MEGA-SCALE SHEATH FOLD OF SOUTHERN COPPER BELT, CANAÃ SHEAR ZONE, CARAJÁS PROVINCE, BRAZIL

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ABSTRACT

Sheath folds are highly non-cylindrical folds frequently linked with shear zones. In cross-sections perpendicular to the stretching direction they display eye-structures, commonly recognized in the field and remote sense images. In this work, using airborne geophysical images and field geology information, we investigate the crustal architecture of the Canaã shear zone, Carajás Province, Brazil. This area is also known as the Southern copper belt, hosting several Neoarchean Iron-Oxide-Copper-Gold (IOCG) deposits. The locations of IOCG deposits in this area delineate an elliptical distribution near the boundary of basement rocks and younger metavolcano-sedimentary sequence. We interpreted that the structural architecture of the Southern copper belt may be reflecting a large-scale upwardly convex sheath-like fold cored by older granulitic basement rocks. This interpretation may bring some contributions to understanding the regional structural control of IOCG deposits in this area, for example, elucidating how the deep-seated (ca. 20 km depth) IOCG deposits (e.g., GT-34 deposit) are now exposed close by to same-aged IOCG deposits of upper crustal levels (1 to 2 km depth).

KEYWORDS: Sheath fold; IOCG; Canaã Shear Zone; Southern Copper Belt; Carajás Province

RESULTS AND DISCUSSION

In the Amazonian Craton, Brazil (Fig. 1A), the Archean fragment known as the Carajás Province has been segmented into the Carajás and Rio Maria domains, which show distinct regional structural patterns (Fig. 1B). The Rio Maria domain represents a Mesoarchean granite-greenstone terrane with regional dome-and-keel architecture, while de Meso- to Neoarchean Carajás domain has large linear structural features (Fig. 1B) (e.g., Oliveira, 2018). However, at local/district scales, the structural pattern of the Carajás domain is far more complex than simple linear features. For example, in the Southern copper belt (Canaã shear zone) many non-cylindrical (sheath) folds and refold patterns are frequently found on both Mesoarchean basement rocks and Neoarchean supracrustal sequences (Fig. 1C, D, E and F). Additionally, from structural lineaments extracted from airborne gamma ray (Fig. 1G) and gravimetric (Fig. 1H) images, a regional elliptical eye-structure may be interpreted. The simplified geological map also delineates the regional eye-structure with the location of older granulitic gneisses near the core, and younger units (e.g., Supracrustal rocks) toward the external layers (Fig. 1I). The stretching mineral lineation in this area are predominantly vertical to sub-vertical, evidencing little horizontal component of the Canaã shear zone (no strike-slip) (Fig. 1J). The measured Sn+1 foliations are mostly steeply dipping NW-SE trending planes, parallel to the

Carajás fault (Fig. 1I and J). Based on the interpreted regional eye-structure, it is suggestive that the Southern copper belt may represent a large non-cylindrical anticline, transected by the Sn+1 mylonitic foliation of the Canaã shear zone (Fig. 1I and J). In contrast, non-cylindrical synclines (keels) may be represented by the surrounding supracrustal sequences (Fig. 1I). In terms of metamorphic records and ages, younger low-grade metamorphic rocks occur in the center of the regional synclines (e.g., Neoarchean Jaspilites), while older high-grade metamorphic rocks (e.g., Mesoarchean granulites) will be placed in the core of the regional non-cylindrical anticlines (Fig. 1I). Therefore, this highly curvilinear folding (or refolding) probably contributed to the tectonic exhumation of the granulitic rocks in this area, in response to the kilometric vertical extrusion along the sheath fold core (Fig. 1I and J).

The interpreted regional sheath fold may also help in understanding the structural control of Neoarchean IOCG deposits in this region. The IOCG deposits seem to delineate the regional eye-structure, occurring close to the contact of basement rocks and the metavolcano-sedimentary sequence (Fig. 1I). However, the GT-34 deposit is relatively far from the supracrustal sequence and the mineralization is hosted by high-grade basement gneisses (Fig. 1I) (Garcia et al., 2020). The GT-34 deposit is the deepest IOCG mineralization of Carajás Province, with an estimated pressure of 5 to 7 kbar (ca. 20 km deep) (Garcia et al., 2020) (Fig. 2). On the other hand, the Neoarchean IOCG mineralization of the Sequeirinho/Sossego deposit, for example, has estimated pressures around 1.4 kbar (ca. 1 to 2 km depth) (Monteiro et al., 2008), evidencing an upper crustal level for the mineralization (Fig. 2). The GT-34 and the Sequeirinho IOCG deposits are both Neoarchean in age (ca. 2.75 to 2.71 Ga) (Garcia et al., 2020; Moreto et al., 2015), so far, a younger tectonic event (2.6 Ga? 2.5 Ga? and/or 2.0 Ga?) is necessary to the actual juxtaposition of this deposits in the same erosional level.

According to previous works, the recognition of regional "culminations" and "depressions" of the Carajás basin has been already discussed from both geophysical (Oliveira, 2018) and field geology (Rosiere et al., 2006). According to Oliveira (2018), from gravimetric data interpretation, this regional architecture may be reflecting an inherited basin-and-range structure of Neoarchean grabens and horsts, later affected by regional folding of the basin closure. In contrast, according to Rosiere et al. (2006), this regional structure may represent the product of a Neoarchean dome-and-keel tectonics. However, in this work, because of the mirrored symmetric patterns observed from both sides of the Carajás fault and the high parallelism of the regional NW-SE foliation planes (Sn+1) of the Carajás domain, we suggest that this regional architecture may represent a cross-section of large-scale vertical sheath folds (Fig. 3A and B). The mirrored symmetry with a "butterfly-like pattern" along the Carajás fault (hinge line) is evidenced by the Estrela dome to the north, which shows a good symmetry with the Canaã dome to the south (Fig. 3A and B). Additionally, the location of the main prominent hills of the banded iron formation (Serra do Rabo, Serra Norte, Serra Sul and Serra Leste) also show a near symmetric distribution (Fig. 3A and B). This, suggest little horizontal strike-slip kinematics along the Carajás fault (no strike-slip). Preliminary, we suggest that the gneissic dome culminations may be reflecting Type-1 to Type-2 fold interference pattern, evidencing a protracted polydeformed evolution of this area. However, further studies are still needed.

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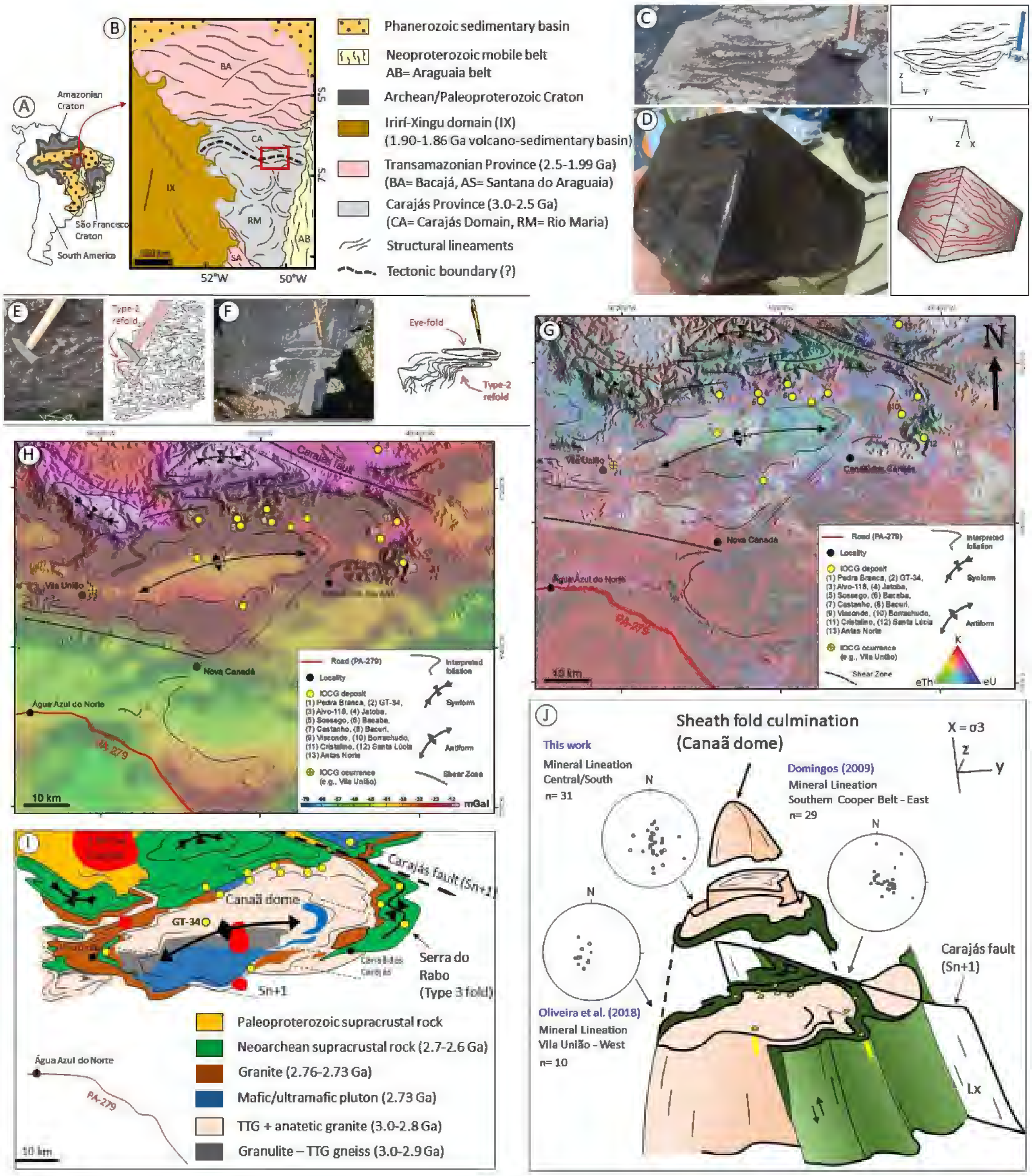

Figura 1. (A) and (B) Regional setting. (C) Eye-fold in granulitic TTG gneiss. (D) Sheath fold in banded iron formation (bif) of Serra do Rabo location. (E) Type-2 refolding of bif and (F) metabasalt of the Serra do Rabo location. (G) Airborne Ternary radiometric (K-eTh-eU) and (H) gravimetric (bouguer anomaly) images with interpreted structural lineaments. (I) Simplified geological map of the Canaã shear zone (Southern copper belt). (J) Interpreted sheath fold culmination (Canaã dome) of the Southern copper belt. Measured stretching lineation from distinct locations evidence extreme vertical shearing, and dome culmination at the Canaã shear zone (Data from this work and literature).

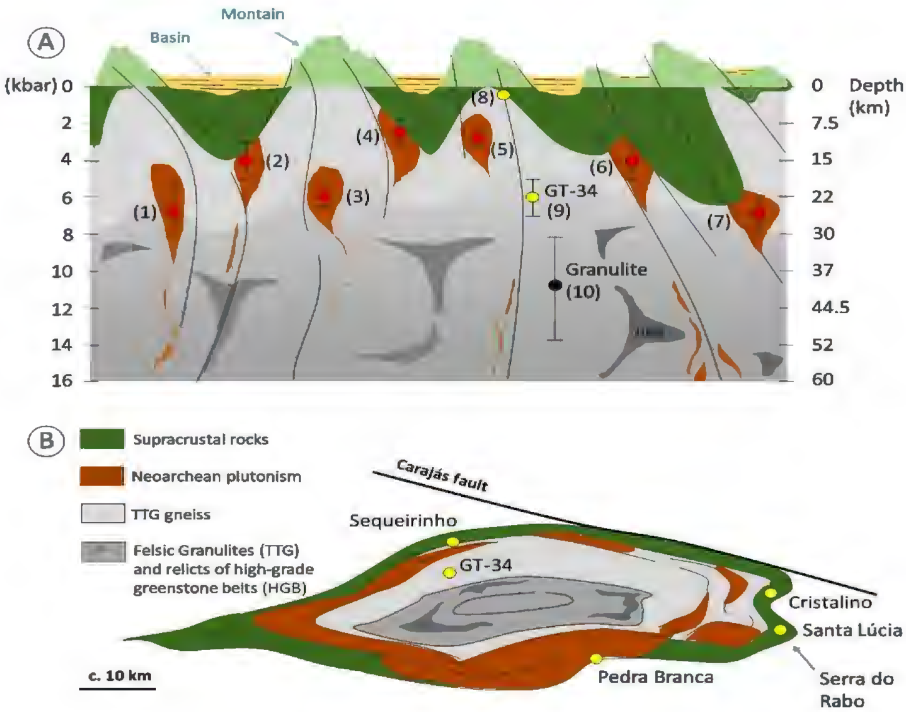

Figure 2. (A) Model with estimated depth in the crust for Neoarchean granite emplacement, IOCG mineralization and granulitic metamorphism at the Canaã shear zone (Southern copper **belt), Carajás Province. Pressure estimation compiled from (1)- Planalto Vila União (5.32-** 8.14 kbar) - Marangoanha et al. (2019b), (2)- Granite Vila Jussára (3.0-5.0 kbar) - Dall'Agnoll et al. (2017), (3)- Planalto Vila União (5.33-6.49 kbar) - Oliveira et al. (2018), (4)- Estrela Granite (1.8-3.1 kbar) - Barros et al. (2001), (5)- Charnokito (2.4-3.1 kbar) - Felix et al. **(2020), (6)- Planalto (3.0-5.0 kbar) - Cunha et al. (2016), (7)- Enderbito Café (6.0-7.5 kbar)** - Marangoanha et al. (2022), (8)- IOCG Sequeirinho (1.4 kbar) - Monteiro et al. (2008), (9)- IOCG GT-34 (5.0-7.0 kbar) - Garcia et al. (2020), (10)- Granulite (8.1-13.7 kbar) - Silva et al. (2017). **(F) Simplified regional eye-structure representing a non-cylindrical anticline (sheath fold) cored by older granulitic basement rocks.**

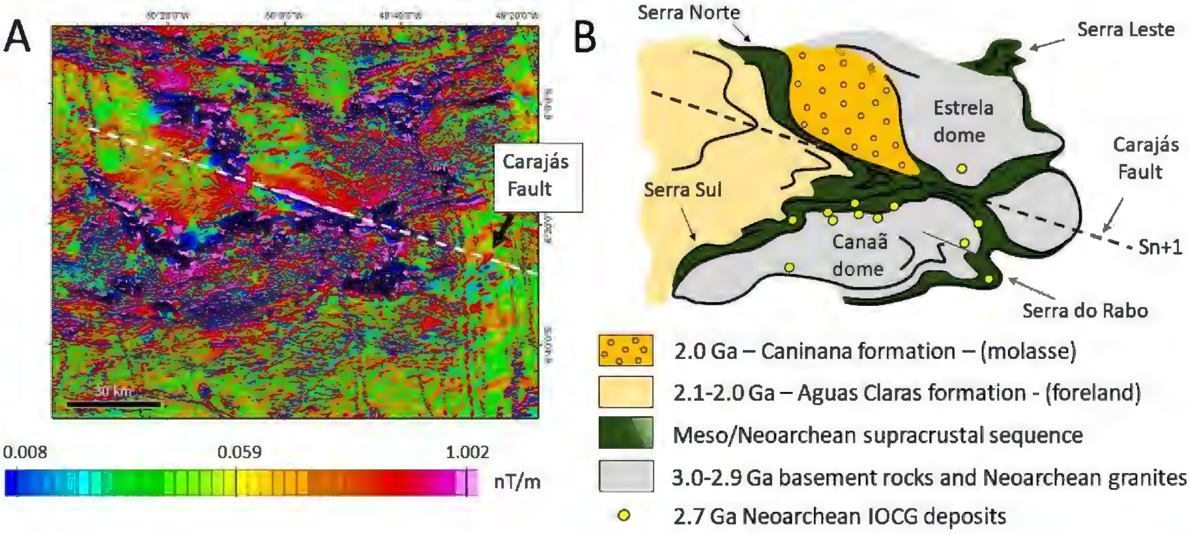

Figura 3 . (A) Aeromagnetic image around the Carajás fault (dashed line). (B) Simplified geological map around the Carajás fault. Note the "butterfly-like" symmetry to the north and south of the Carajás fault (hinge line). This geometry may probably reflect a Type-1 to Type-2 fold interference pattern. However, further structural studies are still needed.