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Archaeo-environmental study of the *Almas* river: mining pollution and the *Cerrado* biome in the end of the nineteenth century in Mid-Western, Brazil

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ABSTRACT

This article proposes to understand the environmental impacts of a gold mining exploration in the *Cerrado* biome or Brazilian Savanna at the end of the nineteenth century in Mid-Western, Brazil. Firstly, the *Cerrado* biome is described according to perceptions about the ecological characteristics, ecological researches conducted, and mainly according to the ecosystem of the *Pireneus* mountains our area of research. Secondly, the historical mining impacts of nineteenth century are presented through reflections on the mining techniques of gold exploration, and through the environmental consequences of metal concentration in the area. Finally, the *eco*-archaeological study of the soil samples from *the Almas* river area in Mid-Western Brazil is demonstrated, as well as, the interpretation about the emergency of historical pollution patterns.

1. The *Cerrado* biome in Mid-Western Brazil

This study is part of a research program intending to combine different processes of analyses to reconstruct the events surrounding the environmental impacts of a gold mining village: *Lavras do Abade*. This mining community was destroyed by a neighboring village, today known as *Pirenópolis* City, at the end of the nineteenth century in Mid-Western, Brazil. According to local narratives, the conflict was the result of a dispute over the control and use of natural resources and water pollution (Costa, 2011).

In this way, the contemporaneous environmental and historical investigations are important elements of this mosaic of information surrounding water pollution and conflict in the old mining village area. The past and present environments of the region where the attack occurred are characterized as a singular and essential reserve of the *Cerrado* biome in Mid-Western Brazil. The *Cerrado* is the second largest biome in Brazil but, despite this, its importance is sometimes minimized due to focus on Amazonian or Atlantic Forest studies. The *Cerrado*, which is the Portuguese word for "closed" or "inaccessible" is the mostly tropical savanna and scrub forest ecosystem of South America [Fig. 1].

1.1. Ecological characteristics of the Cerrado

The *Cerrado* is approximately 1,916,900 km^2; or 740,100 square miles in size, covering all the Brazilian state of *Goiás* and the Federal District, most of *Mato Grosso*, *Mato Grosso do Sul*, and *Tocantins*, the western portions of *Minas Gerais* and *Bahia*, the southern portions of *Maranhão* and *Piauí*, and small portions of *São Paulo*, *Roraima* and *Paraná*. The *Cerrado* also extends into the South American continent; it reaches to the northeastern part of Paraguay and the eastern part of Bolivia. The *Cerrado* accounts for 22% of Brazil's landmass, is bigger than Alaska, and is the largest savanna in South America. According to Motta and others (2002), the *Cerrado* tends to maintain itself with more resilience than other vegetation because the climate and soil factors are not extreme.

The *Cerrado* biome and climate are of importance to the Brazilian ecosystem. Despite its privileged and strategic geographical position, it contributes to significant biodiversity in Brazil. The *Cerrado* is characterized by an enormous range of plant and animal biodiversity. According to the World Wide Fund (Nature), it is biologically the richest savanna in the world. The *Cerrado* borders all of Brazil's major ecological systems, including the Amazon basin in the north, the *Chaco* and *Pantanal* in the west, the *Caatinga* in the northeast, and the Atlantic forest in the east and south. The *Cerrado*'s typical climate is hot, semi-humid, and seasonal, with a dry winter season from May through September or October. The annual rainfall in this biome is around 800–1600 mm.

The majority of the *Cerrado* is localized in the central Brazilian plateau, which is a headwater for the three main hydrographic basins in Brazil. the Amazon, the São Francisco, and the Paraguay, and is responsible for the most extensive agriculture in the country (Gusmão, 1979; Marchetti and Machado, 1979), despite generally poor soil characteristics. According to Motta and others (2002),

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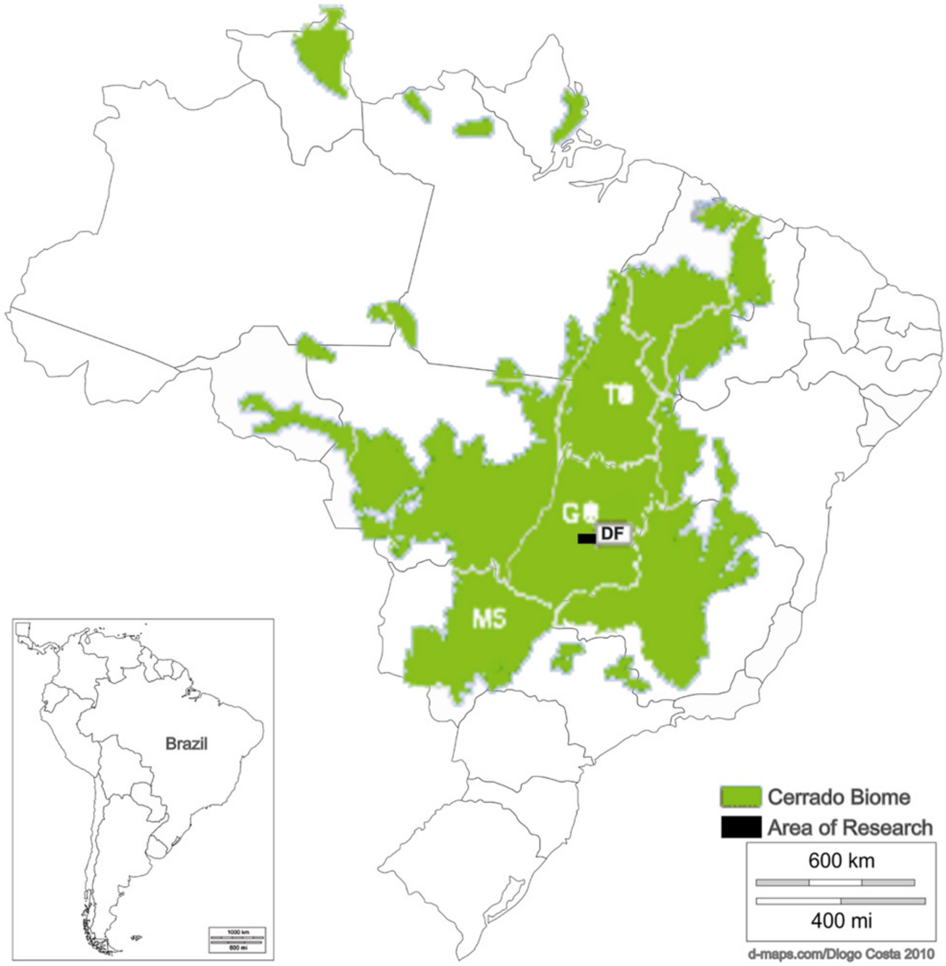


Fig. 1. *Cerrado* biome.

the latosols or oxisols[1] tend to have good physical but poor chemical properties. The good physical properties are mainly due to high aggregate stability, while the poor chemical proprieties are low nutrients, such as phosphorus and calcium, and low micronutrients. Most of the *Cerrado* is located on large plateaus, broken by a network of depressions and river valleys. Several of South America's major rivers, such as the *São Francisco*, *Tocantins*, *Araguaia*, *Xingu*, and Paraguay rivers, have headwaters in the *Cerrado* area.

According to Furley (2006), the *Cerrado* biome has one of the richest flora of the world's savannas and is also equally rich in fauna, other than mammal species, especially birds, fish, reptiles and insects. The flora is characterized by a unique association between xeric aspects[2] and the abundance of water resources, which have adapted to seasonal fires. The *Cerrado* landscape is characterized by extensive savanna formations crossed by gallery forests and stream valleys, which includes various types of vegetation. In this area there are three major types of vegetation: the humid fields and *Buriti* palm paths that are found where the water table is near the surface, the alpine pastures that appear at higher altitudes, and the mesophytic forests[3] on more fertile soils.

Therefore, the savannas are not homogenous: there is a great variation between the amount of woody and herbaceous vegetation, forming a gradient from the open *Cerrado* grasses to the closed forest-like *Cerradão* or canopy forest. According to Klink and Machado (2005), the *Cerrado* has a rich and generally unappreciated biodiversity. More than 1600 fauna species have been identified in the *Cerrado*, including 180 reptile species, 113 amphibians, 837 birds and 199 mammals. Among the invertebrates, the most notable are termites and leaf-cutter ants. They are the main herbivores of the *Cerrado*, important for consuming and decomposing of organic matter, as well as constituting an important food source for many other animal species.

The *Pireneus* mountains, our area of study, is today inside of the *Serra dos Pireneus* State Park [PSP], an ecological unit of preservation of the *Cerrado* created in 1987[4] and containing 2.833 ha. The *Lavras do Abade* archeological site is within the surrounding Environmental Protection Area [EPA], which was created in 2000[5] and contains 22,800 ha. The PSP and EPA are localized on the outskirts of *Pirenópolis*, *Corumbá* and *Cocalzinho* cities, and also include the *Pireneus* peak [1385 m] and *Cabeludo* hill, as well as the watershed division for the Platina and Amazon water basins, which includes the heads of the *Almas* and *Corumbá* rivers. The fauna and flora, as

[1] Latosols are formed by the decomposition of parent rocks, without silica or humus. They appear reddish coloration, due to high concentrations of iron and aluminum.

[2] Plants that require only little water to grow.

[3] Plants adapted to dry conditions.

[4] State Law 10.321/87 (Lamy et al., 2006:06).

[5] State Decree 5.174/00 (Lamy et al., 2006:07).

described before, are characteristic of the *Cerrado* biome, and the condition of the PSP and EPA are well preserved with native exemplars in the area of the *Lavras do Abade* site and adjacent.

The *Almas* river, in the middle of *Pireneus* mountains, begins in the highlands of the *Serra dos Pireneus* State Park, and divides the center of *Pirenópolis* City when it later flows to the northwest and joins the *Araguaia* and *Tocantins* rivers, before finally reaching the *Amazon* basin. The river becomes strong when it reaches the *Belém-Brasília* highway and has many small but treacherous cascades that may have led to its name, the "River of Souls". The *Almas* river today suffers from pollution from the sewers of several towns along its course, as well as the mining activities that populated the mid-western Brazilian *Cerrado* looking for gold and precious stones in the past.

2. Mining impacts of the nineteenth century

The gold mining exploitation in the *Lavras do Abade* was one of the main factors of environmental impacts at the end of the nineteenth century *Cerrado,* Brazil. According to Kelly (1998), the types of environmental effects observed in mining areas are also related to the method of ore extraction. Accordingly, I will first make a retrospective of the mining techniques, and especially the procedures adopted in the *Lavras do Abade* mine. I will then approach the environmental impacts of these techniques and the specificities of each exploitation stage; and third I will present some considerations about the study of historic mining pollutions, including it's limits and particularities in the present day.

According to Pasava and others (1995), mining is the extraction of valuable minerals or other geological materials from the earth, usually from an ore body, vein, or seam. Materials recovered by mining include bauxite, coal, copper, gold, silver, diamonds, iron, precious metals, lead, limestone, nickel, phosphate, oil shale, rock salt, tin, uranium, and molybdenum. Any material that cannot be grown through agricultural processes, or created artificially in a laboratory or factory, is usually mined. Mining in a broader sense can also include the extraction of petroleum, natural gas, and even water.

2.1. Mining techniques and gold exploitation

According to Bowie (1898), the mining system in the nineteenth century was associated with the type of ore deposit, but can be divided into two basic types of exploitation: surface-mining and deep-mining. In the case of *Lavras do Abade* mine, the type used for the ore exploitation of *Pireneus* mountains was the surface mining. Surface mining is a type of mining in which the soil and rock that covers the mineral deposit are totally removed. Surface mines are typically enlarged until either the mineral deposit is exhausted, or the cost of removing the larger volumes of overburden makes further mining uneconomic. Within the surface mine types there are many techniques to remove the soils, and in the case of *Lavras do Abade* mine two types were primarily used: *placer* mining and hydraulic mining.

In his manual of nineteenth century mining, Bowie (1898) explains that *placer* mining is a specific technique of the open cut method which was largely employed since ancient times. In the *Lavras do Abade* mine it was originally conducted since the beginning of exploitation in the area during the eighteenth century, until the arrival of CMG Company at the end of the nineteenth century and the shift to hydraulic mining technique. *Placer* mining refers to the mining technique of looking for minerals in the deposits of sand and gravel in modern or ancient stream beds. This may be done through the open-pit or open-cast procedure or by various forms of turning riverbeds. The name derives from the Spanish word *placer,* meaning "sand bank," and refers to the precious ore found in alluvial deposits. The containing material may be too loose to safely mine by turning the river, and panning is the simplest technique to extract the gold.

According to Longridge's (1902) other manual of nineteenth century mining, in panning, some mined ore is placed in a large metal pan, combined with a generous amount of water, and agitated so that the gold particles, being of higher density than the other material, settle to the bottom of the pan. The lighter ore material such as sand, mud and gravel are then washed over the side of the pan, leaving the gold behind. Once a *placer* deposit is located by gold panning, the miner usually shifts to equipment that can treat volumes of sand and gravel more quickly and efficiently. The same principle may be employed on a larger scale by constructing an inclined sluice box, with barriers along the bottom to trap the heavier gold particles as water washes them and the other material along the box. This method better suits excavation with shovels or similar implements to feed sediment into the device. Where water under pressure is available, water under pressure may be used to mine, move, and separate the precious material from the deposit; this is called hydraulic mining.

The hydraulic mining is so destructive that it was virtually abolished worldwide after the nineteenth century. This was also the main reason for the conflict between the old villages in the *Lavras do Abade* mine. According to Wagenen (1900) in another manual of nineteenth century mining and Bowie (1898), hydraulic mining is a form of art that employs water under pressure to dislodge rock material or move sediment. This form of mining was first used by Antoine Chabot or Edward E. Mattison in Sierra Nevada, California in 1852 to exploit gold-bearing upland paleogravels. However, previously hydraulicing technique had been invented by the Romans, the *ruina montium* or “razing of the hill”, to find gold using high-pressure water jets from a tank situated from 400 to 800 feet above the ground. In the case of *Lavras do Abade* mine, the utilization of hydraulic elevators or aqueducts was also necessary because the nearest water source for the mining area was the *Abade* waterfall, and it did not have the fall necessary to power the hydraulic machine.

Hydraulic mining became the largest-scale and most devastating form of *placer* mining in the nineteenth century (Joseph and Hagwood, 1981). Wagenen (1900) and Bowie (1898) explain that the water was redirected into an ever-narrowing channel, through a large canvas hose, and out a giant iron nozzle – a mechanical device designed to control the characteristics of a fluid flow as it exits from an enclosed chamber into some medium, also called monitor. The extremely high-pressure stream was used to wash entire hillsides through enormous sluices. However, Crouch (2001-2004) explains that in 1884 hydraulic mining was prohibited by federal injunction in California, USA because of the massive volume of debris that clogged the streams. Curiously, it was also in the same year of 1884 that a “similar” hydraulic machine was implanted in the *Lavras do Abade* mine, Mid-Western Brazil. The consequences of its operation to the *Cerrado* biome are discussed next.

2.2. Mining exploitation and environment

The primary environmental effects of hydraulic mining are river sedimentation and turbidity, followed by the high metal contamination. According to Kelly (1998), the environmental impacts associated with mining are largely confined to regions in the vicinity of the appropriate geological formations and downstream of the catchment. However, it is not only the extraction of the mineral which produces pollution, but also its disturbance for 50 or 100 years after the cessation of mining still polluting the water draining out of disused mines and spoil heaps.

Environmental activists describe hydraulic mining as being a more environmentally destructive type of mining because of the large amounts of silt that it adds to previously clear running streams. Water that was diverted to dry land created a boggy mud that destroyed habitats and flooded the land of farmers living downstream. Environmental issues can also include erosion, formation of sinkholes, loss of biodiversity, and contamination of groundwater by chemicals from the mining process and products.

According to Hadley and Snow (1974), mining pollution generally affects all biospheres from the soil to the air, but the element most affected is the water resources of a region. Kelly (1998) also exposes that processing the ores produces the largest amount of contaminated water, because water is both a vital raw material for and a major waste from several of these process. The contamination includes the chemical reagents such as mercury that are added to separate the minerals from the finely ground rock by flotation. In sequence, an excess of flotation reagents and colloidal and supercolloidal minerals are then discharged on the milling effluent. As a result, slag heaps still contain considerable amounts of metals leached in the water for many years after mining has ceased. This pollution procedure for amalgamation of gold with the use of large quantities of mercury also employed in the *Lavras do Abade* mine was called the *patio* process.

According to Miller and Lechler (1998), the mercury amalgamation has been used by Roman smiths for refining gold since ancient times, but was only in 1554 that mercury was used on an industrial scale in Mexico. The *patio* process was so efficient at refining large volumes of low-grade ore that its utilization continued nearly unchallenged through the end of the nineteenth century. Unfortunately, it also led to the release of unprecedented amounts of mercury in to the environment, particularly in North, Central and South America. With the advent of the cyanidation process in 1890, the mercury amalgamation was largely replaced in most temperate environments, but it continues to be widely used by non-organized prospectors of the tropics.

In the *patio* process the ores were crushed typically either in *arrastras* or stamp mills to a fine slime, which was then mixed with salt, water, *magistral* - essentially an impure form of copper sulfate – and mercury, before being spread in a one- to two-foot thick layer in a shallow-walled, open enclosure or *patio*. Horses or mules were driven around on the *patio* to further mix the ingredients, and, after weeks of mixing and soaking in the sun, a complex reaction converted the gold ore in the native metal, which formed an amalgam with the mercury and later is purified with a heat treatment. The principal pollutant of the *patio* process is the metal concentration in the environment.

Kelly (1998) also explain that the *placer* mining is the most "visible" type of mining pollution, because the net effect that causes disruption of the surrounding area as well as direct environmental consequences on the streams. The effects include turbidity in the water as a result of runoff and washwater contaminated by silt and clay, which increased sedimentation, filling interstices between gravels silting the channel. Consequently the deposited sediments can act as a barrier to free movement to the stream. At the same time, however, the metals transferred to the stream sediments cause a range of physical, chemical and biological process over time, not entirely studied.

2.3. Metal concentration and environment

According to Kelly (1998), the best way to study the metal concentrations in the environment is measurement with techniques of filterable and particulate fractions.[6] Therefore, according to Miller and Lechler (1998), there are important particularities concerning the geographical and temporal trends in the metal concentrations and varying grain size. In this way the historical deposits are better, because of the enrichment of trace metals in fine-grained sediment of most aquatic systems during long periods of time, different from modern channel bed sediments.

The measurement of mercury concentration is a key factor for determining the level of mining pollution in a region, but its identification in the field is not an easy task. Miller and Lechler (1998) also explain that mercury in the form of cinnabar is associated with mining and milling debris where sulfide ore bodies are being worked. On the other hand, in the amalgamation process mercury has the potential to be transported as liquid droplets, and as a combination of mercury and gold particles. The three forms of mercury are associated with the coarse-grained fraction of alluvial deposits.

However, Miller and Lechler (1998) note that the problem of measurement in the amalgam particles lies in considering that the densities of mercury [13.23 g cm^3;] and gold [19.28 g cm^3;] have the potential to be hydraulically separated in similar sizes. In this way, they conclude that the better methodology for the measurement of mercury is the spatial – downstream – trend to trace metal concentrations and comparing data collected from similar depositional sites.

For example, Fearnside (2005) presents a curious case of heavy metal contamination and the perpetual danger that this type of metal can cause to the human population. The author discusses a case study about mercury pollution in a dam construction in *Rondonia* state, Brazil. The Amazon soils flooded by the dam reservoir contain mercury from natural sources millions of years old that have been gradually accumulating from deposits in rain and dust from volcanic eruptions and other sources around the world. In this way, the anoxic conditions at the bottom of a reservoir provide the environment needed for methylation of mercury, which increases in concentration by about tenfold with each link in the food chain from plankton to fish, up to people who eat the fish.[7]

As another example, Harrison and others (2003) present the pollution of mining sites since 1920 in Australia. The researchers employ a series of measurements of core and surface sediments to describe the pollution process in the rivers of the region. According to Harrison and others, little has been done to prevent runoff and sediment transport from the mine and processing sites since the cessation of mining. In this way, a 100 year record of temporal pollution fluctuation in the downstream of the mines and around sites was determined. Harrison and others found heavy metal concentrations, including lead, arsenic, zinc, copper, cadmium, mercury and silver in both core and surface sediments.

The same conclusion is reached by Adams and others (2007) with studies about the pollution of an ancient pyrite mine in the state of Massachusetts that was operating between 1882 and 1911. The authors used the previously described methodology to catch the sample: surface water and groundwater were filtered using 0.45 μm filters. After the cations [Na, K, Ca, Mg], transition elements [Fe, Cu, Mn, Zn], silicon [Si] and other indicator species [Al, Pb] were measured using a spectrophotometer, while the anions [Cl, SO_4, NO_2, NO_3, F, Br, PO_4] were determined using a chromatograph. In conclusion the study determined that pollutant loadings and a mass remaining material constitute the mine-water discharged. The pollution will continue to flow into the environment for many decades unless abatement measures are implemented today at the site.

[6] In the filterable technique the water sample passes freely through a filter pore of 0.45 μm, to that the particulate material that includes not only solid minerals and crystals of the metal but also metals absorbed onto humic acids and other surfaces been collected.

[7] "The maximum concentration of total mercury in fish considered safe for human consumption in Brazil was 0.5 mg/kg fresh weight until 1998, when the criterion was revised upward to 1.0 mg/kg fresh weight" (Fearnside, 2005:13).

In summary, the general study of old pollution mines is used today as a predictive model for future mining exploitations, such as the work of Adams and Younger (Adams and Younger, 2000; Younger, 2000) based in computer simulations of water comportment and models of pollution mining. However, Banks and others (1997) present many techniques for recovering water sources affected by the mining impacts with a basis in the geochemistry in the alkaline and acidic mine-water deposits. Therefore the main problem caused by old mining exploitations is the long-term effect of heavy metal concentration in the environment (Grimalt et al., 1999; Younger, 1997).

3. Historical *eco*-archaeology in the *Pireneus* mountains

The previous two segments presented the physical and historical characteristics of the *Cerrado* biome as an environmental background to this research, while the mining impacts are explained through techniques applied in the nineteenth century and its pollution legacy. Otherwise, the historical *eco*-archaeology research in the *Pireneus* mountains area and surroundings show some other patterns of anthropic interference and ecological response besides the one specific mine pollution by heavy metals in the *Almas* river.

3.1. Fieldwork and soil analysis

The remains of heavy metal in the area were collected through soil samples from the archaeological site of *Lavras do Abade*, following the course of *Almas* river. The methodology employed was shallow excavation with a trowel to approximately 10 cm below the ground surface. All soil was collected in plastic bags with UTM references by GPS attached and the samples were then dried in sun light for 8 h to eliminate water residue [Fig. 2].

The first point of collection was inside of the foundry building of the archaeological site. The CP-01 point did not present dense vegetation, with the soil compounded of sand with a brown color and without gravel. The second point of collection was in the beginning of the mine area, next to the gate of water. The CP-02 point presented a dense vegetation and soil formed by much gravel with sand in a brown-yellow coloration. The third point of collection was in the middle of the mining area, next to the exploitation walls. The CP-03 point also presented closed vegetation with gravel and sand forming the soil with clear brown-yellow coloration. The fourth point of collection was at the end of mining area, inside of the *patios*. The CP-04 point presented a disperse vegetation, with the soil compounded by small gravel and sand with brown-red coloration.

The fifth point of collection was in the beginning of *Barriguda* creek – tributary of the *Almas* river, in one sandbank at the creek's margins. The vegetation of CP-05 point was less dense than inside of the mine and the soil almost compounded of sand in a brown-red coloration. The sixth point of collection was in the middle of *Barriguda* creek, next to the water supply and distribution of the city of *Pirenópolis*. In the CP-06 point, the vegetation was dispersed and the soil characterized by humid sand with exposed matrix rocks, and brown coloration. The seventh point of collection was in the beginning of the *Almas* river and end of the *Barriguda* creek. The CP-07 point did not present dense vegetation but small plants, with red colored humid sand soil, and exposed rocks.

The eighth point of collection was at a beach of the *Almas* river in the beginning of the city. The CP-08 point did not present any vegetation and the soil was compounded by brown-red sand with some exposed rocks. The ninth point of collection was in the *Almas* river, next to the building constructions in the middle of the city. The CP-09 point presented small vegetation with the soil in brown-yellow coloration and formed by humid sand with big exposed rocks. The tenth and last point of collection was in the *Almas* river, below a road bridged in the end of the city. The vegetation in the CP-10 point presented as dense, with a brown soil compounded by sand and small disperse rocks.

Dr. Carlos A. B. Garcia and his team analyzed the soil samples in the environmental chemistry laboratory of the Federal University of *Sergipe*. The methodology used was the determination of heavy metals concentration through the dissolution of the soil samples in acids and measurement of product in a spectrometer of atomic absorption (Alves et al., 2006). Following this, the heavy metal concentrations in mg/kg were calculated according to the mass of soil collected, and the result of this was compared with reference values to soil pollution in Brazil (CETESB, 2005).

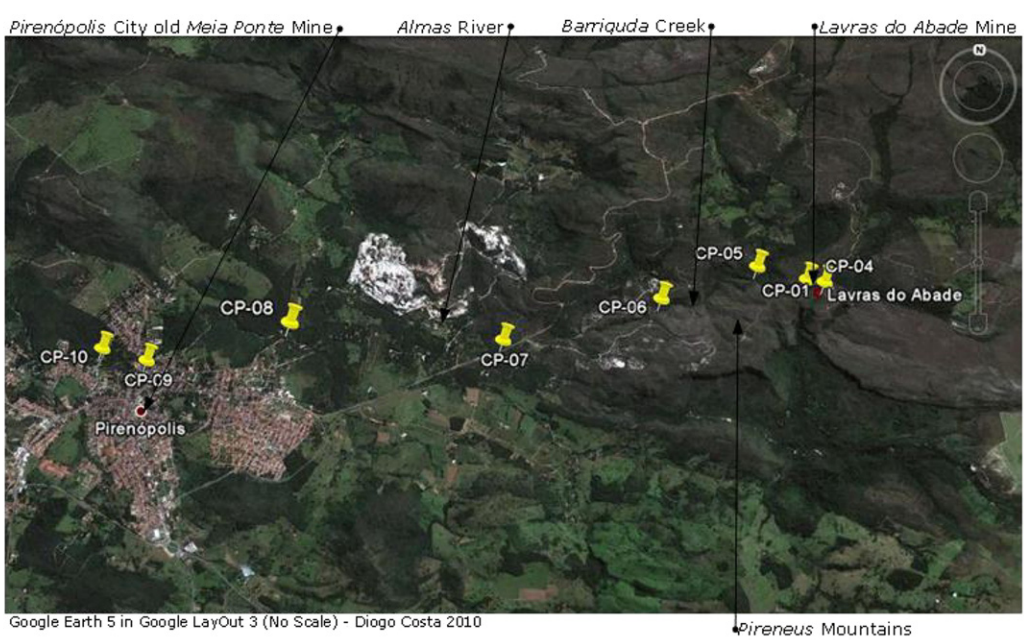


Fig. 2. Soil collection area.

Identification	Metal (mg/kg)					
	Cd	Cu	Zn	Pb	Ni	Hg
CP-01	0.00	19.99	15.98	4.49	4.16	0.04
CP-02	0.00	22.95	16.49	3.49	4.49	0.05
CP-03	0.00	6.99	11.48	2.50	5.49	0.04
CP-04	0.00	6.50	18.49	2.50	8.49	0.02
CP-05	0.00	4.00	11.50	2.00	6.00	0.01
CP-06	0.00	3.49	9.98	2.00	4.49	0.01
CP-07	0.00	2.99	7.48	1.00	2.49	0.01
CP-08	0.00	3.00	9.00	1.50	2.00	0.02
CP-09	0.00	6.00	8.00	2.50	3.00	0.02
CP-10	0.00	5.00	9.50	3.00	3.50	0.03
QRV	<0,5	35	60	17	13	0.05

According to Technological Company of Environmental Sanitation of São Paulo State (CETESB, 2005), the quality reference value or QRV is a concentration value of determined substance in the soil or in the subsoil water, which define clean soil or natural water. The QRV is statically interpreted according to physic-chemical analysis from diverse soil and subsoil water samples. The QRV must be used as referential to actions of soil and subsoil water pollution prevention and control of contaminated areas. In the case of *Lavras do Abade* mine and *Pirenópolis* City study area, no concentration was superior to the QRV indices mg/kg of 35 to Cu, 60 to Zn, 17 to Pb, 13 to Ni and 0,05 to Hg.

3.2. *Heavy metal presence in the Almas river*

Notwithstanding, the Cu, Zn, Pb, Ni and Hg concentrations in the area of research can also indicate other patterns beside the present day mine pollution to be studied. The copper presented one concentration three times more in the CP-02 and CP-01 that in the other eight points of collection. The copper distribution in these two points can be interpreted as directly associated with gold, both forming rich ore deposits in the area of *Lavras do Abade* mine. On the other hand, the pattern established between the distribution of copper in the CP-03 and CP-04, and in the CP-09 and CP-10 can indicate other gold ore deposit in the area of *Pirenópolis* City. Somewhat similar to the copper distribution, the zinc also presented a pattern concentration that indicates its presence one third more that the others in the CP-04, CP-02 and CP-01. The zinc concentration in the area of *Lavras do Abade* mine can also be indicative of the ore composition with gold, while its distribution in the others points of collection was stable and with little increase.

The lead also presented a similar distribution as the copper and zinc, and it was concentrated in the CP-01 and CP-02 of *Lavras do Abade* site, presenting a gradual decay until CP-07. However, the lead also displayed an increase from CP-08 to CP-10, which can be compared with the copper distribution in the area of *Pirenópolis* City. Like the copper and zinc, the lead is also present in the composition with gold as ore deposit. On the other hand, the nickel distribution was different from the other minerals; its concentration occurs only in the CP-04 point and later it is distributed around the CP-05 and CP-03. Other elements worth highlighting about the nickel is that this metal also occurs in the form of ore deposits associated with gold such as copper, zinc and lead, but the nickel distribution in the area between the *Lavras do Abade* mine and *Pirenópolis* Cdity was atypical.

Finally, the mercury distribution follows the copper, zinc and lead distribution with a concentration in the CP-01to CP-03 in the *Lavras do Abade* mine. Next, the mercury decayed until the CP-07, when it has an increase among the CP-08 to CP-10 in *Pirenópolis* City. The mercury is an intrusive element, and is not associated with the native gold ore deposit in the areas. In the same way, mercury is a clear indicator of anthropic actions to the gold extraction. Consequently, the presence of mercury in the *Lavras do Abade* mine and in *Pirenópolis* City serves as a clue to gold exploitation in both areas. However, the mercury presence is historically explained not only by the *Almas* river pollution, at a time that the mercury concentration in the CP-06 is almost null, but also by the historic gold exploitation in the *Meia-Ponte* mine – today *Pirenópolis* City.

In terms of the soil contamination in the area of research, it is clear that the impact was not only in the soil itself, but also in the atmosphere, hydrosphere and surrounding *Cerrado* biota. Similar to the *Lavras do Abade* case, Silva et al. (2004) present a problem of heavy goldmine metal pollution in *Minas Gerais* state, in southeast Brazil. In this mine Cd, Cr, and Pb were not identified in the soil, although there were high concentrations of As, Fe and S, medium concentrations of Zn and low concentrations of Cu and Ni. Silva et al. conclude that there are a huge potential to future acid drainage, by the combination of this elements and consequently contamination of soils, water sources and all food-chains.

According to Guilherme and Marchi (2005) the heavy metal analysis in the soil is the identification of trace elements that are not naturally present in the environment. However, the elevation of determinate trace elements in one area can be the result of anthropic and non anthropic interferences. The natural process could include, for example, rock decomposition, while the anthropic pollution is often associated with mining and industry activities. Guilherme and Marchi also insist that some trace elements are biologically necessary, while others are not. however, any essential trace element in specific concentrate conditions can cause irreversible damages to the environment.

As an example, Guilherme and Marchi (2005) note that the copper is essential to all living organisms in the transport of oxygen, but its concentration can also present moderate to high toxicity level for plants and moderate toxicity for animals. The zinc, similar to copper, is also essential to all living organisms, but in concentration it can present a low to moderate toxicity for both plants and animals. Otherwise, lead does not have a proven function to living organisms, and its concentration can present a moderate toxicity for plants and high toxicity for animals. While nickel presents a function to plants but does not have a known function to animals, in concentration it can present a moderate to high toxicity for plants and a moderate toxicity for animals. Finally the mercury does not have a known function to any living organism, and its concentration can present a high toxicity for plants and animals.

3.3. *Environmental sensibilities or mining patterns*

According to Semerene Costa (1995), the conflict between the *Lavras do Abade* mine and the *Pirenópolis* City over the use of *Almas* river in the end of nineteenth century Mid-Western, Brazil was a result of socio-environmental impacts of gold exploitation and relationships between the local population and the natural world. Semerene identifies this as “environmental sensibilities” or the exploitation of natural resources and the representation of *Almas* river in the organization of local society. According to Semerene, the population of modern *Pirenópolis* City was prevented from carrying out their basic necessities in the river because of pollution of the water caused by mining. This generated conservationist environmental sensibilities and affected the local mechanisms of power.

Semerene is strongly biased toward ecological history, failing to consider alternative explanations such as economic and political factors in favor of only environmental aspects of the conflict. Despite the use of primary sources, the work minimizes economic and political aspects in benefit of environmental aspects only. Notably, no ecological studies are introduced to support his conclusions. Semerene's contribution is mainly the study of "environmental sensibilities" in the nineteenth-century Brazil and the relationship between the company and the population. Second is the inquiry about the contradictory attitudes of old *Pirenópolis* population for the destruction or preservation of natural resources, and the relationship with the river.

In terms of historical mining impacts and the environmental consequences, the work by Isenberg (2005) is a complete descriptive environmental history of mining in California during the nineteenth century. First, Isenberg discusses the environmental, economic and social transformations that the hydraulic mining made in the region of the Sierra Nevada in California. Isenberg illustrates many examples of enterprises and the technology employed in these transformations; to the author the hydraulic mining was not only responsible for the mercury and mud pollution of water sources and surrounding areas, and consequently population diseases, but was also the principle means of industrialization of the West. As an example, Isenberg explains that the technology developed to deliver water to the hydraulic mining in the Sierra Nevada was lately responsible for the supply of water to many Californian cities.

Following this, Isenberg (2005) claims that the urban development of cities was associated with hydraulic mining expansion. The cities, in close relationship with the rivers in the region, worked as commercial centers for the miners, while the same cities suffered from constant pollution and floods, which caused diseases that affected entire populations. With these dilemmas, the cities lived in a constant dichotomy with the mines; on one hand, they were economically and productively dependent on the mines, and on the other hand they were sanitarily affected by the mine dejects. As an example, the author recounts the flood of 1850 and the cholera epidemic that affected the population of Sacramento village as a result. Finally, Isenberg explorers the wood forest used by the miners, first as the main fuel resource and later as primary construction material. In another example, Isenberg shows how the legal battle of the miners to access the redwood forest, after they had drained all wood resources in the Californians mountains and valleys, is another critical fact illustrating the constant modifications that resulted from sawmill technology, and the dangerous impacts of this kind of industry. In conclusion, Isenberg presents the large-scale modifications of the environment that the mills and mine have provoked as the population grew and the timber exhaustion as an obvious consequence.

Isenberg's (2005) work is a complete example of technological modifications and environmental consequences of the mining exploitations; in more specific terms, to the consequences of the hydraulic mining endemic to gold exploitation. However, the historical ecology approach does not present a clear signature in this human action and nature response relationship, because Isenberg does not, like Semerene, explore the dialect present in this relationship. In this way, similar in content, but different in method, this study presents the historical ecology approach of a historical landscape to understand not only the environmental impacts of gold exploitation in the *Lavras do Abade* mine, but also the construction of a memory-place that is reflexive of human actions and natural responses.

Consequently, the *Lavras do Abade* mine and *Pirenópolis* City divided not only a history of conflict and abuse of natural resources, but also one symbiotic existence with the *Almas* river and the *Cerrado* biome. The symbiotic existence is represented by the similar levels of heavy metal - mainly mercury - deposits in both areas of *Almas* river, but with an absence between. In this reason it is possible to affirm that there not are environmental indication of one mine pollution today, but two historical mine pollutions: one by the *Lavras do Abade* mine in the end of nineteenth century and other by the *Meia Ponte* mine – today *Pirenópolis* City – in the eighteenth century. Despite both levels being below today's pollution indices, it is necessary to refer to the period in that both mine activates were executed. Following this thought, it is also valuable to observe that the mercury level in the area of study of *Pireneus* mountains decays at a rate of approximately 33.3% in each point – *Lavras do Abade* mine and *Pirenópolis* City, and that this decay corresponds to one hundred years old difference for each gold mine extraction activity in the *Almas* river.

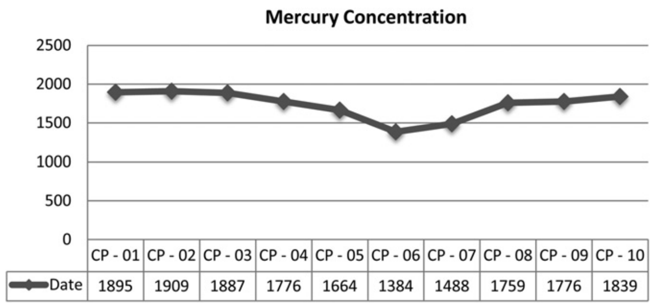
It is not the intention of this study to suggest major interpretations about this fact, but it is also necessary to present the evidence and try to correlate this with the pollution study. What is first conclusive is that there is one apparently decreasing pattern of 33% of mg/kg mercury concentration in the area of study to each one hundred years of goldmine exploitation. The *Lavras do Abade* mine presents an increase of 33.3% more mercury than *Pirenópolis* City, and by its turn the *Lavras do Abade* mine has 33.3% less mercury than the QRV pollution indices of today. In the same way, the time space between one gold exploitation and another in the study area is approximately one hundred years, while it is the same time space between the last gold exploitation in the area and today pollution indices.

In light of this I propose the following formula to determine the date of historical-archaeological mining sites studied according to the measurement of mercury concentration in the area. Where T is the subject of the formula, T_0 is the variable of date that the collect was made, N_0 is the variable of highest mercury concentration in T_0 or the Hg pollution indices to the area, N_ν is the variable of amount of mercury concentration in any the point of collect studied, and C is the constant to the mercury decrease to the specific area, which is of 1/3 to each 100 years.

$$T = T_0 - \frac{\left(Hg\frac{Mg}{Kg}\right)N_0}{\left(Hg\frac{Mg}{Kg}\right)N_\nu}\, xC\left(\frac{1}{3}x300\right)$$

Therefore, other variables could also explain these mercury patterns in the area of *Almas* river, such as the intensity and duration of gold exploitations. Because on one side, we have the industrial mining of *Lavras do Abade* with duration of approximately only five years, but with a high intensity in the gold exploitation. And on the other side, we have the artisanal mining of *Meia Ponte* mine – today *Pirenópolis* City with more than 50 years of duration, but with a low intensity in the gold exploitation. In combination or not with the temporal scale, these factors are also variables that can lead to the mercury patterns evident in the soil samples collected in the *Pireneus* mountains. However, independent of what variable - temporality, intensity or duration - was mainly responsible for the gradual mercury accumulation in this area of the *Cerrado* biome in Mid-Western Brazil, it is indisputable that historical mining pollution was and remains an important impact factor to all societies.

As example we can observe the work of Grattan and others (Grattan et al., 2007; Grattan et al., 2003) about modern communities that are affected by the legacy of historical mining pollutions. In southwestern Jordan an ancient roman copper mining area today serves as the base camp of modern Bedouin inhabitants and stage of metal contamination by a variety of pathways. Grattan and others (Grattan et al., 2003) presents through a meticulous study many ways by which the Bedouins families are daily exposed to the excessive copper concentrations in the sediments through plants, livestock and foodstuffs. Such as in the *Lavras do Abade* case study these nomads' pastors are today affected by ancient mining exploitation, but unfortunately this type of environmental hazard still receives little attention.



Concluding, it is possible, and maybe probable to affirm that the rate of decrease of mercury in the gold exploitation areas studied of *Lavras do Abade* is of 1/3 to each one hundred years. In addition, this pattern can be used as archaeological dating method for historical mining sites or as predictable models for the remediation period of mercury pollution from the activities of the ancient mines. However, it is also a striking environmental example of natural response to the environmental degradation caused by humans in the area. The results presented here not only indicate a possible pattern between old mercury pollution and modern environmental dynamics, but also a future orientation to the archaeological studies of industrial sites.

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