Aluminum in Iberoamerica: Mineral deposits and mining production in Colombia

Report prepared by Servicio Geológico Colombiano for the Metallogenetic Expert Group of ASGMI (Association of Ibero-American Geology and Mining Services)

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1. Introduction

The Republic of Colombia is located in the extreme NW of South America and has a continental surface of 1,141,748 km², with Venezuela and Brazil bordering to the east, Peru and Ecuador bordering to the South and Panama bordering to the NW (Figure 1); its maritime borders are with Panama, Costa Rica, Nicaragua, Honduras, Jamaica, Haiti, the Dominican Republic and Venezuela in the Caribbean Sea and Panama, Costa Rica and Ecuador in the Pacific Ocean. Colombia is the only country in South America with coasts in the Pacific and Atlantic oceans. The Andes mountain range traverses from S to N and, upon entering Colombia, is divided into the Eastern, Central and Western mountain ranges. The savannas of the Orinoquía are located east of the Colombian Andes (to the north on the border with Venezuela), and the jungles of the Amazon are located in the south, bordering with Brazil.

Figure 1. Location of the Republic of Colombia.
Source: Modified from ArcGis-Esri 2020

Colombia is not an aluminum producing country. The country's mining production is mainly related to gold, platinum, emeralds, nickel and coal. There are records of artisanal bauxite exploitation in the upper Cauca River valley to the south, departments of Cauca and Valle del Cauca associated with Neogene pyroclastic rocks and residual soils of Cretaceous basalts. Additionally, there are manifestations of bauxites in the Llanos de Cuivá (department of Antioquia) associated with residual soils derived from Cretaceous diorites and in the Serranía de La Macarena (department of Meta) on sedimentary levels of the Neogene De Losada Formation.

The aluminum required by the Colombian industry (cement, plastics, chemicals and machinery manufacturing) is imported from Brazil (55%), Venezuela (37%), Russia and India in the form of aluminum sheets and obtained from recycled aluminum from separated and classified waste (UPME, 2018).

Isolated and local studies of ocurrences of bauxite in Colombia have been known since 1959, referring to artisanal operations. In 1984, as a result of a special cooperation agreement between the Servicio Geológico Colombiano (formerly INGEOMINAS) and the USGS, a map of mineral resources in Colombia was published (Hodges *et al*., 1984) in which the domains with the greatest possibility of hosting bauxite are the Western Cordillera (domain 3), the Central Cordillera (domains 4 and 7) and the extreme NE of Colombia on the border with Venezuela and Brazil (domain 33). The abovementioned study did not consider anorthosites an aluminum source.

However, anorthosites are restricted to small sectors north of the Sierra Nevada de Santa Marta and east of the Central Cordillera (Moreno-Sánchez, *et al.,* 2020) (Figure 2).

However, anorthosites are restricted to small sectors on the northern side of the Sierra Nevada de Santa Marta, and to the east of the Central Cordillera (Moreno-Sánchez, *et al*., 2020) (Figure 2).

Bauxite occurrences in Colombia were formed in areas with moderate to soft topographies parallel to the current erosive surface, suggesting topographic stability in their generation, which is a condition that places these deposits in an early stage of bauxitization and assigns them a recent age (Rosas, 1979).

2. Geological setting

Considering its relief, Colombia can be divided into the following two domains: i) the Amazon Craton domain, which comprises the Eastern Plains and the jungles of the Amazonia, and ii) the Andean domain, which comprises the Eastern, Central and Western mountain ranges, the Serranía del Baudo, the intramontane valleys of Magdalena, Cauca-Patía and Atrato-San Juan.

In the Eastern Plains, alluvial, lacustrine and eolian deposits are found. The alluvial deposits consist of quartz sands. Most deposits must have undergone at least two erosion-sedimentation cycles, while the lacustrine deposits consist of clays. The eolian deposits correspond to dunes in which the quartz sands are remobilized. These Quaternary deposits have not been subjected to the deformation that affects the Andean domain; thus, in general, these deposits are horizontal and constitute a flat relief where sedimentation dominates over erosion. Below these deposits, the subsoil has a remarkable hydrocarbon potential.

The geological characteristics of the Amazon region are more complex as follows: under the extensive coverage of neogene and quaternary deposits of lacustrine and fluvial-lacustrine origin, which are the continuation of the deposits in the Eastern Plains, a basement formed by igneous-metamorphic Precambrian rocks emerges superimposed in some sectors by a sequence of clastic sedimentary rocks, probably Paleozoic (Nivia, *et al.*, 2012).

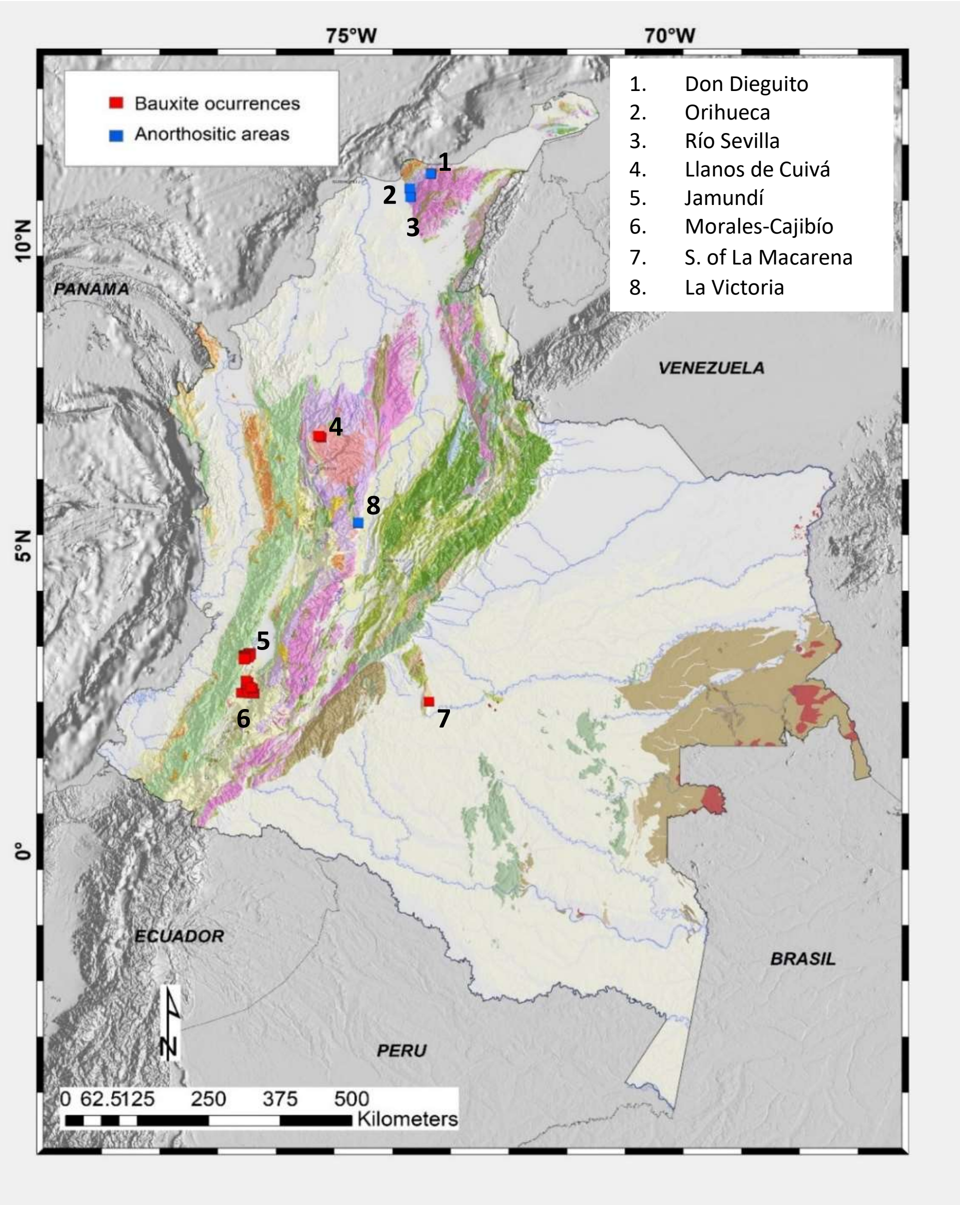

Figure 2. Location of bauxite and outcrops of anorthosites
Source: author

The relief that characterizes the Andean domain -Andean region-, is the result of the deformation of the Earth's crust on a continental margin, where the oceanic plate that constitutes the Pacific Ocean floor is subducted. The available evidence regarding the rocks in the mountain ranges indicates that subduction occurred over the last 200 Ma and influenced the evolution of the crust by continuous and progressive deformation associated with plate tectonics and magma emplacement; however, the occurrence of these processes is preceded by a history of 1400 Ma that has been recorded in the metamorphic rocks in the core of the Central and Eastern mountain ranges. A major event in the history of subduction was the arrival of a fragment of oceanic *plateau* at approximately 60 Ma that were accreted to the continental margin.

In Colombia, the Earth's crust is of the following two types (each with different processes of mineral deposit formation): continental crust rocks, which constitute the core of the Central and Eastern mountain ranges, and rocks formed as oceanic crust between 90 and 70 Ma, which were accreted on the edge of the continent and currently emerge in the Western Cordillera, the Serranía del Baudo and the Pacific Islands (Gorgona). Such an accretionary event forced a reorganization of the plates that led to oceanic crust subduction below the accreted oceanic fragments. This new subduction, which has been maintained to date, has facilitated the occasional melting of the mantle and the formation of igneous rocks, both volcanic and plutonic (Nivia *et al*., 2012).

Before the accretion of oceanic crust to the continental margin, there was a large sedimentary basin on the continental shelf, where most rocks currently present in the Eastern Cordillera were formed. In the Western Cordillera and the Serranía del Baudó range, we find sediments that accumulated on the surface of the oceanic crust in deep oceanic environments before arriving at the continental margin. In both cases, the result is sedimentary rocks, but the conditions of sediment accumulation, such as depth, temperature, pressure, salinity, hydrogen potential, illumination, and biota in both environments, controlled the types of rock and mineral resources to which they may give rise (limestone, barite, gypsum, hydrocarbons coal vs. polymetallic deposits of Mn, Cu, Pb, Zn, etc.). The accretion of the oceanic crust to the continental margin deformed and raised the existing basins but gave rise to others on the portion composed of continental crust (essentially associated with the current Magdalena and Cesar-Ranchería valleys) at the site where the crust types join (depression of the Cauca and Patía rivers) and on the blocks of the oceanic crust (Atrato-San Juan basin-Pacific coastal plain) (Nivia, *et al*., 2012).

3. SGC database

The Directorate of Mineral Resources of the Servicio Geológico Colombiano (Colombian Geological Survey) maintains the *Explora* database, which manages the geophysical, geochemical and metallogenic information generated, that can be consulted in the following link:
https://www2.sgc.gov.co/sgc/mapas/Paginas/geoportal.aspx.

In *Explora*, the metallogenic information, which mainly contains mineral deposits, is divided into general information, deposit information (mineralization, alteration, host rock, age, classification, etc.), information regarding economic aspects and bibliographic references. *Explora* has been a fundamental source of inputs in the preparation and development of the 2016, 2018 and 2020 versions of the *Metallogenic Map of Colombia* (Figure 3). *Explora* is integrated with the Geoscientific Information Integration Engine (MIIG), which can be consulted by internal users of the SGC and external users.

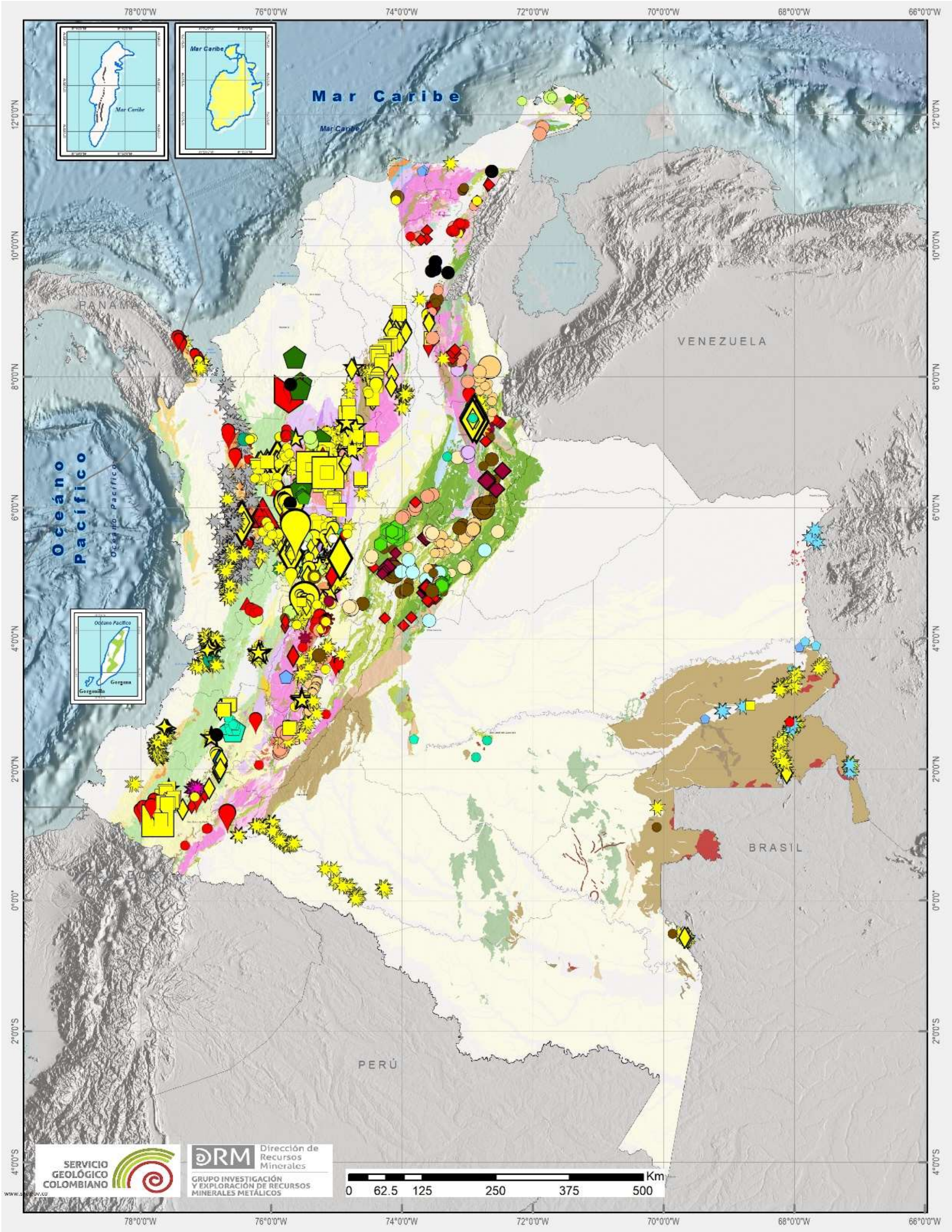

Figure 3. Metallogenic map of Colombia, 2020
Source: author

4. Mineral deposits of aluminum

Hyperaluminous clays Serranía de La Macarena. Clastic rocks of the Lower to Middle Eocene

At the top of the De Losada Formation, located at the southern end of the Serranía de La Macarena (Figure 4), there is a cyclic succession of layers of medium-grain conglomeratic quartz arenites cemented by silica and medium-grain quartz sandstones. Locally, a 10m thick level of mudstones and claystones composed by pisolitic bauxites are located, the area surveyed from this level of bauxites is 3 km ∗ 2 km and has an Al_2O_3 content > 70%, possibilities of open-pit mining, and characteristics that give this sector a high potential (Paba and Van der Hammen, 1959). These authors considered that the pisolitic bauxite in La Macarena was formed from the sedimentation of material resulting from the erosion of weathered biotitic syenites in environments with temperatures above 20 °C and alternating periods of rain and drought that favored leaching, the removal of silica and the accumulation of iron and aluminum oxides. In general, the sequence of the De Losada Formation suggests sedimentation conditions related to confined currents and braided rivers (SGC-UT G&H, 2015).

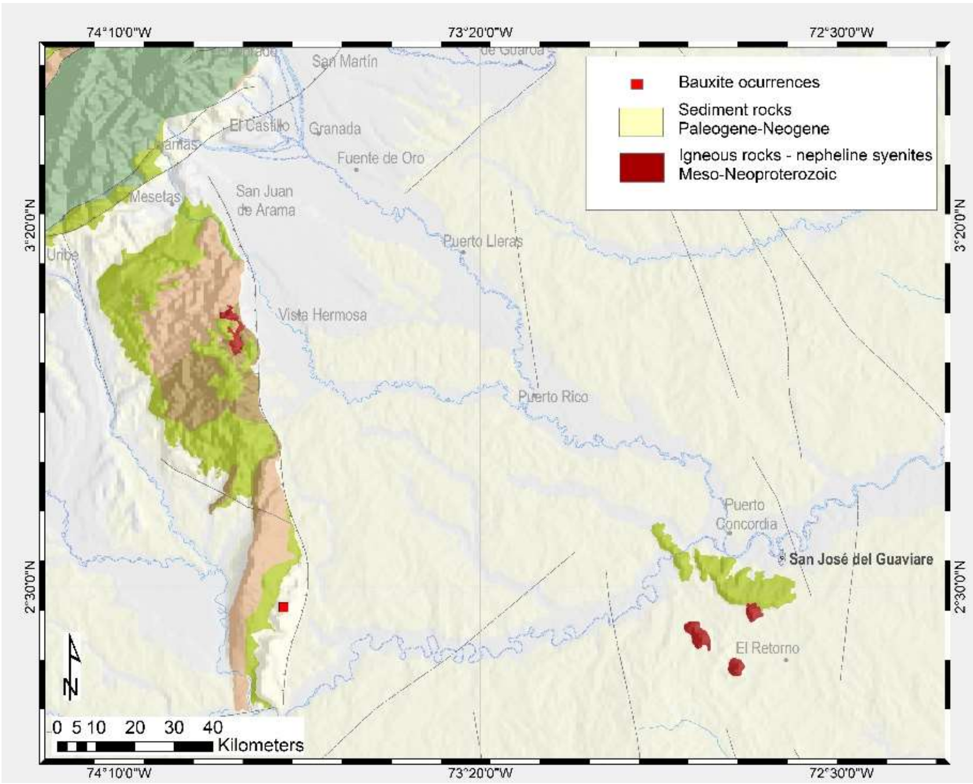

Figure 4 Ocurrence of pisolitic bauxites in the Serranía de La Macarena
Source: author

Northern sector of the Central Cordillera. Residual soils from diorites of the Batolito Antioqueño

Between the municipalities of Yarumal and Santa Rosa (Figure 5), the weathering of diorites associated with the Batolito Antioqueño of late Cretaceous age caused the formation of lateritic clays with gibbsite nodules composed of 52% Al_2O_3, 17% SiO_2 and 2-9% Fe_2O_3 (Table 1). The origin of these lateritic soils is associated with the development of peneplains resulting from the tectonic uplift experienced by the entire sector (Wokittel, 1955; González, 2001). This material is extracted by artisanal mining. The sector is known as Llanos de Cuivá, where at least two occurrences have been recorded in the basin of Madrid Creek, where the bauxitic clays are arranged irregularly and discontinuously and reach 2 m depth in cracked areas (Wokittel, 1955).

Table 1 Chemical analysis of bauxite clays in the Llanos de Cuivá

Sample No.	Al_2O_3 %	SiO_2 %	Fe_2O_3 %
Wo 511	43.67	16.78	15.33
Wo 512	52.38	15.16	8.62
Wo 513	42.18	10.28	26.82
Wo 514	57.84	17.06	7.66
Wo 517	49.05	20.25	5.85
Wo 518	56.77	14.13	6.60
Wo 520	56.67	14.42	3.16
Wo 522	55.29	19.25	4.30
Wo 524	53.09	24.46	5.33

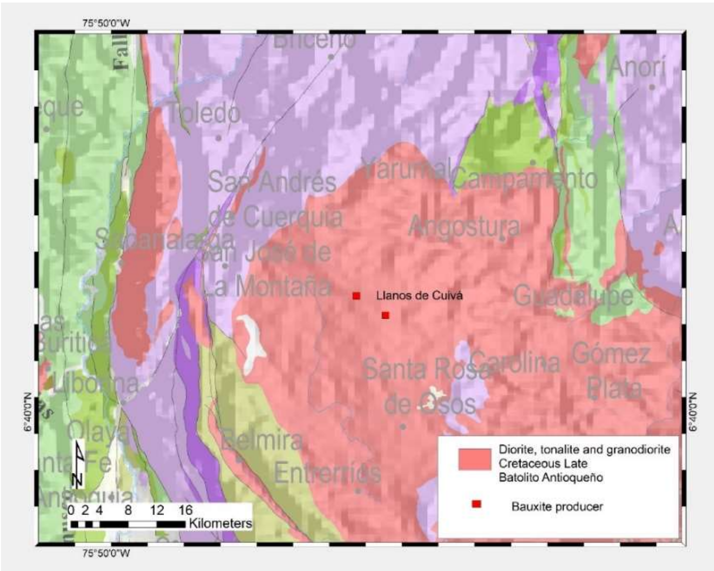

Figure 5 Bauxite occurrences/producers in the Llanos de Cuivá (Antioquia)
Source: author

Another deposit of bauxite called *Santa Isabel* is reported to the N of the Llanos de Cuivá, where it occurs as nodules in clays within sandy levels. The nodules are scattered and reach 2% of the total mass. From some boreholes drilled at a depth not exceeding 5 m, the conformation of this bauxitic body was determined as given by a higher level of yellow limonitic clays between 50 and 80 cm thick with few and scattered nodules of bauxite. Downwards, a level of “lateritic” red clay, which is somewhat sandy, was found, with a bauxite nodule content between 5% and 10%. The deepest and most discontinuous level was described as a sandy layer with a bauxite nodule content of up to 5%.

SE Sector of the Western Cordillera. Residual soils from basalts of the Volcanic Formation

The artisanal mining of bauxite in the municipalities of Jamundí and La Cumbre (Figure 6) is associated with the basalt weathering of the Upper Cretaceous Volcanic Formation. The bauxitic levels are irregular and discontinuous and can be found in both fine and coarse saprolites, where mineralized levels are found in dome-like structures. The content of Al_2O_3 ranges from 52% to 58%, and the content of Fe_2O_3 ranges between 4% and 12% (Bejarano, 1982). Prospecting studies, semidetailed explorations, economic geology and evaluations of deposits and metallurgy (Gemco Ltda., 1976) conducted by local authorities have recorded bauxite lenses and patches conformable with the ground, reaching an average thickness of 1.68 m in areas between 1 and 7.5 km^2, in the area corresponding to the municipalities of Jamundí and La Cumbre. The chemical analyses performed on more than two thousand samples are listed in Table 2. Locally, bauxite recovery tests were performed from 126000 t of mineral contained in an area of 7 ha, yielding 20% of Al_2O_3 revovery (Integral SA, 1985).

Table 2 Chemical analysis of bauxite clays in the municipalities of Jamundí and La Cumbre

Component	La Cumbre (%)	Jamundí (%)
Al_2O_3	41.74	43.08
SiO_2	18.80	14.78
Fe_2O_3	11.20	12.42
Other oxides	4.13	2.74
Humidity	32.79	29.87
LOI	23.62	26.75

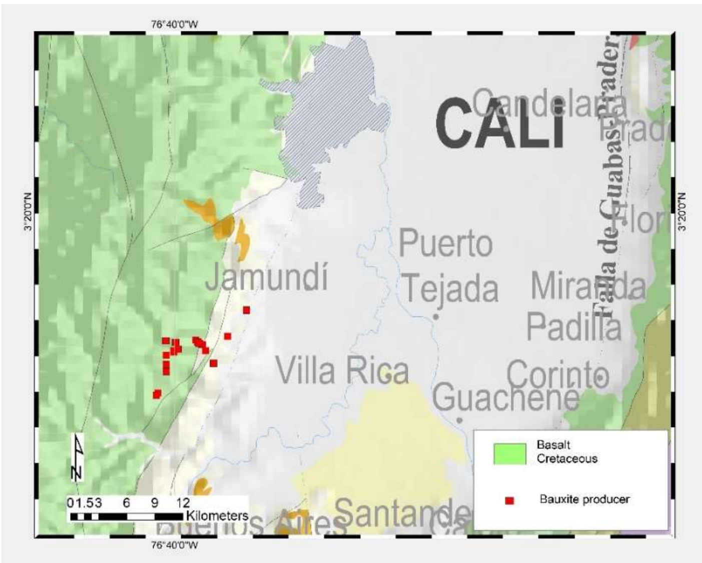

Figure 6 Bauxite occurrences/producers in Jamundí and La Cumbre (Valle del Cauca)
Source: author

In this sector, in 1987, a monthly production of 3000 t of washed bauxite was estimated and mainly destined for the production of alumina sulfate.

SW sector of the Central Cordillera. Pyroclastic deposits, Popayán Formation

Between the municipalities of Morales and Cajibío, in the department of Cauca (Figure 7), occurrences of bauxitic clays formed from the chemical weathering of volcano-sedimentary deposits of the Popayán Formation (Plio-Pleistocene age) were identified, consisting of almost horizontal intercalations of conglomerates and agglomerates with tuffs, ashes, ignimbrites and lava flows.

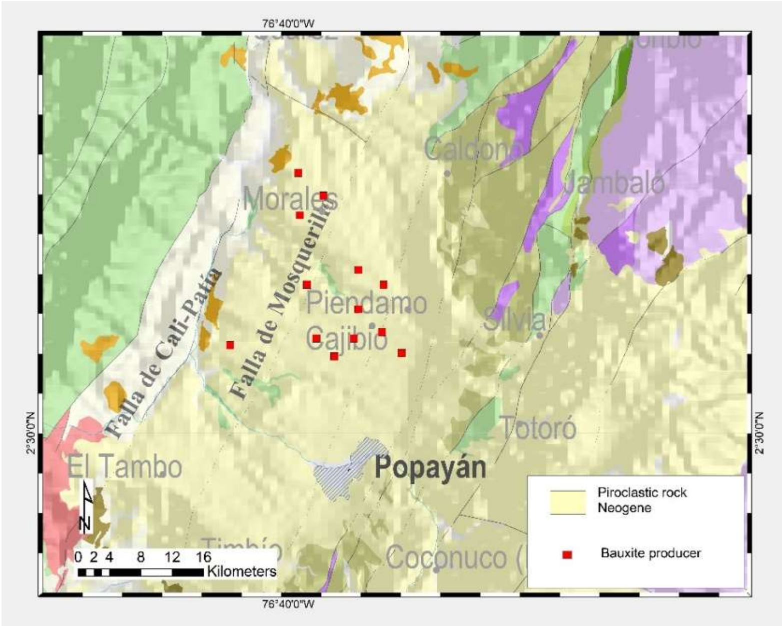

Figure 7 Bauxite occurrences/producers in Cajibío-Morales (Cauca)
Source: author

The bauxite clay layer thickness ranges from a few centimeters to 3 meters, and its location in the soil weathering profile corresponds pedologically to the B horizon (Rosas, 1979). The deposits of bauxitic clays are characterized by their brown color and moderate plasticity, with abundant gibbsite aggregates (irregular, rounded, tabular and cylindrical forms). After washed and sieving contents of 59% Al_2O_3, 3% SiO_2 and 4.5% Fe_2O_3 were reported.

The results of chemical and spectrographic analyses performed on well and channel samples obtained in the framework of the study conducted by the SGC (Rosas, 1976) in the area of Morales and Cajibío allow us to contrast the variation in the percentages of Al_2O_3, SiO_2 and Fe_2O_3 in bauxitic clay and gibbsite aggregates (Table 3).

Rosas (1987), based on detailed studies of bauxite reserves in the SE sectors of the Western Cordillera and SW of the Central Cordillera, its potential is estimated at "400 Mt of low-grade bauxite, from which 100 Mt of high-grade washed bauxite can be obtained"

Table 3 Chemical analysis of bauxite clays in the Morales-Cajibío area

Component	Bauxite clay (%)	Gibbsite aggregates (%)
Al_2O_3	35.70 - 43.87	59.02
SiO_2	20.07 - 32.34	3.02
Fe_2O_3	10.16 - 13.03	4.43
TiO_2	0.74 - 1.11	1.19
CaO	0.03 - 0.08	0.05
MgO	0.24 - 0.71	0.12
MnO	0.04 - 0.10	0.02
LOI	16.67 - 23.41	32.15

5. Mining production

In Colombia, bauxite is extracted by small-scale artisanal mining. In the area of Morales-Cajibío, Department of Cauca, the SGC and mining companies, such as Gemco Ltda. conducted a detailed exploration *(e.g.,* Kaiser Aluminum, Pechiney-Ugine-Kulman did so for La Cumbre-Bitaco-San Antonio, Department of Valle del Cauca). From the surveys in the Morales-Cajibío sector, 80 Mt of bauxitic clays on a dried basis were estimated, of which 20 Mt of gibbsite nodules can be obtained (Ingeominas, 1979). In the Jamundí-La Cumbre sector, the estimate is 18 Mt of bauxitic clays (Gemco Ltda., 1976).

In the Jamundí-La Cumbre sector, there has been a small-scale exploitation of bauxites tested to be used as refractory material from the mixture with white clays in a 1:3 ratio. It is extracted by pick and shovel, and the material is left outdoors for two or three days to promote the formation of nodules. Then, this material is washed and sieved to separate the nodules, which are placed in a container with blades, where it is separated from fine, sterile particles by friction. The recovery of gibbsite nodules by this method is 20% (Integral SA, 1985).

6. Concluding remarks

Colombia is not an aluminum producer. Bauxites in Colombia have been exploited by small artisanal miners and in small areas to obtain aluminum sulfate and refractory materials.

The occurrences and artisanal producers of bauxitic clays are recorded in the departments of Antioquia (Llanos de Cuivá), Valle del Cauca (Jamundí), Cauca (Cajibío and Morales) and Meta (Serranía de La Macarena). In general, the Al_2O_3 contents range between 35% and 58%.

Bauxitic clays in the SE sector of the Western Cordillera from residual basalt soils of the Volcanic Formation (department of Valle del Cauca) and in the municipalities of Jamundí and La Cumbre are extracted using open pit artisanal mining, taking advantage of the thin layer of soil that covers the bauxitic horizons.

The anorthosites in Colombia have not been considered a source of aluminum.

The *Explora* database manages the geophysical, geochemical and metallogenic information generated and is integrated with the Geoscientific Information Integration Engine (MIIG), which can be consulted internally by SGC users and external users.

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