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Reassessment of the geology of the southeastern Tapajós Gold Province, Amazonian Craton, Brazil, based on field, petrographic, and airborne geophysical data

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Abstract

The Tapajós Gold Province, central portion of the Amazonian Craton, is one of the main metallogenic provinces in Brazil, but lack geological studies at an appropriate scale in its southeastern portion. Fieldwork, petrography, and high-resolution airborne geophysics (magnetometry and gamma spectrometry) allowed us to produce a new map at the 1:100,000 scale. In this study, we identified two new geological units: (1) the volcanic and pyroclastic rocks of the Vila Riozinho Formation, previously attributed to the Iriri Group, including a newly described facies of this formation, which comprises a group of rocks with the highest magnetic contents of the study area, and (2) the Serra Alkali Feldspar Granite, which intruded into the Vila Riozinho Formation. Based on available geochronological information these units can be associated to a volcano-plutonic event that occurred in the Orosirian period, at about 1.98 Ga. In addition, our work allowed us to define better the areas of occurrence of other units. The Parauari Intrusive Suite and Iriri Group areas were strongly reduced, whereas the areas of the Creporizão Intrusive Suite and of the Novo Progresso Formation were increased.

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1. Introduction

The Tapajós Gold Province (TGP), which is basically synonymous of Tapajós Domain (Faraco et al. 1997), is located in the south-central portion of the Amazonian Craton (Fig. 1) and is considered one of the main metallogenic provinces of Brazil. A significant part of the province comprises felsic volcanic and volcanoclastic rocks and granitoids, which formed predominantly in two time intervals, 2.02 to 1.95 Ga and 1.91 to 1.87 Ga and are grouped in several stratigraphic and lithodemic units (Vasquez et al. 2017).

Several issues regarding the TGP are still pending, including the limits with adjacent provinces or domains, the tectonic setting in which formed the volcano-plutonic units and the metallogenic evolution (e.g., Lamarão et al. 2002; Vasquez et al. 2017; Juliani et al. 2013; Tokashiki et al. 2015; Borgo et al. 2017; Fraga et al. 2017; Carneiro et al. 2018; Klein et al. 2012, 2017, 2018).

Another issue is the scarcity of geological maps in suitable scales for certain parts of the TGP, which is the case of its southeastern sector, where maps are available only at the 1: 1,000,000 scale (Fig. 2, Vasquez and Rosa-Costa 2008), and produced by regional integration and satellite image interpretation. A preliminary attempt to improve the cartography of the region was made by Guimarães et al. (2015), using outcrop investigation, little petrographic data, but without the use of geophysical information. In addition, the southern sector of the TGP is growing in importance because of the discovery of paleoplacer and hydrothermal gold deposits (Tokashiki et al. 2015; Queiroz and Klein 2018). Furthermore, the host rocks for the hydrothermal deposits are felsic volcanic and volcanoclastic rocks and granitoids from uncertain stratigraphic units.

Therefore, this paper aims to contribute to the understanding of the geology and stratigraphy of southeastern Tapajós Gold Province, based on field geology and petrography, with the support of new high-resolution airborne geophysics (magnetometry and gamma spectrometry). The results will bear implications for the future discussion of the crustal and metallogenic evolution of the southeastern Tapajós Gold Province.

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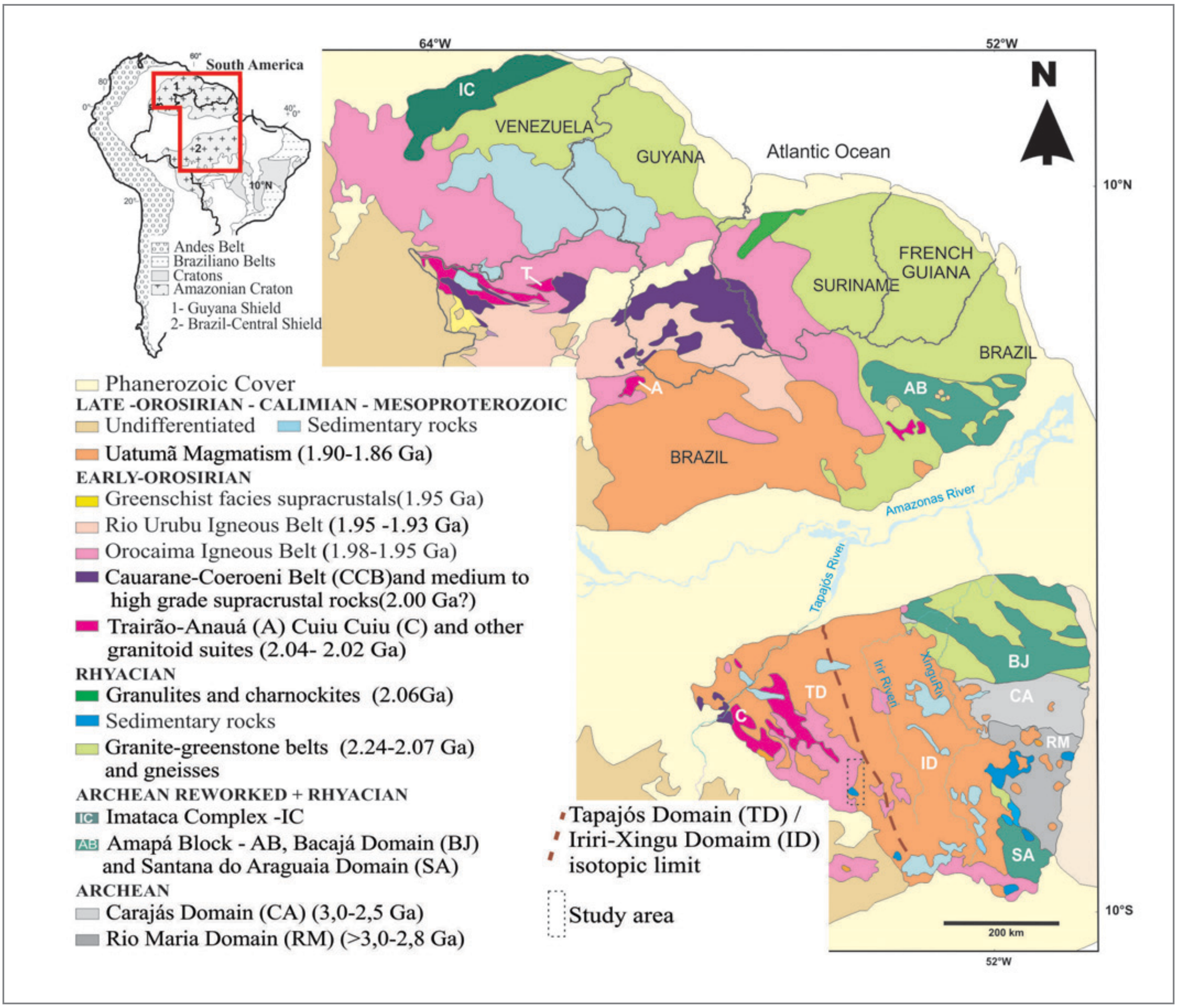

FIGURE 1 – Geological sketch of the Central Brazil Shield (south) and Guiana Shield (north) which form the Amazonian Craton, with location of the study area. Modified from Fraga et al (2017).

2. Geotectonic context

The Amazonian Craton presents heterogeneous lithologic and structural characteristics, which depicts an evolutionary history from the Paleoarchean to the Mesoproterozoic. The craton is part of the South American Platform (Almeida et al. 1981) and includes the Guiana Shield to the north and the Central Brazil Shield to the south, which are separated by Phanerozoic sedimentary basins (Fig. 1).

In the Central Brazil Shield, where the Tapajós Gold Province (or Tapajós Domain) is located, several tectonic/geological domains are recognized (Fig. 1 – Vasquez and Rosa-Costa 2008; Fraga et al. 2017). The oldest sequences of the shield occur to the east, comprising the Archean Carajás and Rio Maria domains, which consist predominantly of granite-greenstone assemblages, intruded by several generations of mafic-ultramafic and granitoid rocks, and covered by volcanic and sedimentary sequences (Santos et al 2000). These domains are limited by the Bacajá Domain, to the north, and by the Santana do Araguaia Domain, to the south, which include Archean remnants tectonically reworked during the Siderian and Rhyacian periods, along with greenstone sequences and granitoids formed during these periods (Transamazonian cycle). The central portion of the shield is represented by the Iriri-Xingu Domain, which contains mostly Orosirian felsic volcanic and granitoid rocks of the Uatumã SLIP (Silicic Large Igneous Province), and by the Orosirian Tapajós Domain/Tapajós Gold Province (Klein et al 2017, Fraga et al 2017).

The Tapajós Gold Province shows its main structures orientated according to the NW-SE direction (Fig. 3), reflecting the main faults and transcurrent shear zones that controlled the positioning of most igneous intrusions and extrusions in the southern half of the domain (which obviously contrasts with the existence of subduction derived magmatic arcs from south to north). The northern part of the TGP is marked by E-W trending structures, which controlled the positioning of several igneous bodies and Paleoproterozoic (Statherian) sedimentary basins (Klein et al. 2002; Santos and Coutinho 2008).

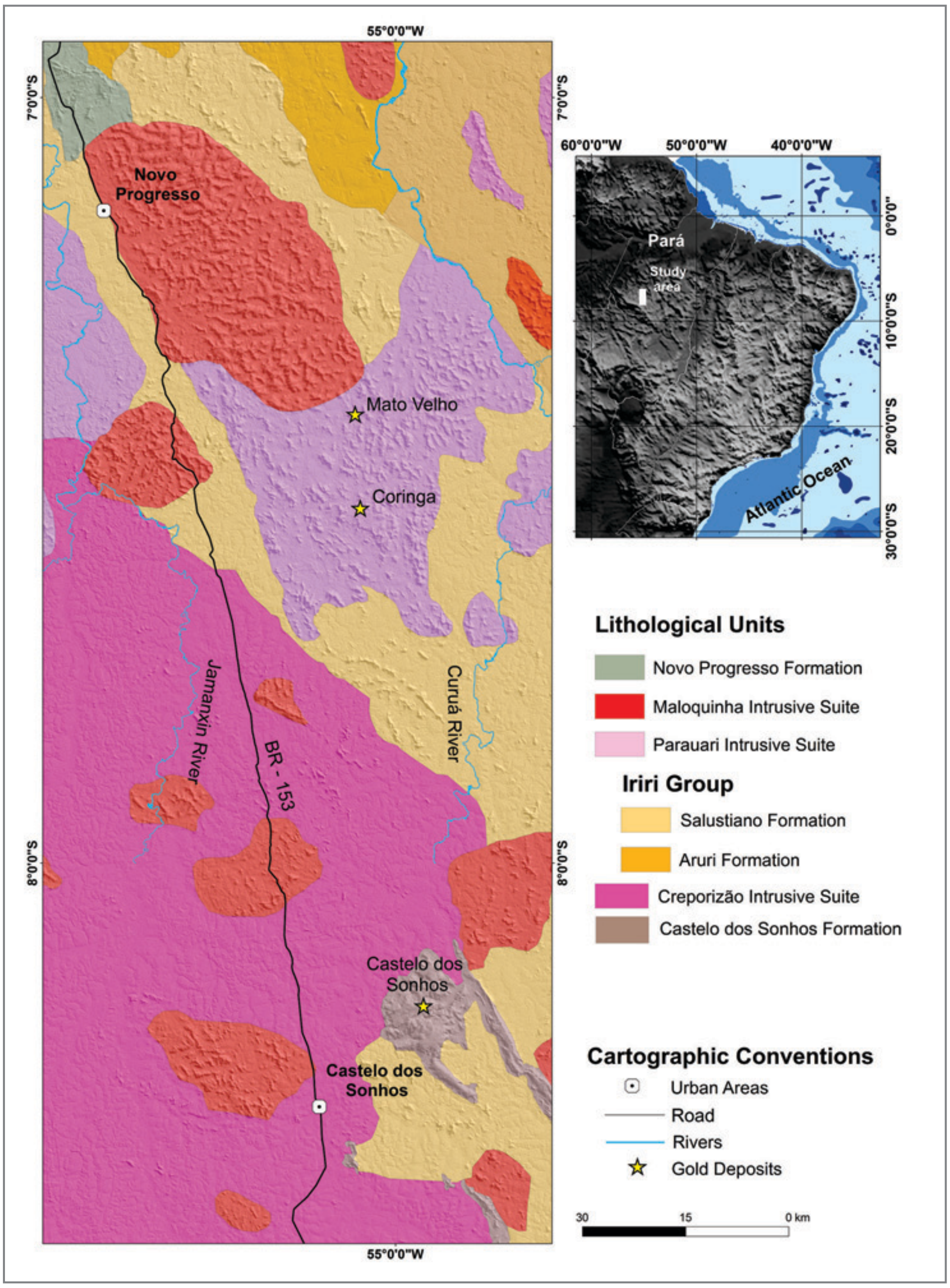

FIGURE 2 – Geological map of Southeast Tapajós Gold Province (modified from Vasquez and Rosa-Costa 2008).

The dominant brittle tectonics of transcurrent and extensional regimes have not modified the stratigraphic stacking of TGP units, which allowed Vasquez et al. (2008, 2017) assemble associations of rocks based on the ages related to each event.

Vasquez et al. (2008, 2017) established that the oldest magmatic event of the Tapajós Gold Province occurred at 2,033-2,005 Ma. This event comprises calc-alkaline rocks, which correspond to the basement represented by granites and orthogneisses from Cuiú-Cuiú Complex, along with the supracrustal rocks of the Jacareacanga Group and volcanic and volcanoclastic rocks of the Comandante Arara Formation (Fig. 2). The rocks of the Cuiú-Cuiú Complex are related to slightly evolved magmatic arc associated to the subduction of oceanic lithosphere, possibly an island arc setting, named Cuiú-Cuiú Arc (Vasquez et al. 2002).

All magmatic events of the Orosirian period, which followed the magmatism of the Cuiú-Cuiú Arc, were concentrated in the central, southeastern and eastern portions of the Tapajos Gold Province. The 2002-1956 Ma event (Orocaima Magmatism) comprises high-K calc-alkaline and shoshonitic magmatism represented by volcanic rocks of the Vila Riozinho Formation, and granitoids of the Creporizão Intrusive Suite (Lamarão et al. 2002; Vasquez et al. 2002; Santos et al. 2004). The transcurrent faults with NW-SE orientation controlled/reoriented the igneous bodies and the formation of the volcano-sedimentary basins related to this event.

After c. 50 Ma, a high-K calc-alkaline magmatism occurred between 1907 and 1864 Ma originated the São Jorge Jovem Granite (Tropas Suite), which was succeeded by the voluminous and widespread high-K calc alkaline magmatic events of the Parauari Intrusive Suite, and basic to intermediate Ingarana

Intrusive Suite (Vasquez et al. 2002, 2017; Santos et al. 2004).

Simultaneously an acidic alkaline magmatism represented by the Maloquinha Intrusive Suite granitoids and its extrusive equivalents of the Moraes Almeida Formation and Iriri Group occurred (Lamarão et al. 2002; Vasquez et al. 2017). The Iriri Group is subdivided into the Salustiano Formation (Andrade et al. 1978), which comprises dominantly acidic volcanic flows (rhyolites to dacites), and the Aruri Formation (Pessoa et al. 1977), composed of pyroclastic and acidic epiclastic rocks.

The youngest magmatic events in the region are diabase dikes correlated to the Jurassic period, a tholeiitic magmatism of the Penatecaua event (Vasquez and Rosa-Costa 2008). These dikes clearly show an aeromagnetometry signature and are oriented according to the E-W and NE-SW directions.

Sedimentary sequences occur in different portions of the domain and in different moments of the geological evolution of the TGP. In the southeast sector, close to the limit with the Iriri-Xingu Domain occur the Castelo dos Sonhos and the Novo Progresso formations. Castelo dos Sonhos Formation is the oldest unit of of the TGP, and is composed of auriferous metaconglomerates and metasandstones deposited by fan and fluvial systems between 2011 and 2050 Ma (Queiroz et al. 2015; Klein et al. 2017). Klein et al. (2017) observed that the deposition of the Castelo dos Sonhos Formation precedes the orogenic evolution of the TGP, and the basin was interpreted as a relic of a larger foreland system related to the Transamazonian orogen occurring to the east in the Amazonian Craton. The Novo Progresso Formation is composed of quartz- and lithic-arenites and siltstones with volcanic/volcanoclastic contributions, and was deposited in fluvial and lake systems. The maximum depositional age was established at 1840 Ma, whereas structural relationships suggest a minimum age of 1780 Ma (Klein et al. 2018). Provenance studies indicate that surrounding Orosirian rocks from Tapajós and Iriri-Xingu were the main sources for the sediments, with subordinate contributions from older and more distant domains of the Amazonian Craton (Klein et al. 2018).

In the west TGP occurs segments of sedimentary sequence orientation E-W, filled by sedimentary rocks of the Buiuçu Formation. It is composed of lithic arkoses and sandstones, with subordinate polymithic conglomerates, siltstones and argillites. Santos et al. (2001) presented a maximum sedimentation age> 1879 Ma for the detrital sources of this basin. On the other hand, Vasquez et al. (2018) state that it corresponds to a continental, or intra cratonic, rift basin, which succeeded post-orogenic magmatism from 1.88 to 1.86 Ga (Uatumã).

3. Geophysical methods

In addition to classic field and petrographic work, we used two airborne geophysical surveys (Rio Curuá e Cachoeiras do Curuá) for magnetic and radiometric interpretation. These surveys are part of the database of the Geological Survey of Brazil (CPRM), which collected information on N-S flight lines spaced of 500 m. The raw data were interpolated with a 125 x 125 m cell and integrated using the suture method of Johnson et al. (1999). The magnetic interpretation was performed on the vertical derivative of the magnetic anomaly, which highlights the near surface sources (Fig. 3A). This interpretation defined the variation of magnetization intensity, principal structural directions, shear relations and depth of structures. As such, the study area was divided into units of magnetic rocks (high and medium magnetization), magnetic discontinuities, and dikes (Fig. 3B). This interpretation follows the method of Isles and Rankin (2013). The radiometric data were interpreted in the RGB ternary image of potassium, thorium and uranium on the digital terrain model (Fig. 4).

4. Geophysical interpretation

The magnetic discontinuities follow, in general, the regional structure of the Tapajós Gold Province with preferential NW-SE direction, as well as the NE-SW trending faults, which apparently form a Riedel pair (Fig. 3B). However, corridors of E-W-trending faults intersect the NW-SE trend, which becomes less spaced and more sinuous in the southwest portion of the area, indicating rocks formed at deeper crustal levels. In the central-western portion of the study area, it is possible to interpret sigmoidal forms due to transtensional regime along E-W-trending shear zones. In the central-eastern sector of the area, there is expressive presence of circular magnetic bodies oriented along the N-W trend.

The most striking feature is an anomalous magnetic pattern that occupies an area around 30 x 15 km in the central portion of the study area (Fig. 3A). This pattern corresponds to a set of volcanic rocks with a distinct signature from the others described elsewhere for the Tapajós Gold Province (e.g., Vasquez et al. 2017), which are ascribed to the Vila Riozinho Formation and that are characterized by low magnetization. Besides the high magnetization, the units in the study area present a rugged relief with relatively high concentrations of potassium, thorium and uranium (Figs. 3 and 4).

To the south of the area, NE-SW-trending lineaments with dike signature are observed. However, these lineaments are scarce in comparison with the rest of the Tapajós Gold Province (Fig. 2). Although Teixeira et al. (2018) presented dike swarms between 1.88 and 1.80 Ga associated with the Uatumã SLIP, Vasquez et al. (2017) described diabase dikes with the same orientation and relates to the younger magmatic events correlated to the Jurassic tholeiitic magmatism of the Penatecaua event. As such, we interpret this direction as formed in the Paleoproterozoic, being reactivated until the Phanerozoic.

The RGB ternary image of potassium, thorium and uranium (Fig. 4) shows the radiometric signatures separated along NW-SE trending contacts. There are a series of bodies with granitoid signature placed along the NW-SE direction. Larger bodies show weak changes in the signatures at their edges, which might have been produced by changes in facies or by hydrothermal processes.

5. Proposed lithostratigraphy

The combination of magnetic, radiometric, field data and petrography allowed the consolidation of a new geological map for the southeastern sector of the Tapajós Gold Province drawn originally at the 1:100,000 scale (Fig 5), greatly improving previous maps (Fig. 2). The stratigraphic units occurring within the study area are described below.

Although the Parauari Intrusive Suite represents an expressive and widespread plutonic event in most of the

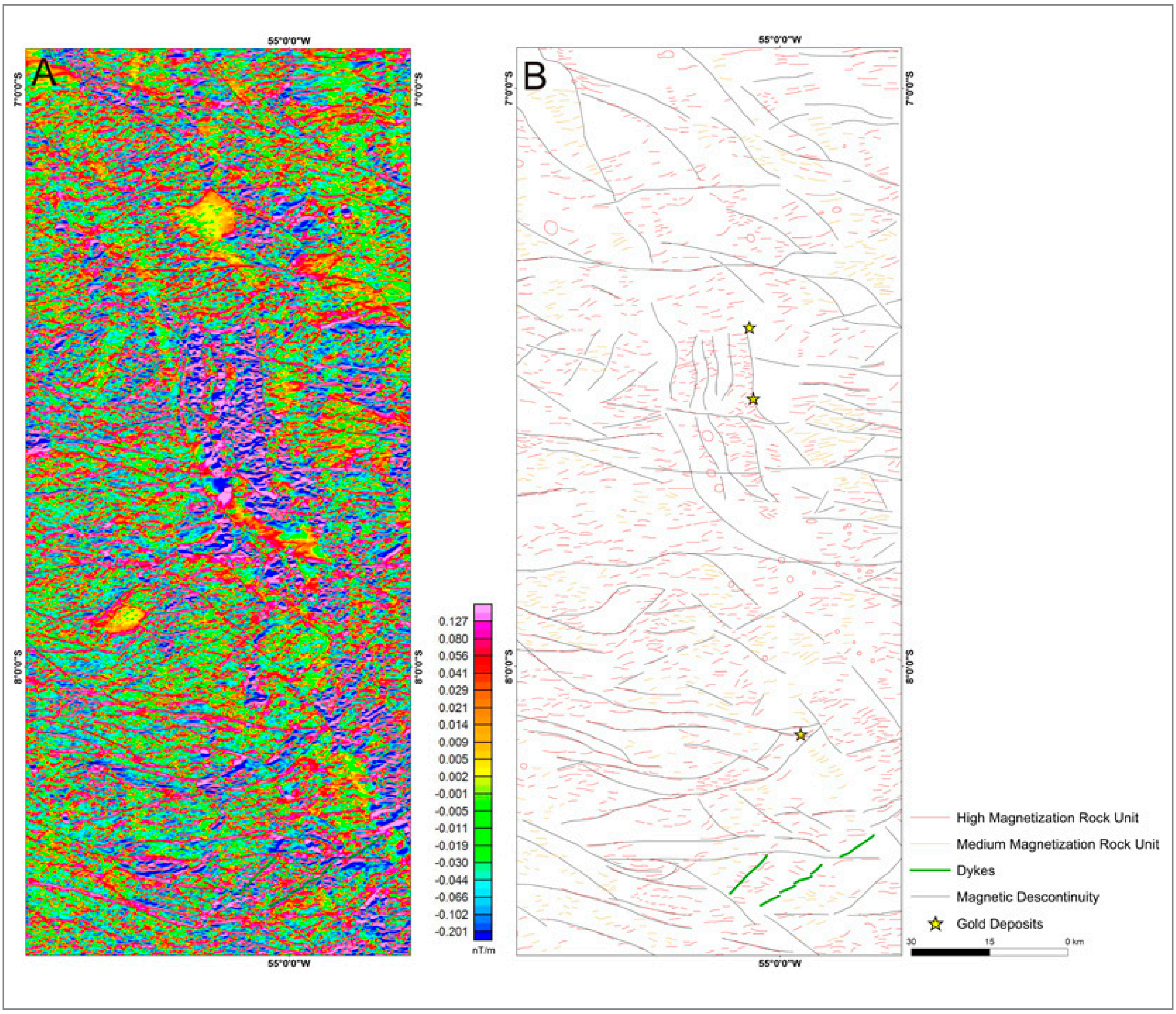

FIGURE 3 – A) Vertical derivative of the magnetic anomaly. B) Structural interpretation

Tapajós Gold Province, it is little represented in the study area. Due to access difficulties in this area, the definition of one body was made only by analogy between the airborne geophysical information (low magnetization, low concentrations of the three radioelements, and isolated portions with high potassium concentrations) and a body with the same shape and size mapped elsewhere by Coutinho (2008). Therefore, no description for this unit is presented in this paper.

The northeastern portion of the studied area coincides with an indigenous reserve region, thus, for geological map modifications, the airborne geophysical information were used and compared with other studied units. In this way, the Iriri Group was maintained in the stratigraphy but not described in this paper either.

5.1. Castelo dos Sonhos Formation

The Castelo dos Sonhos Formation (Yokoi et al. 2001) is a siliciclastic metasedimentary unit located at the boundary between the Tapajós and Iriri-Xingu domains (Fig. 1). Satellite gravimetric information indicates that the crustal region in which this formation emerges is contiguous with that of the Tapajós Domain (Klein et al. 2017). The formation is composed of metamorphosed conglomerates and sandstones. The geophysical information indicates that the sequence presents high concentration of potassium, intermediate concentration of thorium, low concentration of uranium, and relatively low magnetization (Fig. 3). The low uranium grades are in line with the absence of uranium minerals in the sedimentary package, as reported by Queiroz and Klein (2018).

According to Klein et al. (2017), the metaconglomerates are polymictic and composed predominantly of pebbles of quartz and subordinately of quartzite, tourmalinite, schist and rare metavolcanic rocks (Fig. 6A). In general, the pebbles show rounded to sub-rounded shapes and millimetric to centimetric size. Locally, decametric pebbles may occur. In some portions, the quartz pebbles are stretched and fractured, with these fractures being filled by hematite. The metaconglomerates exhibit grayish color, with reddish and

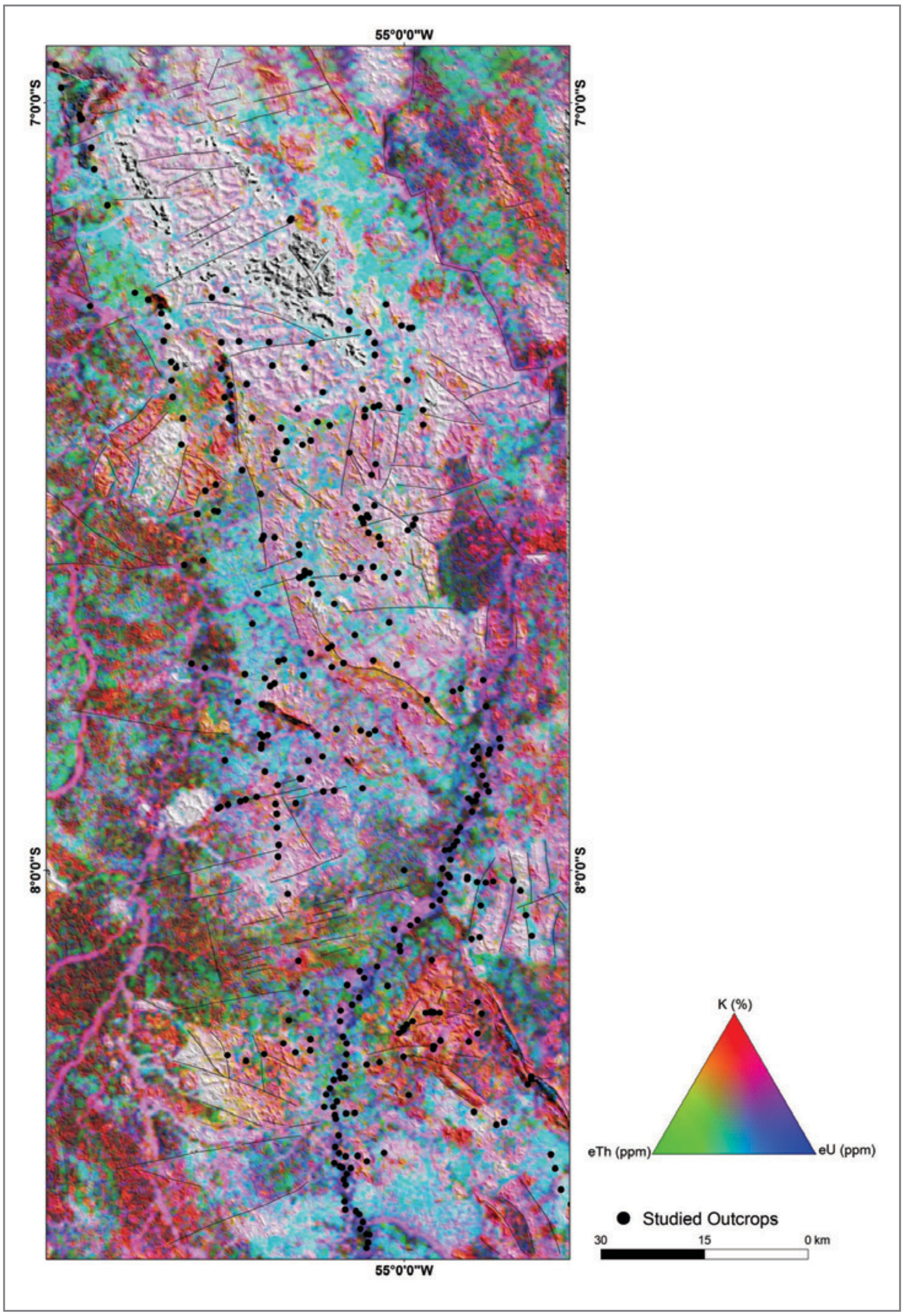

FIGURE 4 – Ternary composition of K, eTh e eU showing the interpreted radiometric domains.

whitish portions according to the presence or absence of hematite impregnation.

The metasandstones present light gray to dark color, with reddish and whitish tones, and are medium- to coarse-grained. They are poorly sorted and composed of quartz and sericite. They present NW-SE bedding (S0) with dip around 12° to SW, or NE-SW cross-bedding with dip around 23° to SE (Fig. 6B). They also present mylonitic foliation. In the southern portion of the area, metasandstones rich in magnetite (ironstones) were also found.

Klein et al. (2017) interpreted the lithological association and the sedimentary structures as evidence of transport in continental environment by interlaced fluvial system, associated with alluvial fans and wind dunes. The sedimentary basin underwent very low metamorphism and synformal folding, and was intruded by andesites and granitoids between 2011 Ma and 1918 Ma (Queiroz et al. 2015), which constrains the minimum age of sedimentation at 2011 Ma. Using U-Pb geochronology in detrital zircon, Klein et al. (2017) established the maximum age of sedimentation at 2050 Ma, and that the source areas of the sediments would be associated with Rhyacian-Siderian orogenic belts, and Mesoarchean terrains located today in the eastern, southeastern, and northeastern sectors of the Amazonian Craton, including portions of the Guiana Shield (see Fig. 1).

Furthermore, the Castelo dos Sonhos basin was considered a relic of a larger foreland basin, whose basement

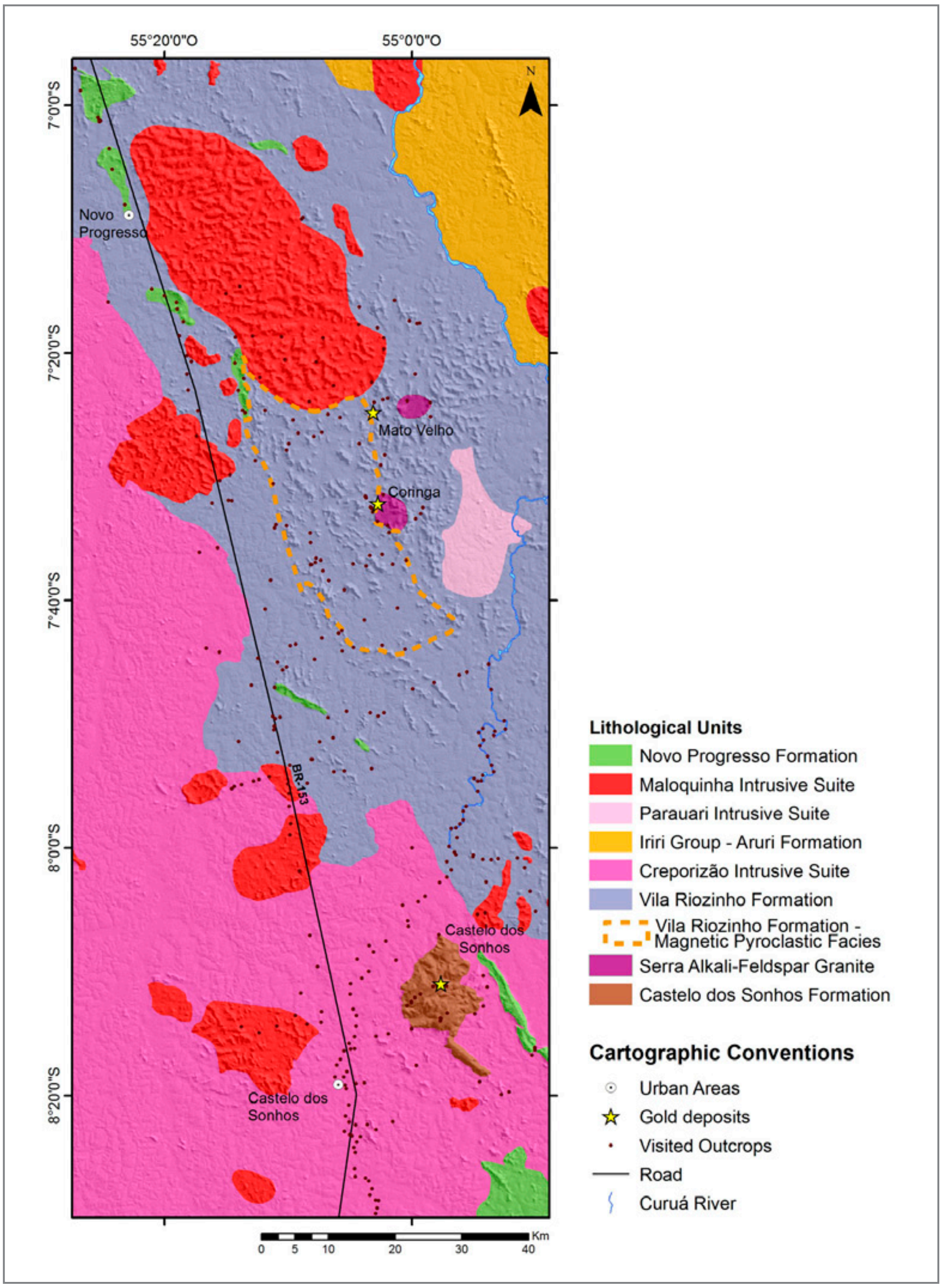

FIGURE 5 – New Geological map of the SE-Tapajós Gold Province.

in the southeast of Tapajós is still unknown, because all the volcanic and granitic rocks of the adjacent areas are younger than the Castelo dos Sonhos Formation.

5.2. Vila Riozinho Formation

Volcanic and pyroclastic rocks form an abundant association in the study area (Fig. 5). In previous works, these sequences have not been mapped and were considered as part of the Parauari Intrusive Suite (Vasquez and Rosa-Costa 2008). Furthermore, Tokashiki et al. (2015) recognized and dated some of the volcanic rocks, but these have not been separated in maps or related to any known stratigraphic unit. In this work they are correlated to the Vila Riozinho Formation, defined by Lamarão et al. (2002, 2005), increasing the area of occurrence of this formation. From the radiometric point of view, they have relatively higher uranium and thorium concentrations than those presented by the younger Iriri Group volcanic rocks.

Rhyolitic ignimbrites, latite, rhyolite, dacite and andesite are the main rock types, which are associated with flattened relief, sometimes cut by granite stocks. In addition, volcanogenic sandstones and conglomerates with rhyolitic ignimbrites were correlated with more rugged relief. This observation corroborates with that of Vasquez et al. (2017) for the same unit to the north.

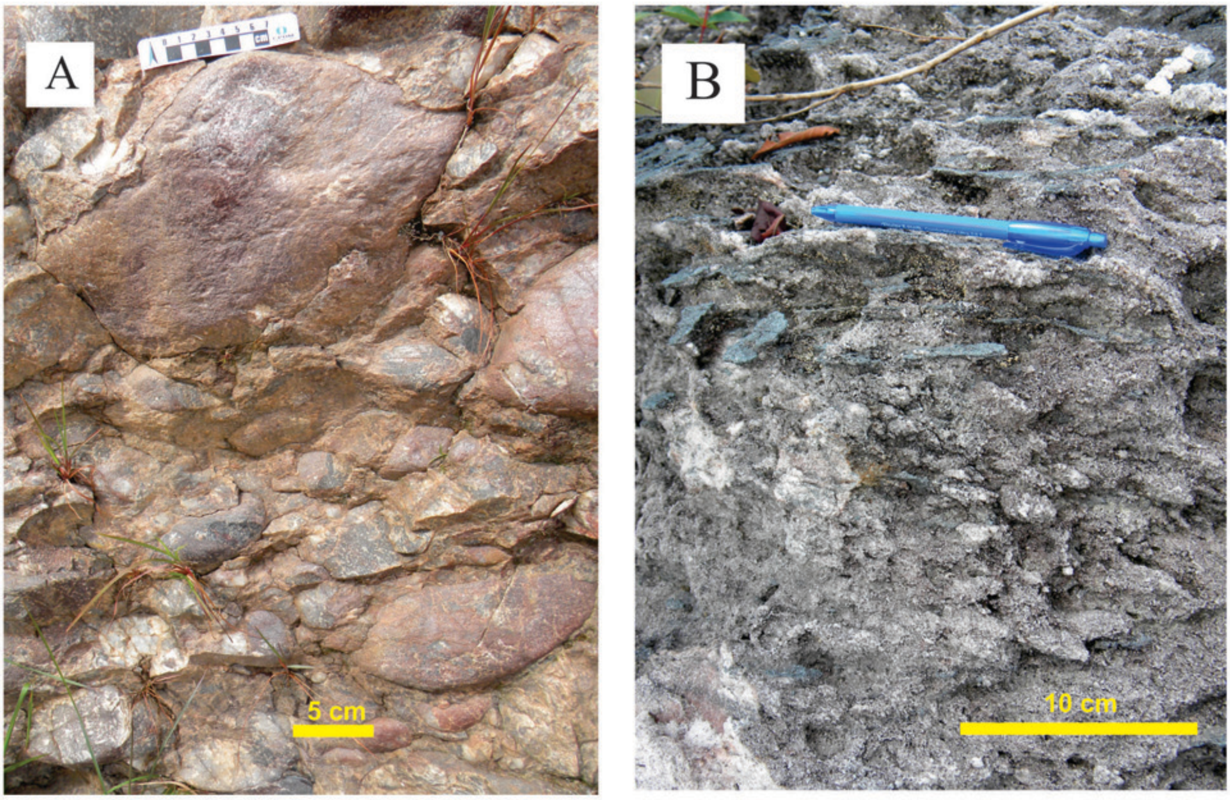

FIGURE 6 – Mesoscopic aspects of rocks of the Castelo dos Sonhos Formation A) Polymictic metaconglomerate with B) Medium-grained gray metasandstone, rich in magnetite, with undulated S0 striking N20W/12SW.

5.2.1. Rhyolitic Ignimbrite

Ignimbrites are abundant and occur as metric blocks, where flow structures are commonly oriented to N25W. These rocks, with a purplish gray matrix, have a reasonable amount of subangular to sub-rounded phenocrysts of quartz, potassium feldspar, plagioclase and lithic fragments (Figs 7A,B,C). Pyrite is commonly found occurring as disseminations and in fractures.

The ignimbrites exhibit preserved diagnostic volcanic structures, such as pumice (devitrified), fiamme, shard, stylolite, and flow structure (Figs 7 D,E,F). The matrix can be glassy, brownish aphanitic with many flow structures, or (in more preserved samples) it can even be microcrystalline to cryptocrystalline and composed of feldspar and quartz, locally having hematite grains that gives a reddish color to the rock. The matrix is strongly sericitized. The accessory minerals in the matrix are apatite, titanite, magnetite, pyrite and chalcopyrite (rare), and sericite, chlorite and carbonate are alteration minerals, the latter occurring also as late veins.

The alkali feldspar phenocrysts are subhedral to anhedral, frequently zoned and have perthite texture. The phenocrysts are locally corroded and usually altered to clay minerals and sericite. In some samples, adularia grains (pseudomorph after potassium feldspar) were also observed within the sericitic matrix.

The plagioclase phenocrysts are subhedral, fragmentary, poorly zoned, strongly corroded at the edges and central portions, and are strongly saussuritized and epidotized. The quartz crystals are subhedral to the anhedral, usually corroded, sometimes skeletal, and fragmentary. Thin lamellae of chlorite have also been identified, as alteration product of mafic minerals.

Two types of veins are observed in some rhyolitic ignimbrite samples. The type 1 is generally composed of quartz, pyrite, chalcopyrite, galena and sphalerite (Fig. 7G). Type 2 are quartz-chlorite veins, which are thinner than type 1 veins.

We also found lenticulite, a specific type of welded ignimbrite, with 75% glassy matrix, shards and many flow structures, and 25% of phenocrysts of quartz, potassium feldspar, plagioclase, which are 1 mm to 1 cm in size.

5.2.2. Latite

The latite shows brownish glassy matrix and many flow structures surrounding the potassium feldspar (48%) and plagioclase (40%) phenocrysts, which are euhedral, of various sizes, completely saussuritized and partially chloritized and epidotized (Fig. 7H). Rounded olivine grains occur widely among feldspars and is locally chloritized, having magnetite and chalcopyrite inclusions. Less frequent and smaller, quartz grains occur in the interstices of plagioclase grains. Elongated chlorite lamellae with bluish interference color occur disseminated, probably as an alteration product of biotite.

5.2.3. Rhyolite

The rhyolite is porphyritic, with alkali feldspar, plagioclase, and rare amphibole phenocrysts set in a very fine matrix. Large crystals of hematite and pyrite are found disseminated (Fig. 7I). The matrix is quartz-feldspathic with sericitic alteration. Fine grains of hematite, alkali feldspar, zircon, apatite and titanite are disseminated in this matrix.

The phenocrysts of alkali feldspar are strongly altered to clay minerals, fractured (fractures filled by chlorite, sericite and magnetite) and epidotized. Some crystals are replaced by carbonates. The phenocrysts of plagioclase are locally fractured and almost completely sericitized. There were possible amphibole phenocrysts, which were completely pseudomorphosed by a mixture of chlorite, magnetite and titanite. Cavities in the rhyolite are filled with carbonate and sericite.

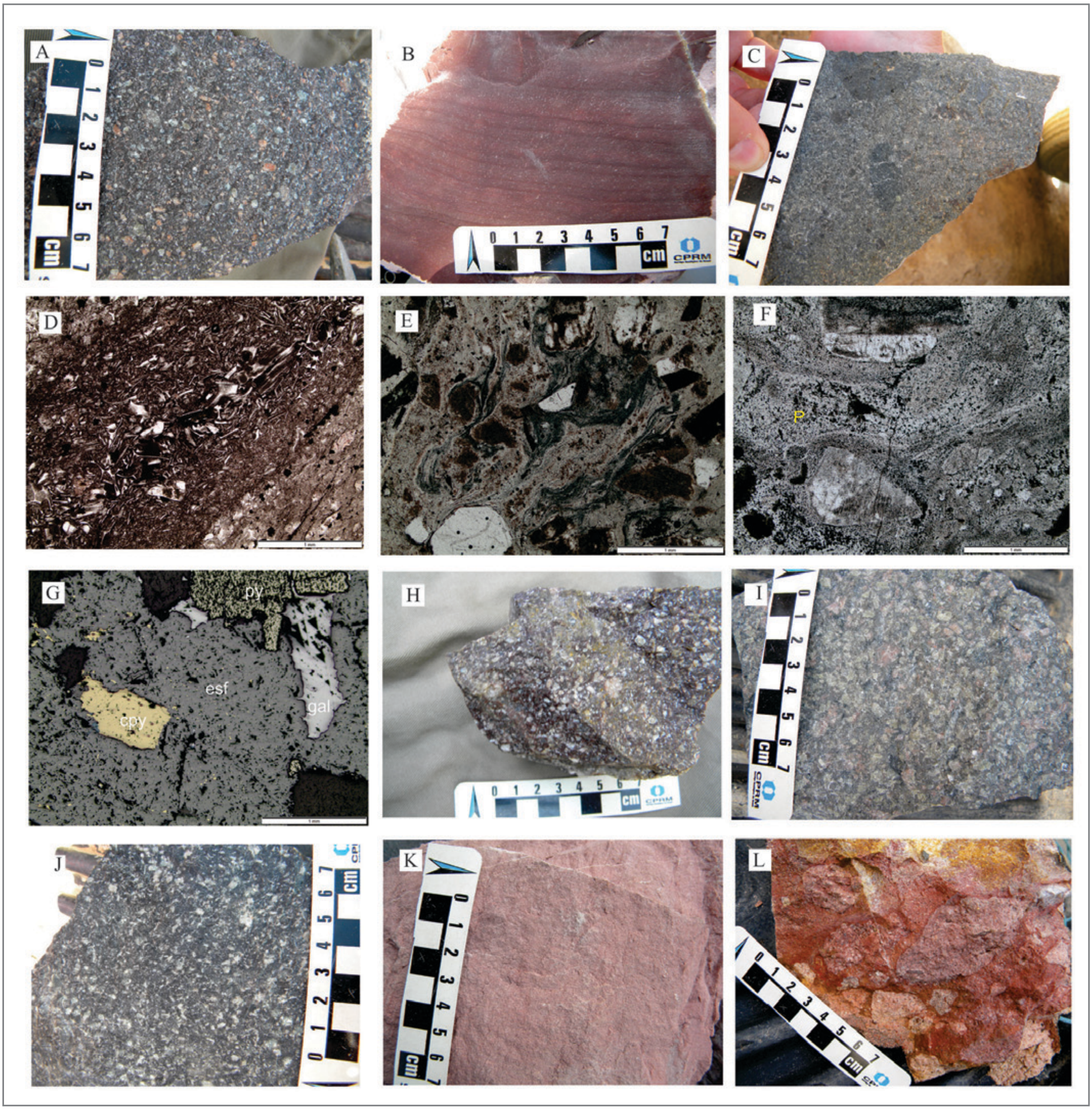

FIGURE 7 – A) Mesoscopic and microscopic aspects of rocks of the Vila Riozinho Formation. A) Ignimbritic rhyolite sample with phenocrysts of quartz, potassium feldspar, plagioclase and gray matrix; B) Reddish rhyolitic ignimbrite due to hematite alteration, with flow structures; C) Rhyolitic ignimbrite with gray matrix and lithic fragments; D) Photomicrograph of rhyolitic ignimbrite showing shards (cusp forms); E) Ignimbrite showing flow texture between phenocrysts; F) Ignimbrite with devitrified pumice (P) and flow structure; G) Photomicrography of type 1quartz vein with pyrite (py), chalcopyrite (cpy), sphalerite (sph) and galena (gal); H) Latite showing phenocrysts of potassium feldspar and plagioclase; I) Porphyritic rhyolite with phenocrysts of quartz, potassium feldspar, plagioclase ; J) Fine grained andesite with plagioclase phenocrysts; K) Fine pinkish-colored sandstone; L) Volcanic conglomerate with reddish matrix and angular lithoclasts.

5.2.4. Dacite

The dacite shows porphyritic texture, thin to aphanitic gray matrix with cryptocrystalline to microcrystalline quartz, and phenocrysts of potassium feldspar, plagioclase and quartz, rare olivine crystal are present. Devitrified elongated pumices and magnetite grains have also been observed as disseminations.

The potassium feldspar is elongated, twinned and a weakly sericitized. Plagioclase may be twinned, and weakly saussuritized and sericitized. Quartz occurs as disseminations in the matrix and filling fractures. Olivine crystals occur in association with magnetite. Chlorite lamellae present green to pale green pleochroism and result from biotite alteration, likewise olivine and feldspars.

There are many epidote-chlorite veins, with local pyrite and chalcopyrite, which also occur disseminated. Except for the presence of hematite alteration, the alteration of the dacites is similar to that observed in the rhyolites.

5.2.5 Andesite

The andesite is a medium to fine grained rock, with microcrystalline to porphyritic texture. The matrix is holocrystalline, quartz-feldspathic composition with chlorite, epidote, apatite and hematite disseminated (Fig. 7J). Plagioclase phenocrysts are 54% of rock and are subhedral, elongated, and are partially to completely saussuritized. Chlorite and carbonate are also products of the alteration of plagioclase, whereas epidote was produced after pyroxene and magnetite occurs filling microfractures.

5.2.6. Sandstones and conglomerates

Rounded blocks of light to rosy gray colored and fine-grained tuffaceous sandstone show flat stratification, veins and fractures filled by quartz, and localized disseminated pyrite and chalcopyrite (Fig. 7K). The conglomerates have a reddish (hematite) matrix with subangular to subrounded, centimetric sandstone and ignimbrites clasts (Fig. 7K,L).

5.2.7 Magnetic pyroclastic facies

This new occurrence of pyroclastic rocks, is separated here in map (Fig. 5) as a facies of the Vila Riozinho Formation based on its distinctly different magnetic properties (high magnetism) and petrographic features. Mores studies (geochemical and geochronological) are necessary to better constrain the stratigraphic position of this facies.

This magnetic facies forms regions of rugged relief and comprises the most magnetic rocks in the study area, also showing high counts in the three radioelements. The magnetic pyroclastic facies consists essentially of ignimbrite sequences of rhyolitic composition, and minor occurrences of breccias.

The ignimbrites show preserved flow structures, pumices, and porphyritic texture (Fig. 8A,B), and have aphanitic to microcrystalline quartz-feldspathic matrix, which may or may not be sericitized. Structures of volcanic flow, pumices (with spherulitic texture), shards and stylolite, typical of welded to densely welded ignimbrites can be observed in the matrix (Figs 8 D,E,F,G). Occasionally, the presence of hematite in the matrix gives a reddish color to the rock, which usually present shades of gray and brown (Fig. 8C). Alteration minerals such as titanite, apatite, chlorite, magnetite and ilmenite, and some sulfides (pyrite, chalcopyrite, galena and sphalerite) may also occur in the matrix.

K-feldspar phenocrysts may present Carlsbad twinning and are partially to completely replaced by chlorite, sericite and carbonate. The plagioclase phenocrysts are weakly sericitized and epidotized, and it is still possible to observe albite twinning along with neoformed crystals. Some quartz phenocrysts also occur. This assemblage suggests rhyolitic composition.

Fractures filled with carbonate and discontinuous veins of quartz (with comb texture) + chlorite + titanite + carbonate + sericite cut across the ignimbrites. Veins having pyrite + chalcopyrite + galena + sphalerite locally cut the quartz veins.

The volcanic breccia shows angular clasts of varying sizes, composed of sandstone immersed in a reddish matrix. The cavities in this breccia are filled with quartz crystals, as well as pyrite (Fig. 8H). Reddish-pink sandstone occurs associated with this breccia.

5.3. Creporizão Intrusive Suite

The largest surface extension of granitic rocks in the study area is associated to the Creporizão Intrusive Suite, as it was originally stated in Vasquez and Rosa-Costa (2008) (Fig. 2). The Creporizão Intrusive Suite has relatively low to intermediate concentrations in the three radiometric channels (Fig. 4).

In southeast of TGP this suite is composed of equigranular to porphyritic biotite-syenogranite and monzogranite, with medium grain size and whitish gray color (Fig. 9A). Locally, reddish colors are due to hematite alteration. It is common the presence of other varieties as hornblende granodiorite (Fig. 9B) and quartz monzonite. All varieties may show sericitization, saussuritization, epidotization.

Structurally, the rocks show fractures mainly oriented to N10-35E/80-86SE, which are occasionally filled by quartz. We have not observed the ductile tectonic fabric, which are described elsewhere in the Tapajós Gold Province (e.g., Vasquez et al. 2002).

In microscopic analysis, it is possible to observe zoned plagioclase grains and some grains with myrmekite intergrowth and microcline (Figs. 9 C, D). The potassium feldspar shows preserved perthite and, when associated with quartz grains, they form granophyric texture. Locally, the phenocrysts are reddish due to hematite alteration.

The hornblende crystals may be fractured and have corroded edges when in contact with quartz, and inclusions of biotite, magnetite and titanite (Figs. 9 E, F). Chloritized grains are also commonly found. Rare fractured orthopyroxene grains were recognized.

The biotite lamellae have brown to yellow pleochroism, and local association with magnetite, hematite and ilmenite. Biotite is replaced chlorite of bluish interference color (pennine variety). Titanite, apatite, zircon and fluorite are accessory phases, in addition to disseminated magnetite, hematite, ilmenite, pyrite and chalcopyrite (in smaller amounts).

5.4. Serra Alkali Feldspar Granite

In the central portion of the study area, we have defined the occurrence of two alkali-feldspar granite bodies (Serra Alkali Feldspar Granite, Guimarães et al. 2015), occurring

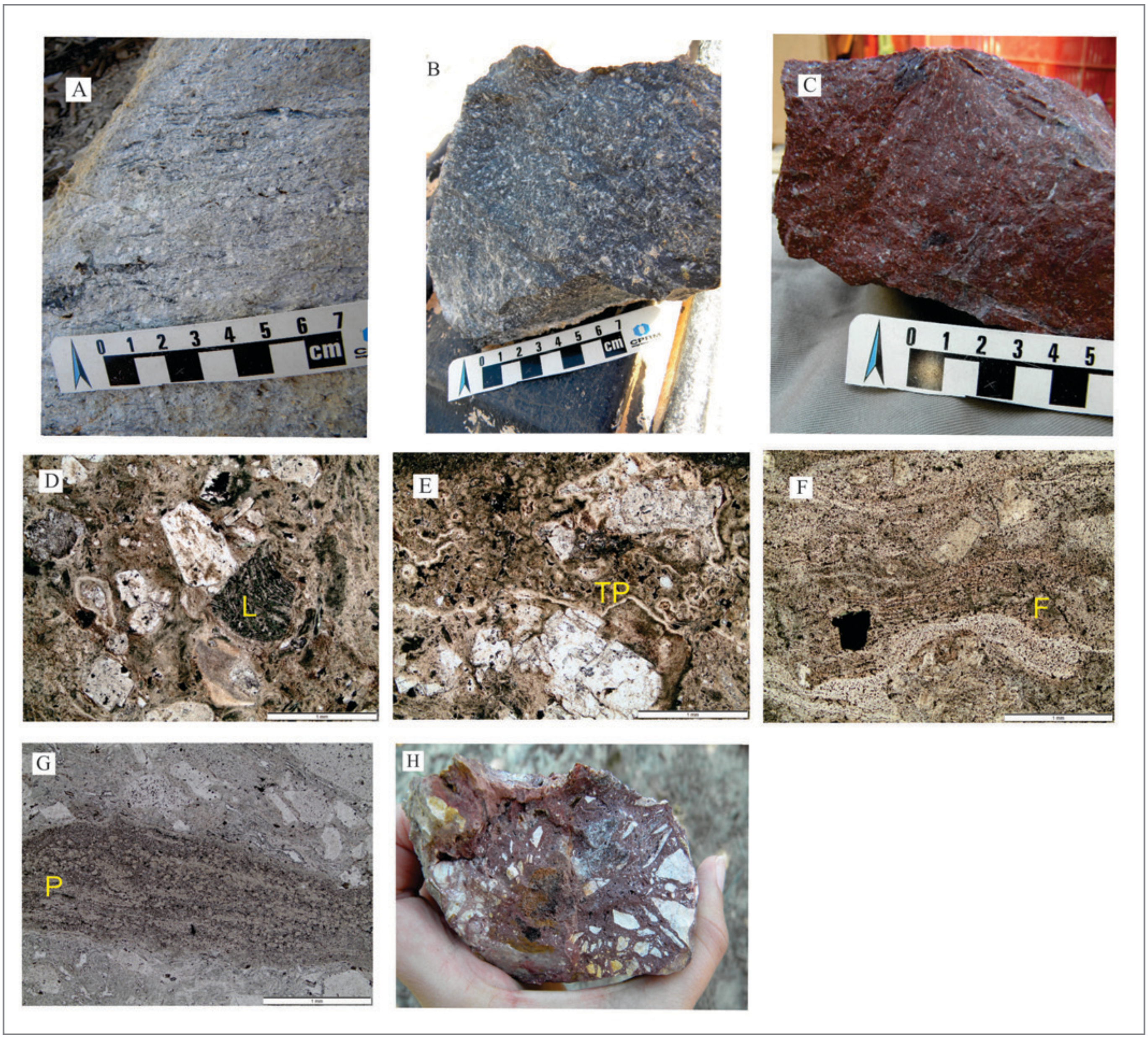

FIGURE 8 – Mesoscopic and microscopic aspects of rocks of the magnetic pyroclastic facies of the Vila Riozinho Formation. A) Ignimbrite outcrop with flow structures and stretched pumices; B) Gray ignimbrite sample with fine porphyritic texture; C) Ignimbrite with fine porphyritic texture and matrix with hematite alteration; D) Ignimbrite photomicrograph showing matrix flow between phenocrysts and lithic fragments (L); E) Ignimbrite photomicrograph with tube pumices (TP); F) Ignimbrite photomicrograph showing matrix flow between stretched phenocrysts; G) Ignimbrite photomicrograph with pumices (P); H) Volcanic breccia sample with red matrix and angular phenocrysts and pyrite boxwork occurrence.

in contact (intrusive/tectonic?) with the magnetic pyroclastic facies of the Vila Riozinho Formation. The gold mineralization of the Coringa deposit is partially hosted at the contact between the Vila Riozinho Formation and one of the bodies of the Serra granite (Fig. 5). The granitic body presents high concentrations of the radioelements potassium, thorium and uranium when compared to those of the Creporizão Intrusive Suite. On the other hand, its radiometric signature does not stand out due in the comparison with the Vila Riozinho Formation rocks to the west (Figs. 3 and 4).

The Serra Alkali Feldspar Granite holds fine- to medium-grained equigranular pinkish rocks with no ductile tectonic fabric (Fig. 10A, B). About 60% of the rock is composed of subhedral crystals of potassium feldspar (3.0 to 4.0 mm), which shows pinkish to reddish colors, and weak sericite alteration. Quartz makes up about 35% of the rock, are smaller and rounded milky crystals. Granophyric texture in quartz and potassium feldspar grains is commonly found (Fig. 10 C). The mafic phase is represented by brown biotite lamellae (5%), which are weakly chloritized (pennine variety), with associated magnetite. When strongly altered, the granite presents intense red color, which is the result of hematite alteration and feldspar argillization.

In zones proximal to mineralization, it is frequent to observe disseminations of pyrite and chalcopyrite. The pyrite is euhedral and pale yellow in color. The chalcopyrite appears as anhedral grains, strongly yellow in color, with little covellite at the edges, and as few inclusions in pyrite.

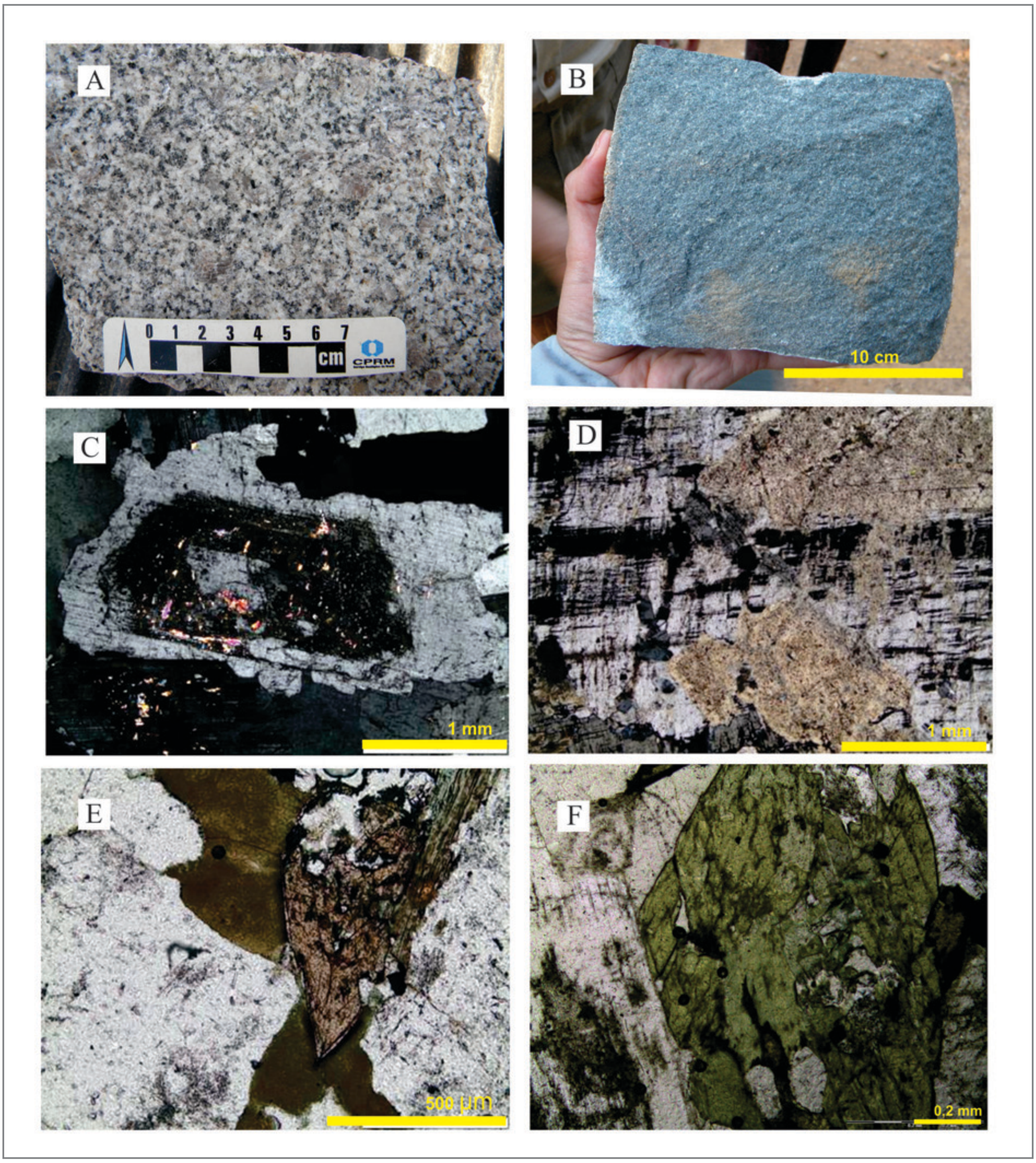

FIGURE 9 – Mesoscopic and microscopic aspects of the Creporizão Intrusive Suite (CIS). A) Gray equigranular monzogranite; B) hornblende granodiorite; C) zoned plagioclase phenocryst with epidote grains in the core; D) partially sericitized microcline phenocryst; E) titanite grain associated with chlorite lamella, adjacent to a brown biotite lamella F) hornblende phenocryst with inclusions of magnetite and quartz.

5.5. Maloquinha Intrusive Suite

The Maloquinha Intrusive Suite crops out as several stocks distributed throughout the study area. This unit intruded both the Creporizão Intrusive Suite and the Vila Riozinho Formation (Fig. 5). In general, it stands out by the high relief and shows intermediate to high concentrations of the three radiometric elements, along with intermediate magnetization (Fig. 4). However, it is locally observed an inverse correlation between magnetization and thorium concentrations.

The Maloquinha Intrusive Suite consists of pinkish, medium- to coarse-grained inequigranular to porphyritic rocks, which are mostly magnetic. We have identified the syenogranite and monzogranite varieties, and subordinate quartz-monzonite. Rapakivi texture is common (Fig. 11A, B), and the suite also exhibit pegmatite and aplite pockets. These features (pegmatite and aplite) denote a significant participation of late fluids and crystallization at shallow depths.

The concentration of mafic minerals (essentially biotite, rare hornblende) is variable depending on the location within the granitic body, decreasing towards the pluton margins. Locally, it is observed a magmatic flow structure with general orientation of K-feldspar grains to N40-60W/10SW. Pyrite

FIGURE 10 – Aspects of the Serra Alkali Feldspar Granite. A) Fine-grained equigranular pinkish granite; B) drill holes from the Coringa deposit with the same granite of "A"; C) granophyric texture; D) twinned potassium feldspar crystal; E) sericitization of potassium feldspar.

occurs disseminated and in fault planes (N25E/76 SE), whereas chalcopyrite is disseminated in the rocks.

Discontinuous veins and fractures filled by quartz are common (Fig. 11C). We have also observed fine-grained, pink colored, magnetic dikes with saccharoidal texture and incipient banding, which we interpreted to be syn-magmatic in origin. Occurrences of diabase dikes are also commonly found cutting across the granites.

In microscopic analyses, we observed granophyric texture, along with fluorite, apatite, titanite, zircon and allanite as accessory phases. Magnetite, hematite and ilmenite are generally concentrated near the brown biotite lamellae, which in turn are partially to completely replaced by chlorite. Sericitization of the potassium feldspar and saussuritization of plagioclase is also observed.

5.6. Novo Progresso Formation

In the Southeast region of the Tapajós Domain, NNW-SSE-trending elongated and discontinuous hills are composed of sedimentary rocks dominated by sandstones and siltstones with volcanic contributions (Guimarães et al. 2015; Klein et

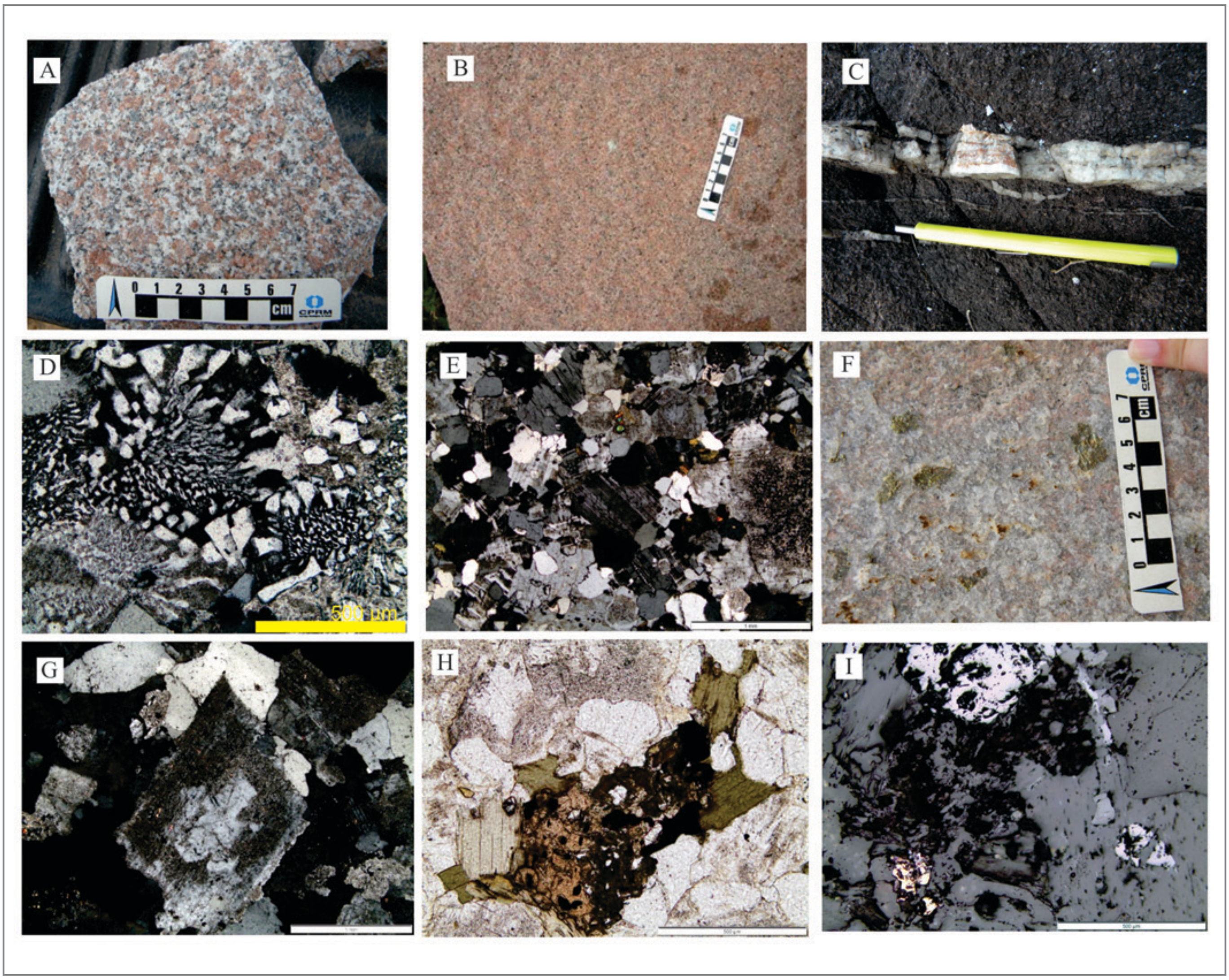

FIGURE 11 – Mesoscopic and microscopic aspects of the Maloquinha Intrusive Suite. A) Medium-grained inequigranular syenogranite; B) fine-grained equigranular syenogranite; C) fractures filled by quartz in syenogranite; D) granophyric texture in syenogranite; E) monzogranite with saussuritization of plagioclase; F) syenogranite with pyrite in fault planes; G) zoned K-feldspar phenocryst; H) anhedral titanite, dark green biotite laminae with apatite inclusions in syenogranite; I) magnetite and disseminated pyrite in monzogranite.

al. 2018). In this work we defined new occurrences of the formation (Fig. 5), in addition to those previously described in Guimarães et al. (2015) and in Klein et al. (2018).

This unit shows geophysical signature characteristic of sedimentary rocks, which are the low concentrations in the radioelements and low magnetization.

The formation is surrounded by granites of the Maloquinha, Parauari and Creporizão intrusive suites, felsic metavolcanic and pyroclastic rocks of the Vila Riozinho Formation and Iriri Group, and by metasedimentary rocks of the Castelo dos Sonhos Formation (Fig. 5). Contacts with these units are probably faulted and erosive. The rocks show sedimentary structures (stratification and lamination) that strike predominantly to N15-55°W/3-45°NE, which is grossly parallel to the regional structures (Klein et al. 2018).

Klein et al. (2018) reported the following lithological components: (1) massive to layered sandstone with plane-parallel and cross stratification and channeled sets, (2) relatively thick packages of purple to pinkish laminated siltstones, and (3) rhythmic intercalations of laminated siltstones and laminated, microcrystalline quartz-rich “cherty” rock.

U-Pb LA-ICP-MS data in detrital zircon from a lithic arenite show two well-defined peaks at 1846 and 1968 Ma, and statistically secondary peaks. These results indicate that surrounding Orosirian rocks from the Tapajós Gold Province and Iriri-Xingu Domain (including their counterparts in the Guiana Shield), and from the Rondonia-Juruena Province were probably the main sources for the sediments. This is consistent with the low maturity of the sediments and proximal sources. The maximum depositional age was set at 1840 Ma (Klein et al. 2018).

6. Concluding remarks

Intensive fieldwork, petrography, and high-resolution airborne geophysics, in addition to published information, allowed improving significantly the knowledge about the geology and stratigraphy of the southeastern portion of the Tapajós Gold Province. The main findings of our work is as follows:

a) All units cropping out in the study area have their geophysical signature described and defined.

b) Most of the areas that were previously mapped as Parauari Intrusive Suite (1.89 Ga) and Iriri Group (1.88 Ga), in fact comprise felsic volcanic and pyroclastic rocks, which, based on available geochronology, we ascribe to the Vila Riozinho Formation (1.98 Ga).

c) We defined two new units: (1) the Serra Alkali Feldspar Granite, which probably intruded the Vila Riozinho Formation, and (2) a magnetic facies of the Vila Riozinho Formation, which holds the rocks with the highest magnetic contents of the study area.

d) The rocks that surround the Castelo dos Sonhos basin are granites, and not volcanic rocks as previously stated, which we ascribe to the Creporizão Intrusive Suite.

This contribution forms the basis for future works, which have to deal with the crustal evolution of the southeastern Tapajos Gold Province, employing geochemistry, U-Pb geochronology, and Sm-Nd and Lu-Hf studies. These studies will allow a more confident discussion about the tectonic setting in which formed the mapped lithological units, and the crust forming events that produced this part of the Amazonian Craton.

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