PALAEOSURFACES MAPPING AND ASSOCIATED SUPERGENE COPPER DEPOSITS IDENTIFICATION AS MINERAL EXPLORATION TOOL ITAPEVA AND RIBEIRÃO BRANCO REGION – RIBEIRA VALLEY, STATE OF SÃO PAULO, BRAZIL

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ABSTRACT – A few examples of supergene ore formation and their interaction with morphogenesis (palaeosurfaces) and weathering mineralogy are discussed. Geomorphological and mineralogical records to characterize palaeosurfaces associate the weathering of primary minerals and their relationship with concentrations of cooper and iron ore deposits in southeastern state of São Paulo, Brazil. We have distinguished two palaeosurfaces generated by several weathering phases and controlled by the geological framework. The first and oldest upper palaeosurfaces (900 – 1000 m a.s.l.), situated in Riberão Branco (Alto do Brancal), were developed on silico-limestones. It is formed by typical iron laterites enriched by secondary products of cooper. The second and younger level palaeosurfaces located in Itapeva (Santa Blandina and Bairro do Sambra). This palaeosurface is formed by copper percolating through the weathered rock (saprolite). Other features can be observed like neo-formed products in laterites. They are classified into two types: clay like silico-cupriferous products (with noticeable amounts of iron) and copper minerals (crysocolla, in their flat slopes). These features allowed the presence of copper ores and their morphogenesis control will help in the exploration and prospecting of supergene ore mineral.
Keyword: Palaeosurfaces, supergene copper, vale do Ribeira, Santa Blandina, Alto do Brancal, São Paulo, Brazil.

RESUMO – *L.F.B. Ribeiro & M.C. Siqueira Ribeiro – Mapeamento de Paleosuperfícies associadas a identificação de depósitos supérgenos de cobre como ferramenta de exploração mineral na região de Itapeva e Ribeirão Branco- Vale do Ribeira, estado de São Paulo, Brasil.* Alguns exemplos de formação de minério supérgeno e sua interação com a morfogênese (paleosuperfícies) e resistência mineralógica são discutidas aqui. Registros geomorfológicos e mineralógicos na caracterização paleosuperfícies associam o intemperismo de minerais primários e sua relação com as concentrações de cobre e minério de ferro no sudeste do estado de São Paulo, Brasil. Distinguiram-se duas paleosuperfícies geradas por várias fases de intemperismo e controladas pela estrutura geológica. A primeira, mais antiga, é a paleosuperfície superior (900 - 1000 m de altitude), situado em Ribeirão Branco (Alto do Brancal), foram desenvolvidas em rochas silico-calcários. É formada por lateritas de ferro enriquecido por produtos secundários de cobre. O segundo nível de paleosuperfície é mais novo está localizado na região de Itapeva (Santa Blandina e Bairro do Sambra). Esta paleosuperfície é formada por percolação de cobre através da rocha alterada (saprolito). Outras características podem ser observadas como produtos neoformados em lateritas. Eles são classificados em dois tipos: a argila como produtos silico-cuprífero (com quantidades significativas de ferro) e de cobre minerais (crisocola, fixas nas vertentes). Essas feições reconheceram a presença de minérios de cobre e seu controle morfogénetico ajudando na exploração e prospecção de minérios supérgenos.
Palavras-chave: Paleosuperfícies, cobre supérgeno, Vale do Ribeira, Santa Blandina, Alto do Brancal, São Paulo, Brasil.

INTRODUCTION

Deep chemical weathering on peneplained landsurfaces can produce supergene ore deposits whose content of minable elements may be related to their pre-concentracion in the host rocks. During certain moments in Earth history, special sub-aerial and supergene environments led to extreme geochemical separation, enrichment or depletion of certain elements (Valenton, 1983, 1985; Melfi et al., 1979).

Element stability during weathering processes depends upon the bounding energy of the primary mineral, the different behavior of polyvalent elements in relation to Eh conditions and the chemical composition of the interstitial solution during decomposition and neoformation. According to Valenton (1985), the mineral or element stability in the supergene layer may be grouped as follows:

1. Those which are relativity stable in minerals like hematite (Fe), cassiterite (Sn), zircon (Zn) and gold (Au);
2. Those with became enriched by neomineralization (layer silicates, Al, Ni, Cu);
3. Neomineralization oxides and oxihidrates (Al, Mn, Fe, Co, Ni) correlative to parent rocks
4. Neomineralization of the carbonates, sulfates, phosphates and arsenates (Cu, P, Al);
5. Supergene minerals or element concentration is related to morphology and topography.

The Santa Blandina cupriferous mineralization is constituted by a weathered skarnite. It is formed by supergenous concentration of copper and residual laterites enrichment of iron and copper. This mineralization is a case example for the studies and mechanisms of accumulation of supergene copper. Previous studies carried out in the area by Creach (1988) and Creach et al. (1991, 1992) characterized the copper supergenous accumulation, both from a mineralogical viewpoint, as well as in cristalochemistry. From such studies it may be concluded that, during the weathering process, copper was liberated from the structure of the primary sulphites. Consequently, these primary sulphites were incorporated to the infiltrating solution that took part in the alteration of the escarnites and the whole-rock limestone, and in the elaboration of the secondary phases (carbonates, oxides and silicates). The copper is found associated in the silicate phase, constituted by esmectites and interstratified with kaolinites- esmectites and crysocolla (Creach et al., 1992).

This work intends to contribute upon the relation of the palaeosurfaces with the distribution and genesis of the supergenous deposits and iron/copper laterite profiles in the Itapeva (São Paulo) region and adjacent areas.

LOCATION AND GEOLOGICAL SETTING

The research area is located in the southern region of the state of São Paulo, between the Guapiara, Itapeva and Riberão Branco areas (Figure 1). The main routes in the study area are the Presidente Castelo Branco highway (SP-280) from Sorocaba and the Raposos Tavares highway (SP-270) from Itapetininga. There are other routes like SP-127 from Capão Bonito and SP-258 to Itapeva (São Paulo) that provide access to the area.

The study area is included in the southern segment of the Mantiqueira Tectonic Province, dominated by structures related to the Neoproterozoic Brasiliano/Pan African Orogeny from 640 to 480 Ma (Cordani et al., 2000; Heilbron et al., 2000, 2004). The geological framework is dominated by several long NE trending fault zones, which separate many tectonic blocks. It contains Mesoproterozoic (ca. 1,750-1,450 Ma) and Neoproterozoic supracrustal sequences (ca. 800-600 Ma) revealing a polycyclic evolution (Cordani et al., 2000; Basei et al., 2009).

The area comprises the Apiaí Folded Belt (AFB), which is a domain of the southern portion of the Ribeira Belt. In the Paraná and São Paulo states, southern Brazil, it is composed of met volcanic-sedimentary rocks, of low to medium metamorphic grade, grouped in the Açungui Supergroup (Campanha and Sadowski, 1999). The Neoproterozoic granitic rocks are represented by the Cunhaporanga, Três Córregos and Agudos Grandes batholiths which intrude the supracrustal rocks. Both groups are affected by latter granitic stocks (Corrêas, Sambra and Itaoca granite). In the study areas of Santa Blandina and Alto do Brancal (Figure 1), the rocks have undergone intense mineralization process associated with a syn tectonic granitic batholith. This granitic batholith is in contact zone with limestone lenses which caused the skarnite generation (Arruda, 1971). The metassomatic process led to cupper remobilization and concentration in the skarnite zone, in the shape of pockets and veins with sulfide, chalcopyrite and bornite. This mineralization zone extends for 400 meters long by 150 meters and is flanked by metasedimentary and amphibolitic rocks (Creach et al., 1991, 1992).

The Paraná Basin sequence area formed by conglomerates ans sandstones rocks of the Itararé group and siltites correlated of the Furnas Fm.These sequences were tilted and the surface was uplifted, partly eroded and unconformably overlain by a thick sequence (~1500 m) of Early Cretaceous Paraná continental flood basalts (Renne et al., 1992, 1996). In some parts, the area chracterized by these lithologies is cut by basic dykes, mostly with a NW, and rarely with a NE, direction, associated to the Guapiara alignment. The fault reactivation effects caused deep changes in the drainage network pattern, the palaeosurfaces and the dissection of the copper deposits.

METHODOLOGY

A general topographical overview for a preliminary study, based on field work and digital elevation data, was obtained. Large-scale landforms in the study area were identified using a Digital Elevation Model (DEM)

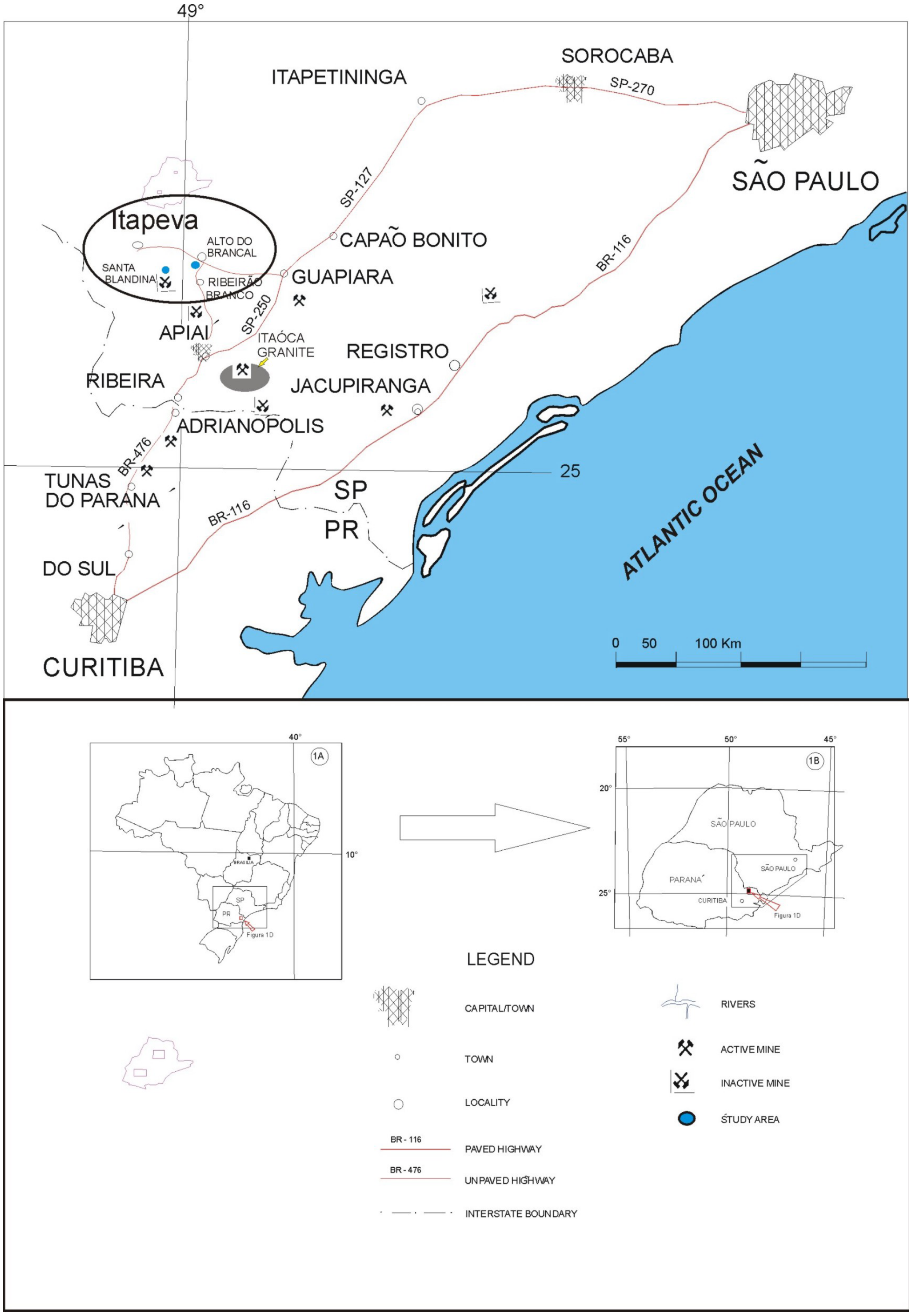

FIGURE 1. Study area (Modified after Daitx, 1996).

imported by *ArcGIS software*. The large-scale landforms have been analyzed by the major morphological elements: the drainage network pattern and the palaeosurfaces distribution. The DEM was used to construct a model of distribution and height of the plateau remnants above sea level.

Landform analysis was carried out in a digital elevation model (DEM) in a 50x50 meters resolution square grid, constructed by topographic maps. Based on the given information of the study area, the analysis was applied according to the methods developed for mapping and recognizing these landforms postulated by King (1956), Twidale (1997), and Granell-Pérez (2004). In this map, altitudes of the palaeosurfaces and valleys were identified through the numerical digitalization of various topographic contours.

A general topographical overview was obtained by a study based on field work and digital elevation data (Ribeiro, 2008) and the description of landforms in the southeastern part of the study area by taken from Arruda (1971) and Ponçano et al. (1981).

After this procedure, the landforms were analyzed in several steps. Firstly, a surface/slope map of the southern study area was designed. Areas with slope angles less than 6.5° were defined as palaeosurfaces, extracted and colored according to height above sea level. After the elimination of flat valley bottoms at high and medium elevations, the final map with flat palaeosurface levels was obtained. These palaeosurface levels were constructed on closed topographic contours representing restricted summits. The mapping resulted in a description of the several palaeosurface levels and the identification of fault blocks.

Palaeosurface levels could be interpreted in different ways: as indicators of river-dissected, denudation surfaces or as the result of the interaction of the climate stability. The analysis of the landforms in the study area resulted in the identification of two planation surfaces at higher elevations. The first palaeosurface level is situated at 660-720 m a.s.l. on the low lying block to the north of the Sambra and Santa Blandina areas and it has undergone deeper erosion than other areas nearby. Another palaeosurface level was mapped at 860-920 m a.s.l. on the higher block of the Alto do Brancal area (Figure 1) but it has not suffered as deep erosion as the other palaeosurface recognized before.

The morphological description of the paleosols followed the procedure proposed by Thomas (1994), Widdowson (1997) and Twidale (2002) and the soil terminology by Ollier (1991). In Figure 2, surface deposits were recognized, by means of the soil description in profile, which consisted in the construction in profiles of the soils and paleosols found on the mapped palaeosurfaces.

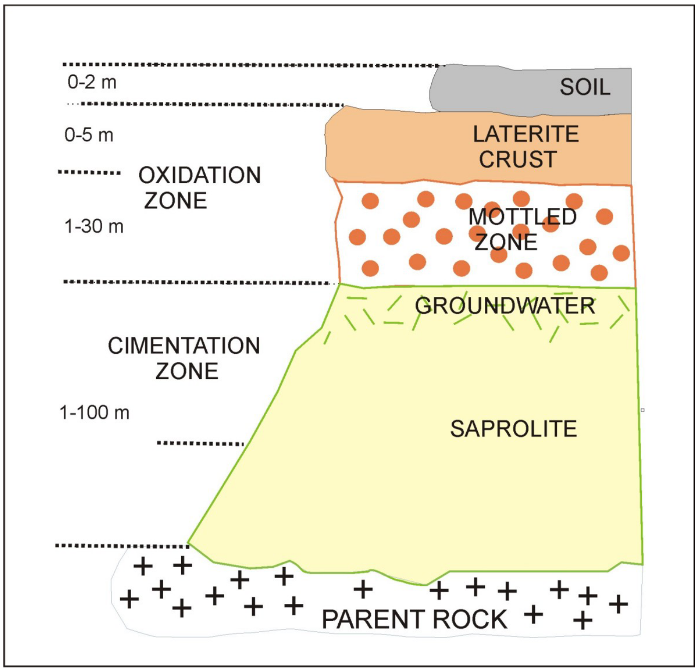

FIGURE 2. Typical textbook illustration of a laterite profile (modified after Ollier, 1991); Rock structure is usually preserved in the saprolite and mottled zones indicate that these zones consist of *in situ* weathered rock with no volume alteration.

DISCUSSION

Through our investigations in the study area, we can state that it underwent a distinct series of cyclic events characterized by phases of deep weathering, where the accommodation space was provided by large scale tectonic deformation, alternating with periods during which the supergene deposits were firstly uplifted and then dissected.

After cartographic recognition, fieldwork was conducted and the palaeosurfaces that characterize these areas were recognized, namely:

The first palaeosurface level represented in the map by a red color was recognized in the northern area, near Itapeva (SP) (Sambra and Santa Brandina areas) with elevations ranging from 660 to 720 m a.s.l., developed on the Furnas Formation and the Itaiacoca Group. It is comprised by granite and limestone, respectively (Theodorovicz et al. 1988), with the presence of two diabase dykes, highly fractured and altered to Oxisols with the presence of esmectites, kaolinites and goethite. In this palaeosurface level, it was observed that the distribution of hills is highly dependent on density of joints and fractures and it is known that deep weathering is favored by structural weaknesses in bedrock and it enhances landform patterns controlled by fractures and joints. This is represented by the reddish color related to Oxisols (Figures 3 and 4).

The second palaeosurface level is located in the southern area (Figure 3, yellow colored area), in the Alto do Brancal (Ribeirão Branco county) with the altitudes ranging between 860-920 m (Figure 4). In the palaeosurface level, two laterites phases interspersed with sand paleosols were recognized, which allowed considering this as the oldest surface.

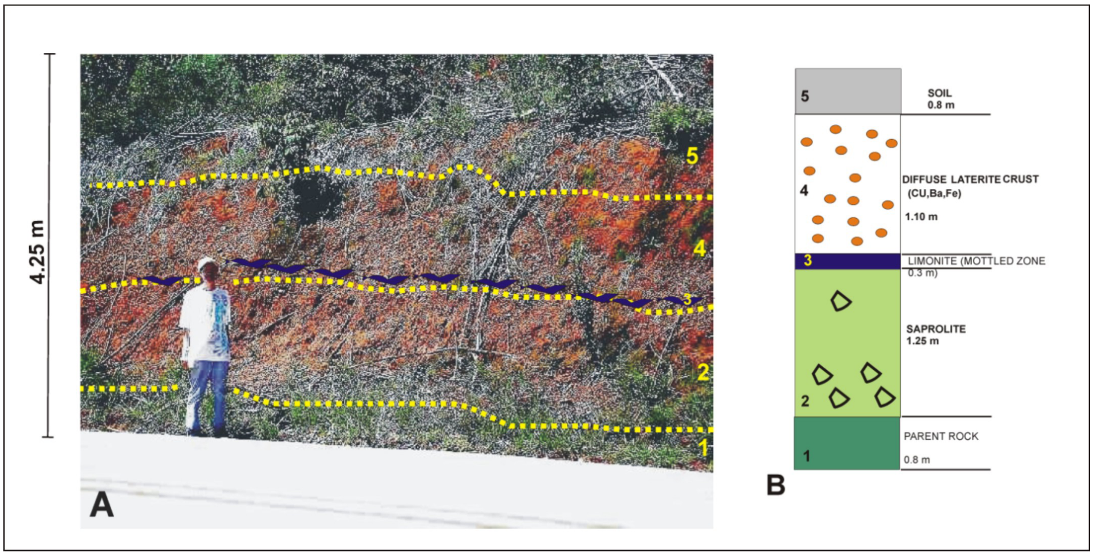

FIGURE 3. **A**) Oxisoils with the presence of a diffuse laterite horizon. Itapeva – Ribeirão Branco Road, km 42 (right lane); **B**) corresponding profile. Figures represent the thickness of each layer.

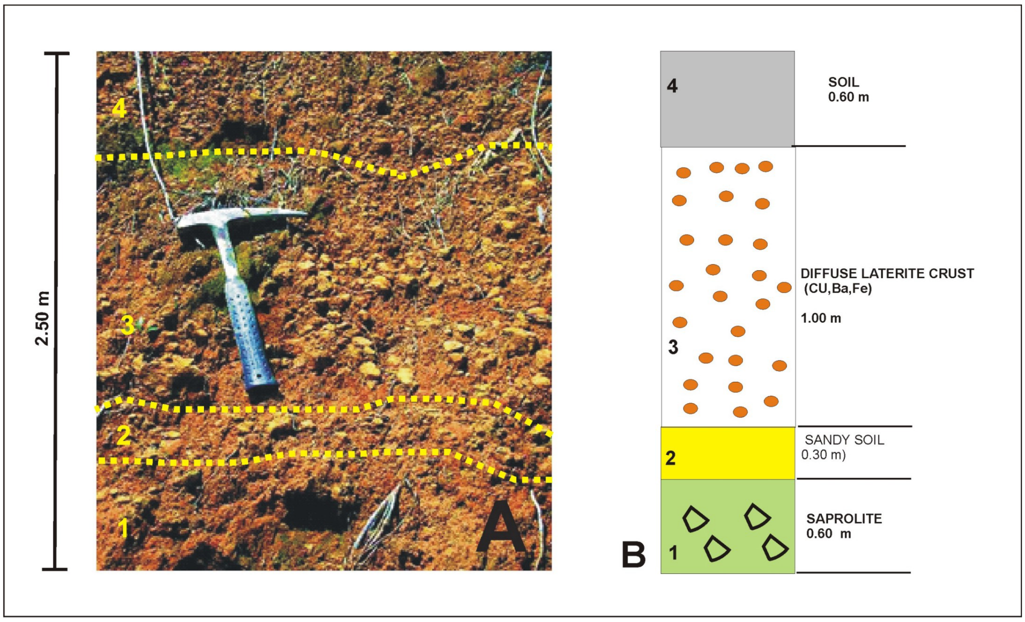

FIGURE 4. **A**) Outcrop showing laterite profile with paleosols at the base and buried sandy. Oxisoils, Ribeirão Branco road Alto do Brancal (right lane); **B**) Profile corresponding to the section shown in the photograph. Figures represent thickness of each layer.

In the area where the Second Palaeosurface level was observed during field work, the distribution of hills is highly dependent on the relative density of joints and fractures.

The landform analysis in the second palaeosurface level led to the identification of a higher and well preserved surface flat level, particularly well developed in the northeastern part of the study area. It was observed that the palaeosurface level distribution is dependent upon the host rock weathering and its resistance rate, which is affected by the velocity and changes in the chemical and mineralogical alteration and the geological and geomorphological factors. These mechanisms forced deep weathering due to changes in landform patterns controlled by fractures and joints, thus generating residual copper deposits.

In the northern area, where the palaeosurfaces (red area in Figure 5) were developed on basalts, they are forming oxisols and, where they formed on the Furnas Fm. sandstones, rare sandy soils These sandy soils are overlying a profile change of almost 25 meters thick (Creach et al., 1991) that corresponds to the saprolite with argilomorphic products (Kaolinitte, montmorilonite and smectite) and large amounts of chrysocolla. These deposits were formed by the action of the in situ changes and the drainage (Figure 2 and Figure 6 A, B).

In the southern area where the second palaeosurface is located (yellow areas in Figure 5), the laterites are a large iron ore deposit formed by two-level laterite formation. Analyzing the profile of the Figure 6 C, it can be seen that there is a small copper deposit in this area, located on the lower slope, but at a much higher altitude than in previous instances, which is represented only by oxidized copper minerals (azurite, malachite). Azurite occurs in the rock and also features in the laterite profile therefore the migration of copper was from the rock to the saprolite zone, but only iron migrated to the surface forming laterite profile.

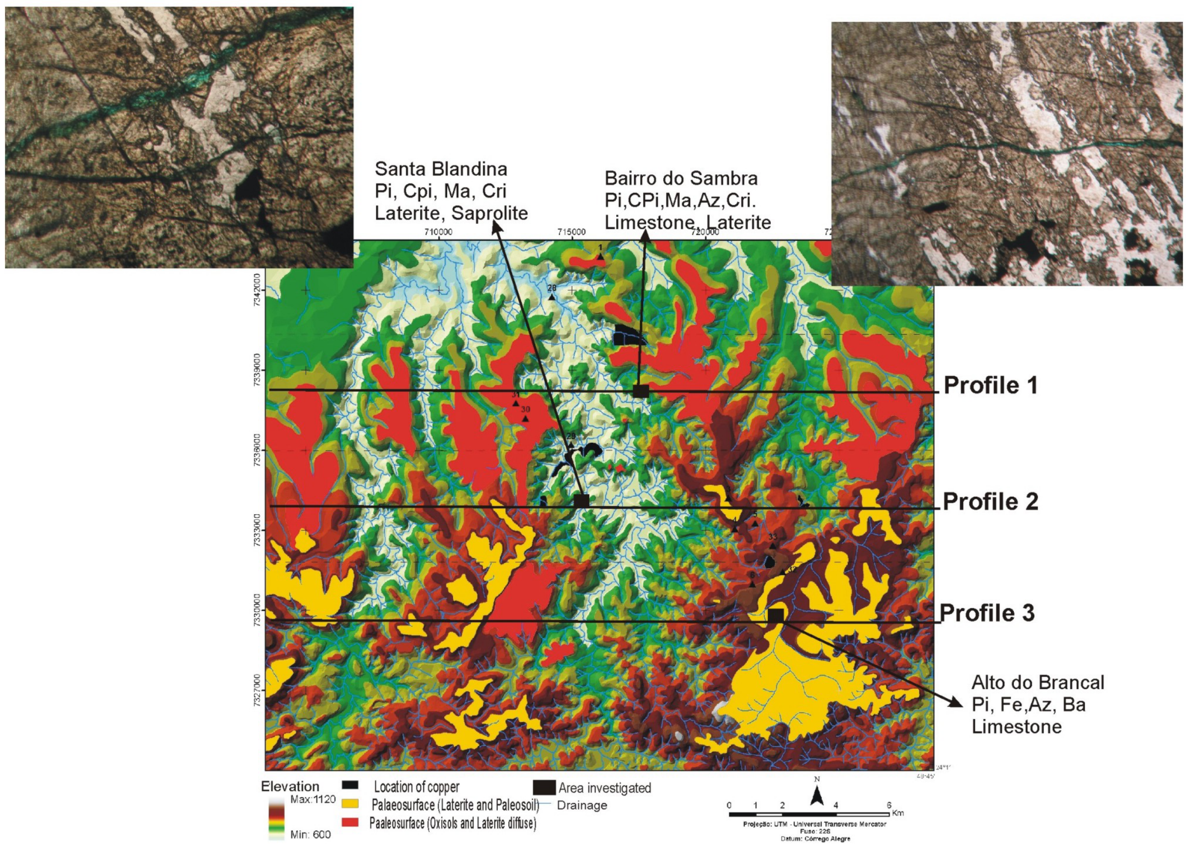

FIGURE 5. Digital elevation model showing the two palaeosurface levels (red and yellow levels) and copper occurrences (black areas) in the studied region. Abbreviations: Pi: pyrite; Fe: iron; Az: azurite; Ba: barite; Cpi: Chalcopyrite; Ma: Malachite; Cri: Crysocolla.

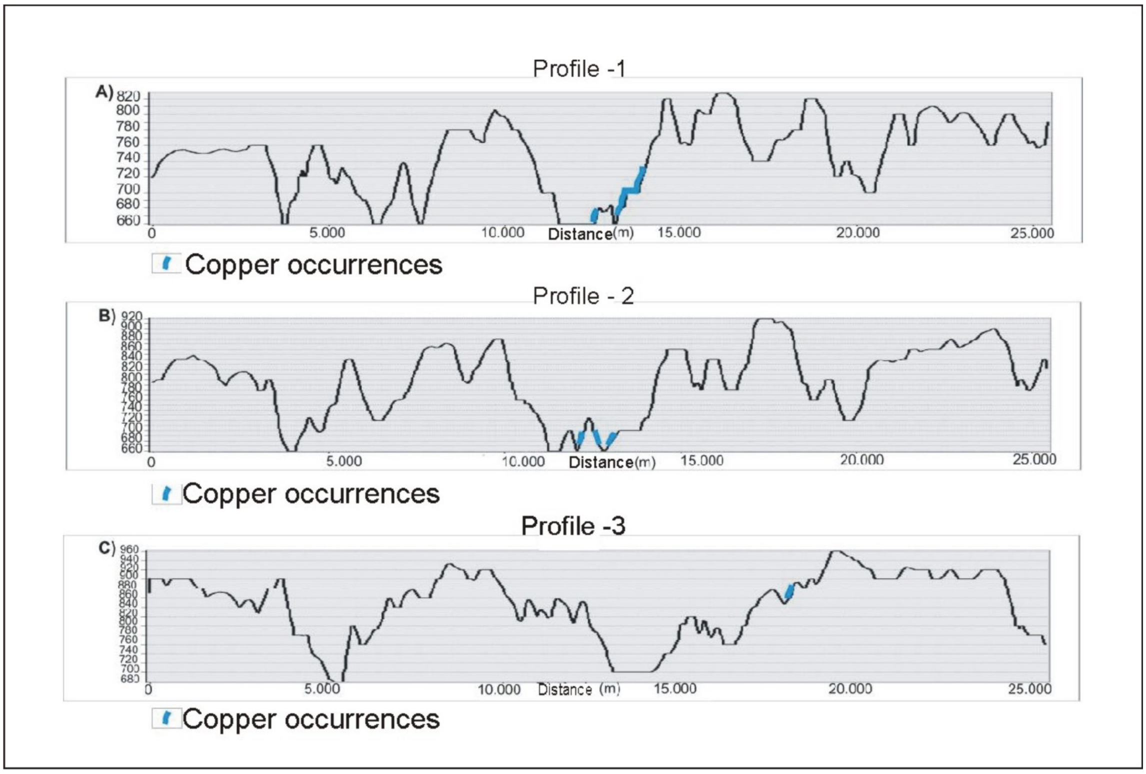

FIGURE 6. Topographic profiles with the distribution of copper occurrences in the Itapeva and Ribeirão Branco areas (SP).

CONCLUSIONS

The combined results of the geomorphological and chemical analyses (Ribeiro, 2009), together with the soil description in the studied areas, allow the following conclusions:

Palaeosurface level 1 is the lowest level and a larger occurrence of rock alteration has been preserved there (25 m of saprolite horizon), together with the presence of silicate minerals, such as chrysocolla and clays. Copper was accumulated in the cementation zone in the form of chrysocolla and malachite. In this profile, Fe has accumulated residually forming an iron hat, nowadays partially removed and modified.

Palaeosurfaces level 2 is the higher of the two preserved levels. It presents in situ lateritic horizons showing two overlapping climate phases, which are indicated by traces of copper in the saprolite. The migration of iron to the residual area occurs with the concomitant elimination by leaching and hydrolysis of the oxidized zone, which defined the boundaries of the extension reaction (alteration haloes), with outcropping azurite and other oxidized copper ores.

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