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Figure 1. Colombia.

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ized Chibcha population which was subjugated by the Spaniards. [7]. A good climate, rich soils and water in abundance were other assets which ended up transforming this city in the capital of the newly founded kingdom of Nueva Granada. In the southwest, Cali (1536) and Popayan (1537) were important during colonial times, but only Cali became a major city during 20th century, due to its vicinity to the harbor of Buenaventura and the richness of surrounding cultivable land. Despite of the wealth of the gold mines exploited by slave labour owned by Popayan aristocracy, this city declined during 20th

century. The province of Antioquia became independent from Popayan in 1575. Two main towns existed there: Santa Fe de Antioquia (1541) and Rionegro (1541), which became a “city” in 1786. The region relative prosperity came from gold mine exploitation [8], distributed in many districts (Figure 2).

3. Medellin Natural Setting

Medellin is located in a broad valley situated in the northern part of the Central Cordillera. The bottom of the

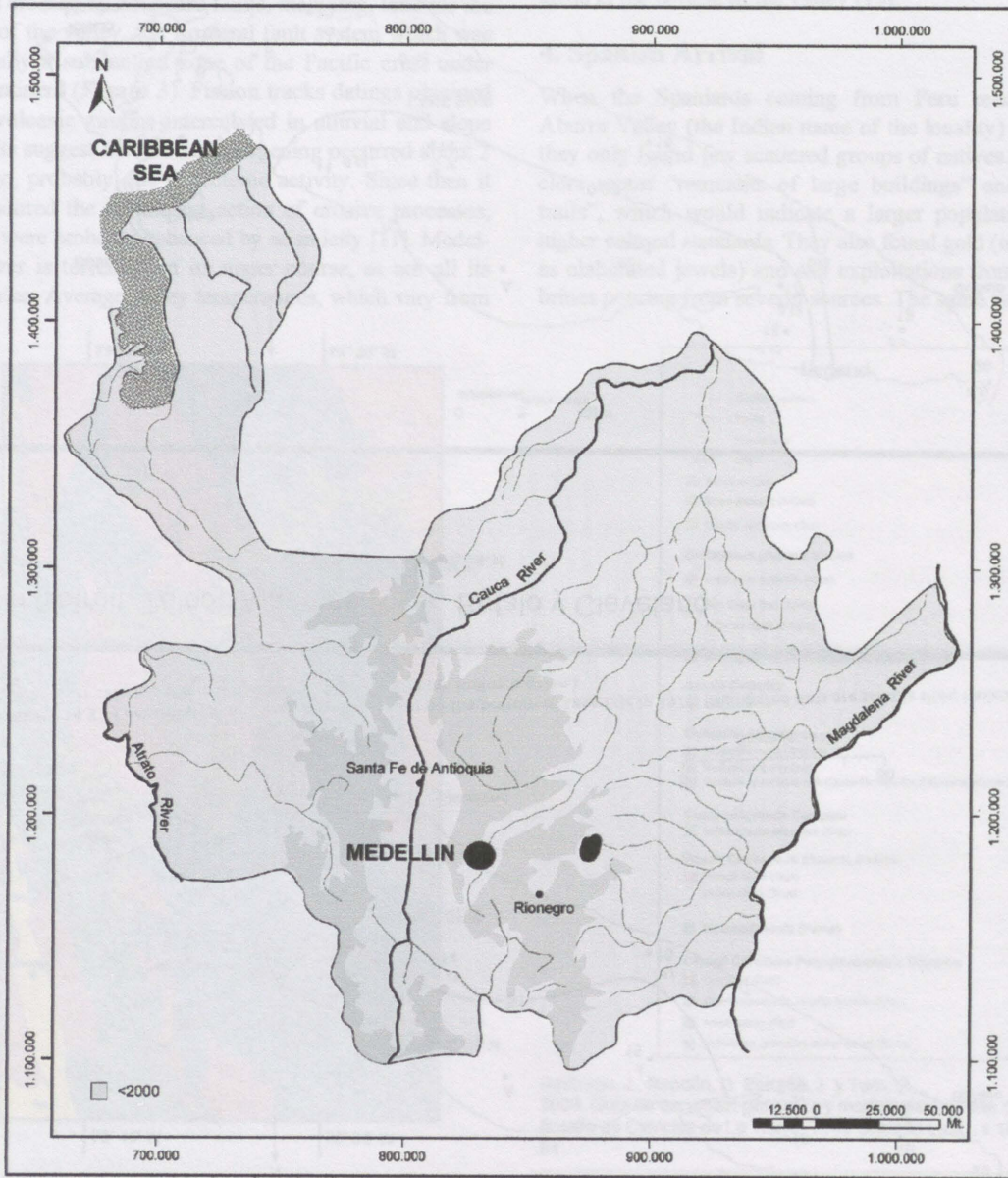


Figure 2. Department of Antioquia, Colombia.

valley is at about 1500 masl and it is surrounded by little dissected plateaus at 2000 and 2600 masl approximately. The valley maximum width is about 8 km and it consists of two stretches of 30 km in north and northeast direction, respectively. The valley bottom is filled by alluvial deposits of irregular thickness and most of its slopes are covered by complex deposits derived from the upper rises [9]. The geology of the valley is complex: Precambrian, Paleozoic and possibly Mesozoic metamorphic rocks, marine diabases, serpentinized dunites and Cretaceous and Tertiary igneous rocks (Figure 3) [10]. The area is crossed by abundant faults, including, towards the south of the valley, the Romeral fault system which was originally a subduction zone of the Pacific crust under the continent (Figure 3). Fission tracks datings obtained from volcanic zircons intercalated in alluvial and slope deposits suggest that the valley opening occurred about 2 Ma ago, probably due to tectonic activity. Since then it has endured the permanent action of erosive processes, which were probably enhanced by seismicity [11]. Medellin River is torrential in its upper course, as are all its tributaries. Average valley temperatures, which vary from

15°C to 22°C according to altitude and rainfall of 1500 to 3000 mm per year have fostered deep rock weathering, mass movements and flashfloods. The nature of soils varies with rock type and rainfall. The southern part of the valley is covered by a one meter thick volcanic ash layer, which also appears in the upper parts of the slopes and in the surrounding plateaus. These ashes were produced by several eruptions of the Ruiz Tolima massif, located 150 km south [12]. The original vegetation of the valley consisted of Andean forest, which covered the entire area excepting the steepest slopes and the marshy areas in the bottom of the valley [13].

4. Spanish Arrival

When the Spaniards coming from Peru reached the Aburra Valley (the Indian name of the locality) in 1541, they only found few scattered groups of natives. Chroniclers report "remnants of large buildings" and "stone trails", which would indicate a larger population with higher cultural standards. They also found gold (in graves, as elaborated jewels) and salt exploitations from natural brines pouring from several sources. The same year, after

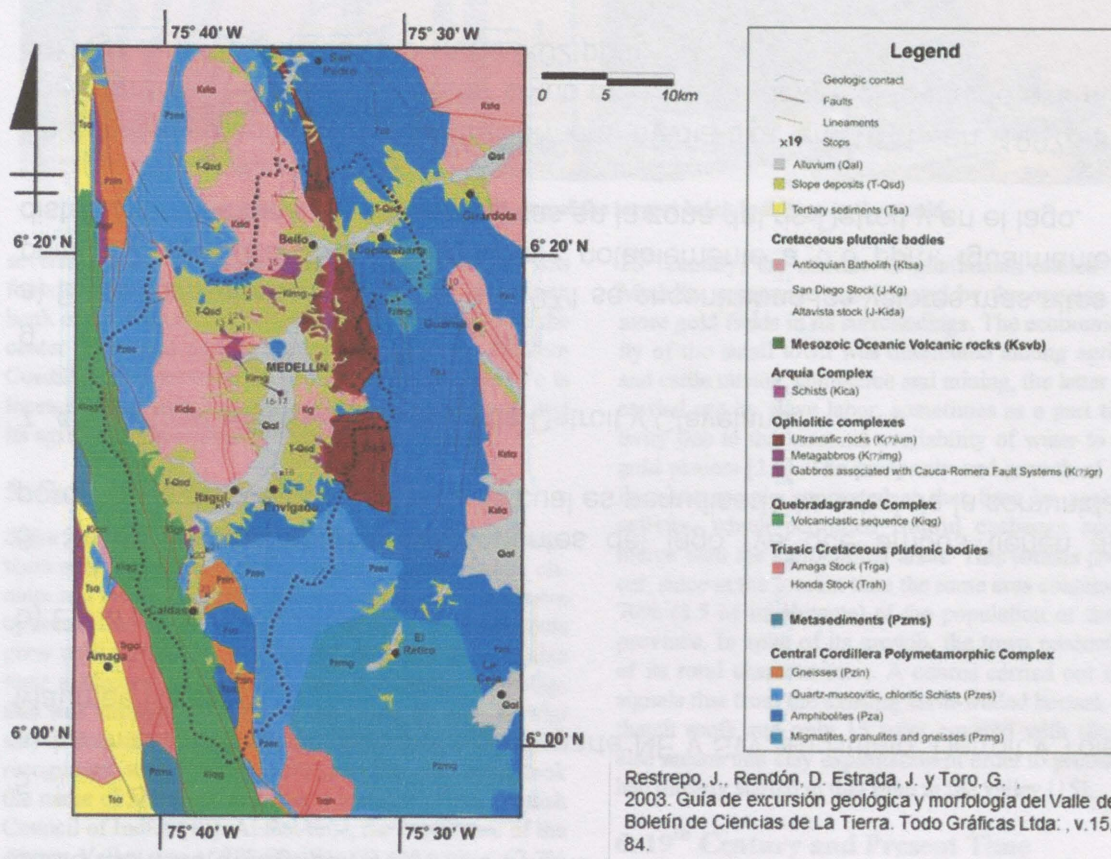


Figure 3. Geological map of the Medellin region.

Restrepo, J., Rendón, D., Estrada, J. y Toro, G. , 2003. Guía de excursión geológica y morfología del Valle de Aburra. Boletín de Ciencias de La Tierra. Todo Gráficas Ltda. , v.15, p. 73 - 84.

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Figure 4. Medellin cathedral, one of the largest brick buildings in the world.

several intents, the town of Santa Fe Antioquia was founded at the foot of Western Cordillera, on the western bank of the Cauca river. Its main objective was to be the center of several mining camps located in the Western Cordillera and downstream the Cauca River. Santa Fe is located in a dry canyon with scarce cultivable areas and its agricultural prospects are thus quite limited.

5. Colonial Times

Since the beginning of 17th century, Spaniards and mestizos established farms in the Aburra Valley: middle climate and fertile soils provided there good crops and were optimum for cattle raising. The number of inhabitants grew until they asked the Council of Indies to recognize their settlement as a "Villa", an autonomous township; this was strongly opposed by the Santa Fe people, who saw there a challenge to their city hegemony. Finally, the recognition was given in 1675, and the new town took the name of Medellin, to honor a member of the Spanish Council of Indies [14]. At that time, the population of the Aburra Valley was of 288 families (21.5% whites, 67.7% mestizos and mulattoes, 10.8% Indians). At the end of

18th century, the number of inhabitants totaled 14,500. Medellin commerce was boosted by the opening of two more gold fields in its surroundings. The economic activity of the small town was distributed among agriculture and cattle raising, commerce and mining, the latter mainly carried out by slave labor, sometimes as a part time activity due to the seasonal availability of water to exploit gold placers [2,8]. The prosperity and growth of Medellin were mainly supported at that time by agricultural activity, which permitted fruitful exchange and commerce with the surrounding areas. This sounds paradoxical, since at the present time the same area contains about 70% (3.5 M inhabitants) of the population of the entire province. In spite of its growth, the town retained much of its rural characteristics. A census carried out in 1786 signals that from the existing earth-walled houses, 87 had thatch roofs and only 15 were covered with tiles. This also means that clay exploitation in order to produce tiles had already started at that time in the valley [15].

6. 19th Century and Present Time

The village kept growing in size and wealth in spite of

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economic havoc caused by the independence wars and later by several civil wars. The urban expansion included houses, churches and other public constructions, and forced the adoption of building materials of better quality like bricks (Figure 4), which were obtained from surrounding clay deposits and also other weathered rocks, like dunite derived laterite. The Medellin River was deflected in the southern part of the valley in order to exploit alluvial gold [1]. Urban growth pushed crops and pasture toward the upper slopes of the valley. Another unexpected consequence was the impossibility, in the middle of 20th century, to exploit an iron ore lateritic deposit in the eastern slope of the valley. When investors succeeded in raising the funds necessary for the project, terrain prices due to urbanization had rendered it unfeasible. Many new buildings were erected and industry, particularly textile manufactures, was implanted. Simultaneously, the production of hydroelectrical energy started in several tributaries of the Medellin river through the building of dams in the upper part of their basins and of plants in the valley. Urbanization and road construction forced the canalization of the river, which used to meander in the middle of swampy lowlands. Another

consequence was the covering of tributaries, thus transformed into streets.

Railways and roads were constructed, the city expanded and it consists at present of an almost complete conurbation which covers most of the valley (Figure 5); however, Medellin remains a relatively isolated locality in Colombia, excepting through the use of air transportation. The building of tunnels will somewhat improve this situation, but communication by road with sea harbors and other main cities remains an important problem.

7. Natural Resources

7.1. Construction Materials

The city consisted initially in thatched houses with earth walls, which meant that the materials were extracted in the same place where the house was built. A little more advanced stage was the use of adobe, which required extraction, drying and transportation. A further step was the adoption of bricks and tiles. These materials are still widely used in the Aburra Valley, with different degrees of modernization of the factories. Clays are exploited in the western slope of the valley; their sources are the wea-

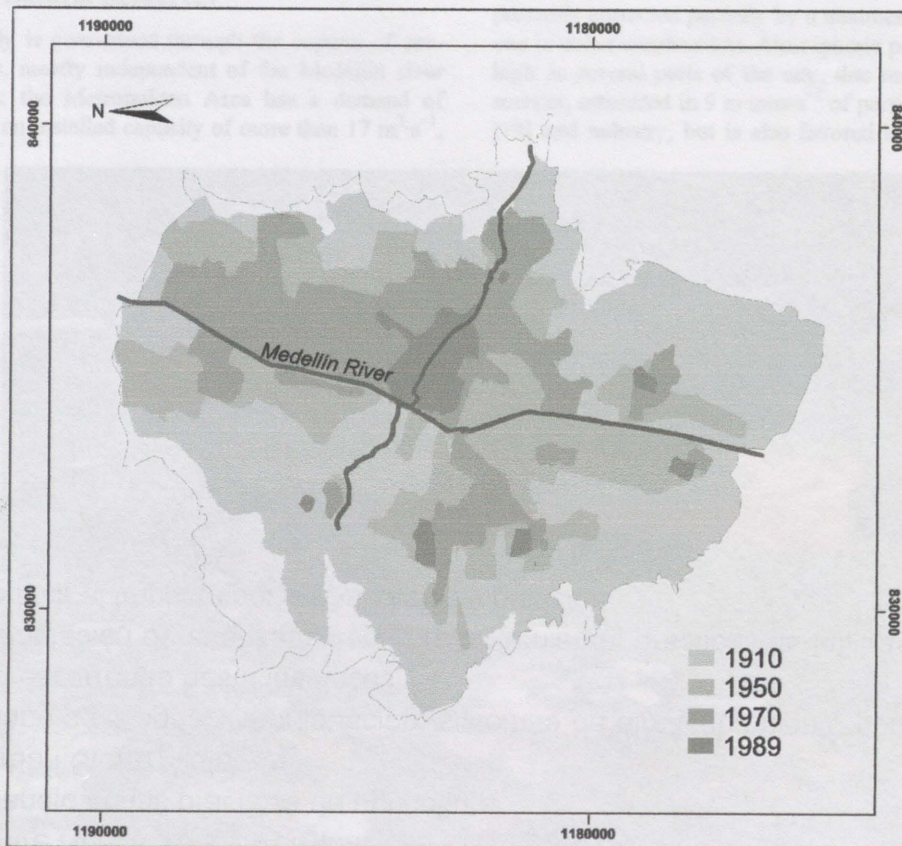


Figure 5. Medellin urban expansion.

thered materials of a dioritic pluton [16].

Another important building material consists of "arenilla", a grey sand and clay material also produced by rock weathering, which is used with cement to prepare blocks. Aggregates are mined extensively in alluvial plains and also quarried from fractured rocks; the extraction of the alluvial deposits is carried out by direct excavation and simultaneous pumping of infiltrated waters down to depths reaching 50 m. When exploitation ceases, water table rises and the hole becomes a deep lake filled with contaminated water. This problem has received no solution until now and jeopardizes the availability of valuable level terrains, already quite scarce in the valley (Figure 6).

In some places of the valley, material extraction has completely leveled hills and changed the landscape. Estimated approximate reserves of building materials in the Aburra Valley were given by Ramirez & Caballero [17] at follows:

Sand: $19 \times 10^6 \text{ m}^3$

Aggregates: $48 \times 10^6 \text{ m}^3$

Clays: $3 \times 10^6 \text{ m}^3$

7.2. Other Natural Resources

Water supply is guaranteed through the capture of several streams, mostly independent of the Medellin river upper basin: the Metropolitan Area has a demand of $9 \text{ m}^3 \cdot \text{s}^{-1}$ and an installed capacity of more than $17 \text{ m}^3 \cdot \text{s}^{-1}$,

of which less than 10% comes from Medellin River upper tributaries. Scarcity of land suitable for urbanization and even for road construction is now felt acutely in the Aburra valley. Steep slopes and unstable soils were not an obstacle for illegal squatters who settled in the upper part of the valley in areas now recognized as highly exposed to risks. Invaders also built slums along rivers banks prone to flash floods. Relocation of part of this population have obliged the municipal government to develop original solutions: high rise buildings, constructed even in areas where surficial mass movements would prohibit the construction of single houses, but where stability is now controlled by appropriate deep foundations. The destruction of soil and vegetation have obvious consequences on the hydrological behavior of the earth surface: urbanization means zero infiltration, an increase in runoff and a decrease in evapotranspiration, which signify smaller lag times and higher peak discharges; these results have signified enhanced hydrologic hazards.

8. Human Impacts

Besides material extraction and soil destruction, human impacts include surface water contamination, which is presently corrected partially by a treatment plant; another one is under construction. Atmospheric pollution is quite high in several parts of the city, due mainly to mobile sources, estimated in $9 \text{ m} \cdot \text{tons} \cdot \text{a}^{-1}$ of particulate materials [18] and industry, but is also favored by a partial tem-



Figure 6. Mining of alluvial aggregates in the Aburra Valley.

perature inversion which occurs in the valley during the warming hours. Total atmospheric emissions are given in **Table 1** and a comparison with several other cities is shown in **Figure 7**.

Furthermore, about 2400 tons of solid garbage are presently produced daily in the Aburra valley. Thirty years ago they were deposited in the river flood plain and formed an artificial hill which was later occupied by illegal settlers (**Figure 8**). Due to health problems, inhabitants have been relocated. Garbage is now disposed in a sanitary landfill located at about 40 km from the center of Medellin. The ecological footprint of the Aburra community is 2.6 ha per inhabitant, (higher than Colombian's average: 1.9 ha per capita) which multiplied by a total population of about 3.0 M inhabitants give a surface about 66 times the real size of the valley [19]. The present per capita water consumption is 63 liters and most is extracted from outside of the Aburra Valley watershed. The present average Medellin River flow is 32.8 liters, which would only supply the needs of 45,000 inhabitants. Finally, the calculated forest area necessary to absorb the carbon dioxide produced in the valley would be about 726,000 ha, a surface 6 times larger than the valley.

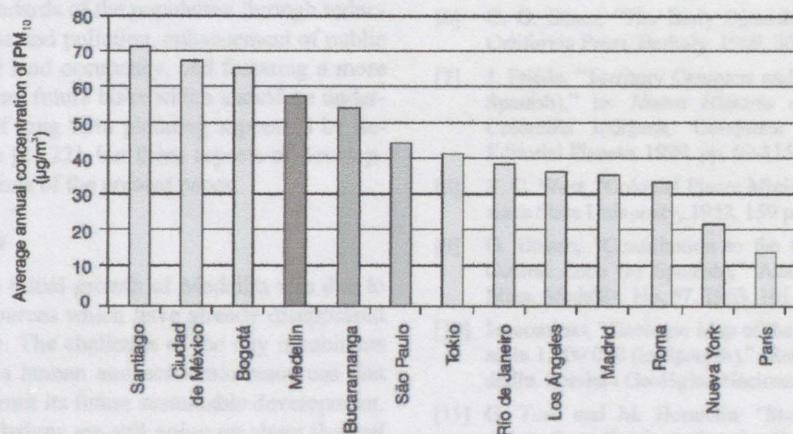
9. Discussion

Three and a half centuries ago, availability of natural resources was certainly a very good reason to explain the foundation of Medellin: a healthy climate, a locality well endowed in fertile soils propitious for crops and cattle raising and the vicinity of gold mine fields eager to consume what the valley produced. Although mining suffered several declines since that time and agriculture was progressively replaced by urbanization, the city retained its commercial vocation. Accumulation of capital and implantation of industry since the beginning of 20th century completed the evolution. Abundant and relatively inexpensive hydroelectric power contributed to competitiveness. Building materials extraction in the valley is still important but it has become almost a nuisance for communities. Despite its remote and isolated location in the middle of mountains, with no navigable rivers, railroads and roads replaced mule trails and enabled the importation of raw materials and the exportation of manufactured goods, in spite of Twinam's [20] realistic observation: "In many ways, Antioquia was a poorly suitable region for industrialization".

The ideal human occupancy of the valley was proba-

Table 1. Total atmospheric emission in the Aburra Valley. Data from AMVA-UPB,2009[18]

Component	Industrial (tyr ⁻¹)	Vehicles (tyr ⁻¹)	Biogenic (tyr ⁻¹)	% per component
CO	13054.7	109266.8	319	54
NO _x	5496.1	15987.4	6021	10
COT	8097.1	28755.8		19
MP	4386.3			2
PM ₁₀	2986.0	2011.2		2
SO _x	25528.1	1037.7		12
INORGANIC	1946.1			1
Total per Source	61,494	157,059		100
% per source	27	70	3	



Source: Ref. 22.

Figure 7. Average annual concentration of PM10 in selected cities.

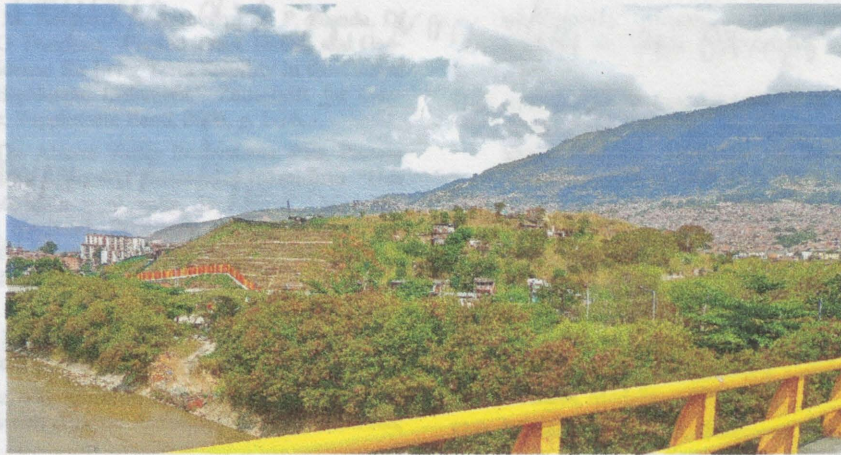


Figure 8. Abandoned garbage deposit which was occupied by illegal housing, now.

bly at the middle of 20th century, when the population reached about 500,000 inhabitants. The present population is more than 3.5 M. Services and industry have replaced agriculture, which is now limited to very specific areas in the valley, and industry itself is moving to the surrounding regions. In spite of local government fragmentation (the valley is divided into 10 independent municipalities), important efforts have been carried out to improve the living standards of the population: metropolitan train and cable cars, cultural centers, public libraries and high quality public schools, high schools and universities. In the next decades, Medellín's situation with respect to natural resource supplies will probably not be an excessive concern for water and energy. Building materials will probably have to be brought from farther places, as will raw materials used for the local industries. These transfers will become much easier when the projected highways connecting the Aburra valley with the other Colombian regions will be carried out. Improving living standards of the population through reduction of natural risks and pollution, enhancement of public transportation and land occupancy, and fostering a more equitable society are future tasks which should be undertaken by means of long term planning supported by democratic elections [21,22], but these aspects of development exceed the aims of the present paper.

10. Conclusion

In conclusion, the initial growth of Medellín was due to initial natural resources which have already disappeared almost completely. The challenge of the city inhabitants now is to generate human and economic resources that will eventually permit its future sustainable development. Meanwhile, speculations are still going on about the real factors that made Medellín the second city of the country in population and wealth, despite its modest and late ori-

gin.

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