# *Astronium graveolens* tree – mineral exploration guide in search for copper and potential use of this plant for reforestation of mining waste

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***Abstract*:** Geological mapping and sampling of sediment-hosted copper-silver mineralization in NE Colombia identified the association of the *Astronium graveolens* tree (*Diomate Gusanero*) with the elevated presence of copper (up to 317 ppm) and silver (up to 24 ppm) in plant ash. During the dry season, when most plants lose their leaves, young *Astronium graveolens* seedlings growing along copper sulfide rich showings retain their green foliage. This observation allowed authors to effectively use this plant as an exploration guide in search for copper mineralization and *Astronium graveolens* can be potentially considered as a geobotanical indicator plant. The observed resistance of *Astronium graveolens* to the presence of copper sulfides suggests that this tree could be also a potential excellent species for reforestation and reclamation of tailings and other mining waste.

***Keywords*:** NE Colombia, *Astronium graveolens* tree (*Diomate Gusanero*), exploration guide, copper mineralization, copper sulfides, mining waste reclamation

## INTRODUCTION

Biochemical studies and the resistance of plants for the presence of various elements have been carried out in many places in the world. In the sediment hosted deposits of the Copper Belt in Congo and Zambia, several biological species have been identified that are closely associated with the presence of copper (Brummer & Woodward 1999). The same type of Gusanero tree (*Astronium graveolens*) as presented in this study was also studied in Brazil and revealed tolerance to the elevated lead content in soil (Araujo et al. 2020). The association of Zn moss (*Pohlia Wahlenbergii*) is well documented at the Howard's Pass deposit in Yukon (Lee et al. 1984, Dunn 2007). In Sweden, the "copper plant," *Viscaria alpina* (*Silene suecica*), was used for mineral exploration (Godin 1976) that led to the discovery and subsequent construction of the Viscaria mine in activity from 1982 to 1997 (Frietsch et al. 1997). Also in Sweden, the *Lychnis alpina* (*Caryophyllaceae*) shows significant resistance to increased copper concentrations in soil (Nordal et al. 1999). Several other authors such as Cannon (1957, 1960), Cochrane (1963), Gregory & Bradshaw (1965), Reilly (1969), Beard (1975), Dunn (2007), Martinsson & Wanhainen (2013), Hallberg et al. (2016) addressed the association, resistance and/or tolerance of several plants to various elements.

The aim of this study was to determine which part of *Astronium graveolens* tree (leaf, trunk/branch or root) contains the highest amount of copper and silver and also to compare biochemical assay results with the geochemistry of soil and rock samples collected in the vicinity of this plant.

## REGIONAL GEOLOGICAL SETUP

This article addresses the eastern part of the Cesar-Rancheria Basin (CRB) that is classified as mid-mountain, located between the Sierra de Santa Marta mountains on the NW side and the Perijá massif on the SE.

The Santa Marta-Bucaramanga Fault system separates CRB from the Lower Magdalena Valley Basin located to the south (Lugo & Mann 1995, Cediel et al. 2003, Hernandez et al. 2003, Mora & Garcia 2006, Sanchez & Mann 2015). In the CRB, the Jurassic and early Cretaceous rocks are cut by southeast-dipping reverse faults (Sanchez & Mann 2015). The elevation ranges from around 300 m to over 1600 m.

The CRB basin is divided into the southern part the Cesar Basin (CB) and the northern part the Ranchería Basin (RB). These basins are separated by uplifted block of Valledupar (Sanchez & Mann 2015). The CRB forms approximately a 12,000 km$^2$ intermountain basin located about 200 km from the Caribbean Plate subduction zone that slides under the South America.

The stratigraphic profile of the CRB basin consists of Paleozoic rock formations discordantly overlaid by Triassic, Jurassic and Cretaceous formations covered by Paleogene-Neogene sediments. The Paleogene-Neogene sediment package mainly consists of carbonate-rich rocks, mudstones, and unconsolidated gravels. These youngest rock formations are host for the coal deposits (Cerrejón deposit). Cretaceous formations are mainly represented by limestone and evaporates that have been exploration targets for the oil and gas industry. The Jurassic formation (La Quinta Formation) consists mainly of clastic (siltstone, sandstone and conglomerate) and volcanoclastic rocks that discordantly cover older Paleozoic formations and basement rocks (Forero 1970, Caceres et al. 1980, Ujueta & Llinas 1990). A simplified stratigraphic profile of the CRB is presented in Figure 1.

The Jurassic La Quinta formation is the host for the sediment-hosted Cu-Ag mineralization that is addressed in this paper. This sediment-hosted Cu-Ag mineralization of NE Colombia continues south, forming a regional semi-continuous belt that stretches from Colombia through Ecuador to Peru.

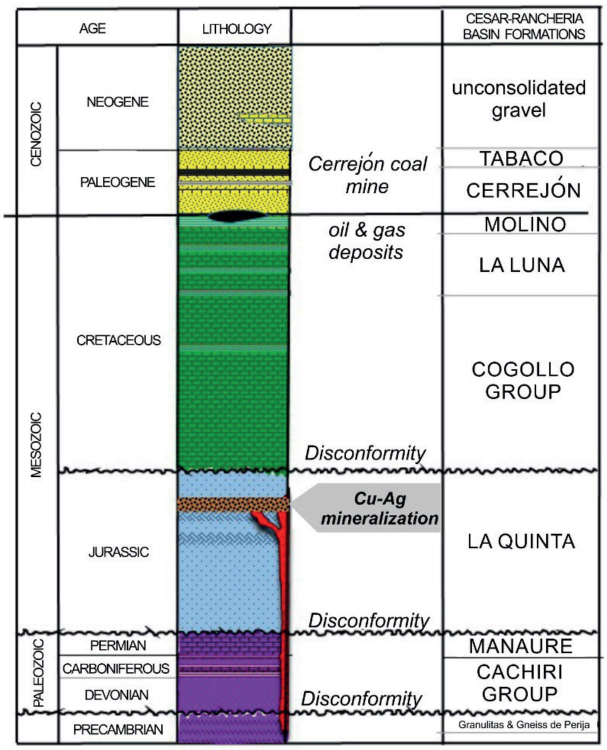


***Fig. 1.*** *Simplified stratigraphic profile of the Cesar-Rancheria Basin (modified after Mora & Garcia 2006)*

Mineralization described in this paper is associated with a red bed environment hosted in volcano-sedimentary sequences. Regional rock sampling of the Cu-Ag mineralization hosted in the La Quinta formation returned up to

344,000 ppm Cu and 305 ppm Ag. Mineralogical studies identified the presence of chalcocite, digenite, covellite, chalcopyrite, native copper, cuprite, malachite, azurite, chrysocolla and native silver (information from Max Resource Corp.).

## MATERIALS AND METHODS

The study was conducted in eastern part of the Cesar-Rancheria Basin, where sediment-hosted copper-silver (Cu-Ag) mineralization crops out. *Astronium graveolens* is a common tree species that grows from Mexico to Brazil. This tree can grow up to 1 m in diameter and reach 20 to 30 m height. It grows at elevations between 150 to 1000 m and in climate zones around 25°C and with 300 to 1200 mm of annual rainfall. *Astronium graveolens* has a solid clear trunk, and its wood is brown to red, has high density, and is resistant to moisture which gives it a high durability reputation. *Astronium graveolens* plants can grow fast (30–45 cm in 6 months) and like soil that has neutral pH, good drainage, and less than 40% clay content (Martin & Flores 2003, Roman et al. 2012).

It was observed that during the dry season, when most plants lose their leaves young *Astronium graveolens* seedlings growing along copper showings retain their green foliage (Figs. 2–4).

This observation allowed the authors to effectively use this plant as an exploration guide in search for copper and also inspired authors to do a case study of copper content in different parts of the *Astronium graveolens* plant. The study objective was to determine which part of the *Astronium graveolens* tree (leaves, trunk/branches or roots) contains the highest amount of copper and silver and to compare biochemical assay results with geochemistry of soil and rock samples collected in the vicinity of this plant.

For this study seven sample sites were selected over a distance of around 15 km (Fig. 5). In all selected locations Gusanero trees grew along sediment-hosted copper showings and copper mineralization could be easily identified via green copper oxide stains visible on studied outcrops.


***Fig. 2.*** *Astronium graveolens copper-liking tree*

***Fig. 3.*** *Astronium graveolens trees during dry season growing along copper showings*

***Fig. 4.*** *Astronium graveolens seedlings (red circles) during dry season and the trend of copper mineralization (yellow dashed lines)*

To be able to compare copper content in different parts of the *Astronium graveolens* plant, three separate sample types (leaves, trunk/branches, and roots) were collected from each sample site. Root samples were not washed but dirt/soil/rocks were cleaned by shaking it off. All collected sample type was placed into a separate sample bag and shipped for assay to ALS Global laboratory (ALS).

At each sampling site, three soil samples were also collected at approximate depth of 10–20 cm and approximately perpendicular to the trend of the mineralized horizon. One soil sample was collected in the proximity of the mineral showing and the location of the *Astronium graveolens* plant sample. Additionally, two soil samples were collected approximately 25 m from the mineral showing (one sample was collected in the foot wall and one in the hanging wall of the mineralized horizon).

Due to poor soil development and basically lack of a mineral (B) horizon, soil samples were collected from the C horizon (Leptosol). Also, because of a lack of fine soil fraction, each soil sample was treated as a rock sample and not sieved but placed into a plastic bag and shipped for assay to ALS.

At each copper showing where *Astronium graveolens* plant samples were collected, a continuous rock chip sample was taken perpendicular to the trend of mineralization. Each rock sample was placed into a plastic sampling bag and shipped for assay to ALS.

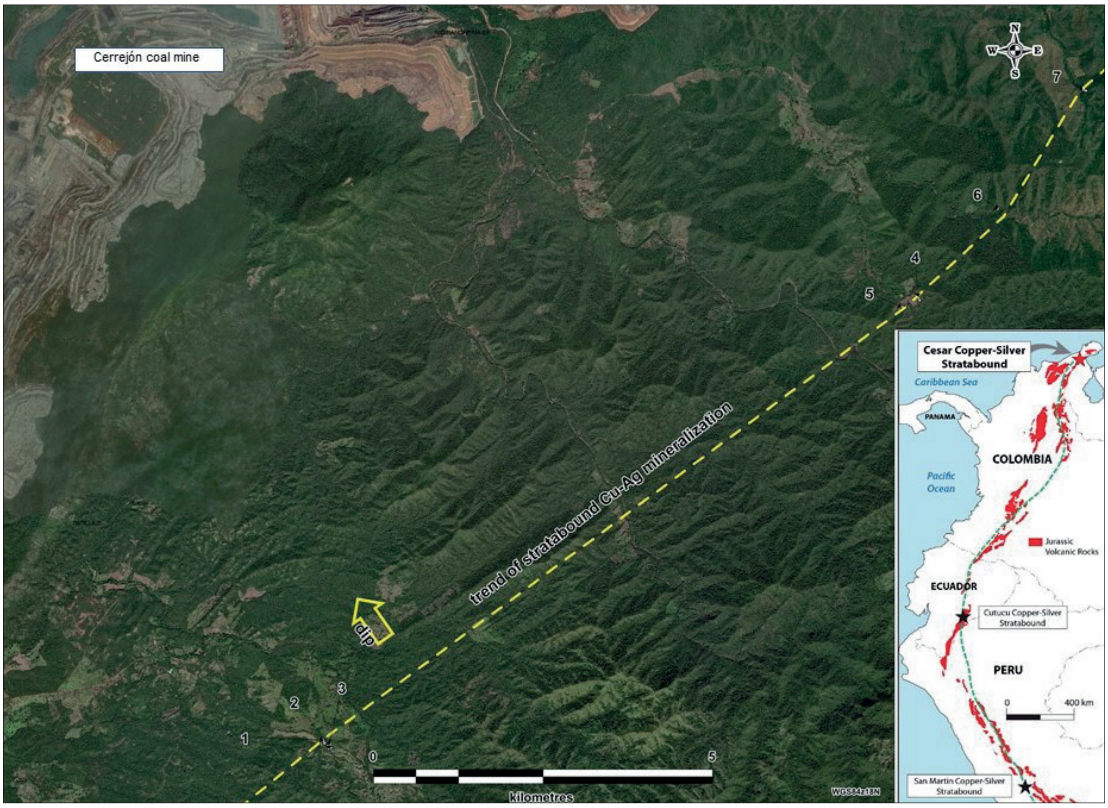


***Fig. 5.*** *Location of Astronium graveolens tree sample sites and assumed trace of sediment-hosted, Cu-Ag mineralization in NE Colombia (modified after Spikings et al. 2015 and Google Earth)*

## ANALYSES

All analyses were conducted at ALS Global laboratory with bio-samples analyzed in Vancouver, Canada and rock and soil samples in ALS laboratory in Lima, Peru.

Biochemical samples of *Astronium graveolens* plant (leaves, trunk/branches and roots) were ashed for 24 hours at 475°C and analyses were done on 0.25 g sample using ALS ME-VEG41a procedure. The ALS ME-VEG41a procedure uses lower detection limit for copper 0.0005 ppm and for silver 0.00005 ppm. Ashing resulted in the concentration of many elements of interest, specifically copper and silver. Each sample was analyzed for 53 elements, but this paper addresses solely copper and silver.

All rock and soil samples were dried and pulverized to pulp. The assay procedure consisted of four-acid digestion with an ICP finish (ALS procedure ME-ICP61). Four-acid digestion is able to dissolve most minerals, and although the term "near-total" is used, not all elements are quantitatively extracted in some sample matrices. A four-acid digestion utilises a combination of nitric, perchloric, and hydrofluoric acid with a final dissolution stage using hydrochloric acid. Each sample was analyzed for 33 elements, but this paper addresses solely copper and silver. Analyses was done on a 0.25 g sample and in the ME-ICP61 procedure the detection limit for copper is 1–10,000 ppm and for silver 0.5–100 ppm.

## RESULTS AND INTERPRETATION

Comparison of the chemical analyses of soil, rock samples and ashed biochemical plant material (branches/trunks, roots and leaves) is presented in Table 1. Reported weighted of analyzed ash (for leaves, bark and roots) was 8 to 19 times less than the original weight of the organic sample before ashing. The concentration of the reported result is based on the ashed sample. Weight of the sample and weight of the ash has not been factored in the reported concentration.

***Table 1***
*Copper and silver assay results of rock, soil and ashed plant samples of the Astronium graveolens tree*

| Zone sampled | Rock sample number | Cu [ppm] | Ag [ppm] | *Astronium graveolens* biochemical sample number | Part of plant sampled | Cu (in ash) [ppm] | Ag (in ash) [ppm] | Soil sample number | Soil sample location | Cu [ppm] | Ag [ppm] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 425977 | 8,700 | 1.80 | 875596 | leaves | 162.0 | 0.109 | 875599 | hanging wall | 61 | <0.5 |
| | | | | 875597 | trunk/ branches | 27.8 | 0.007 | 875600 | same as 875597 | 291 | <0.5 |
| | | | | 875598 | roots | 317.0 | 0.235 | 875901 | foot wall | 66 | <0.5 |
| 2 | 875031 | 529 | 0.25 | 875902 | leaves | 110.0 | 0.048 | 875907 | hanging wall | 28 | <0.5 |
| | | | | 875903 | trunk/ branches | 42.6 | 0.005 | 875906 | same as 875903 | 657 | <0.5 |
| | | | | 875904 | roots | 300.0 | 0.108 | 875905 | foot wall | 66 | <0.5 |
| 3 | 875024 | 8,570 | 3.10 | 875908 | leaves | 198.0 | 0.070 | 875913 | hanging wall | 22 | <0.5 |
| | | | | 875909 | trunk/ branches | 48.6 | 0.008 | 875912 | same as 875909 | 31 | <0.5 |
| | | | | 875910 | roots | 29.0 | 0.015 | 875911 | foot wall | 56 | <0.5 |
| 4 | 875739 | 47,000 | 26.60 | 875920 | leaves | 143.5 | 0.050 | 875923 | hanging wall | 36 | <0.5 |
| | | | | 875921 | trunk/ branches | 22.0 | 0.005 | 875924 | same as 875921 | 552 | <0.5 |
| | | | | 875922 | roots | 70.1 | 0.113 | 875925 | foot wall | 436 | <0.5 |
| 5 | 875728 | 29,200 | 17.60 | 875914 | leaves | 125.5 | 0.056 | 875917 | hanging wall | 110 | <0.5 |
| | | | | 875915 | trunk/ branches | 33.9 | 0.014 | 875918 | same as 875915 | 220 | <0.5 |
| | | | | 875916 | roots | 37.9 | 0.020 | 875919 | foot wall | 59 | <0.5 |
| 6 | 425916 | 344,000 | 305.00 | 875926 | leaves | 167.5 | 0.032 | 875929 | same as 875927 | 65 | <0.5 |
| | | | | 875927 | trunk/ branches | 33.5 | 0.009 | | | | |
| | | | | 875928 | roots | 36.8 | 0.023 | | | | |
| 7 | 875514 | 5,480 | 7.90 | 875931 | leaves | 116.5 | 0.047 | 875935 | hanging wall | 51 | <0.5 |
| | | | | 875930 | trunk/ branches | 48.4 | 0.005 | 875934 | same as 875930 | 61 | <0.5 |
| | | | | 875932 | roots | 119.0 | 0.050 | 875933 | foot wall | 61 | <0.5 |

Biochemical assay results obtained from the ashed branch/trunk material contained the lowest amount of copper. Much higher copper and silver assay results were obtained from ashed leaves and roots, and both leaves and roots exhibited comparable assay results. The maximum concentration of copper was obtained from roots with values up to 317 ppm. Leaves accumulated up to 198 ppm Cu while trunk and branches just 49 ppm Cu. Silver values obtained from roots reached 24 ppm and from leaves 11 ppm. In the case of the trunk, the silver range varied from 0.01 to 0.04 ppm. Obtained silver values are considered by the authors at the background level (Dunn 2007). There was no correlation observed between the highest copper assay value obtained from the copper rich outcrop and assays from the biochemical sampling.

Based on the limited amount of soil samples collected, soil samples collected at the base of the plant and in vicinity of the mineral showing had the highest copper content, up to 667 ppm Cu. Also, in a few cases, down slope dispersion produced an elevated copper content of up to 436 ppm. All soil silver assay results, regardless of location, were at the lower detection limit.

## CONCLUSION

During the dry season, when most plants lose their leaves young *Astronium graveolens* trees growing along sediment-hosted copper-silver mineralization retain their green foliage. This observation allowed authors to effectively use this plant as an exploration guide in search for copper mineralization and *Astronium graveolens* can be potentially considered as a geobotanical indicator plant.

Out of three separate types of biochemical samples collected (leaves, trunk/branches, and roots), ashed leaves and roots contain the most abundant amount of copper ranging from 22 to 317 ppm and silver from 0.01 to 0.24 ppm however obtained silver values are considered by the authors at the background level (Dunn 2007). If future bio-sampling is carried out, it is recommended to collect just *Astronium graveolens* tree leaves as they are easier to collect.

Observed resistance of *Astronium graveolens* to the presence of copper sulfides suggests that this tree could potentially be an excellent species for reforestation and reclamation of tailings and other mining waste.

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