A FLUID INCLUSION STUDY IN THE HYDROTHERMAL VOLCANOGENIC SULFIDE AND OROGENIC GOLD MINERALIZATION AT THE SERRA DO IPITINGA, AMAZON, BRAZIL

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Resumo ESTUDO DE INCLUSÕES FLUIDAS EM MINERALIZAÇÃO SULFETADA VULCANOGENICA HIDROTHERMAL E DE OURO OROGENICO NA SERRA DO IPITINGA, AMAZONIA, BRASIL O Grupo Ipitinga (2,27 Ga), na serra homônima, consiste em uma unidade metavulcanossedimentar, constituída por metavulcânicas máficas e ultramáficas, rochas a cordierita-antofilita e a quartzo-clorita, às quais estão sobrepostos metassedimentos químicos (BIFs tipos óxido e silicato) e clásticos. Parte das lavas básicas foi hidrotermalmente alterada em condições similares às de sistemas hidrotermais atuais, ao longo dos eixos de expansão oceânicos, formando rochas a quartzo-clorita e mineralizações sulfetadas do tipo vulcanogênico hidrotermal sindeposicional, constituídas de pirrotita, pirita, calcopirita, esfalerita, com ouro e prata associados, além de traços de galena, molibdenita e telureto de prata. Toda a unidade vulcanossedimentar foi deformada por cisalhamento rúptil-dúctil, assumindo a atual configuração estrutural de cinturão de cisalhamento NW-SE, com mergulhos subverticais, geralmente para NE. Durante esse episódio, os fluidos hidrotermais originaram veios de quartzo auríferos. Doze tipos de inclusões fluidas identificadas no Grupo Ipitinga, discriminam dois sistemas de fluidos relacionados a três eventos hidrotermais peculiares. As rochas a quartzo-clorita (basaltos hidrotermalmente alterados), as principais hospedeiras das mineralizações sulfetadas, contêm onze tipos de inclusões fluidas. Oito deles ocorrem exclusivamente nessas rochas, geradas a partir de reações fluido-rocha durante o primeiro evento hidrotermal (I). Esse evento envolveu um fluido aquo-carbônico consistindo principalmente de CH₄ e H₂O, com traços de N₂ e H₂S. Inclusões de CO₂ com traços de CH₄, H₂S e N₂, são subordinadas. A predominância de CH₄ sobre CO₂ no sistema de fluido aquo-carbônico, é coerente com os modelos propostos para a geração de mineralizações sulfetadas vulcanogênicas exalativas nos sistemas hidrotermais de dorsais meso oceânicas. A presença de CH₄ nas rochas resultantes do primeiro evento hidrotermal no Grupo Ipitinga, evidencia a ação de um processo metamórfico-hidrotermal em um ambiente similar aos atuais centros de expansão. Os valores de temperatura e pressão calculados para a geração da mineralização sulfetada no Grupo Ipitinga compreendem os intervalos de 250-450°C e 0.7 – 2.3 kbar, respectivamente. Fluidos aquosos salinos relacionados ao segundo evento hidrotermal (II) ocorrem somente nas rochas a cordierite-antofilita. Os veios de quartzo originados em um terceiro evento hidrotermal (III), relacionado ao cisalhamento dúctil, contêm inclusões de um fluido aquoso salino que pode também ser encontrado em quartzo das rochas a quartzo-clorita. Além dos dados acima apresentados, o estudo das inclusões fluidas também indicou uma cronologia relativa para os eventos metamórfico-hidrotermais no Grupo Ipitinga.

Palavras-chave: inclusões fluidas, sulfeto, ouro, metano, sistema hidrotermal

Abstract The *Ipitinga* Group (2.27 Ga) at the *Serra do Ipitinga* consists of a meta-volcano-sedimentary unit of mafic and ultramafic metavolcanics, cordierite-antophyllite and quartz-chlorite-bearing rocks underlying chemical (oxide and silicate-type BIFs) and clastic metasedimentary rocks. Part of the mafic and ultramafic lavas was hydrothermally altered, which gave rise to quartz-chlorite-bearing rocks and hydrothermal syndepositional exhalative volcanogenic sulfide mineralization, formed by pyrrhotite, pyrite, chalcopyrite and sphalerite with Au and Ag and traces of galena, molibdenite and silver telluride. All the meta-volcano-sedimentary unit was deformed by ductile-brittle shearing and transformed in present-day NW-SE trending shear belts with a subvertical – NE dip. During this deformational shearing episode, hydrothermal fluids yielded gold-sheared lodes. Twelve types of fluid inclusions identified in the *Ipitinga* Group distinguish two fluid systems related to three peculiar hydrothermal events. The quartz of the quartz-chlorite-bearing rocks (hydrothermally - altered basalts), the main host of the volcanogenic sulfide mineralization, contains eleven types of fluid inclusions. Eight of these occur only in these rocks, which can be considered to have resulted from fluid-rock reactions related to the first hydrothermal event (I). This event involved an aqueous carbonic fluid consisting mainly of CH₄ and H₂O, with traces of N₂ and H₂S. CO₂-bearing inclusions are subordinate and contain traces of CH₄, H₂S and N₂. The predominance of CH₄ over CO₂ in the aqueous carbonic fluid system is coherent to proposed models for the generation of exhalative volcanogenic sulfide mineralization in mid-oceanic ridge hydrothermal systems. The presence of CH₄ in the first hydrothermal event in the *Ipitinga* Group is evidence of an ocean-floor metamorphic-hydrothermal process, in an environment similar to present-day ocean spreading centers. Pressure and temperature values for the sulfide mineralization were considered to be in the range of 0.7 – 2.3 kbar and 250 – 450°C, respectively. Aqueous saline fluid related to the second hydrothermal event (II) occurs only in the cordierite-antophyllite rocks. Quartz veins are the products of a third hydrothermal event related to ductile shearing (III) and contain inclusions of an aqueous saline fluid which can also be found in quartz of the quartz-chlorite-bearing rocks. The fluid inclusion study also pointed out the relative chronology for the hydrothermal-metamorphic events in the *Ipitinga* Group.

keywords: fluid inclusion, sulfide, gold, methane, hydrothermal system

INTRODUCTION The paleoproterozoic meta-volcano-sedimentary *Ipitinga* Group (Ricci *et al.*, 2001 – Fig. 1) contains

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Figure 1 – Geological map of the Serra do Ipitinga region.

marks of hydrothermal events, producers of significant mineralogical alterations in the rocks. It also holds hydrothermal syndepositional exhalative volcanogenic sulfide mineralization and sheared gold veins, both of them related to those events.

The fluid inclusion study was carried out in quartz of the volcanogenic mineralization host rocks, in quartz of sheared quartz veins and in quartz of cordierite-antophyllite rocks, revealed the physical-chemical parameters of the *Ipitinga* Group fluids, distinguished two fluid systems (aqueous-carbonic and aqueous saline) related to three peculiar hydrothermal events and indicated the relative chronology for the hydrothermal-metamorphic events in that group. Isochores calculated for the CH_4 - rich inclusions present in quartz-chlorite-bearing rocks, pointed out the pressure range (0.7 – 2.3 kb) for the generation of volcano-

genic mineralization, in a temperature interval of 250 – 450°C.

THE IPITINGA GROUP AND ASSOCIATED MINERALIZATIONS The *Ipitinga* Group at the *Serra do Ipitinga*, NW *Pará* State, consists of a mafic and ultramafic metavolcano sequence (2.27 Ga – McReath & Faraco, 2006) underlying oxide - and silicate - type BIFs and clastic metasedimentary rocks (Faraco, 1997 – Fig. 4). Part of the mafic volcanics was hydrothermally altered under greenschist facies conditions, similar to mid-ocean-ridge axis hydrothermal systems, which gave rise to mafic schist and quartz – chlorite – bearing rocks (QCR). The latter are interpreted as hydrothermally-altered basalts (Mottl, 1983) and occur as large clots within the metavolcanic sequence. They are the main host of a hydrothermal syndepositional

Figure 2 – Geological map of the Serra do Ipitinga.

exhalative volcanogenic sulfide mineralization, which consists of pyrrhotite, pyrite, chalcopyrite and minor sphalerite, with associated Au, Ag and traces of galena, molybdenite and silver telluride. The temperature range for the generation of this first hydrothermal event, calculated from Al-saturated chlorite (Cathelineau & Nieva, 1985), is 273°C to 320°C, with an average value of 308°C, and represents the first metamorphic – hydrothermal event (M1).

Metamorphism under amphibolite facies (M2) transformed the basic volcanics to amphibolites, and part of the QCR to cordierite-anthophyllite-bearing rocks, at about 547°C (Faraco, 1997 and Reinhardt, 1987). The observed mineral assemblages of the BIF's (hematite-quartz-schist, hematite-grunerite-schist, hastingsite-almandine-quartz-schist) and clastic metasedimentary rocks (quartz-muscovite-cordierite-schist, quartz-muscovite-andalusite-schist, kyanite-muscovite-quartz-schist, muscovite-quartzite) were also formed during M2.

The whole meta-volcano-sedimentary *Ipitinga* Group was deformed by brittle-ductile shearing (M3) which produced NW-SE striking shear belts with subvertical-NE dip (*Ipitinga* Ridge). The shearing episode caused formation of mylonites and polymetamorphic and hydrothermally-altered rocks, that show retrogressive metamorphic parageneses (epidote, and rocks with neoformed carbonate, chlorite, sericite, muscovite, actinolite, biotite). Quartz veins generated during this event crosscut the meta-volcano-sedimentary sequence and can host disseminated pyrite, chalcopyrite and covellite, with associated gold, interpreted as a shear zone-hosted lode-gold or orogenic gold mineralization, following Groves *et al.* (1998) nomenclature. Moreover, the *Ipitinga* Ridge consists of a 150 km –range of NW-SE ridges called *Serra do Ipitinga* (Fig. 1). It represents the closing

of an ocean back-arc basin (*Ipitinga* Group – 2.27 Ga, T_{DM} 2.3 – 2.1 Ga, $\epsilon Nd_T = +2 - +6$) due to the subduction and collision on the edge of a continent (Faraco, 1997, Faraco *et al.*, 2006a,b,c, McReath & Faraco, 2006). These data also give evidence that gold lode deposits are generated in a convergent tectonic setting (Fyfe & Kerrich, 1985).

A last thermal metamorphic event was produced by granitic intrusions (M4), generating basic and sedimentary hornfels.

Four hydrothermal episodes were identified, each related to a correspondent metamorphic event. Geochemical data indicated a volcanic environment similar to modern back-arc basins for the *Ipitinga* Group (Faraco, 1997). Additionally, results from Nd isotopic studies yielded an isochronous age of 2.27 Ga (McReath and Faraco, 2006), in accordance with the 2.11 Ga (Gruau *et al.*, 1985) and 2.25 Ga (Gibbs & Olszewska, 1982) ages for rocks from French Guyana which are correlated to the *Ipitinga* Group (Faraco, 1997, McReath & Faraco, 2006). The REE patterns obtained for the BIFs are equivalent to those of paleoproterozoic banded iron-formation worldwide (Faraco *et al.*, 1992). Petrological, chemical, metallogenetic and isotopic data for the *Ipitinga* Group also allow its correlation with the paleoproterozoic Birimian meta-volcano-sedimentary belt of the West African Craton (Faraco, 1997).

TEXTURAL FEATURES OF THE MAIN MINERALIZATION HOST ROCKS

Quartz-chlorite-bearing rocks These host rocks, detected through drilling, occur exclusively underground. They are light-green with a characteristic silky brightness and an anisotropic foliated fabric, formed by chlorite foliation planes, intercalated with irregular millimetric deformed bands of quartz and sulfides. The rocks can also be found as tec-

Figure 3 – Fluid inclusion types in quartz – chlorite - bearing rocks, main (host of the volcanogenic mineralization), in quartz veins and in cordierite – anthophyllite rocks of the Ipitinga Group. Th: total homogenization temperature; ThCH₄: CH₄ homogenization temperature; ThCO₂: CO₂ homogenization temperature; Tm ice: ice melting temperature; δ CO₂ (g/cm³): CO₂ density equivalent; δ CH₄ (g/cm³): CH₄ density equivalent; CH₄ liquid: L1; H₂O liquid; V: vapor; S: solid

tonic breccias, where rock fragments and sulfide fenoblasts occur in a quartz-chlorite matrix.

The main microtextural relationship between the sulfides is the replacement of ruptile pyrite by ductile pyrrhotite, chalcopyrite and sphalerite, that occurs from incipient to prominent stages in a lenticular mylonitic arrangement or in a breccoid setting.

The pyrite shows a ruptile behavior under M1 hydrothermal metamorphism as well as under M3 deformation. This happens because both events are of green schists faces whose P-T conditions lead to ruptile deformation (Craig & Vokes, 1993).

Gold-quartz-veins These veins were generated during the hydrothermal event (III) related to ductile shearing (M3) and enclosed in the meta-volcano-sedimentary sequence, often parallel to NW-SE regional foliation. They are formed essentially by quartz and can also contain tourmaline, carbonate and epidote. Pyrite, chalcopyrite, covellite with associated gold (0.02 – 0.14 ppm) are present occur. Covellite is intergrown with chalcopyrite as films in several directions, forming nets or replacing its borders.

FLUID INCLUSIONS Fluid inclusions were investigated in quartz from the sulfide mineralization host rocks (M1 event), as well as from the cordierite – anthophyllite rocks and silicate – type BIFs (M2 event). Petrography, microthermometry and RAMAN spectroscopy were performed. Fluid inclusions in quartz veins related to the regional M3 metamorphism and confined to shear zones were also studied. The fluid inclusions related to the emplacement of the granite intrusions during M4 event could not be included in this study due to their extremely small size.

Quartz - chlorite - bearing rocks Eleven types of fluid inclusions were individualized in quartz of this rock type and were grouped into those consisting of CH₄ (which traces of N₂ and H₂S), CH₄ – H₂O and minor CO₂ – bearing ones. The most abundant among these types, are dark, rounded (10 – 30µm) and monophase inclusions. They occur in fissures or cavities of the host quartz, preferentially aligned along intragranular planes (type 1 – Fig. 3; Figs. 4 a-b). During cooling, they nucleate a gas phase

Figure 4 – Fotomicrography of the different types of fluid inclusions at Serra do Ipitinga. A: CH_4 inclusions (type 1) in quartz crystals of the quartz-chlorite-bearing rock, main host of the volcanogenic mineralization; B: detail of a CH_4 inclusion from A; C: detail of aqueous – carbonic inclusion (type 2) consisting of a clear liquid aqueous phase and a darker of CH_4 , N_2 and H_2S (bubble); D: aqueous carbonic inclusions (type 4) aligned along fracture planes, consisting of a liquid aqueous phase and a CH_4 gas bubble, with subordinate H_2S , N_2 and CO_2 .

Figure 5 – Histogram of Th CH_4 for type 1 fluid inclusions. Homogenization takes place to the liquid state.

Figure 6 – Raman spectrum of the type 1 inclusions.

between -95 and -90°C which homogenizes to the liquid phase between -93 and -83°C , with a maximum concentration of values in an interval of -86 to -85°C (Fig. 5). This microthermometric behaviour indicates that these inclusions are CH_4 -rich, confirmed by Raman spectroscopy analysis which yielded CH_4 (91.1%) with traces of N_2 (8.2%) and H_2S (0.7%) (Figs. 6, 7). The homogenization for these CH_4 -rich inclusions correspond to CH_4 density values ranging from 0.19 to 0.28 g/cm^3 .

Type 4 inclusions are uncommon and mostly composed essentially of a dark gaseous phase (CH_4 , with traces of H_2S , N_2 e CO_2) and, subordinately, a clear aqueous phase. They are rounded, elongated and 6 to 16 μm long (Figs. 3 and 4d).

Type 5 inclusions, detected only in a sample, are dark, monophase, rounded to subangular (15 to 25 μm), with a irregular cotourn, locally concentrated or aligned along fracture planes (Fig.

9a). The densities range from 0.938 to 1.015 g/cm^3 and the homogenization temperatures of CO_2 from -16.3 until -1.62°C . They contain almost exclusively of CO_2 , with traces of H_2S , CH_4 and N_2 (Fig. 10). The CH_4 and N_2 give rise to decrease of the CO_2 melting temperature to -57.21°C . In the same sample there are also smaller monophase CO_2 inclusions (type 6 – Fig. 3), composed only of CO_2 . They are dark, rounded or polygonal and aligned along fracture planes (Fig. 9b). The homogenization temperatures of CO_2 extend between -12.4 and 1.84°C and the densities range from 0.985 – 0.917 g/cm^3 .

CO_2 inclusions and H_2O – CO_2 inclusions (respectively types 7 and 8 – Fig. 3) are extremely rare in the host rocks of the mineralization. The first are light and dark, monophase, rounded (5– 7 μm , some can reach 17 μm), distributed (spreaded) without preferential orientation. The homogenization temperature vary from -1.4 to 6.8°C . The angular to subangular two - phase H_2O – CO_2 inclusions (type 8 – Fig. 3) have the ratio V_v/V_t between 0.2 to 0.4 and occur as negative crystals (6 – 13 μm). The CO_2 homogenizes to the liquid phase around 9°C . On the heating they crepitate after 206°C .

The figure 11 shows the CH_4 isochores, calculated from Swanenberg's (1979) equation. The temperature interval of the

Figure 7 – Raman spectrum of the type 1 inclusions, with detection of H_2S and N_2 traces. Aqueous carbonic inclusions are composed of an aqueous and a carbonic phase (CH_4 with traces of N_2 and H_2S , type 2 – Fig. 3). They coexist with the type 1 inclusions and generally have a predominant carbonic phase, but some show dominant L1 aqueous phases (Fig. 4c). There are also three-phase inclusions (type 3 – Fig. 3), consisting of an aqueous liquid phase, gaseous CH_4 , with traces of N_2 and a carbonate mineral, generated by saturation (Figs. 8).

Figure 8 – Raman spectrogram of carbonate in type 3 inclusions.

Figure 9 – A: Planes of CO_2 inclusions (type 5) scattered in quartz of the host volcanogenic mineralization; B: CO_2 inclusions aligned along fracture planes; C: Aqueous inclusions (type 9a), aligned along planes.

Figure 10 – Raman spectra of the CO_2 – type 5 inclusions, with traces of H_2S , N_2 and CH_4

Figure 11 – Minimum and maximum P - T conditions for the generation of the volcanogenic mineralization in the first hydrothermal event in the Ipitinga Group, based on the CH_4 isochores and on the established thermal limits for host rock mineral associations.

equilibrium chlorite-albite-epidote-actinolite-quartz and chlorite-quartz varies from 250 to 450°C (Mottl, 1983). Therefore, the temperature and pressure conditions for the volcanogenic mineralization are given by the intersection of the CH_4 isochores and the thermal stability limits for those associations. At 450°C the pressures vary from 0.9 to 2.3 kb; and at 250°C from 0.7 to 1.6 kb.

Cordierite-anthophyllite rocks These rocks were generated during M2 metamorphism and occur intercalated with amphibolites. They are often anisotropic with a banded texture, where cordierite and anthophyllite irregular bands are alterned. Magnetite, ilmenite, rutile, apatite and biotite can also be present. Cordierite - anthophyllite rocks are found in several parts of the world resulting from both regional and thermal metamorphism of the hydrothermally-altered basalts (Vallance, 1967; Chinner & Fox, 1974; De Rose-Spence, 1969; Froese, 1969; Treloar *et al.*, 1981; Reinhard, 1987), such as in Mantouwadge, Canada (James *et al.*, 1978) and in the Kvikne Mines, Norway (Lydon, 1988b).

The aqueous (3 - 10 μm) liquid-gas inclusions (type 11 - Fig.

Fig. 12 – Diagram showing the processes acting on the aqueous fluids of type 10 and 12 inclusions (based on Shepherd et al., 1985).

3) are angular (rarely rounded or irregular) and aligned along preferential planes. The ice melting temperatures vary from -12 to -10 °C corresponding to salinity values ranging from 12 to 19% NaCl. They homogenize to the liquid phase between 150 and 180°C. These inclusions occur only in the cordierite-anthophyllite rocks, and their fluids are related to the second hydrothermal-metamorphic event (II).

Sheared quartz veins . The types 9a-b; 10a-b and 12 a-b of aqueous inclusions occur in these veins (Fig. 3). The two-phase type 9a inclusions (5 - 17 μm) align along fractures (Fig. 9c). Their ice melting temperatures are lower than the eutectic temperature of the H_2O -NaCl system (-21.1°C), indicating that salts other than NaCl (for example, Ca, Fe, Al, Mg chlorides or sulphates) are dissolved in the aqueous phase. The ice melting temperatures vary from -41.4 to -25°C , corresponding to salinity values from 24 to 28 wt % CaCl_2 equivalent (Crawford, 1981). These inclusions are frequent in the sheared quartz veins where the total homogenization temperature varies from 100 to 150°C, and also occur in the host rocks of the sulfide mineralization with total homogenization temperature from 100 to 230°C. All these temperatures represent the action of regional shearing in these rocks.

The monophasic type 9b aqueous inclusions (11-25 μm) are irregular, often elongated, and aligned along shearing planes. The ice melting temperatures vary from -32.5 to -29.4°C and salinity is about 26 wt% of the CaCl_2 equivalent. The coexistence in the veins of the two-phase type 9a inclusions and monophasic type 9b inclusions with equivalent salinities indicate that the latter occur under metastable conditions (Roedder, 1984; Roedder & Belkin, 1988).

The two-phase type 10a aqueous inclusions are angular (25-29 μm and 7-9 μm), with $V_{\text{v}}/V_{\text{l}}$ about 0.15. These inclusions align along planes parallel to those that contain type 9a. Nevertheless, their ice melting temperatures (-26 to -13°C) are greater and they have salinity values (16 to 22 in wt % NaCl equivalent) lower than those fluid inclusions (Fig. 3).

The two-phase type 12a aqueous inclusions are angular or rounded, spread in the shear planes transverse to those that contain the type 9a and the type 10a. The ice melting temperatures vary from -6°C to 0.21°C , their salinity values are between 0.6 and 7.5 wt% NaCl equivalent (Fig. 3). The interval of total homogenization temperatures is 140°C - 180°C. These inclusions also occur in the sheared quartz veins containing pyrite, chalc-

pyrite and covellite.

The type 10b and 12b aqueous inclusions (Fig. 3) present, respectively, in barren and covellite-bearing quartz veins are monophasic and irregular (7 - 15 μm). The ice melting temperature (-19.7 to -11.6°C) and the salinity values (~ 14 wt% NaCl equivalent) in the first type, contrast with their corresponding values in the second type ($T_{\text{m ice}} = -2.2^\circ\text{C}$ to -0.3°C and salinity = 3 wt% NaCl equivalent). The covellite presence can be related to the salinity decrease. Overmore, it is worth to emphasize that this sulfide occurs only in the sheared quartz veins crosscutting the meta - volcano - sedimentary *Ipitanga* Group, and never associated to the volcanogenic sulfide mineralization.

The variation and evolution of the aqueous saline fluids can be observed through the homogenization temperature (Fig. 12). For the 10 and 12 type inclusions, the main feature is the presence of two distinct points of domains between the critical curve and the halite saturation curve. Each of them represents fluids with distinct salinities. The type 10 inclusions are more saline than the type 12 ones and the distribution of data suggests fluid mixing. The younger type 12 fluid also underwent cooling and heating. As both fluids are related to regional shearing, the distribution of the points suggests a decrease of the liquid residual phase.

Fluid inclusion studies in the *Ipitanga* Group show that twelve types of fluid inclusions are present and lead to the identification of two fluid systems related to three hydrothermal events. The first event produced an aqueous carbonic fluid, represented by the eight types (type 1 up to type 8 - Fig. 3) of inclusions found only in the quartz-chlorite-bearing rocks, host to the sulfide mineralization. This fluid represents an heterogeneous aqueous-carbonic fluid, consisting of CH_4 and H_2O , with traces of N_2 and H_2S . CO_2 is subordinate in relation to CH_4 .

The aqueous saline fluid system, with different salinities and lower temperatures, is related to the regional shearing event. These fluids also affected the quartz-chlorite-bearing rocks. Therefore, the fluid inclusion study also allowed determining the relative chronology of the hydrothermal - metamorphic events.

Type 1 inclusions consist essentially of CH_4 and minor amounts of N_2 and H_2S . The primary feature of these inclusions and their compositions agree with the model proposed by Hutchinson (1982), according to which in a submarine exhalative environment, the sea water and the cognate saline water circulate initially in a descending flux, in such a way that at a shallow level there would be sulfate reduction through a ferrous silicate producing pyrite and magnetite. Afterwards the metals of the silicate structures are leached and transported as chloride complexes. At a deeper level, the water is reduced, reacting with the Fe-silicates to produce magnetite + H_2 and in the last stage of the descending convective process the CO_2 reacts with the Fe-silicates, resulting in magnetite and carbonate, with generation of increasing saline fluid rich in H_2 and C, which is then combined producing reduced and highly saline fluid, rich in CH_4 and C_2H_6 to originate, in a higher level, the exhalative process in the oceanic floor, with sulfide precipitation.

Thus, considering that the quartz-chlorite rocks from *Serra do Ipitinga* resulted from mineralogical transformations when sea water reacted with basalts along mid-ocean ridges at a temperature interval of 250 - 450°C, it is possible that during this process, the quartz-chlorite rocks trapped part of the CH_4 rich fluids generated just before the sulfide deposition stage.

These considerations are reinforced through the study of the origin of methane, where abiogenesis is considered the main source of this gas in high temperature hydrothermal systems of the mid-ocean ridges (Welhan, 1988). Methane is derived from the rocks themselves so, the presence of the CH_4 inclusions in the quartz-chlorite rocks reinforces the characterization of M1 as an

ocean floor's metamorphic-hydrothermal process, also suggesting an environment equivalent to present ocean ridges for the generation of those rocks.

The CH_4 -isochores and temperature interval (250–450°C) for the generation of the quartz-chlorite rocks and chlorite-albite-epidote-actinolite-quartz, indicate a range of 0.7–2.3 kb for the generation of the volcanogenic mineralization in the Ipitinga Group.

Gold associated with the sulfides was probably transported as AuCl_2^- , in a high-temperature, relatively oxidized fluid acid, where precipitation occurs due to an increase of the pH, a decrease of the fO_2 or of the activity of Cl⁻ and a decrease in temperature (Huston & Large, 1989), in the same way as it occurs in the highest level of the exhalative process in the oceanic floor.

Gold is present in sheared quartz veins due to its remobi-

lization from Ipitinga Group through deformational and metamorphic processes, characterizing a lode-gold or orogenic gold mineralization (Groves *et al.*, 1998).

The aqueous saline fluids related to regional shearing were cooled and mixed with colder and less saline fluids. The younger fluid of the type 12 inclusion was cooled and boiled. The relation between salinity and homogenization temperature demonstrates decreasing salinity of the residual liquid phase.

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