

Appendices

Manuscript Title: The methodological approach and general guidelines of the Itacaiúnas Geochemical Mapping and Background Project, Eastern Amazon

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Appendix A - Additional georeferenced socio-environmental information used for the project development.

Appendix B - Quality control of additional analytical methods used in the ItacGMBP.

Appendix A – Additional georeferenced socio-environmental information used for the project development

A.1 Land cover and land use changes

In the IRW region, the pristine landscape is dominated by tropical rainforest with subordinate areas of montane savanna. During the past four decades, different land uses have been established, such as pastureland, mineland and urban areas (Souza-Filho et al., 2018; Souza-Filho et al., 2016). Currently, pasturelands occupy 51% of the IRW, while forests represent only 48% (Nunes et al., 2019). The Brazilian government's strategy for human settlements in the Amazon has changed since the 1970s. Initially, occupation of the Amazon began with agricultural settlements of small farms; however, in the 1980s, large development projects, such as mining projects, hydroelectric dams and ports, were planned and implemented in the Amazon to accelerate the occupation of the region (Diegues et al., 1997). Hence, land cover and land use changes in the IRW were also associated with the opening of a rudimentary road network in the southeastern Amazon region associated with settlements and cattle ranching, which facilitated inland timber exploitation (Barber et al., 2014; Laurance et al., 2009). On the other hand, in more recent times, to conserve natural forests in the Amazon region one of the main strategies of the Brazilian government has been the creation of indigenous lands and protected areas (Nepstad et al., 2006), which in the IRW cover an area of 11,700 km². This area represents approximately 25% of the study area (Fig. A.1). Figure 2 (presented in the research article) illustrates the present status of the land cover and land use in the IRW.

In the context of the present paper, the IRW can be subdivided into four main geological segments (Figure A.2b): the Carajás Province that embraces: i) Rio Maria - Sapucaia - Canaã dos Carajás domains (RM-S-CC) in the south, which are dominantly composed of Mesoarchean granitoids (Almeida et al., 2017; Feio et al., 2013; Moreto et al., 2015), mafic-ultramafic greenstone belts, multiple Neoarchean stocks of ferroan to magnesian granite bodies and granulitic and charnockitic units (Figure A.2c); ii) Carajás Basin (CB), in the center, which formed during the Neoarchean (Gibbs and Wirth, 1990; Machado et al., 1991; Martins et al., 2017) and corresponds to a rift-related basin filled with mafic-felsic metavolcano-sedimentary rocks metamorphosed under greenschist-facies conditions (Martins et al., 2017) and banded iron formations (BIFs; Carajás Formation), which are responsible for the large iron deposits of the CMP (Gibbs and Wirth, 1990; Machado et al., 1991; Tolbert et al., 1971; Vasquez et al., 2008). The main units of the described segments of the Carajás Province are intruded by syntectonic Neoarchean A-type-like granitoids (Barros et al., 2009; Dall'Agnol et al., 2017), layered mafic-ultramafic complexes (Vasquez et al., 2008), and Paleoproterozoic anorogenic A-type granitic plutons (Dall'Agnol et al., 2005; Machado et al., 1991; Santos et al., 2013; Teixeira et al., 2018; Teruiya et al., 2008). The third segment of the IRW, located in its northern areas, is the Archean to Paleoproterozoic Bacajá Domain (BD) of the Transamazonas Province. This domain is mainly composed of metasedimentary rocks, mafic metavolcanic rocks and Archean mafic and felsic granulites. The fourth segment of the IRW corresponds to the Proterozoic Araguaia belt (AB), which is located in its eastern part of the IRW and is dominantly composed of Neoproterozoic metasedimentary rocks, with subordinate mafic-ultramafic rocks, Phanerozoic sedimentary rocks, Quaternary lateritic crusts and unconsolidated sediments. Within these geologic domains, large world-class mineral deposits occur. Hence, different mining companies have developed iron, copper and nickel mines since the 1980s (Figure A.2c).

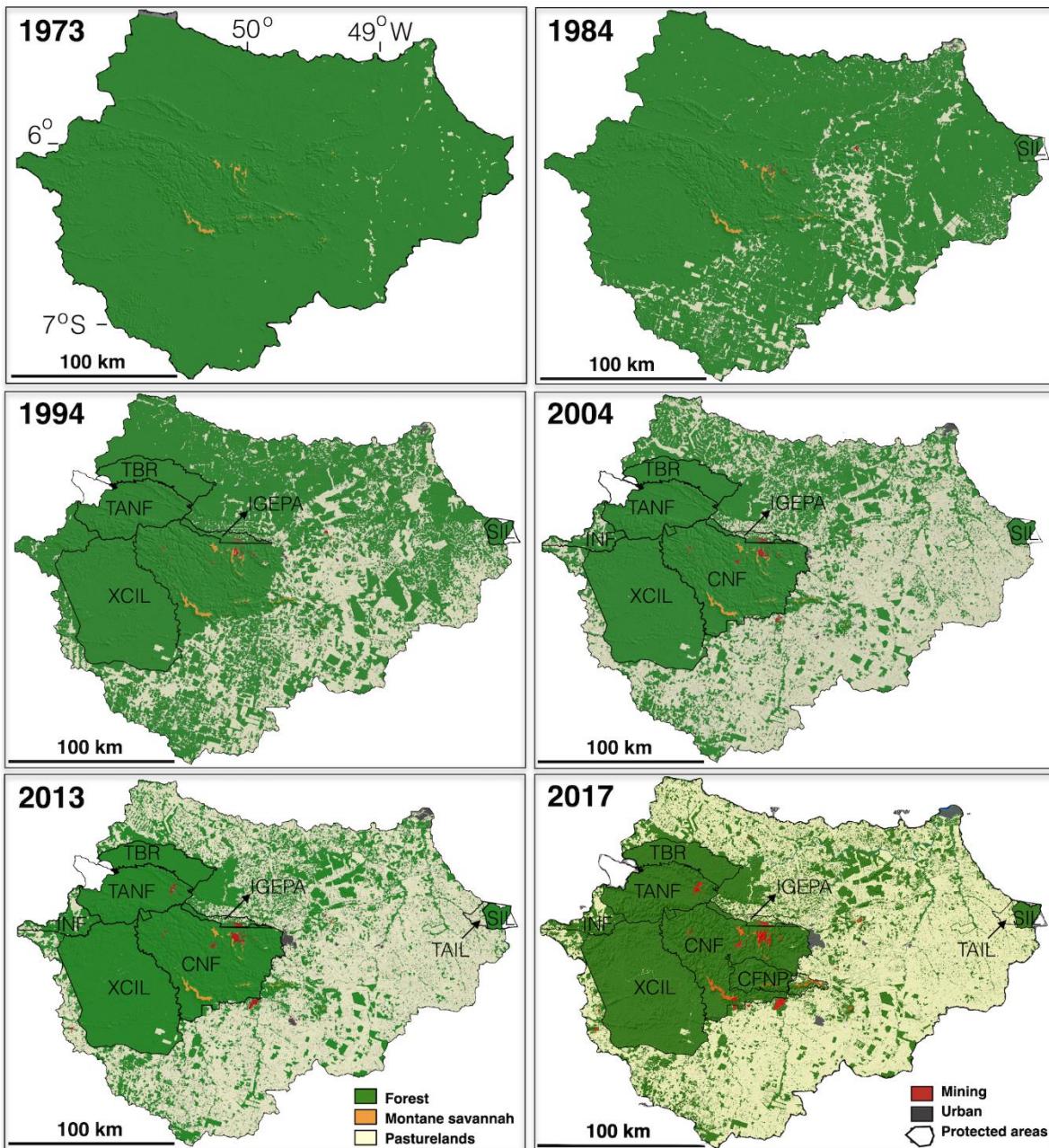


Figure A.1. Classified images showing temporal and spatial variation of land cover and land use in the Itacaiúnas River watershed for the years 1973, 1984, 1994, 2004, 2013 and 2017. The black line polygon defines indigenous lands and environmental protected areas (ILPAs). ILPAs were established in the following years: Sororó Indigenous Land - SIL = 1983, Tapirapé-Akiri National Forest – TANF = 1989, Tapirapé Biological Reserve – TBR = 1989, Environmental Protected Area of the Igarapé Bahia – EPAIG = 1989, Xikrin-Cateté Indigenous Land – XCIL = 1991, Carajás National Forest – CNF = 1998, Itacaiúnas National Forest – INF = 1998, Tuwa Apekuokawera Indigenous Land – TAIL = 2012, and Campus Ferruginosos National Park – CFNP = 2017. Modified from Souza-Filho et al., 2016).

A.2. Geology

The IRW has a relatively complex geology because it is located on the borders of several tectonic provinces: the Carajás Province occupies its central and southern parts, the Bacajá Domain of the Transamazonian Province occupies its northern part, and the Araguaia

Belt occupies its eastern area (Figure A.2b). Carajás Province (Figure A.2a) is the main Archean domain of the Amazonian craton (Feio et al., 2013; Vasquez et al., 2008), and it contains one of the largest iron ore reserves in the world (Grainger et al., 2008; Tolbert et al., 1971) and has great economic relevance in the global distribution of metal commodities, such as iron, nickel and copper (Nakajima et al., 2018). It is important to emphasize that the Amazonian states generated US\$ 12.6 billion in 2017. Analysis of the values of the traded production showed that iron was responsible for 63.6%, followed by copper (16.2%), aluminum (7.6%), and gold (6.5%) (Souza-Filho et al., 2021).

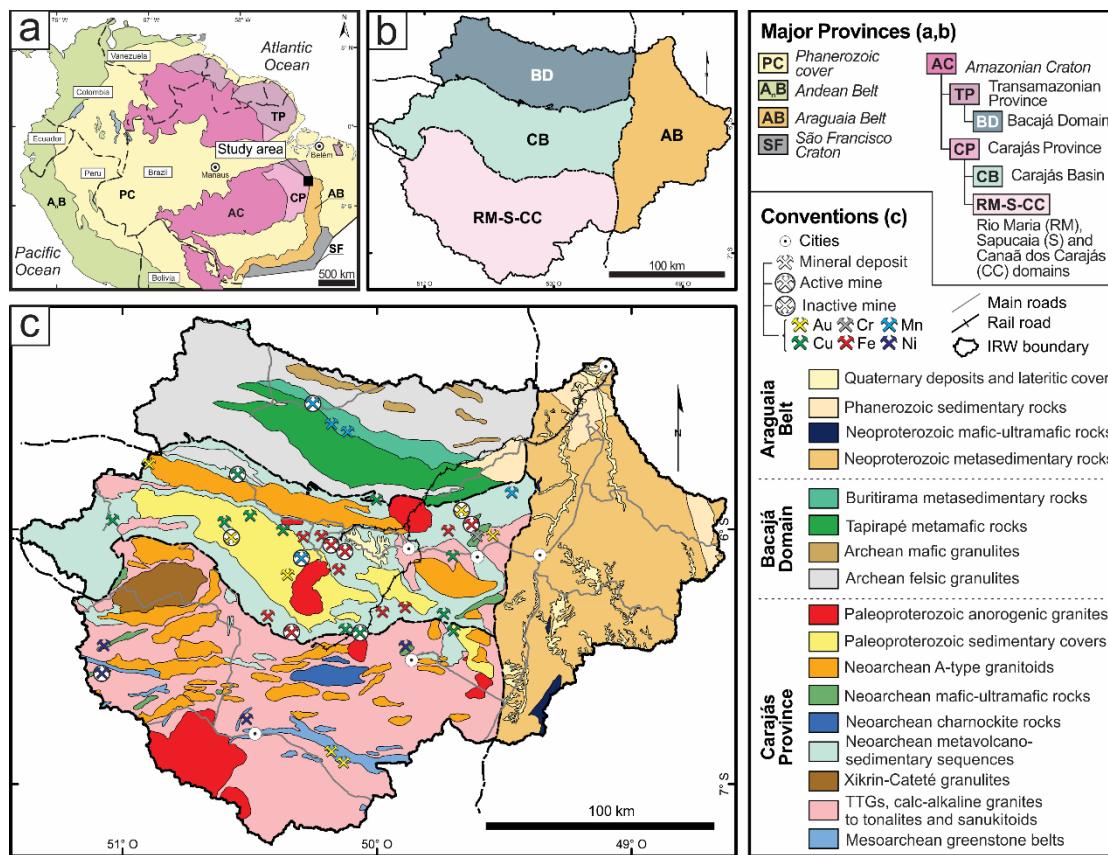


Figure A.2. Simplified geological map of the Itacaiúnas River watershed (modified from Sahoo et al., 2019; Teixeira et al., 2017; Vasquez et al., 2008; and Alvarenga et al., 2000).

A.3 Geomorphology and landscape

The landscape in the IRW is characterized by two geomorphologic units. The most widespread unit is marked by a peripheral depression with elevations ranging from 200 to 300 m, where elongated small hills with convex crests (Piló et al., 2015) are developed on the rocks of the AB, the RM-S-CC domains and the BD. The other geomorphologic unit is characterized by a dissected plateau carved out of the rocks of the Archean Carajás Basin, known in the region as Serra dos Carajás (Carajás Ridge), or of the Paleoproterozoic Seringa batholith in the southwestern IRB. The Carajás Plateau is located in the center of the IRW, and its main segments are named the North, East, South, Tarzan, Bocaina, Cristalino, and

Pium ridges. The tops of plateaus are feature laterites, hematite breccia and conglomerates that occur at elevations ranging from 500 m to 904 m (Figure A.3a). Iron ore mining projects started in the 1980s on the North ridge and later on in the East and South ridges in 2012 and 2016, respectively (Vale, 2017).

The IRW landscape varies significantly across its vast area. In the central and southwestern areas, there are high dissected plateaus and steep slopes. The northern and eastern sectors of the IRW are marked by hills and open valleys with alluvial plains. In the southern sector (RM-S-CC domains), wavy relief occurs with hills, elongated crests, and steep slopes. Figure A.3b shows the geomorphological landscapes in the IRW, including the tops of plateaus, steep slopes, hills, elongated hills, ridges, erosive wavy relief, alluvial valleys, and water bodies.

A.4 Climatology and hydrology

This area features a tropical humid climate, with a mean annual air temperature of approximately 26°C to approximately 28°C during the dry season (June to November) (Moraes et al., 2005). The total annual rain precipitation ranges from 1800 to 2300 mm, with a total mean of approximately 1550 mm during the rainy season (December to May) and 350 mm during the dry season (June to November), characteristic of a monsoon climate (Alvares et al., 2013).

From January to May, the rainy season occurs in the region, and the water discharge of the Itacaiúnas River ranges from 761.56 to 1,530.06 m³/s, with an average of approximately 1,126 m³/s. This value is 5.8 times higher than the average of the dry period, from June to October, when the average is approximately 194 m³/s. This seasonal flow behavior can be directly associated with the spatial-temporal variability in the Itacaiúnas river watershed - IRW (Silva Júnior et al., 2017).

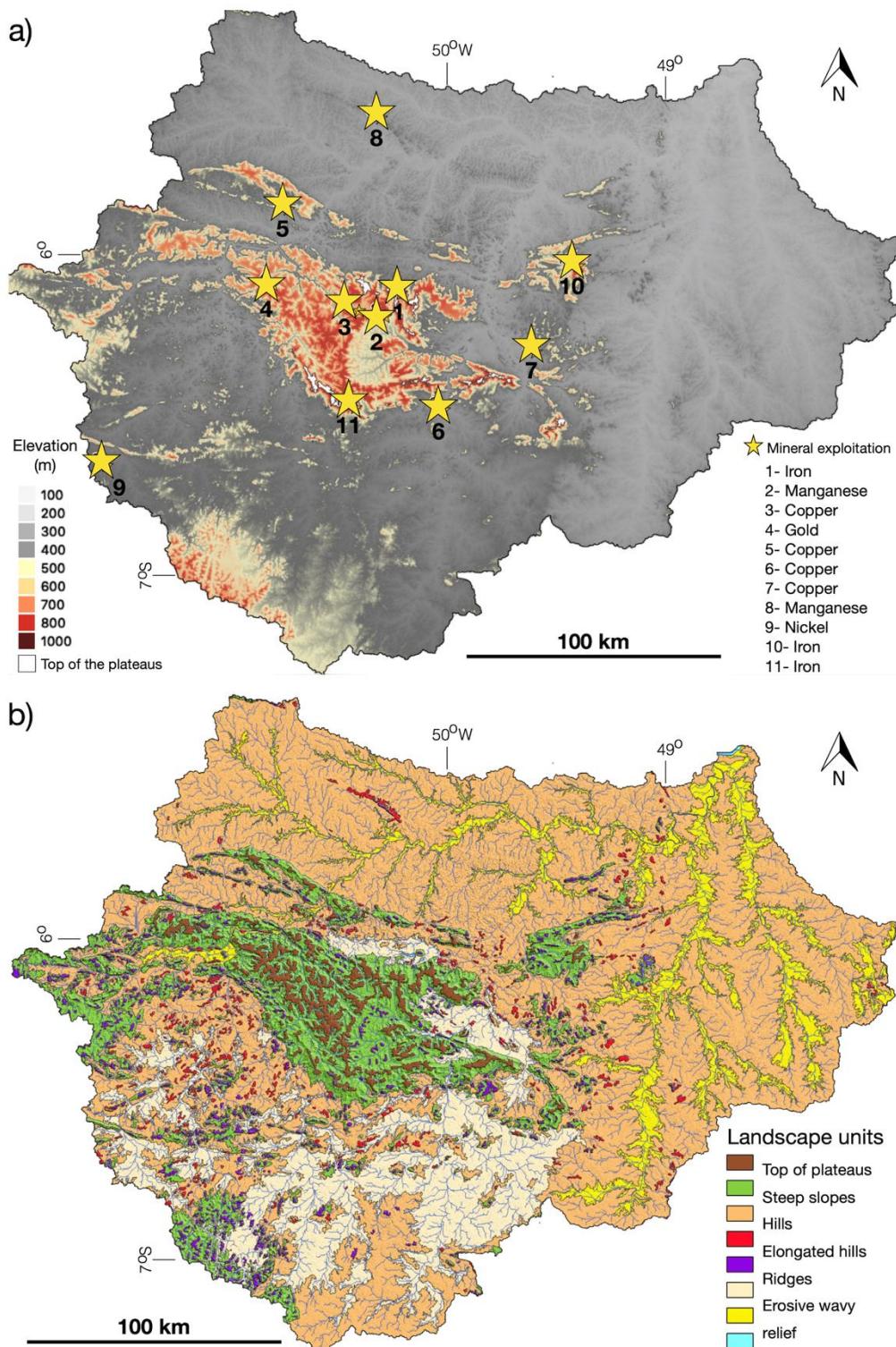


Figure A.3. a) Shuttle Radar Topography Mission (SRTM) elevation map of the study area showing the Carajás and Seringa plateaus and peripheral depression. The top of the Carajás Plateau is marked by the occurrence of laterites and hematite breccias. The locations of active iron, copper, manganese, and nickel mines are indicated. b) Itacaiúnas River watershed geomorphological landscapes.

Appendix B – Quality control of additional analytical methods used in the ItacGMBP.

Geochemical parameters analyzed in the ItacGMBP. For each parameter, it is presented the measurement unit, the lower limit of detection (LLD), the analytical methods and precision control results using relative standard deviation (RSD, %) values for each group of samples: surface soil (SS; number of pairs of duplicates - n = 73), bottom soil (SP; n = 73), stream sediment (SC; n = 33) and stream water in the dry (ES; n = 28) and rainy (EC; n = 29) seasons.

Soils and stream sediments							Stream water						
Parameter	Unit	LLD	Method (ALS code)	%RSD			Parameter	Unit	LLD	Method	%RSD		
				SS	SP	SC					ES	EC	
Al ₂ O ₃	%	0.01	ME-XRF26	3.0	2.4	5.2	Electrical conductivity	µS/cm	1	MP	3.9	11.5	
BaO	%	0.01	ME-XRF26	15.0	10.8	20.9	Dissolved oxygen	mg/L	0.1	MP	3.6	1.2	
CaO	%	0.01	ME-XRF26	10.6	7.5	8.8	pH	-	2	MP	0.2	0.8	
Cr ₂ O ₃	%	0.01	ME-XRF26	19.2	19.4	20.4	Redox potential	mV	-	MP	5.7	6.4	
Fe ₂ O ₃	%	0.01	ME-XRF26	2.3	3.1	4.1	Total dissolved solids	mg/L	5	MP	17.4	16.4	
K ₂ O	%	0.01	ME-XRF26	3.3	4.1	6.3	Temperature	°C	-	MP	3.2	0.5	
MgO	%	0.01	ME-XRF26	3.5	4.7	8.1	Turbidity	NTU	0.1	Neph	61.5	39.1	
MnO	%	0.01	ME-XRF26	8.0	6.1	6.0							
Na ₂ O	%	0.01	ME-XRF26	11.2	8.2	10.6							
P ₂ O ₅	%	0.01	ME-XRF26	6.5	5.5	12.5							
SO ₃	%	0.01	ME-XRF26	9.7	13.4	20.9							
SiO ₂	%	0.01	ME-XRF26	1.5	1.2	1.4							
SrO	%	0.01	ME-XRF26	0	14.0	0							
TiO ₂	%	0.01	ME-XRF26	3.0	2.9	10.0							
Total	%	0.01	ME-XRF26	0.7	0.6	0.5							
Loss on ignition	%	0.01	OA-GRA05x	3.0	2.7	8.0							

Notation: ME-XRF26 = Fused pellet + X-ray fluorescence (XRF); OA-GRA05x = thermogravimetric analysis; ME-MS4I = Aqua regia soluble concentrations + Inductively Coupled Plasma Optical Emission Spectrometry (ICP-AES) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS); MP = Multiparameter probe; Neph = Nephelometer; IC = Ion chromatography; '*' values not calculated (large proportion of samples below LLD); '-' Not applicable.

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