Structural control of Au–Pd mineralization (Jacutinga): An example from the Cauê Mine, Quadrilátero Ferrífero, Brazil

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Abstract

Precambrian banded iron formations (BIFs) in the Quadrilátero Ferrífero host a special kind of Au–Pd mineralization known as Jacutinga. The main orebodies are hosted within the Cauê Syncline, a SW-verging fold that involves Paleoproterozoic metasedimentary rocks in the Itabira District, a regional synclinorium with BIFs in the core of synclinal folds in the northeastern part of Quadrilátero Ferrífero, Minas Gerais. Structural analysis reveals two important features of the district: the polydeformed character of the rocks and the importance of brittle structures in the control of the orebodies. Two deformational events are recognized in this area. The first event developed the main foliation, S1, that is the enveloping surface of the Cauê Syncline. The second event is better defined in the northern boundary of the structure where it is represented by a right-lateral wrench fault zone that has developed a foliation, S2, that truncates S1. This wrench fault was also responsible for the development of a system of fractures (Frm) that host the Au–Pd mineralization. The auriferous bodies of Cauê Syncline (Y, X, Área Central, Aba Norte, Noroeste and Aba Leste/Abá Leste Inferior) were generated during this second event. Shear fractures (R, R′ and P) and tension fractures (T) developed in response to the wrench fault system under brittle conditions. The best-developed, and most commonly mineralized fractures are R and T in all auriferous bodies. Elsewhere, the best mineralization occurs in the contacts of hematite bodies (soft/hard) and intrusive rocks with fractured itabirites. Other mineralization (Aba Norte, Área Central and X) is hosted on the contacts of other units.

A system of fractures, as well as their intersections, thus represents the structural control on Jacutinga bodies and is responsible for the geometry of the orebodies. Of importance, there is no control by mineral/stretching lineations, fold axes and other ductile structure on the geometry and plunge of the orebodies.

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1. Introduction

Ancient miners referred to a shiny black-feathered bird as Jacutinga, and also used the expression Jacutinga to refer to gold-bearing bodies. The Jacutinga is an auriferous orebody, of hydrothermal origin hosted by Superior-type banded iron formations (BIFs) and apparently restricted to the Quadrilátero Ferrífero (Iron Quadrangle) in Minas Gerais, Brasil. Since the beginning of the 18th Century, Jacutinga orebodies have been mined by mining companies and prospectors.

From a geological point of view, this unusual type of gold mineralization has been the object of more recent, detailed studies but many questions regarding the nature of the mineralization processes remain unclear. From the...
standpoint of structural controls, this paper is the first to describe the geometry and relationships between the orebodies and the host rocks. Several authors have dealt with the Jacutinga question. Henwood (1846, 1871), Hartt (1870), Ferrand (1894), Hussak (1900, 1906), Scott (1902), Harder and Chamberlin (1915), Calvert (1915) and Bensusan (1929) mainly addressed mineralogical descriptions of the ore. More recently, Oliveira (1932), Guimarães (1961, 1970), Polônia and Souza (1988), Leão De Sá and Borges (1991), Varajão (1994), Olivo (1994), Olivo et al. (1995), Cabral (1996), Galbiatti (1999) concentrated their attention on the study of genetic aspects and structural control of the orebodies.

The most important mined areas in the 19th Century were Gongo Soco, Bananal, Cata Preta, Maquiné and Itabira (Fig. 1). However, there are several other small occurrences in the eastern Quadrilátero Ferrífero where the thrust and wrench fault tectonics prevail.

This paper addresses the Jacutinga deposits of the Cauê Syncline in the Itabira District on the northeastern boundary of the Quadrilátero Ferrífero (Figs. 1 and 2). The Itabira Iron District comprises the following iron mines: Cauê (at the core of the Cauê Syncline), Chacrinha, Onça, Periquito, Dois Córrregos and Conceição, where the Companhia Vale do Rio Doce (CVRD) mines both iron and gold. Although Jacutinga orebodies are developed in all mines, only the Jacutinga-type orebodies from Cauê mine are reported here. Beginning in 1984, CVRD have produced 8 tonnes of gold with an additional reserve of about 2.5 tonnes from this deposit. The ore grade was about 30 g/t Au in 1984, and is now approximately 3.0 g/t Au. The annual production is about 500 kg of gold. PGE are associated with gold in all mines. The percentages of such elements in the bullion are variable, with the following averages: Pd (4.0%), Pt (0.1%), Ag (0.6%) and Cu (0.5%).

The main focus of this study is on the question of the geometry and control of the Jacutinga bodies of the Cauê Mine within the Cauê Syncline. Previous data in the literature (Leão De Sá and Borges, 1991; Olivo, 1994; Olivo et al., 1995) suggest that the mineralized bodies are controlled by ductile structures, such as mineral stretching lineations and fold axes. However, detailed field mapping during prospecting and mining have demonstrated that the geometry and plunge of the orebodies are controlled by brittle structures such as fractures and fracture systems. This new concept on the
geometry and overall control of the bodies have provided greater efficiency in exploration of auriferous bodies and their mining, with significant impact on the gold production at the Cauê Mine.

2. Geological setting

Presently-known Jacutinga deposits are hosted exclusively in Lake-Superior type Banded Iron Formations (BIFs) of the Minas Supergroup, a Paleoproterozoic platform sedimentary sequence (Dorr, 1969). This supergroup, together with Archean basement rocks and greenstone terranes, comprises the basement of the southern São Francisco Craton, the Quadrilátero Ferrífero, in eastern Brazil.

The Quadrilátero Ferrífero is a 7000 km², typical dome-and-keel province in which basement crops out in domal structures whereas supracrustal rocks are exposed in keels (Fig. 1). There are three main lithostratigraphic units in the Quadrilátero Ferrífero. The oldest is Archean basement, including gneisses, migmatites and granitic intrusions, which range in age from 2.8 to 2.7 Ga (Carneiro et al., 1995). These crop out in domal bodies and result from short-lived accretory processes during the late Archean (Machado et al., 1992; Carneiro et al., 1995). The Archean greenstone terrane is represented by the Rio das Velhas Supergroup which consists of a basal metavolcanic unit with mafic-ultramafic lava flows, an intervening metasedimentary–metavolcanic felsic unit, and an upper clastic metasedimentary sequence. The bulk of these rocks have been metamorphosed to the greenschist facies of regional metamorphism (Herz, 1978). Felsic lavas yield a 2776 Ma U–Pb in zircon age (Machado et al., 1992).

The Minas Supergroup is a metasedimentary sequence that unconformably overlies the Archean basement. Metamorphism reaches greenschist facies and locally amphibolite grade (Dorr, 1969). It consists of three main lithostratigraphic units, the lowermost a clastic basal unit (Caraca Group), with sandstones, conglomerates siltstones and pelites. These metasedimentary rocks are overlain by Lake-Superior type BIFs (Cauê Formation) that grade upwards to a carbonate sequence whose Pb/Pb ages indicate a deposition age of
ca. 2.42 Ga (Babinski et al., 1993). The uppermost metasedimentary sequence consists largely of clastic sedimentary rocks ranging from sandstones to pelites. The structure of the Minas Supergroup rocks is strongly controlled by successive tectonic episodes that affected the area. NE and NW-verging structures are related to the Paleoproterozoic Eburnian (ca. 2.0 to 2.1 Ga) orogeny that involved NW contraction (Alkmim and Marshak, 1998). The main Jacutinga deposits are hosted in NE-trending structures, the Itabira Synclinorium and the Gandarela Syncline (Jacutinga occurrences 1/2 and 3/11, respectively on Fig. 1). The dome-and-keel architecture is related to the SE-driven extensional collapse at the end of the Paleoproterozoic orogeny (Alkmim and Marshak, 1998). The eastern part of the Quadrilátero Ferrífero was strongly reworked by an E–W Brasiliano–Panafrican (650 to 570 Ma) contraction. Previous structures are completely obscured by Brasiliano structures whose intensity increases towards the Brasiliano Araçuaí Fold belt (Alkmim and Marshak, 1998; Brueckner et al., 2000).

The Itabira District is sited over a regional synclinorium. The synforms are defined by the outcrop traces of the BIF (Fig. 2). The synclinorium involves some synformal structures, with the Cauê and Conceição iron mines in the nuclei, and also some antiforms, with the Chacrinha and Periquito iron mines in the core.

3. Structural analysis of the Cauê Mine area

Field mapping and detailed structural analysis of the Cauê syncline area supports a polyphase evolutionary model for the Itabira Synclinorium. The structural features can be grouped into two deformational events. Event 1 (D1) generated the Itabira Synclinorium (Dorr and Barbosa, 1963; Chemale and Quade, 1986) through E–W contraction. Related structures comprise the oldest rock fabric of the area and include an S1 foliation (the regional cleavage), an associated mylonitic foliation, Sm1, better developed along local shear zones, B1 asymmetric WNW-verging folds, an intersection lineation, L1 (S1×S0) and a mineral/stretching lineation, Lm1/Le1 (Fig. 3). Poles S1 in Fig. 3 show a conical girdle with axis trending east representing the geometry of the Cauê Syncline. Mesoscopic and minor fold axes parallel stretching/mineral lineations, both also trending east. The general vergence of the B1 folds of the Itabira Synclinorium indicates mass transport towards the WNW. This is in accordance with the NNE contractual tectonics that Alkmim and Marshak (1998) considered as being Paleoproterozoic in age.

Event 2 (D2) is responsible for the development of an E–W right-lateral wrench shear zone that truncates the regional cleavage, S1, along the northern boundary of the Cauê Syncline (Hasui et al., 1991, Figs. 2 and 4). Event D2/phase 1 generates a brittle fabric that is represented by a set of structures, including a foliation, S2 (spaced cleavage), intersection lineation, L2 (S2×S1), mineral/stretching lineation Lm2/Le2, and mineralized fractures Frm (Fig. 3). Spaced cleavage, S2, trends E–W, with steep dips S or N and asymmetric B2 mesoscopic folds. B2 fold axes parallel mineral/stretching lineation, Lm2/Le2, both structures trending east. A late stage of Event 2 (phase 2) was responsible

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Fig. 3. Summary of the main structures in the Cauê Mine. Event 1 (S1 foliation poles diagram, 1716 measurements; Lm1/Le1 – 118 measurements; B1, 48 measurements). Event 2/phase 1 (S2 foliation poles diagram, 101 measurements; Lm2/Le2, 78 measurements; B2, 30 measurements; Frm – poles, 751 measurements and L2, 17 measurements). Event 2/phase 2 (Lcr, 36 measurements; B3, 37 measurements; Frs – poles diagram, 279 measurements).
for the generation of N–S trending brittle fractures, Frs, without associated mineralization, and related NE-trending crenulations, Lcr, and upright normal folds, B3 (Fig. 3). These elements truncate both foliations (S1 and S2), and, therefore, post-date them.

The 200 m-wide shear zone generated a system of fractures through which mineralized fluids ascended. Geometric and kinematic analysis of the sets of fractures is consistent with an E–W oriented contractional stress field.

The set of structures described in the Itabira District can be correlated with the phases and events previously described in the Quadrilátero Ferrífero by several authors (Endo, 1997; Marshak and Alkmim, 1989; Chemale et al., 1991; Alkmim and Marshak, 1998).

4. Description of the gold-bearing bodies of the Cauê Mine area

Six gold-bearing bodies occur in the Cauê Mine, within the limits of the Cauê Syncline: Y, X, Aba Norte (AN), Aba Leste (AL), Área Central (AC) and Noroeste (NW). The bodies occur in different spatial positions (Fig. 4) and are hosted by different lithologies. The most important high-grade bodies are Y, Aba Norte and Área Central. Granulometric distribution analysis refers to orebody Y. Recorded granulometric range varied from 0.0025 to 1.3 mm, with high gold concentrations in the lower intervals (Souza et al., 1986).

The Y Body was known in the past as the body of Mine Seven (Dorr and Barbosa, 1963), and is located in the center of the Cauê Syncline (Fig. 4). When iron mining reached the previously mined bodies, many galleries were intercepted and the mining of gold was recommenced. Since the beginning of the project, this body has been the most productive of the Cauê Mine.

Host rocks to the Y Body are friable itabirites composed of bands of quartz and hematite, with concentrations of magnetite that have been transformed into kenomagnetite (weathered magnetite, Morris, 1980). Hematite normally has a lepidoblastic to granoblastic texture and quartz is granular to elongate.

The auriferous ore comprises a number of different layers as described below.

Goethite bands are composed of goethite in association with hematite and magnetite. Kaolinite may occur in variable proportions. In places, hematite and gold are also associated with the goethite. Quartz bands comprise mainly coarse quartz grains and nodules of quartz cemented with goethite and some specularite, with zones of cryptocrystalline quartz and rare amethyst. Hematite bands with weathered magnetite also contain goethite, quartz and kaolinite. In kaolinite bands, white kaolinite occurs everywhere in thin films and is commonly associated with goethite and hematite, and some magnetite. Magnetite bands contain magnetite transformed into martite or to kenomagnetite. Magnetite concentrations occur as elongated and compact nodules.
with hematite in places. Talc and specularite concentrations normally occur in all bands described above.


In Y Body, level 802, the thickest bands in an ore sample were separated and analyzed. Ore grades in goethite, hematite and quartz bands, respectively, are 390.57, 271.27 and 15.34 g/t, respectively. Magnetite crystals are abundant in the concentrate from all auriferous bodies, and there is a positive correlation...
between gold grade and magnetite concentration, both in concentrates and in bulk ore from the processing plant.

The thicknesses of the ore zones are variable, from millimeters to over 50 cm, the most common being 1 to 20 cm (Fig. 5). The thinner zones have the highest gold grades. In the auriferous bodies of the Cauê Mine, there is no decrease of the thickness with depth according to the description of Henwood (1871) of Gongo Soco mine.

Fig. 6. General map of the Y orebody. A – general map of Y orebody; B – general map of Y orebody with grades > 5 g/t; C – general map of Y orebody with grades > 10 g/t.
Gold-bearing host rocks of the bodies X, Área Central and Aba Norte are itabirites and bodies of soft and hard hematite. Magnetite concentrations can occur in the itabirites of the Área Central and Aba Norte bodies and, more rarely, in the X Body. Hematite bodies are predominantly soft, except in the Aba Norte Body and in portions of the Área Central Body where they can be compact. In these auriferous bodies, the mineralization occurs predominantly at the contact between the lithologies described above. However, there are also many mineralized fractures that truncate the itabirites. The mineralization occurs in goethite, hematite and magnetite bands. Specularite, quartz and kaolinite are associated minerals, and rutile, tourmaline and pyrolusite are accessory minerals. The contact-hosted orebodies are everywhere thicker than those hosted in fractures in the itabirites. The average thickness is 0.2 m, but can reach up to 1.5 m in the Aba Norte Body.

The principal characteristic of the X Body is an equivalent amount of manganese in the host rocks. The mineralization occurs at the contact between fractured itabirites and foliated soft hematite with manganese. Free gold is associated with hematite and goethite. Quartz, talc and specularite occur in variable proportions and kaolinite bands are common in the orebody, which has an average thickness of about 0.2 m.

The Área Central Body has the same characteristics as the X Body, except for low manganese content. The mineralization is at the contact between fractured itabirites and bodies of soft or hard hematite, or in fractures that truncate the itabirites (Galbiatti, 1999). The auriferous ore is composed of goethite bands, hematite and magnetite with accessory talc, kaolinite, specularite and quartz. Free gold occurs in the goethite, hematite and magnetite bands. Kaolinite is abundant in the ore with a positive correlation between gold grade and kaolinite (Galbiatti, 1999).

Similar to the Y Body, the Aba Norte Body was mined in the past as part of the Santana Mine (Henwood, 1846). It is located on the north flank of the Cauê Syncline and can be subdivided into three bodies: Aba Norte 1, 2 and 3. Gold mineralization is hosted in fractures in friable BIF, in bodies bounded by the contact between fractured and friable BIF and bodies of soft or compact hematite (Aba Norte 1). It is also hosted in bodies located at the contact between fractured and friable BIF and intrusive rocks (Aba Norte 2), and at the contact between BIF and chlorite schists of the Nova Lima Group (Aba Norte 3).

The ore is composed of goethite and hematite bands with specularite, quartz and kaolinite, and accessory talc, rutile and magnetite. The thickness of the mineralized zone is about 0.3 m, locally reaching 1.5 m in tension fractures.

Platinum group minerals are associated with Jacutinga in all auriferous bodies from the Itabira District. The minerals identified are: isomertieite (Clark et al., 1974), arsenopalladinite, palladseite/native palladium (Olivo et al., 1995) and platinum, hongshiite and tetraauricuprite (Galbiatti, 1999).

5. Structural control of the orebodies

Recent researchers with a focus on structural geology have characterized these bodies as having strong ductile structural controls with the control being attributed to stretching and mineral lineations (Cabral, 1996) and/or fold axes (Leão De Sá and Borges, 1991; Olivo, 1994; Olivo et al., 1995).

In this study, detailed structural mapping of Y Body (Figs. 6, 7 and 8) documents the control on gold mineralization as a system of fractures in two main directions, N30–70E and N20–40W. The structural analysis of the fractures and earlier foliations indicates that there is no relationship between them. Fig. 9 clearly shows the disparity between fractures (Fig. 9D) and the regional cleavage (Fig. 9A, B), which displays a conical girdle, a situation unique and restricted to the central

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Fig. 7. Longitudinal sections of Y orebody. A – longitudinal section of Y orebody; B – longitudinal section of Y66 orebody.
area of the Cauê Mine. The mineralization is not hosted primarily within the cleavage planes, but may extend out from the fractures to the foliation in the host rock.

The first selectively mined level was level 893 m, with a median ore grade of 45 g/t. Median ore grades of about 25 g/t were then reached down to level 844 m. There, a decrease in the ore grades progressed to the current grade of 3.0 g/t in level 823.

In the 49 m from level 893 to level 844, the body maintained a single structural control within two main fractures (Fig. 6B and C). From level 844 to level 823, a decrease in ore grades was related to loss of the principal well-mineralized fractures, as more low-grade impoverished fractures were intersected. Starting from the 823 m level, a complex system of fractures was characterized, as shown on Fig. 6A. Only when the
lodes have grades above 5 g/t (Fig. 6B) and 10 g/t (Fig. 6C) is it possible to characterize the broader orientation of the auriferous ore.

Despite the complex and widespread fracture arrays, two main sets of fractures can be defined. The first is the pattern between levels 893 and 844 where there are two main fractures with high and constant ore grades. Vertical fractures (N70E/90°) and inclined fractures (N30E/40°SE), that intercept each other characterize this system (Fig. 6B).

The second is the pattern of fractures located below the 823 level. From this level, the fractures have several orientations, forming a complex pattern with varied, but lower, grades than the upper fracture zone. Amid this complex pattern, two groups of almost parallel fractures with more constant grades can be defined. They have been called “Y Body 66” and “Y Body 67” (Fig. 6B).

Detailed mapping of key areas of the Y Body 66, on levels 811–808–805, shows that there are several interconnected fractures rather than a single planar fracture (Fig. 8). The fractures define an enveloping surface with a N40–70°E trend, in contrast with the EW-trending cleavage in this area, thus confirming the contrast between the regional cleavage and the mineralized fractures in Y Body. The mineralization in the fracture set concentrates as linear plunging bodies, with centimetric to metric lateral extensions, with exceptional ore grades that can reach values 1000 times the average of the mineralized body.

Detailed mapping of the Aba Norte Body at level 915 m shows that the highest ore grades are at Aba Norte 1, in bodies related to the wrench shear zone that truncates the northern limb of the Cauê Syncline, herein named ZTANCA (the Portuguese form for Wrench shear zone of northern limb of Cauê Syncline; Fig. 2). An associated sub-vertical S2 foliation transposes the S1 foliation and dips both north and south (Figs. 11C1 and 12F1).

The shear zone truncates BIFs (itabirites) and also schists of the Nova Lima Group. The fault zone is not exposed in basement rocks of the Cauê Mine, due to extensive soil cover on both sides of the structure. However, some other wrench faults with the same trend truncate basement rocks close to the Cauê Mine. The main wrench shear zone is named ZTDFI (the Portuguese form for Wrench shear zone of the Itabira Ferriferous District; Fig. 2).

Fig. 10. Photographs from auriferous bodies of the Cauê mine. Idiomorphic gold crystal from a tension fracture from Aba Norte 1.

5.1. Kinematic analysis of the auriferous bodies

As discussed below, the fracture array described above was generated during the D2 event, which was synchronous with the development of a wrench shear zone that truncates the northern limb of the Cauê Syncline, herein named ZTANCA (the Portuguese form for Wrench shear zone of northern limb of Cauê Syncline; Fig. 2). An associated sub-vertical S2 foliation transposes the S1 foliation and dips both north and south (Figs. 11C1 and 12F1).

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The right–lateral wrench shear zone is interpreted to have generated shear fractures (R, R’ and P) and tension fractures (T) with R and R’ developed in conjugate pairs in accordance with the Riedel pattern. In all the auriferous bodies, R and P fractures are better developed and better mineralized. T fractures are more abundant close to the wrench shear zone (Fig. 12E, F). R fractures are more abundant in some bodies (Fig. 12B, C, D) whereas T (Fig. 12E) and R, R’ and T (Fig. 12A, F) dominate others. Mineralization clearly decreases away from the shear zone.

From a kinematic point of view, all fractures that trend northeast, N30°–70°E, are right-lateral synthetic structures. These fractures, in places, have an accentuated normal component (Fig. 5B). The fractures in the northwest quadrant, trending N10°–50°W, are left-lateral antithetic structures. There is an angular difference (dihedral angle) between the conjugate pairs of R/R’ fractures in different areas. In the north and central area of the mine, the rocks are more brittle and the dihedral angles are lower. In the northwest area, the rocks are more ductile and dihedral angles are greater (Fig. 12B, F).

The mineralized fractures more commonly occur in the packages of itabirites and in bodies of powdery hematite, but can also occur in compact hematite bodies, where the mineralization is more common at the contact with fractured itabirites.

E–NE and W–SW trending fractures and shear zones commonly truncate the schists of the Nova Lima Group and gneisses of the basement. There is complete infilling with goethitic material in some fractures, whereas similar fractures are mineralized in BIFs. This shows that the basement rocks and the Rio das Velhas Supergroup were both involved in the fracture system.
that controls gold mineralization, even if fractures in these rocks are not well mineralized.

In terms of the stress field at the Cauê Mine at the time of the mineralization, the existing structural elements, such as tension gashes, fold vergences and the spatial distribution of the system of fractures suggest two compressional directions: E–SE/W–NW and E–W. The fractures study suggests an E–W compression direction, with R and P fractures trending NE and R' fractures trending NW. The field data show that synthetic fractures trend NE, antithetic ones NW, and the tension fractures E–W.

5.2. Plunge control on auriferous bodies

Three types of plunge are defined: the plunge of the ore zones in the plane of the fractures, the plunge at the contact between hematite bodies and fractured itabirites and the plunge of the intersection of mineralized fractures.

In terms of the plunge in the plane of the fractures, longitudinal section A–A'–located in Y Body, between levels 893 and 844, is a good example (Fig. 7A). The section has an attitude of N70E/vertical. It is located exactly in the vertical plane of the mineralized fracture, and therefore determines the accurate positioning of 59 m in extension along the dip and 15 m-wide-concentrations of the auriferous ore. In this zone, the ore grade was extremely high, reaching values above 1.0 kg/t. The plunge of the ore zone is N70E/28°. The ductile structures trend from N80E to S70E, 20° (mineral stretching lineation) and N80E to S80E, 20° (fold axes).

Longitudinal section B–B', is located in Y Body 66, between levels 844 and 799, with an attitude of N60E/
70°SE (Fig. 7B). The ore grades of the set of fractures comprising the Y Body 66 are projected into this plane. The width of the mineralized zone reaches 40 m and the extension along the dip is currently 120 m. The plunge of the zone is N60E/35°. At this section, mineral stretching lineation trends S70E, 15°. The average gold grade is 5.0 g/t. The plunge has the same characteristics as in the Y Body, but grades decrease in the lower levels. The highest ore grades are located in the center of the set of fractures and decrease laterally.

Gold mineralization also parallels the contact between soft/hard hematite bodies and fractured itabirites. Therefore, the plunge varies because the hematite bodies have different spatial positions. For example, AC and X bodies are in the central part of the mine whereas the AN Body is located inside the E–W trending wrench shear-zone (Fig. 12). Longitudinal section C–C′ is located in the Aba Norte deposit along the contact between the AN Body and the hematite body: it thus contrasts with sections A–A′ and B–B′. The mineralized zone is 40 m in width, and extends 50 m up to the last mined level (level 800). The plunge is E–W/67°. Importantly, within the wrench shear zone, the plunge of the mineralization is sub-vertical, whereas the mineral stretching lineation is sub-horizontal (Fig. 5D).

An evaluation of the longitudinal sections indicates that there is a concentration of grades in the central part of the mineralized zones (BB′ and CC′) and that ore grades decrease laterally. The plunge of the mineralization in the Y and AN bodies is N20° E/28° to N60°E/35° within planes of fractures striking N60°–70°E and dipping 30 to 70°. Orientations of the foliation and mineral/stretching lineation (Figs. 12A, B, E and 11C1) confirm that their trend is completely different from the plunge of the ore zone, showing that the plunge is controlled by a fracture system that post-dates D1 deformation in the Itabira District. This clearly negates the ductile structural controls interpreted by Leão De Sá and Borges (1991), Olivo (1994) and Cabral (1996).

Another plunge direction results from the intersection of mineralized fractures. Structural data suggest that the intersections of some fractures are coincident with auriferous concentrations. An example is Y Body, where the system of fractures is better developed and the mineralization is confined within it. The mineralized fractures trend 150/38° (P), 153/68° (R), 6/74° (T) and 8/32° (R′) (Fig. 9F), and the intersections between the tension fractures and the shear fractures plunge 82/34°, 87/20° and 88/8°. The intersection between synthetic fractures is 69/8° and between the synthetic and antithetic fractures, 72/20° and 78/15°.

The maps show that the intersection 72/20° is close to the attitude of the plunge of mineralization between levels 893 and 844. Additionally, sampling maps indicate that several enriched auriferous bodies occur in groups with attitudes of 72/20°, parallel to the 70/28° trend of the intersection of the R and P fractures along longitudinal section AA′ described above (Fig. 7A).

Some intersections between fractures have plunges close to those of the mineral/stretching lineations and folds axes, but field data clearly indicate that the fracture array is the predominant control.

6. Conclusions

The Jacutinga is an auriferous ore type, of hydrothermal origin, hosted in fractures that truncate the BIFs (itabirites) and at the contact between those rocks and soft/hard hematite bodies and intrusive rocks. The Jacutinga has free gold, PGM and a lack of sulfides, with an at least partly secondary mineralogy of goethite, specularite, talc, kaolinite, manganese oxide, quartz, hematite and magnetite. The more common accessory minerals are tourmaline, monazite, zircon, apatite, ilmenite, epidote and rutile. Gold grade is extremely variable, including extremely rich ore zones.

Two deformational events affected the Cauê Mine area in the Itabira District. The first event, D1, is the most prominent and responsible for the generation of the ductile cleavage, S1. The second event D2-phase 1 is represented by a wrench shear zone along the northern flank of the Cauê Syncline, with the generation of a S2 foliation, overprinting the pre-existing fabric. A mineralized system of fractures was then developed. The final D2-phase 2 generated crenulations and fractures.

The structural analysis presented above demonstrates an important structural control on mineralization in the Jacutinga ores at the Cauê Mine. The auriferous bodies occur in brittle fractures that truncate itabirites and, more rarely, the hematite bodies, and at the contacts between fractured itabirites and bodies of soft/hard hematite. The fracture systems are related to the development of a wrench shear zone developed in the northern part of the Cauê Syncline.

Such systems include conjugate pairs, R/R′, in all the studied bodies, and associated P and T fractures. Mineralization is hosted largely in the R, P and T fractures, more commonly in R and T. The auriferous bodies of the Cauê Mine are controlled by the intersection of fractures that
truncate the regional foliation. The plunge of the mineralization is controlled by the intersection of brittle fractures, and is not parallel to the mineral/stretching lineations or fold axis or any other ductile structures as previously suggested in the literature.

Development of this new concept on the geometry and dominantly brittle control of the orebodies has been responsible for more efficient exploration and mining, with significant impact on gold production at the Cauê Mine.

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