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The Serra da Borda Breccia Field, Aguapeí Mobile Belt, SW Amazonian Craton, western Brazil: geologic characterization based on field and petrographic data

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Abstract

Siliceous breccias with accompanying massive to banded metachert have been found hosted in metasandstones of the Fortuna Formation, the lower unit of the siliciclastic, mostly psammitic, Aguapeí Group. This group developed mainly in a late Mesoproterozoic aborted continental rift or aulacogen of the Sunsás-Aguapeí Province (1.2-0.95 Ga), whose evolution led to the stabilization of the southwestern fringe of the Amazonian Craton, promoting its final consolidation. Regionally, the breccias and related metachert form four main linear, NW-SE strike-parallel trends that lie symmetrically about the hinge zone of synclinal folds. These trends are known to occur for a length of 25 km and a width of up to 4 km, so that the main breccia occurrences are distributed over an area of ca. 100 km^2 herein termed the Serra da Borda Breccia Field after the hills where they have been found in SW Mato Grosso state, western Brazil. The breccias display a multitude of textures and structures, e.g., massive, roughly tabular, bank-like outcrop morphology, dense to disperse packing and jig-saw to mosaic to chaotic clast distribution. They usually contain metachert fragments set in a fine-grained siliceous-clastic material, but fragments of crystalline quartz aggregates and of metasandstone are present as well. Stratified breccias with a clearly clastic sandy matrix also occur. Associated with the breccias are massive to banded metachert as well as sinter-like vuggy siliceous rocks with vugs following banding. This picture suggests strongly that the breccias constitute strata-bound syn-sedimentary bodies. On grounds of their outcrop and textural features, the breccias and associated metachert are provisionally interpreted as hydrothermal phreatic products of syn-sedimentary eruptive hot-spring activity completed by debris flow deposition, with the involvement of rift-related growth faults.

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1. Introduction

Siliceous breccias and associated metachert have been found in the Serra da Borda hills, SW of the Mato Grosso State, western Brazil. They are hosted in metasandstone of the Fortuna Formation, the lower unit of the Aguapeí Group (e.g., Ruiz 2005), and, although distributed over a relatively large area, they have never been mentioned in the literature. The main purpose of the present article is to make public the occurrence of these siliceous rocks by describing their main features and geologic relationships, and providing a provisional interpretation of their occurrence. The methodology used in the work was essentially outcrop examination and thin section description with bibliographic support. Due to the difficulty in dealing with the strongly varied textural aspects inherent to breccia bodies, the photographic recording was of particularly intensive use. Although metallogenic implications are not addressed in this paper, features as those described here are commonly found in association with precious and base metals epithermal deposits in many places elsewhere (e.g., Simmons et al. 2005).

2. Geologic setting

The siliceous breccias and associated metachert that crop out in the Serra da Borda hills are hosted in metasandstones of the Fortuna Formation, which is the lower unit of the Aguapeí Group (Fig. 1). According to Ruiz (2005), Saes et al. (2006) and Teixeira et al. (2010), this group is made up of a siliciclastic package including alluvial, eolian and shallow marine sediments deposited as a platform cover. Part of this cover underwent deformation and greenschist facies metamorphism within the limits of the NW-SE-trending Aguapeí fold-and-thrust belt developed in an intracratonic aborted rift or aulacogen. Ruiz (2005) refers specifically to the incidence of greenschist metamorphic facies for the Aguapeí Group rocks in the Serra da Borda region. Yet according to Teixeira et al. (2010), the Aguapeí belt exhibits only localized deformation and low-grade metamorphism, as denoted by upright to NW-dipping gentle folds and NW-trending shear zones.

The Aguapeí belt evolved in the late Mesoproterozoic in the Sunsás-Aguapeí Province (1.2-0.95 Ga) and represents

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a reflex offshoot of the Sunsás orogen (1.1-1.0 Ga) whose main element lies further SW in the form of the homonymous collisional belt. Both the Aguapeí and the Sunsás belts are situated in the southwestern fringe of the Amazonian Craton (Fig. 1), having developed during the last litho-tectonic episode leading to the final stabilization of this region and the consolidation of the craton as a whole (Lacerda Filho et al. 2004; Ruiz et al. 2006; Geraldes et al. 2006; Bettencourt et al. 2010; Teixeira et al. 2010).

According to the above-mentioned authors, with particular reference to Ruiz (2005) and Bettencourt et al. (2010), the basement of the Aguapeí belt consists of the Jauru (1.78 – 1.42

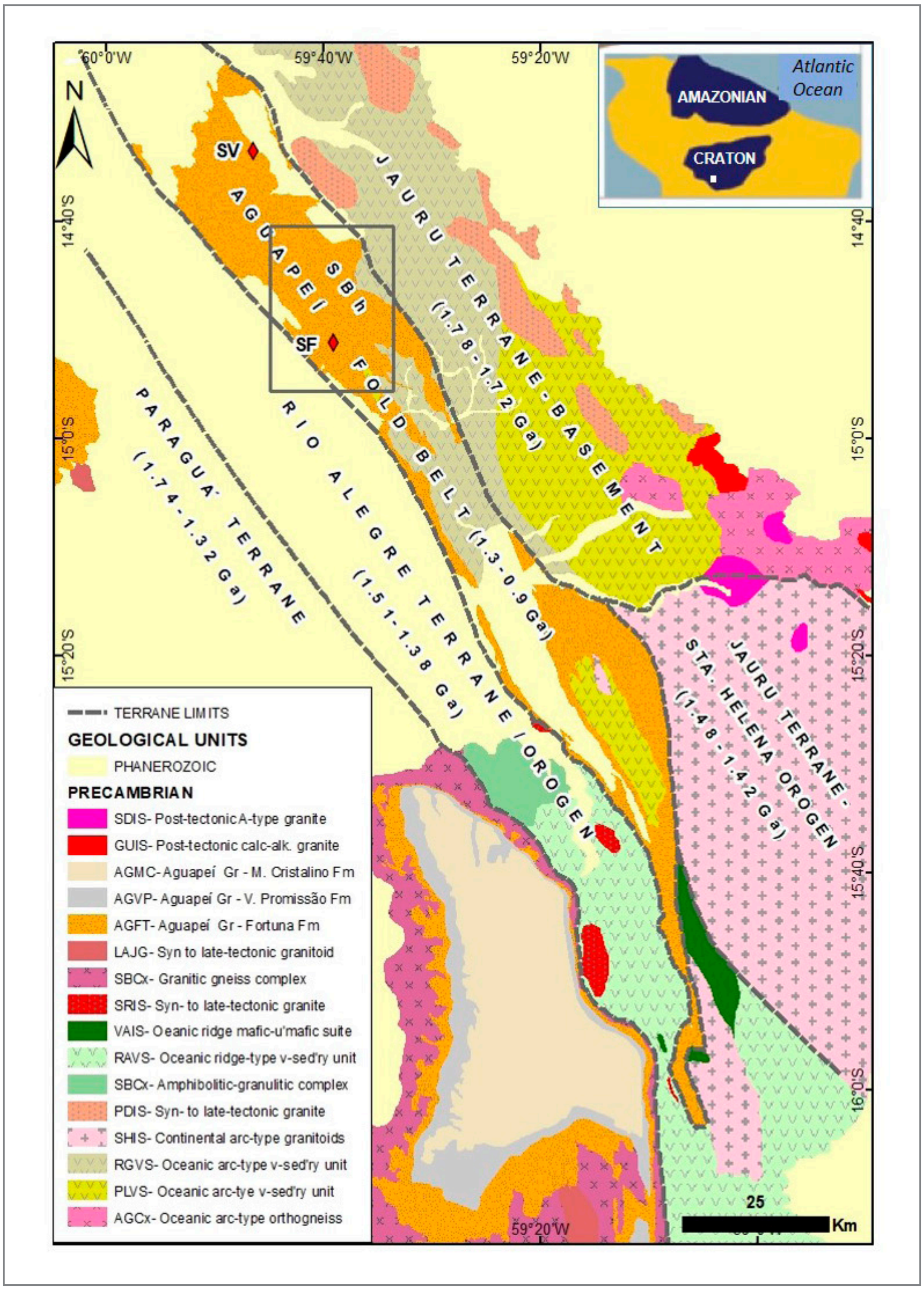

FIGURE 1 – Geology map of the Aguapeí fold belt region showing main tectonic elements and geologic units of the Serra da Borda hills (SBh), the siliceous breccia and metachert occurrence area (black outline), and the location of the São Francisco (SF) and São Vicente (SV) gold mines (modified after Lacerda Filho et al. 2004; Ruiz 2005; Bettencourt et al. 2010; Teixeira et al. 2010). JAURU TERRANE: AGCx- Alto Guaporé gneissic complex, PLVS- Pontes e Lacerda volcanic-sedimentary unit, RGVS- Rio Galera volcanic-sedimentary unit, SHIS- Santa Helena intrusive suite, PDIS- Pindaituba intrusive suite. RIO ALEGRE TERRANE: SBCx- Santa Bárbara granulitic complex, RAVS- Rio Alegre volcanic-sedimentary unit, VAUS- Vale do Alegre ultramafic suite, SRIS- Santa Rita intrusive suite. PARAGUÁ TERRANE: SBCx- Serra do Baú gneissic complex, LAJG- Lajes granitoid. AGUAPEÍ BELT: HGFT- Fortuna Fm, AGVP- Vale da Promissão Fm, AGMC- Morro do Cristalino Fm. LATE GRANITES: GUIS & SDIS- Guapé & São Domingos intrusive suites.

Ga) and the Rio Alegre (1.51– 1.38 Ga) terranes, which bound the belt to the east and west, respectively (Fig. 1). Further west lies the Paraguá terrane. The limits of the Aguapeí belt are defined by shear zones or thrust faults.

The Jauru terrane is represented in the neighborhoods of the Aguapeí belt by a Paleoproterozoic basement (1.76-1.72 Ga) and the Santa Helena orogen (1.48-1.42 Ga). The former is composed of oceanic arc-related orthogneisses of the Alto Guaporé complex and the associated volcanic-sedimentary Alto Jauru group (Bettencourt et al. 2010). For Lacerda Filho et al. (2004), however, the latter unit immediately east of the Aguapeí belt consists of two arc-related volcanic-sedimentary complexes - Rio Galera and Pontes and Lacerda - with maximum ages of 1.6 and 1.5 Ga, respectively. The Santa Helena Orogen (1.48 – 1.42 Ga), in turn, comprises syn- to late- collisional Andean-type magmatic arc granitoids of the homonymous suite and late- to post-kinematic granites of the Pindaituba intrusive suite. Calc-alkaline and A-type granites of the Guapé (1.0 Ga) and São Domingos (0.91 Ga) intrusive suites are found in the Jauru terrane. They are considered post-kinematic with respect to the Sunsás orogeny. Late tholeiitic mafic dike swarms are also known in the ambit of the Jauru terrane (Ruiz 2005; Bettencourt et al. 2010).

The Rio Alegre terrane, lying west of the Aguapeí belt, is made up of the Santa Bárbara mafic granulitic complex with maximum age of 1.6 Ga, the Rio Alegre volcanic-sedimentary sequence of mid-oceanic ridge setting (1.51 Ga), an associated mafic-ultramafic suite (1.51-1.49 Ga), and the syn- to late-kinematic, oceanic arc-type Santa Rita felsic intrusive suite (1.44-1.38 Ga). Further west of the Rio Alegre terrane lies the Paleoproterozoic to Mesoproterozoic Paraguá terrane, which was stable with respect to the Sunsás deformation as indicated by a flat-lying Aguapeí cover package (e.g., Bettencourt et al. 2010). For these authors, the units of this terrane cropping out in the region shown in Figure 1 consist of basement gneisses grouped in the Chiquitania Complex, the syn- to late- and late- to post-kinematic granitoids of the Pensamiento Complex (1.37-1.31 Ga), and granitic bodies of the Guapé Intrusive Suite (1.0 Ga). Lacerda Filho et al. (2004) in turn recognize in this portion of the Paraguá terrane the Serra do Baú gneissic complex in the SE, and the Lajes granite in the NW, with ages of 1.8 Ga and 1.6 Ga, respectively.

Economic mesothermal gold veins occur hosted in the Fortuna Formation and have been explored in the Serra da Borda hills region at the São Francisco and São Vicente mines distant some 40 km from each other (Fig. 1). Gold mineralization has been considered as related to the final stages of the Sunsás orogenic episode, being in part controlled by the above-mentioned bordering shears and thrusts (Scabora and Duarte 1998; Fernandes et al. 2005a, 2005b; Fernandes et al. 2006a, 2006b; Alvim 2007; Ruiz et al. 2014).

3. Results

3.1. Distribution of the breccias

The breccias and associated metachert occurrences of the Serra da Borda hills, in the northern portion of the Aguapeí belt, are particularly abundant in the region of the São Francisco gold deposit (Fig. 1). Field relationships observed in this area were essential for the geologic characterization of the siliceous rocks. Accordingly, the breccias and related metachert generally constitute small ridges oriented parallel to the general NW-SE direction of the Aguapeí aulacogen and the bedding trace of the adjacent siliciclastic rocks of the Fortuna Formation, as exemplified in Figure 2.

Furthermore, four main breccia trends have been identified in the region, following the mentioned general regional NW-SE structural trace and lying symmetrically about the hinge zone of synclinal folds (Fig. 3). The largest of them extends for over 20 km in length and up to a few tenths of meters in outcropping width.

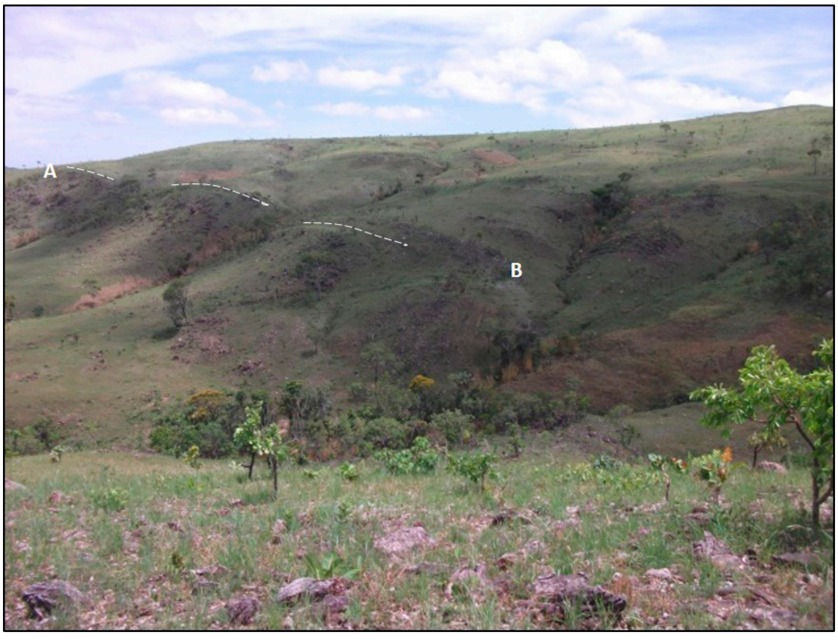

FIGURE 2 – View of the Serra da Borda hills to the northeast of the São Francisco mine with part of the break of slope ridge (A-B) sustained by siliceous breccias, as indicated by traced lines.

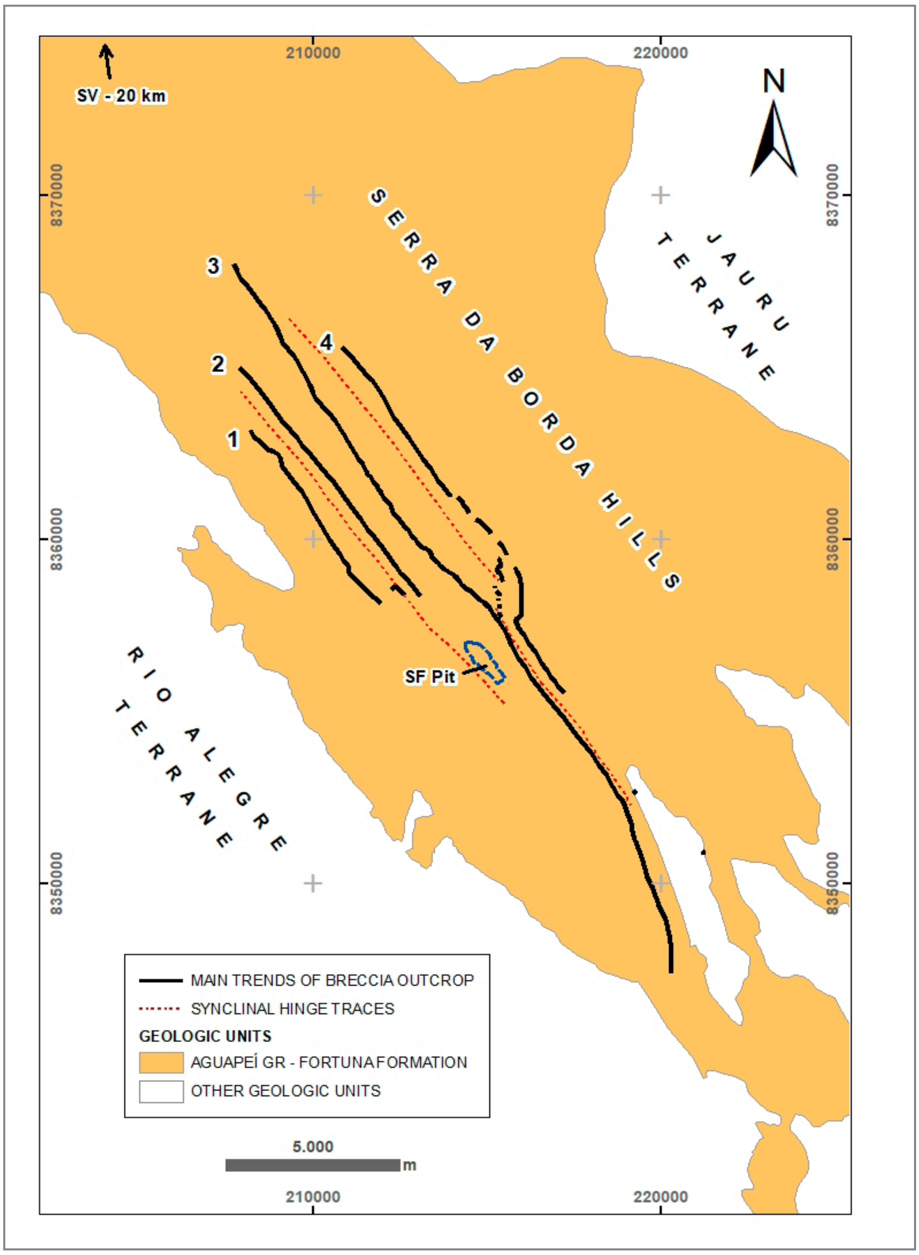

FIGURE 3 – Simplified geology map of the area outlined in figure 1, showing the main trends of the breccias in the vicinities of the São Francisco mine, Serra da Borda hills (modified after Lacerda Filho et al. 2004 and Scabora 2014, with additional data from one of the authors of this article). Location of the São Francisco (SF) mine pit and the São Vicente (SV) deposit indicated.

According to Figure 3, the breccia trends are well defined for about 25 km in the NW-SE direction and up to 4 km in the NE-SW direction, being therefore distributed over an area of approximately 100 km^2. Laznicka (1988) categorizes discrete breccia occurrences in terms of their areal extent of distribution. In agreement with this classification, the main breccia trends under scope constitute a breccia field and may, therefore, be conveniently denominated the Serra da Borda Breccia Field.

To the north of these main trends, two other smaller ones are known, extending only for a few hundred meters, at the so-called Esperança Creek and Breccia Hill prospects, near the São Vicente deposit. Besides this, apparently lesser breccia outcrops also occur east of the southern portion of the longest breccia trend shown in Figure 3.

3.2. Field and petrographic description of the breccias and associated rocks

At the outcrop scale, the main feature of the breccias is the development of massive, roughly tabular, bank-like rock bodies, which in several places show up parallel to the bedding of the adjacent metasandstones (Fig. 4A, B, C). In more detail, the breccias generally show white angular fragments up to a few tenths of centimeters across of fine-grained siliceous rock or metachert set in a fine, gray to pale red or brownish, quartz-rich material (Fig. 4B, C). Cobble- to granule-sized siliceous fragments also occur embedded in the adjacent pinkish metarenite wall rocks (Fig. 4D, E) and fragments of this rock are also found in the breccia. The size, form, and distribution of the clasts are very variable so that a multitude of brecciated textures and structures are generated. The packing of the breccias ranges from dense to disperse (i.e., from clast- to matrix-supported) (Fig. 4C, E, F), textures vary from jig-saw to mosaic to rubble to chaotic, and lath-like fragments occur as well (Fig. 4F, G). Fragments may lie along preferential beds and the cement may show a scoria-like texture. Additionally, the plucking out of clasts by erosion leaves behind the cement with a peculiar cavernous structure (Fig. 4H).

Associated with the breccias massive to banded metachert occurs (Fig. 5A, B), part of it displaying sinter-like vuggy textures with vugs following banding (Fig. 5B, C, D) or with globular elements up to a few decimeters in diameter

FIGURE 4 – Features of the breccia outcrops. (A) Typical siliceous breccia outcrop in the form of bank-like rock bodies. A bed of metasandstone lies under the breccia unit. (B) Bank-like breccia formed of pebble-sized clasts. A metasandstone layer showing cross-bedding overlies the breccia unit. (C) Roughly stratified breccia bank, containing siliceous rock fragments of different sizes. (D) Pebbles and granules of metachert embedded in metasandstone. Note that clasts are roughly imbricated along the bedding. (E) Matrix-supported breccia containing cobble- and pebble-sized siliceous fragments embedded in metasandstone. (F) Breccia containing clasts and laths of quartz set in a limonitic siliceous cement. (G) Breccia showing jigsaw to chaotic structure and many lath-like fragments. (H) Cavernous structure in breccia due to partial plucking out of fragments by erosion.

(Fig. 5E). In places, white, cherty rock occurs apparently interlaminated with pink sandstone (Fig. 5F). Millimeter-sized cavities and quartz-coated geodes are also observed and, locally, polished surfaces reveal slickensides. Some breccia outcrops in turn exhibit a shearing foliation that equally affects rocks of the Fortuna Formation nearby. On top of this, the breccia bodies occasionally host quartz veins which are similar to those that occur in the adjacent metasedimentary rocks and have been classified as orogenic.

Petrographic studies of the breccias have revealed that most of the fragments contained in these rocks consist of angular to lath-shaped metachert particles composed of microcrystalline quartz of rather uniform grain size (Figs. 6A, B, C, D). However, some breccias contain, besides metachert, other particles made up of crystalline fine-grained subhedral quartz aggregates (Fig. 6E, F). These aggregates do not preserve zoned or faceted quartz forms typical of vein infill textures, so they possibly derive from recrystallization of chalcedony or microcrystalline quartz. Fragments in the breccias are in some cases enclosed in a cement of microcrystalline quartz with associated iron oxide (Fig. 6A, B), but in many other instances the embedding material seems to be a mixture of clastic, fine-grained quartz grains, sericite, clay minerals, iron oxide, and a siliceous cement (Fig. 6C, D, E, F). Metachert clasts that occur clearly incorporated in metarenite can be seen in figures 6G and 6H. The metarenite, in this case, shows only negligible evidence of metamorphism, a feature that comes in support of the observation of Teixeira et al. (2010) about the uneven distribution of low-grade metamorphism in the Aguapeí belt.

Banded metachert associated with the breccias shows a sharp millimeter-sized layering, marked by colorless layers that alternate with brownish iron-oxide-stained laminae (Fig. 7A, B). The massive metachert is formed of an equigranular microcrystalline quartz aggregate containing some coarser-grained, possibly recrystallized, patches (Fig. 7C). Sinter-like siliceous rocks are also made up of microcrystalline, cherty quartz, but are only weakly or crudely banded and show cavities that tend to be elongate parallel to bedding (Fig. 7D).

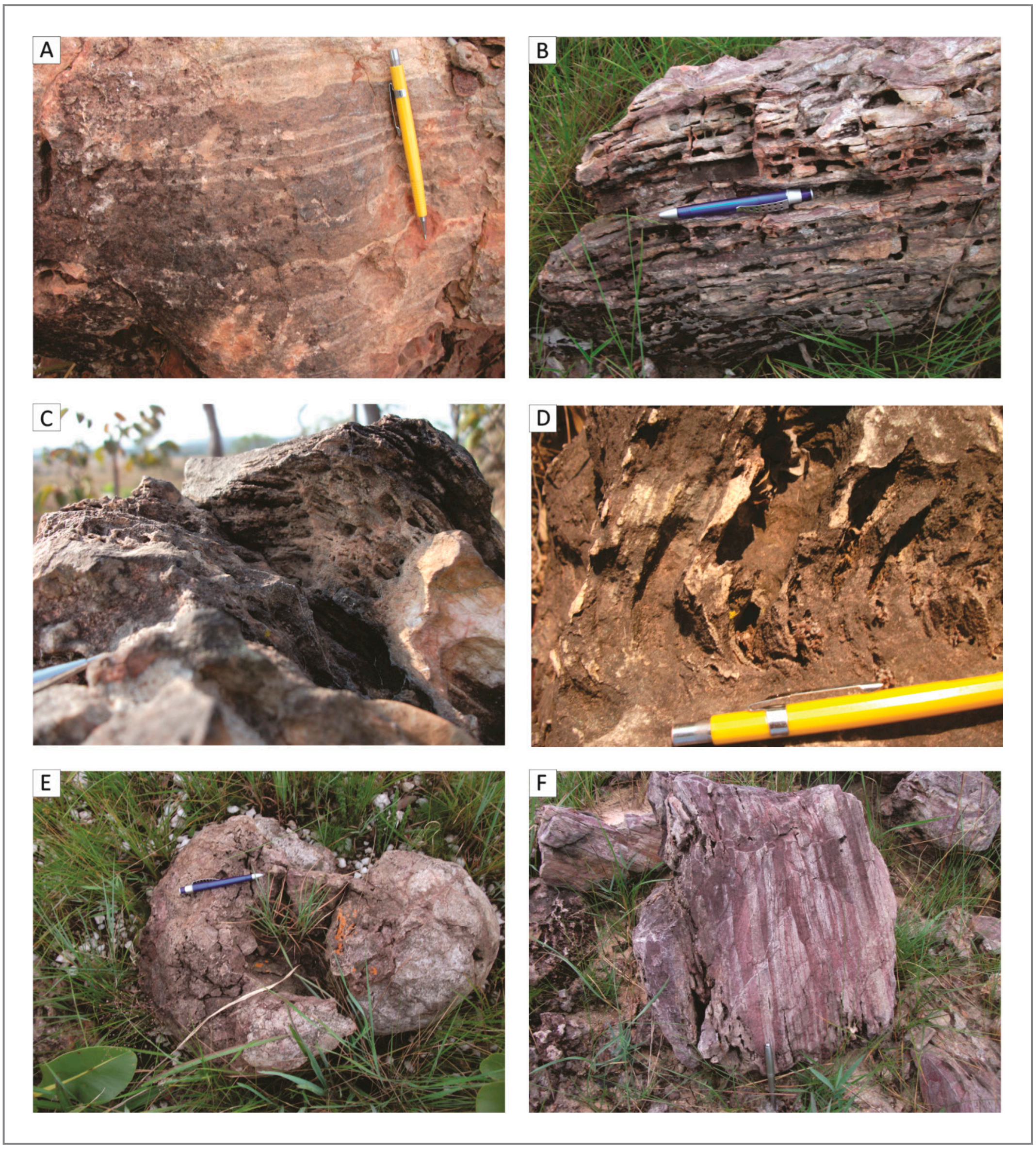

FIGURE 5 – Features of associated metachert outcrops. (A) Sharply banded metachert. (B, C, D) Banded cherty rock with a vuggy texture developed roughly parallel to the banding. (E) Siliceous globular structures as indicated by curved outlines. (F) Possible metachert layers (white) interbedded with red metasandstone.

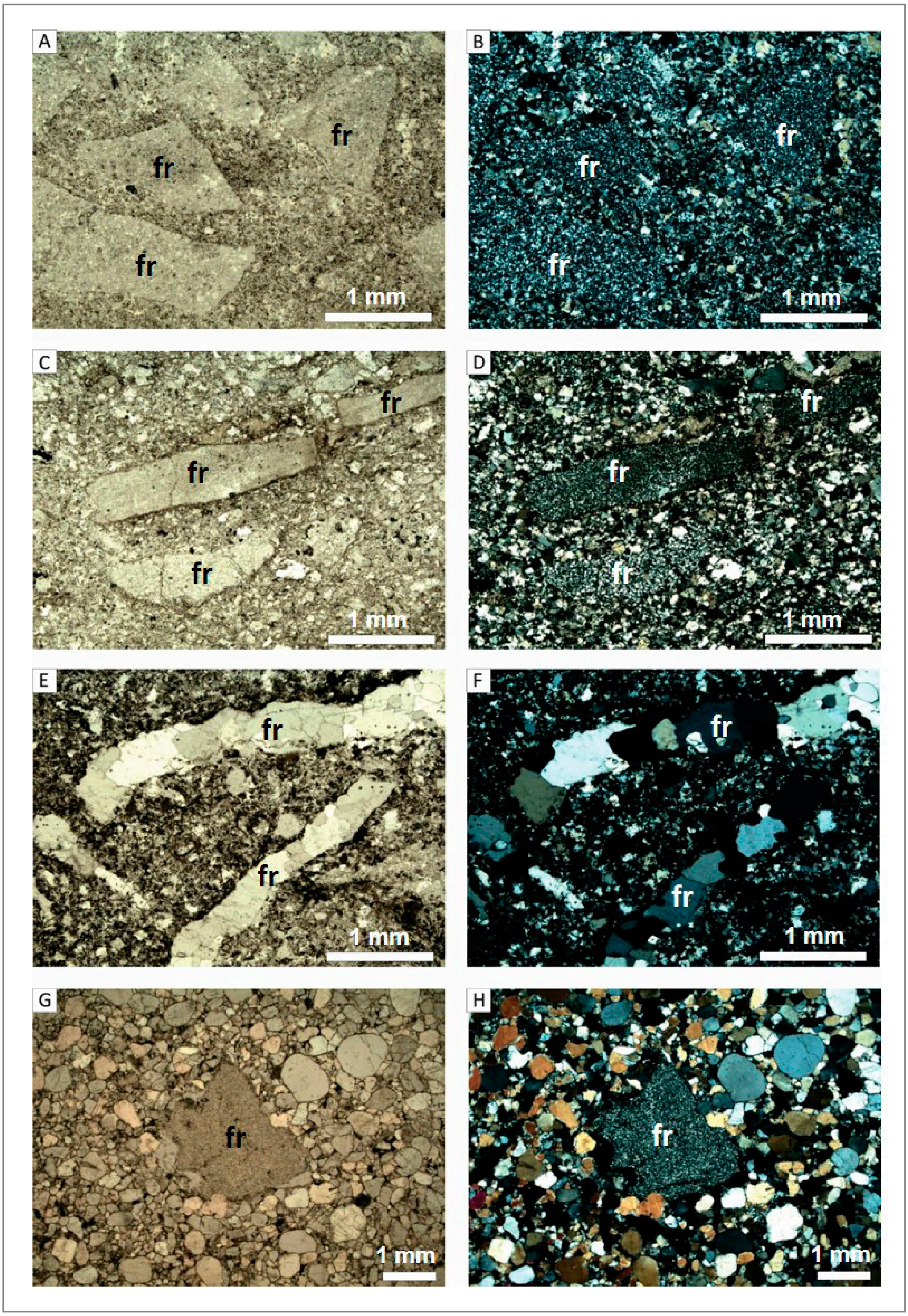

FIGURE 6 – Microscopic features of the breccias. (A) Angular metachert fragments (fr) set in siliceous microcrystalline cement. Plane-polarized light. (B) Same image taken under cross-polarized light to show that the metachert fragments (fr) are made up of microcrystalline quartz of a fairly small and uniform grain size; (C) Lath-shaped metachert fragments (fr) set in fine, possibly clastic-siliceous, embedding material. Plane-polarized light. (D) Same image taken under cross-polarized light. (E) Elongate fragments (fr) made up of subhedral quartz crystals enclosed in a fine, possibly clastic-chemical, material. Plane-polarized light. (F) Same image taken under cross-polarized light. (G) Subangular metachert fragment (fr) set in a metarenite matrix which in this case displays negligible evidence of metamorphism. Plane-polarized light. (H) Same image taken under cross-polarized light.

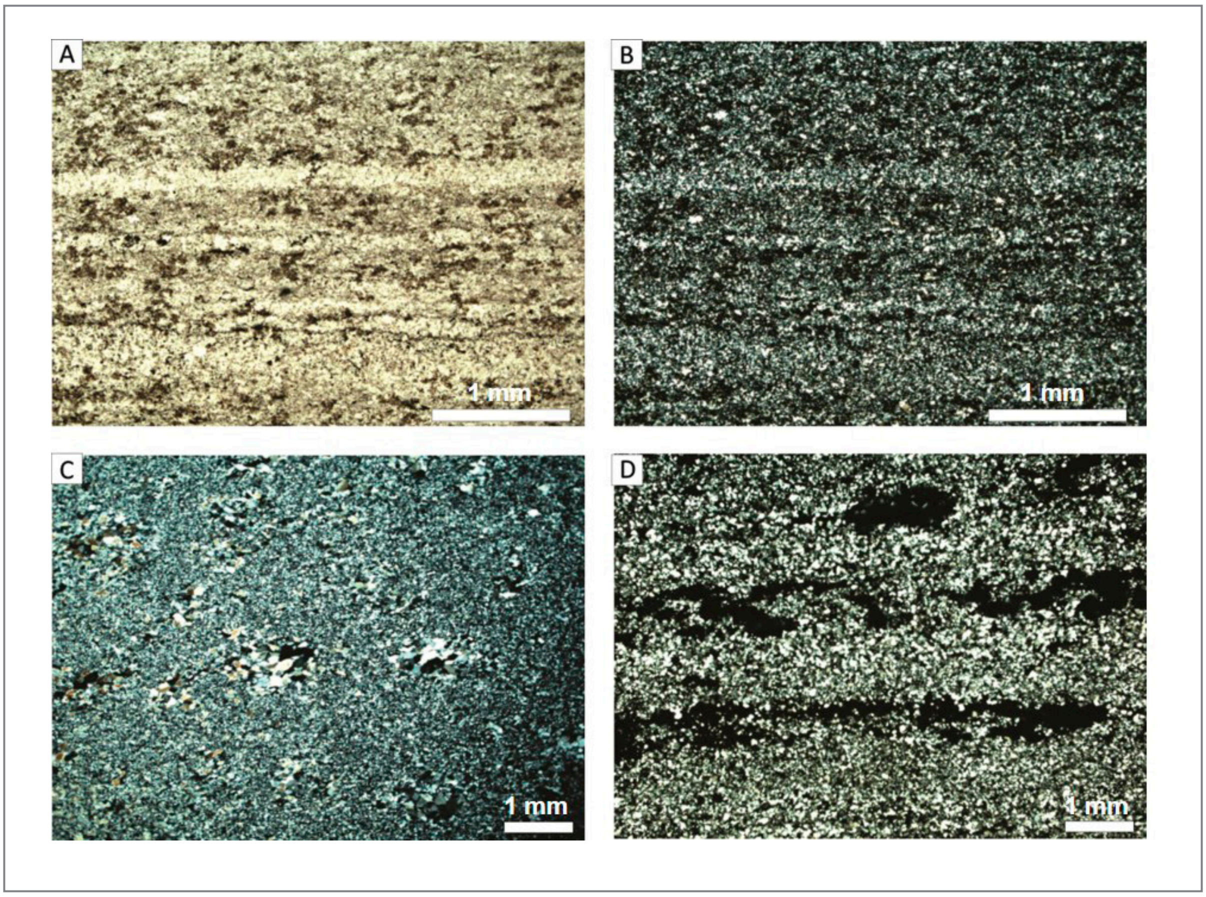

FIGURE 7 – Microscopic aspects of metachert associated with the breccias. (A) Sharply banded metachert. (B) Same image under cross-polarized light. (C) Massive metachert made up of microcrystalline quartz with patches of coarser, possibly recrystallized, quartz grains. Cross-polarized light. (D) Weakly banded metachert containing elongate cavities along the bedding suggestive of siliceous sinter. Cross-polarized light.

4. Discussion and interpretation

The overall distribution of the breccia units parallel to the general NW-SE direction of the bedding of the Fortuna Formation strongly suggests the strata-bound nature of the breccias. Besides this, the symmetrical arrangement of the four main breccia trends in relation to syncline hinge traces (Fig. 3) also points not only to this aspect but also to that the breccia bodies may be continuous down the bedding planes at depth and, consequently, may have been folded conformably along with the enclosing siliciclastic package of the Fortuna Formation.

Other pieces of evidence of the strata-bound nature of the breccias include the bank-like outcrop morphology (Fig. 4A, B, C), which as mentioned may show up parallel to the bedding of adjacent metasandstones, the interlamination of metachert and metasandstone as well as the disposition of the siliceous fragments along clearly-defined beds and intercalated in the metasandstones themselves (Fig. 4D). This last point is also important in the sense that it shows that the chert clasts were already available at the time of sedimentation, attesting that this material is, inescapably, of syn-sedimentary nature. To reinforce this aspect, cobbles and pebbles of metachert turn up incorporated dispersedly into the sandstone matrix (Fig. 4E), while, on the other hand, fragments of sandstones occur in the breccias. On top of this, the mentioned incidence of shearing and of orogenic quartz veins on the breccias suggests or rather indicates that the breccias underwent the same tectono-metamorphic history of the hosting Fortuna Formation sedimentary package.

As to the interpretation of the breccias properly, it is provisionally envisaged that they are of the hydrothermal phreatic eruptive type, connected to hot spring activity, with heat probably originating from an igneous source at depth, or even from the rift tectonic setting itself, involving only meteoric and connate, non-magmatic waters (Nelson and Giles 1985; Sillitoe 1985; Hedenquist and Henley 1985; Laznicka 1988, 1989; Lawless and White 1990). In the case of Serra da Borda, the specific igneous heat sources at depth, as well as eruptive centers, remain undefined. This notwithstanding, the process can explain the strata-bound morphology of the breccia bodies and its association with massive to banded metachert, in part exhibiting elongated vugs and cavities following banding that have been considered a typical feature of sinters (e.g., Sillitoe 1993) (Fig. 5B, C, D). Globular textures (Fig. 5E) have also been reported from sinters (Nelson and Giles 1985). Moreover, chaotic breccias (Fig. 4G) also occur in this kind of hydrothermal environment, originating from sinter plates broken and deposited by collapse in the bottom of water bodies (e.g., in the San Quentin sinter of McLaughlin, California; Laznicka 1988; University of California 2007).

These features altogether evidently do not conform to the pattern observed, for instance, in breccias of purely tectonic brittle origin which usually form steeply-dipping to upright tabular bodies that have no banded hydrothermal products associated with. Moreover, the hydrothermal eruptive activity devised would permit the input of silica in solution to the essentially siliciclastic depositional environment of the Fortuna Formation. Metasandstones of this formation, by the way, occasionally exhibit in the vicinities of the strata-bound breccia bodies cross-bed sets of decametric length typical of wind-blown sands, a feature which is in keeping with the subaerial environment preconized for the occurrence of hot springs.

Syn-sedimentary growth faults, common in rift-type environments, are seen as part of the breccia geologic setting, constituting elements of structural control of hydrothermal activity as well as of source areas for associated intraformational breccias with sandy matrix. The mentioned structural control on the channeling of fluids could even, for instance, lead to the implantation of discordant breccia bodies. Finally, the incidence of later, essentially tectonic brittle brecciation - as evidenced by the occurrence of polished slickensided surfaces - should not be ruled out.

5. Conclusions

Siliceous and sandy breccias with associated metachert – altogether of a likely strata-bound morphology - have been observed in the Serra da Borda hills, SW of the Mato Grosso state, western Brazil, hosted in a siliciclastic package deposited extensively as a cratonic cover. The package has been deformed in an aborted rift or aulacogen structure during late Mesoproterozoic times in the so-called Aguapeí belt of the Sunsás-Aguapeí Province in the SW portion of the Amazonian Craton.

The breccias form four main trends parallel to the regional NW-SE geologic strike distributed symmetrically about synclinal hinge zones over an area of approximately 100 km^2 and are herein grouped under the designation of Serra da Borda Breccia Field.

The breccias and associated metachert are provisionally interpreted as products of hydrothermal eruptive activity related to hot springs and of debris flow having as common structural elements growth faults that are usually active in the rift-type tectonic environment preconized for the evolution of the Aguapeí belt.

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