gabbro ("magnetic schist") with lenses of prophyritic anorhobic at the top. In this interpretation, the iron-rich metagabbro appears at the north and south of the basal gabbro due to repetition by folding (Fig. 3).

3. The Riacho do Incó unit, composed of tholeiitic basalt flows with interlayered sedimentary rocks and metagabbro sills.

Fazenda Brasileiro is one of a series of gold deposits along the Faixa Weber whose production reached about 1,000 kg of gold in October 1986 by open-pit mining and heap-leaching of the weathered ore. At present, the transition from open-pit to underground mining is in progress and a selected ore block provided an estimate of 7.9 x 10⁶ ton of ore, with an average grade of 8 g/t (Teixeira op. cit.).

The major orebodies at Fazenda Brasileiro are found within the "magnetic schist" (iron-rich metagabbro), associated with crosscutting carbonate-quartz-albite-sulphide veins and quartz veins a few millimeters to a decimeter thick (Teixeira et al. op. cit.). In the former, gold is mainly found as inclusions or along fractures in sulphide ch1 slats, notably arsenopyrite, and pyrite whereas in the latter gold occurs disseminated.

Both vein types are enveloped by zones of hydrothermal alteration in which the metamorphic assemblage of greenschist facies has been replaced by new mineral associations with a distinct zonation (Marimon et al. 1986). Towards the veins, chlorite gives place to albite and carbonate, magnetite is replaced by pyrite and arsenopyrite, and less commonly there is an increase in biotite with a decrease in quartz.

**RESULTS** Fluid Inclusion Data **ANALYTICAL PROCEDURES**

Microthermometry is the most frequently used non-destructive method in the analysis of inclusion fluids in minerals. It involves the observation of phase changes at low and high temperatures which can be attained by a heating/freezing stage mounted on a normal petrographic microscope. The microthermometry apparatus used in this work is for Chaixmeca type, whose major feature is the capability of readily achieving temperatures between -190°C and 600°C by combining a system of circulating refrigerated liquid N₂ and a resistive heater (Poty et al. 1976).

Doubly-polished sections, 50 to 60 µm thick, were made from the quartz-feldspathic breccia, quartz-albite-sulphide vein and quartz vein, all mineralized samples collected from the Fazenda Brasileiro sequence. These sections were studied under the microscope to select areas of suitable inclusions for microthermometry. Then, small chips (0.5 cm x 0.5 cm x 0.5 cm) containing the selected areas were detached from the doubly-polished sections and inserted in the heating/freezing stage.

The calibration of the microthermometry apparatus was obtained for low temperature runs using a natural H₂O-CO₂ inclusion in quartz, from the Tessiner Alps (Switzerland), with the previous knowledge of its CO₂ melting point (-56.6°C). Potassium dichromate (Tf = 398°C) from Merck P.A. was used to calibrate the stage for high temperatures. These procedures indicated that the average precision of the stage may be placed within ± 0.2°C and ± 0.5°C for low and high temperature intervals respectively. Temperatures measured with the heating/freezing stage were: melting of CO₂ (TmCO₂), melting of ice (Tmi), melting of clathrates (TmCi), CO₂ homogenization (TmCO₂), and homogenization (Tth). Furthermore, several inclusions were also submitted to Laser Raman Microprobe (LRM) to supplement information provided by microthermometry.

In the LRM technique, a monochromatic laser beam is
Plate 1 - A. Diffuse swarms of carbonic inclusions (type A) within quartz of the quartz-feldspathic breccia. Very subordinate $H_2O-CO_2$ inclusions also occur in these groups. Bar scale = 100 µm; B. detail of typical monophase carbonic inclusions which occur in diffuse swarms. Quartz-feldspathic breccia. Bar scale = 20 µm; C. isolated group of $H_2O-CO_2$ inclusions (type B) within quartz of the quartz-feldspathic breccia. Bar scale = 20 µm; D. late low salinity aqueous inclusions (type C) along a healed fracture. Massive quartz vein. Bar scale = 10 µm; E. $H_2O-CO_2$ inclusions in massive quartz vein. Bar scale = 20 µm; F. isolated $H_2O-CO_2$ inclusion, with the carbonic phase filling over 90% of the inclusion volume. Massive quartz vein. Bar scale = 20 µm.

Note that in C, E, and F, quartz crystals are outlined by intergranular inclusions focused by a microscope objective into an individual phase within inclusion cavity, allowing Raman spectroscopy on a microscopic scale. The Raman effect is the shift in frequency that the laser light undergoes during inelastically scattered light emitted by the sample. Raman scattering is of analytical interest, since it is caused by a component-specific molecular
vibrational and rotational phenomena in the sample (Wopenka & Pasteris 1986). The LRM has been used effectively in the study of fluid inclusions to identify different kinds of volatiles (e.g. CO\textsubscript{2}, CO, H\textsubscript{2}S, CH\textsubscript{4}, C\textsubscript{2}H\textsubscript{6}, N\textsubscript{2}) in metamorphic and igneous rocks as well as hydrothermal ore deposits (Rosasco et al. 1975, Dhanelincourt et al. 1979, Xavier 1987). Simple ionic species, like Ca\textsuperscript{2+}, Na\textsuperscript{+}, K\textsuperscript{+}, Cl\textsuperscript{-}, however, are not appreciably Raman active in pure crystalline form or in aqueous solutions, although there have been several attempts to obtain such data (Dubessy et al. 1982).

The LRM used to analyse the carbonic phase of the investigated inclusions in the present work was of Dilor Microdil Instruments, as described by Dhanelincourt et al. (op. cit). The precision of the results was estimated around 10 to 20\% of the obtained values.

**TYPES OF FLUID INCLUSIONS**

Three types of inclusions were recognized:

*Type A* inclusions are single-phase, composed mainly of CO\textsubscript{2} and occur in large groups without planar orientation. They show negative crystal contours (polygonal or diamond shaped) or irregular shapes, ranging from 5 \textmu m to 20 \textmu m. They are classified as monophase carbonic inclusions (Pl. 1B).

*Type B* inclusions consist of two discernible phases at room temperature, H\textsubscript{2}O and CO\textsubscript{2}. The volume ratio between these two phases is variable, but the CO\textsubscript{2} phase is generally dominant and occupies most of the volume cavity of the inclusion. They are 5 \textmu m to 20 \textmu m in size, show negative crystal contours and can be found coexisting with type A inclusions, isolated or even in small groups in the interior of quartz crystals. They are classified as mixed H\textsubscript{2}O-CO\textsubscript{2} inclusions (Pl. 1CES).

*Type C* inclusions are dominant aqueous two-phase, containing liquid and vapor phases at room temperature (H\textsubscript{2}O/H\textsubscript{2}CO\textsubscript{3} > 0.9). Most of type C inclusions are in the range from 2 \textmu m to 10 \textmu m and show variable shapes. In the quartz-feldspathic breccia and sulphide-bearing vein, these inclusions appear mainly along healed fractures and are most likely to represent late aqueous late fluids. In the quartz vein, however, they occur either isolated or in groups with planar arrays, forming patches within the more abundant type B inclusions.

Translucent and opaque minerals in inclusions are rare but when present they do not seem to be true daughter minerals, but accidentally trapped phases. This hypothesis is supported by several lines of evidence: a. only a few inclusions contain these solid phases; b. there are no uniform phase ratios in those inclusions which contain the solid; and c. they do not dissolve on heating (Roedder 1984).

**MICROTHERMOMETRY AND RAMAN SPECTROSCOPY**

Previous microscopy provided the basis for a selection of inclusions for microthermometric investigations.

This helped to identify and select inclusions whose fluid content has preserved some of the main characteristics of the mineralizing fluids responsible for the gold transport and deposition. Thus, some of the factors which were taken into account are: a. mode of occurrence – only relatively isolated inclusions or isolated group of inclusions were considered as reliable; and b. no evidence of leakage or necking-down.

The melting temperatures of CO\textsubscript{2} (T\textsubscript{mCO\textsubscript{2}}) in types A and B inclusions in the quartz-feldspathic breccia, quartz-albite-sulphide vein, and quartz vein range from -60.3°C to -57.0°C (Fig. 4). This conspicuous depression of T\textsubscript{mCO\textsubscript{2}} in relation to the melting temperature of pure CO\textsubscript{2} (-56.6°C) indicates that the inclusions fluids are not composed solely of CO\textsubscript{2}, but there might be minor amounts of other components dissolved in their carbonic phase.

Several inclusions were submitted to Laser Raman Microprobe analysis and confirmed the presence of variable amounts of N\textsubscript{2} and CH\textsubscript{4}, as the components responsible for the above T\textsubscript{mCO\textsubscript{2}} depression (Table 1). LRM data revealed...
high CH₄ contents (> 10 mole %) in the inclusions of the quartz-feldspathic breccia and quartz-albite-sulphide vein and low CH₄ contents (> 5 mole %) in the quartz vein. The N₂ content is variable in the samples, with XN₂ up to 16.6 mole % (Table 1).

Homogenization of CO₂ (ThCO₂) in types A and B inclusions takes place invariably in the liquid state and within a wide range of values (-15.0°C to 17.0°C) in the quartz-feldspathic breccia and quartz-albite-sulphide vein (Fig. 5). ThCO₂ in type A inclusions of the quartz-feldspathic breccia show a maximum frequency between -4.0°C and 3.0°C, whereas ThCO₂ in type B inclusions are scattered and no frequency peak can be recognized. In the quartz-albite-sulphide vein, ThCO₂ in types A and B inclusions concentrates preferentially between 6.0°C and 7.0°C and 11.0°C and 12.0°C respectively (Fig. 5).

Contrasting with the above data, ThCO₂ in type B inclusions of the quartz vein defines a narrower range of values (11.0°C to 26.0°C), with a maximum frequency between 14.0°C and 15.0°C (Fig. 5).

In order to estimate the minimum trapping temperature of the fluids, high temperature measurements were carried out in type B inclusions to determine their total homogenization temperature (Th). This phenomenon occurs in the gaseous state, but accurate values could not be obtained because of several optical limitations or decrepitation before complete homogenization. The few data available depicted in figure 6 show that Th values range from 250°C to 400°C for type B inclusions, with maximum frequencies around 350°C and for the quartz-feldspathic breccia and 250°C and 300°C for the quartz vein. There are no data available on Th of type B inclusions of the quartz-albite-sulphide vein. Type C inclusions in the quartz-feldspathic breccia and quartz-albite-sulphide vein show Th values between 80°C and 120°C and are considered as representatives of aqueous fluids which circulated after the main stages of mineralization at higher crustal levels (Fig. 6).

In the quartz vein, the Th values for type C inclusions range from 120°C to 400°C and define a frequency peak between 220°C and 240°C, close to the frequency peak of the associated type B inclusions (Fig. 6).
The data on the relative amounts of CH4 and N2 dissolved in the carbonic phase of types A and B inclusions determined by Laser Raman Microprobe (Table 1) were combined with microthermometry to assess the influence of these minor components on the ThCO2, as well as determine the chemical system in which the inclusion fluids should be interpreted.

Figure 7a reveals that despite the large variation in the composition of the inclusion fluids, the ThCO2 of their carbonic phase lies always within a narrow interval. In the case of type A inclusions of the quartz-feldspathic breccia, plots of ThCO2 versus CH4 content do not yield any definite positive correlation (Fig. 7b).

Two important conclusions can be inferred from the above behaviours: 1. The large range of CO2 homogenization temperatures seen in the histograms is a reflection of fluid density rather than due to any pronounced compositional effects; and 2. Since the composition has a minimum (if any) influence on the ThCO2, the minor components dissolved in the carbonic phase of type A and B inclusions can be neglected and their fluid content can be interpreted as pure or pure-mixed systems, as well as their isochors easily calculated.

As a consequence, the isochors and related densities of the inclusion fluids considered as the colset samples of the temperatures of a certain group of cognetic inclusions are important because they provide a close estimate of their chemical composition and an order of magnitude of the density of the fluid likely to have generated them. In ideal conditions, that is, for pure or pure mixed systems (CO2, H2O, H2O-NaCl, and H2O-CO2), these two parameters can be well established within a fairly good degree of certainty. However, this is not the rule for most of the geological situations, but rather the exception, since fluid inclusions have been shown to be more chemically complex than pure systems, due to the presence of other components dissolved in the gaseous (CH4, N2, H2S, CO2, etc.) and aqueous (Mg2+, Ca2+, K+, Fe2+/3+, etc.) phases.

THE RELATIONS BETWEEN MICROTHERMOMETRIC DATA AND THE COMPOSITION OF THE INCLUSION FLUIDS

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Table 1: Microthermometry and Raman spectroscopic data for types A and B inclusions in the mineralized samples: VCO2/Vt = volume ratio between the carbonate phase and the total volume of the inclusion; Xi = molar fraction of substance i in the inclusion; dV density of the CO2; a = global density of the inclusion fluid. The global composition of the carbonic inclusions (type A) was directly obtained by the Raman spectroscopy, whereas for the H2O-CO2 inclusions (type B) it was calculated by the method of Rambo et al. (1985)
mineralizing fluids in this present work can be found in the CO₂-CH₄-H₂O-CO₂-NaCl and H₂-NaCl systems.

Figure 9 — CO₂-CH₄-N₂ ternary diagram, with plots of the chemical composition of the carbonic phase of the investigated inclusions obtained by Raman spectroscopy. Note that again mineralizing fluids form three distinct fields (I, II and III) with contrasting chemical characteristics and has been emphasized elsewhere. The values of the bulk densities of the mineralizing fluids show a relatively constant values, in general ranging from 0.85 g/cm³ to 0.90 g/cm³.

Table 2 — Global characteristics of the mineralizing fluids

<table>
<thead>
<tr>
<th>MINERALIZING FLUIDS</th>
<th>AVERAGE TEMPERATURE (°C)</th>
<th>CHEMICAL COMPOSITION (mole%)</th>
<th>VAPOR PRESSURE (mmHg)</th>
<th>AVERAGE DENSITY (g/cm³)</th>
<th>REPRESENTATIVE FLUID INCLUSIONS</th>
<th>THOCO² (± 1°C)</th>
</tr>
</thead>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Type A veryauber and type B sulphide</td>
<td>400</td>
</tr>
<tr>
<td>I</td>
<td>H₂A</td>
<td>40.9</td>
<td>0.6</td>
<td>0.4</td>
<td>0.85</td>
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<tr>
<td>II</td>
<td>H₂A</td>
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<td>2.5</td>
<td>0.6</td>
<td>0.85</td>
<td>60</td>
</tr>
<tr>
<td>III</td>
<td>H₂A</td>
<td>74.3</td>
<td>8.0</td>
<td>1.3</td>
<td>0.85</td>
<td>100</td>
</tr>
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</table>

Salinities of the aqueous phase of type B inclusions were derived from the melting temperatures of clathrates (TmCl, see Collins 1979) whose values ranged from 7.0°C to 16.0°C, with a maximum frequency at 8.5°C (Fig. 10a). For type C inclusions, salinities were determined by the ice melting temperatures which provided values ranging from -5.0°C to 1.0°C without a recognized frequency peak.

These temperature data provided low estimates for the salinity of the trapped fluids, invariably below 10 equivalent weight percent of NaCl for types B and C inclusions (Fig. 10b).

DISCUSSION AND CONCLUSIONS Microthermometric and Raman spectroscopy investigations on carbonic, mixed H₂O-CO₂, and aqueous inclusions in the main orebodies of the Fazenda Brasileiro gold deposit defined the mineralizing fluids as dense (0.85-0.90 g/cm³) and hot (> 400°C) solutions composed essentially of CO₂ (89.7-85.4 mole %) and minor amounts of CH₄ and N₂, which gradually evolved to more aqueous fluids (40-62.5 mole % H₂O) of low salinity (< 10 eq. wt% NaCl) at lower temperatures (250-300°C). It was also possible to distinguish three groups of mineralizing fluids, namely I, II, and III, with
Figure 10 - A. Histogram of melting temperature of clathrates (TmCl) and ice (Tmi) for types B and C inclusions, respectively; B. estimates of the salinity of the mineralizing fluids based on TmCl and Tmi (Collins 1979)

corresponding microthermometric and spectroscopic results (Figs. 8 and 9).

Based on these data, it is conceivable that the transport of gold and its deposition in the quartz-feldspathic breccia and quartz-albite-sulphide vein were carried out by CO₂-Ch₄ dominant fluids I and II at temperatures above 400°C. The presence of low salinity H₂O-CO₂ fluids is recognized in very small amounts in these earliest stages of mineralization, denoting a first introduction of H₂O in the system. This situation is supported by the coexistence of carbonic and mixed H₂O-CO₂ inclusions in the investigated samples. In contrast, the mineralizing fluid III trapped in the vein is water-dominated, colder, low salinity fluid, containing less than 35 mole% CO₂.

Beside composition, density, and salinity, fluid inclusion data also provide information on the minimum pressure and temperature during trapping, except for the case of simultaneous trapping of immiscible fluids (H₂O-rich and CO₂-rich fluids, boiling fluids, etc., c.f. Roedder & Bodnar 1980).

Isochors for type A and B inclusions in the quartz-feldspathic breccia and quartz-albite-sulphide vein were calculated based on their average compositions and bulk density (Table 2), and the known volumetric properties of CO₂-Ch₄ and H₂O-CO₂-NaCl systems (Swaneenberg 1979, Bowers & Helgeson 1983). In figure 11, the intersection of the isochors corresponding to carbonic fluids with densities of 0.90 g/cm³ and 0.85 g/cm³ with the line which denotes the average temperature of total homogenization for type B inclusions (Th = 380°C) in the quartz-feldspathic breccia and quartz-albite-sulphide vein, establish a minimum range of pressure of 2.2-2.5 kb for the entrapment of these fluids. Assuming that the pressure effect is negligible (Sharp et al., 1985), the assemblage arsenopyrite + pyrite gives an upper stability temperature of 491°C. Using this temperature as an upper unit, the isochors define an upper pressure limit between 2.7 kb and 3.2 kb (Fig. 11).

![Figure 10](image1)

Figure 10 - A. Histogram of melting temperature of clathrates (TmCl) and ice (Tmi) for types B and C inclusions, respectively; B. estimates of the salinity of the mineralizing fluids based on TmCl and Tmi (Collins 1979)

![Figure 11](image2)

Figure 11 - P-T diagram with the estimated intervals for the two stages of gold deposition (dotted and shaded area). The larger inner rectangle depicts the P-T range of the regional metamorphism defined by Silva (1983), in the mid-portion of the Rio Iapirucu greenstone belt: 1 and 2 = critical curves for H₂O-30 mole % CO₂ and H₂O-50 mole % CO₂, respectively (Bowers & Helgeson 1983); 3 = upper thermal limit for arsenopyrite-pyrite stability (not pressure corrected) (Sharp et al. 1985); 4 = average total homogenization temperature (Th) of H₂O-CO₂ inclusions in the quartz-feldspathic breccia

If the coexistence of H₂O-CO₂ and H₂O inclusions in the massive quartz vein is interpreted in terms of simultaneous trapping at the time of an event of fluid unmixing or mixing, P-T conditions can be estimated by the intersection of their isochors (Roedder & Bodnar 1980). Isochors of these inclusion fluids show a point of intersection at 300°C and 1.4 kb, which lies close to the critical curve for H₂O + 30 mole% CO₂ at 270°C and 1.2 kb (Fig. 11). These estimates are in accordance with the average total homogenization temperatures of the H₂O-CO₂ inclusions (Th = 250°C).

The high content of CO₂ and the presence of CH₄ in the inclusion fluids, the stability of albite rather than muscovite and the close association of gold with sulphides, notably arsenopyrite and pyrite, in the advanced hydrothermal alteration zone (Marimon et al. 1986), suggest neutral to alkaline S-bearing fluids under conditions of low fO₂ (high ΣH₂S/ΣSO₂) as responsible for the gold solubilization and
transport. Under the above conditions, thio-complexes as Au(HS)₂⁻, H₂Au(HS)₂⁻ or H₂Au(HS)₂⁻ are likely to be of most importance in the transport of gold since experimental investigations have shown their high solubility in high temperature neutral to alkaline reduced solutions (Seaward 1982).

Another evidence for the transport of gold by thio-complexes is provided by the Ag/Au ratio which is less than 1 at the Fazenda Brasileiro gold mine. Cole & Drummond (1976) in the attempt to assess the behaviour of gold under several pre-established conditions have demonstrated that Ag/Au < 1 are attained in low Cl⁻ (0.1 molar), moderate to high pH, high ΣS/ΣSO₄ ratio (> 10⁶) solutions. According to these authors, these conditions would be favourable for the transport of gold by thio-complexes such Au(HS)₂⁻.

Other ligands, such as thioarsenide As₂S₃ or As₂S₄²⁻, thioantimonite or complexes with NH₃, Br⁻ and I⁻ might have an important role in the transport of gold, but unfortunately there are no experimental data on such species at any temperature (Seaward op. cit.).

Carbonyl complexes (e.g. Au(CO)₃⁻) have been postulated by Kerrich & Fyfe (1981) as important ligands in the environment of transport and deposition of gold in some Archean gold deposits which have formed at temperatures up to 450°C. However, the carbonyl bond with Au(I) is weak (Puddephatt 1978), with CO being vulnerable to substitution by other ligand having a greater affinity for gold, particularly at high temperatures.

In the quartz-feldspathic breccia and quartz-albite-sulphide vein, gold might have precipitated by a decrease in the a²⁻ with the deposition of metal sulphides during fluid/rock reactions, as following (Phillips & Groves 1982 and 1983):

\[
FeO \text{ (in silicates)} + H Au (HS)₂⁻ + \frac{1}{4} O₂ = Au⁺ + FeS₂ + \frac{1}{2} H₂O \tag{1}
\]

\[
Fe₂O₃ (\text{in the magnetic schist}) + 3 H Au (HS)₂⁻ = 3 Au⁺ + 3 FeS₂ + 4 \frac{1}{2} H₂O \tag{2}
\]

In the quartz vein, gold precipitation might have taken place due to fluid with the introduction of H₂O in the system causing dilution in CO₂, decrease in pH, oxidation and destabilization of gold complexes.

Carbonic and mixed H₂O-CO₂ fluids defined in this fluid inclusion study have been extensively described in metamorphic rocks of medium to high grade facies (Crawford 1981, Tourret 1981). Devolatilization of basal sequences of greenstone belts when submitted to amphotile to granulite facies metamorphism could yield CO₂-rich or H₂O-CO₂ fluids similar to those inferred from fluid inclusions and low porosity under metamorphic conditions would lead to low salinities (Fyfe et al. 1978, Phillips & Groves 1983).

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REFERENCES


NOTÍCIAS

ESCUELA LATINOAMERICANA DE QUÍMICA INORGÁNICA

Quanto à realização do segundo encontro de Química Inorgânica, em Santiago (Chile), em dezembro de 1987, e do I Congresso Interamericano, em maio de 1988, em Jalapa (México), foi decidido iniciar a organização da Escuela Latinoamericana de Química Inorgânica, cujo primeiro encontro dar-se-á ao final deste ano, na cidade do México.

Entre os objetivos da “Escuela” destacam-se os de fomentar o conhecimento mútuo dos químicos inorgânicos da região, suas linhas de pesquisa, sua infraestrutura disponível e as experiências em desenvolvimento na área de Química Inorgânica.

Os organizadores desejam organizar um diretório com nomes e endereços de pesquisadores e docentes na área. Os interessados devem escrever para:

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