ENVIRONMENTAL IMPACTS AND ACID DRAINAGE OF COAL MINING IN CUNDINAMARCA DEPARTMENT, COLOMBIA

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ABSTRACT

Coal in Cundinamarca is exploited by small and medium operations that use underground systems, and they have not involved appreciable levels of technology in none of the mining stages. As main negative environmental effects can be mentioned acid drainage generation, taken place by sulfides oxidation (pyrite present in the mineralized body); particulate matter production (coal dust) that is emitted to the atmosphere, surface waters, soils, biota and to the labor force (health and safety risk). Also it is important the improper disposal of coal wastes, that affect soils, waters and biota; biota and soils affectation as product of vegetal cover removal, and over use of forest resources. As positive socioeconomic effects can be mentioned employment and royalties generation, as well as impulse to the economy. pH and conductivity measurements allowed to evidence acid mine drainage occurrence (AMD), which contains high levels of ions in solution, possibly heavy metals (toxic) leached from the mineralized body. Along the carboniferous area, acid mine drainages (pH 2.6-5.5) with high values of conductivity (up to >3000 µS/cm) were detected. Previous datas (INGEOMINAS, 1981, 1985, 1992), showed that although total sulfur contents in Cundinamarca's coal are quite low (0.84%), correlation among acidity generation (AMD) and sulfur concentrations (pyrite FeS_2) in the exploited coal exists. Although the AMD causes economic losses and they produce affectation on the biota, soils and waters, studies do not exist about their characterization. AMD characterization study is recommended in this area, as basis to propose mitigation and remediación plans for those affected mining areas.

INTRODUCTION

Colombia is the first Latin American coal producer and the 7th world exporter. It has important coal reserves, fact that is of great interest to asses its current state for planning sustainable development, in order to assume successfully the challenges of the next century. The coal reserves are distributed along the Andean mountainous chain and they are located in the Central Region as well as in the Colombian Atlantic Coast (Tables 1, 2).

Large-scale projects (Surface mining) normally incorporate technical and organizational infrastructure and provide environmental management with acceptable standards. The companies have enough resources to conduct monitoring activities and to implement reclamation plans. On the other hand, the traditional small mining located in the central area of the country do not possess appropriated technical conditions. Low investments, limited profitability, inadequate commercialization channels, unstable markets and deficiencies in its basic infrastructure characterize these mines. Most small-scale mines do not individually result in excessive environmental damage. However the cumulative effects of these small operations often create significant environmental degradation.

Region	Measured (mill.Ton)	Indicated (mill.Ton)	Coal Type
Guajira	3670	-	Thermal
César	1933	589	Thermal
Córdoba	381	257	Thermal
N. Santander	68	101	Thermal & Coking
Santander	57.1	114	Thermal & Coking
Cundinamarca	241.9	538.7	Thermal & Coking
Boyacá	170.4	682.7	Thermal & Coking
Antioquía	90	225	Thermal
Valle del Cauca	20.1	22.4	Thermal
Cauca	16.4	66.8	Thermal

Table 1. Colombian coal reserves (ECOCARBON, 1996; MINERCOL, 1998).

Mining type	Exploitation system	Production (Ton/year)	Location	National prod. (%)	Employ (%)L
Large	Open Pit	>800000	Guajira, César	66.3	23.2
Medium	Undergroung	30000-50000	César, Antioquía,	16.3	17.4
	Open Pit	24000-800000	Cundinamarca		
Small	Underground	<30000	Cundinamarca, Boyacá, Santander, N.Santander, Valle	17.4	59.4

Table 2. Mining Type (ECOCARBON, 1998, CERI, 1999).

One of the most prominent problems associated to coal mining which produces economic and environmental consequences is the generation of acid mine drainage (AMD). Even though AMD is known from Roman times and its toxicity and effects, as well as its origin have been studied deeply from the 60th years, in Colombia its knowledge is limited and their environmental effects are totally unknown. In some carboniferous areas of Valley, Antioquía, Santander and Cundinamarca departments have been reported acid drainages (AMD), however these drainages have not been evaluated and neither treatment systems have been designed.

AREA DESCRIPTION

Colombia is located in the North of South America, and the study area is located on the Oriental Mountain range in Cundinamarca Department. Cundinamarca concentrates most of the Colombian industry and it has mineral resources such as emeralds, coal, iron, phosphates, gypsum and construction materials. The Boyacá-Cundinamarca carboniferous area is the most important of the Eastern Cordillera (3.200 km^2) and one of the main sources of thermal coal (coking coal) of Colombia. It includes the Bogotá Savanna, as well as the Ubaté, Samacá, Tunja, Duitama, and Sogamoso-Jericó Valleys (INGEOMINAS, 1981). Coal production in Cundinamarca is concentrated on the Lenguazaque, Tausa, Sutatausa, Cucunubá and Guachetá municipalities. This area belongs to the Checua-Lenguazaque-Samacá syncline. In this area several coal consumers exist, two thermo-electric plants and the Paz del Rio's steel plant. Cundinamarca department is one of the most important coal consumers (20.52% of the national consumption) whose consumption is directed to the industrial sector (47%), electricity production (50%) and domestic use (3%) (ECOCARBON, 1996; MINERCOL, 1998).

SOILS, LIFE ZONES AND CLIMATE

Cundinamarca's soils have agricultural, cattle and forest vocation; however nowadays they confront denudation, erosion and over use problems. The natural forest has diminished sensibly due to agriculture expansion, wood coal consumption and forest fires. Wild forest relics exist in the sumapaz Moor and in the Medina Headlands. The wild fauna registers great decrease due to its natural habitat destruction and the illegal hunt.

In Cundinamarca, the following life zones exist: tropical dry forest (bs-T), humid montano forest (bh-M), dry premontano forest (bs-PM), low montano dry forest (bs-MB) and tropical humid forest (bh-T). Low precipitation exists towards the southwest of the Bogotá Plateau, and high precipitation is occurs towards the "Piedemonte Llanero". The typical climatic zones in Cundinamarca are warm (27%, "Piedemonte Llanero" and Magdalena Valley), temperate (28%, Eastern and Western flanks), cold (33%, Bogotá Plateau and cordillera's flanks) and "páramo" (moor) (12%, Sumapaz moor, mountainous cords). In the carboniferous region the following life zones exist: humid montano forest (bh-M) corresponding to "sub-páramo" (altitude 3000-4000 m a.s.l., T 2-12°C, precipitation 500-1000 mm/y with high relative humidity and low evapotranspiration), and low montano dry forest (bs-MB) in the Ubate Valley (altitude 2000-3000 m a.s.l., T 12-18 °C, precipitation 500-1000 mm/y).

HYDROLOGY

Cundinamarca has an Eastern hydrologic system (Meta river and its tributaries), and a Western system (Magdalena river and its tributaries). It has 14 main drainage basins, 15 lagoons, 10 mineral and thermal water sources; and 9 reservoirs. The central part of the carboniferous area is crossed by the Lenguazaque river affluent of the Ubaté River that drains to the Fuquene lagoon. The Cucunuba lagoon is located towards the south of the area, and receives all the area drainage system.

GEOLOGY (CARBONIFEROUS AREA)

This area contains several carboniferous strata NE orientated, extended for 90 km. The coal is contained in the Guaduas Formation of Maastrichtian to Paleocene age, it is constituted by compact claystones, carbonaceous claystones, sandstone banks and motley mudstones, with numerous layers of coal located towards the inferior and mediates part of the Formation. The Guaduas Formation is located between the Guadalupe Group (Maastrichtian), that is formed typically by prominent sandstone banks and in smaller proportion for siliceous claystones, and the Arenisca del Cacho Formation (Paleocene-Eocene), which is constituted for sandstones from thick to conglomeratic grain with thin claystones interlayers (INGEOMINAS, 1981).

The carboniferous "Checua-Lenguazaque" basin belongs to the Ubaté-Chiquinquirá Valley, that is part of the Eastern Cordillera plateaus and it is located to the North of Cundinamarca and South of Boyacá. The Ubate Valley is a plain NE-SW orientated, covered by Quaternary sediments, it is located to 2560 m a.s.l., and limited to the East and West for Cretaceous rocks escarpments.

The carboniferous area is located towards the Eastern border of the Valley and it presents four escarps formed by hard rocks (sandstones), separated by soft rocks that model a characteristic topography. Towards 2600 m a.s.l., in the base of the Valley, the potent sandstones of the Arenisca Tierna Formation of the Guadalupe Group appear. Towards 3000 m a.s.l., the second escarp appears corresponding to the Arenisca La Guia of the Guaduas Formación (less potent than the previous one), which it is separated by claystones levels of the inferior part of the Guaduas Formación.

The Arenisca La Guia level presents the highest coal in range. According to Sarmiento (1990) this level is approximately 100-m tick and it corresponds to a supramareal and lacustrine depositional environment. It is a Group of thick and medium quartz sands layers with intraclasts in the base. Claystones and mudstones interlayers are presented, in thin and lenticular parts, in occasions with leaves impressions.

On the Arenisca La Guía, a soft and lightly upward level is presented, it is formed by claystones and mudstones, in occasions with abundant organic matter. Its depositional environment (Sarmiento, 1990) has been described as closed and open swamps and supramareal, and estuarine channels in the base. This relief is interrupted by the more abrupt geomorphologic expression of the Arenisca La Lajosa. The higher part of the western flank of the sincline corresponds to the Arenisca del Cacho scarp (>3400 m a.s.l.). These expressions are quite continuous and they extend along the western flank of the Checua-Lenguazaque sincline, with small interruptions in a big depression, possibly originated by erosive processes on the Lenguazaque and Cucunubá Valleys.

METHODOLOGY

INGEOMINAS in cooperation with the Cundinamarca's Government carried out the Mining Inventory of this Department, in those areas producers of coal, emeralds, industrial minerals and construction materials. In development of the project was gathered local information on: geology, mining phases and associated environmental impacts, (INGEOMINAS, 1997, 1999).

To identify the impacts produced for mining coal in Cundinamarca it was used matrix analysis. In these analysis, qualitative matrices identify the impacts of mining activities on components of the natural and human environment. Considering the mining as a temporary territory occupation it was elaborated qualitative matrices, which took in account the mine life cycle (exploration, development, operation, transportation, commercialization and closure – rehabilitation, reclamation phases). The impacts were classified applying the following assessment criteria: magnitude, scope, duration, type, reversibility, and mitigability.

Mine waters were assessed and measured pH, T °C, and conductivity (mine drainage, sedimentation ponds and surficial streams). Acid mine drainage generation (AMD) was identified in this area. Based on previous studies (INGEOMINAS, 1981, 1985, 1992), and considering sulfur analysis (total and species) and oxide contents in ashes, a preliminary approach about the origin and significance of AMD in this area was made.

RESULTS AND DISCUSSION

Coal in Cundinamarca is exploited for small (98.3%) and medium operations (1.7%) using underground systems. Around the coal mines some coking plants have been built. Approximately 70% of Colombias's coke production is exported and the residual one is consumed for the national steel industry.

Coal Mining in Cundinamarca is characterized for low technological level. The mines are very inefficient with most of the work carried out by hand. Conditions in these mines have led to low productivity, low profitability and mineral resources lost (Figure 1, Table 3).

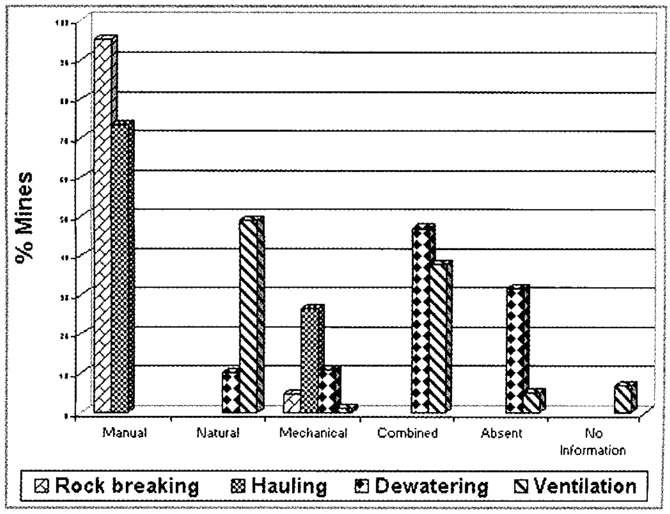

Figure 1. Coal mining operations in Cundinamarca.

Municipalities	Mines	Active mines	Production (Ton/y)
Cucunubá	103	82	383.410
Guachetá	42	36	227.000
Lenguazaque	47	43	203.560
Sutatausa	40	38	200.000
Tausa	25	16	140.000
Total	257	215	1.153.970

Table 3. Coal production in Cundinamarca.

ENVIRONMENTAL IMPACTS

Low technology level as well as lack of environmental management, have made critical the environmental impacts, so many affectations remain as cumulative effects in this area. Matrix analysis showed that all the mining operations produce effects in the biophysical and socioeconomic components of the environment (Figure 2, Table 4).

The most affected components are: the landscape that has been modified and the atmosphere which is sink of particulate matter contributed by refuse piles, denuded soils and coal stocks. Soils have lost the vegetative cover and it has suffered erosion as result of organic cover removal and accumulation of solid wastes. The morphology has been modified, the vegetation disturbed and the native species replaced by strange ones. Surficial waters quality has been degraded due to particulate matter contribution and acid drainages, coming from mining exploitations, reception (AMD).

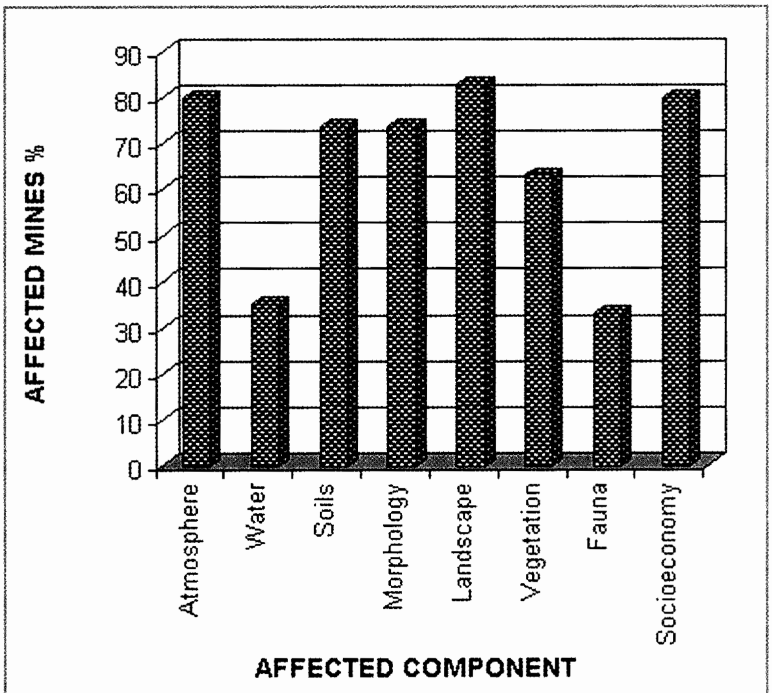

Figure 2. Environmental components effected for coal mining in Cundinamarca.

Beneficial impacts include employment (2671 direct employs) and royalties generation (US$176.706/1998), infrastructure construction, and regional economy grown.

The effects on the atmosphere and water are negative and highly significant, and they were classified as **Class 1**. Affectations on soils, morphology and landscape are negative of medium magnitude, and they were classified as **Class 2**. The socioeconomic effects are positive and highly significant, and they were classified as **Class 1**, (Table 5).

EFFECT	MINING OPERATION	AFFECTED COMPONENT
NEGATIVE		
Particulate matter contribution	Rock breakage, haulage, soil removal, refuse piles	Air, water degradation
Gas emission	Loading, haulage	Atmosphere degradation
Acid drainage generation	Rock breakage, wastes	Water, soils degradation
Loss of soils & erosion	Soil removal, wastes	Soils degradation
Morphology & landscape	Soil removal, wastes	Morphology, landscape modification
Species & communities	Soil removal, loading, haulage	Biota disruption
POSITIVE		
Employment	All operations	Socioeconomic effects
Royalties	All operations	Socioeconomic effects
Economic development	All operations	Socioeconomic effects
Regional infrastructure	All operations	Socioeconomic effects

Table 4. Main impacts caused for coal mining activities in Cundinamarca.

ACID MINE DRAINAGE (AMD)

Coal mining disturbs large volumes of geologic material and exposes them to the environment. Through this exposure to air and water, sulfide minerals commonly associated with coal are oxidized and hydrolyzed resulting in AMD. AMD is a low pH, sulfate rich water with high concentrations of acidity. Acidity in AMD is comprised of mineral acidity (Mn^{+4}, Fe^{+3} and Al^{+3} and other metals depending on the deposit) and hydrogen ion (H^+) acidity. The primary reactants for AMD generation are pyrite (FeS_2), H_2O and O_2, with bacteria's intervention, particularly *Thiobacillus ferrooxidans*, acting as catalysts (Skousen and Ziemkiewicz, 1996). In connection with acid mine drainage in coal mining, the most important implication is water acidity that produces economic losses (infrastructure corrosion) and also it produces imbalances in the biota, water and soils.

Cundinamarca's coal has low total sulfur concentration on average (TS) (0.84%) (ECOCARBON, 1996), however seams exist with higher concentrations (1.12-2.38%), which present relatively high levels of pyritic sulfur (23.9 to 60.7% of total S). AMD was identified in Cucunubá (18 mines, pH 2.9-5.5, conductivity 981-4350 μS/cm); Lenguazaque (8 mines, pH

Impact	Type	Magnitude	Scope	Duration	Reversibility	Mitigability	Class
Atmosphere degradation	N	Medium	R	Long	Reversible	Mitigable	**1 (H)**
Water degradation	**N**	Medium	R	Long	Reversible	Mitigable	**1 (H)**
Soil degradation	**N**	Medium	Local	Long	Reversible	Mitigable	**2 (M)**
Morphology & landscape modification	**N**	Medium	Local	Long	Irreversible	Mitigable	**2 (M)**
Biota disruption	**N**	Medium	Local	Long	Reversible	Mitigable	**2 (M)**
Socioeconomic effects	**P**	High	R	Medium	Reversible	Mitigable	**1 (H)**

N: Negative P: Positive R: Regional H: High M: Medium L: Low
Table 5. Impact characterization and impact significance determination.

3-4.5, conductivity 142->3000 µS/cm); Guachetá (6 mines, pH 2.7-4.4., conductivity 431->3000 µS/cm); Tausa (12 mines, pH 2.6-5.4, conductivity 66-2490 µS/cm); and Sutatausa (2 mines, pH 3.8-4.4, conductivity 612-2280 µS/cm). According to these results, in Cundinamarca carboniferous area it was evidenced the generation of AMD, which are carriers of high concentrations of ions in solution, possibly heavy metals (toxic pollutants) leached from the exploited carboniferous body. Although in the whole area AMD was identified, the most affected areas are located in the municipalities of Tausa (69%) and Cucunubá (38%) (Tables 6 and 7).

Municipality	Total mines	Mine drainage	Acid drainages	AMD (%)
Cucunubá	103	47	18	38
Guachetá	42	16	4	16
Lenguazaque	47	27	8	30
Sutatausa	40	16	2	13
Tausa	25	16	11	69
Total	257	121	43	35.5

Table 6. Acid Mine Drainage (AMD) in Cundinamarca's carboniferous area.

Municipality	Mine	pH	T °C	TS%	PyS%	SS%	OS%	ECµS/cm
Tausa	Jamaica	2.7	18.1	0.76	0.14	0.01	0.61	2490
Cucunuba	Curubo	3.1	18.2	1.47				1811
Cucunuba	Montecristo	3.2	18.2	1.35	0.36	0.35	0.64	2700
Cucunuba	Cruzada	3.4	16.8	1.98	0.78	0.02	1.18	3000
Guacheta	Joya	3.5	16	0.79	0.03	0.03	0.73	1447
Sutatausa	Maracaybo	3.7	18.9	0.82	0.05	0.1	0.67	1688
Tausa	Alisos	3.8	18.3	0.51	0.01	0	0.5	3000
Tausa	Diamante	3.8	13.2	0.61	0.02	0	0.59	2280
Tausa	Campanario	5.2	12.8	0.91				118
Cucunuba	Buanevista	5.3	16.4	0.91	0.08	0	0.83	680
Tausa	Nihico	5.4	13	0.63				115
Cucunuba	Capellanía	6.4	17.6	0.72				2650
Tausa	Esperanza	6.7	25	0.57	0.01	0	0.56	3600
Lenguazaque	Sultana	6.8	18	0.8	0.11	0.01	0.68	674
Tausa	Morena	6.8	16.5	0.77				550
Lenguazaque	Rubi	7	19	1.59	0.79	0	0.8	2535
Sutatausa	Llano	7	24	1.68	0.84	0	0.84	799
Guacheta	Mejía	7.1	15.8	0.46				370
Guacheta	S.Luis	7.1	18.8	0.44	0.01	0	0.43	676
Lenguazaque	Cajon 2	7.2	20.1	0.47	0.07	0	0.4	556
Lenguazaque	Ramada 1	7.2	19.4	0.45	0.03	0	0.42	592
Cucunuba	Espino	7.4	20.8	0.48	0.06	0	0.42	928
Cucunuba	Esperanza	7.5	20.1	0.45	0.02	0.01	0.42	480
Sutatausa	Golondrina	7.5	16.9	0.63				1080
Lenguazaque	Cajon	7.6	12.7	0.45	0.02	0	0.43	518
Lenguazaque	Ramada 2	7.6	18.5	0.5				590
Tausa	Piedra Molin	7.6	11.9	0.53	0	0	0.53	854
Cucunuba	Faro	7.7	17.9	0.51				541
Lenguazaque	Ramada 3	7.7	23.9	0.52				673
Sutatausa	Candelaria	7.7	16.4	0.3				972
Cucunuba	Triunfo	8.1	16.6	0.58	0	0	0.58	2870

TS: Total S; PyS: Piritic S; SS: sulfate S; OS: organic S
Table 7. Mine drainages in Cundinamarca's carboniferous areas.

The total S content bears in general little relation to mine drainage quality, however in the case of Cundinamarca's coal drainages, it was observed that increments in total S concentration in coal correlate to lower pH and higher conductivities values in the mine drainage (Figure 3).

Acid mine studies have demonstrated that acidity level and heavy metals concentration, are determined by abundance, form and pyrite associations, as well as for the coal depositional environment (paleoenvironment) (Wildeman, 1991). The AMD occurrence in this carboniferous area is related to pyritic S concentration in the coal-bearing stratas (23.9 to 60.7% of the total S), possibly framboidal pyrite presented as discreet particles in the coal seams (INGEOMINAS, 1985). The coal seams exploited in this area (Tkg2 and Tkg3) have generated acidity. They correspond to the Guaduas Formation levels whose depositional environment has been described as "supramareal and lacustrine" (Tkg2) and as "closed swamps, open swamps, supramareal and estuarine channels" (Tkg3) (Sarmiento, 1990). These characteristics agree with studies carried out by Caruccio in Eastern Kentucky (Caruccio et al., 1977; Caruccio, 1979), who attributed higher reactivity to framboidal pyrite (oxidative weathering), specially if it is present in coal deposited in marine or brackish water environments.

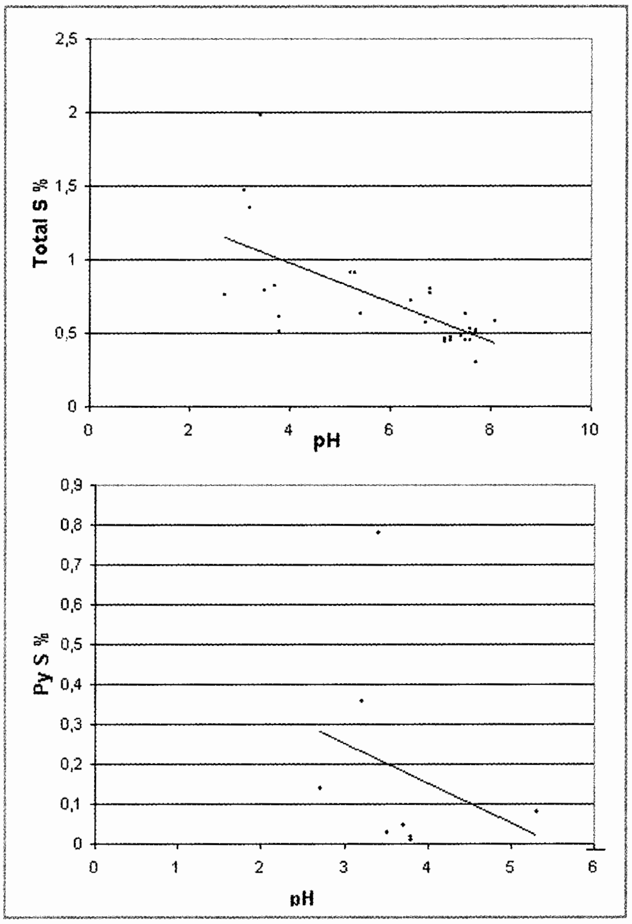

Figure 3. pH and Total Sulfur (Total S) tendency (left); and pH and pyritic sulfur (Py S) tendency (right).

Previous studies (INGEOMINAS, 1985) reported as main components of coal ashes to: Si, Al, Fe, and Ca, that on the whole reach 95.3%; and as smaller components to: Mg, Na, K and Ti. The same study suggested that Si is predominantly as quartz (SiO_2), aluminum as diaspore (AlO(OH)) and iron as pyrite (FeS_2). The ashes have total acid contents (63.99 - 98.53%) notably bigger than total bases concentrations (1.38 - 31.18%). In Cundinamarca's coal, the iron oxides are generally low (mean 3.83%), however they showed high variability and they have reached values up to 24.6%. The aluminum oxides showed appreciable concentrations in the analyzed coal (12.09-34.94%). The pyrite occurrence (FeS_2) is generalized and it does not present a defined enrichment tendency (towards a specific zone into the carboniferous area), while the diaspore (AlO(OH)) apparently is located in fissures and seam unions (INGEOMINAS, 1985).

Mine drainages acidity in the Cundinamarca's coal areas could be attributed to the oxidative weathering of iron (sulfides) and aluminum minerals. They showed high concentration and also location variability; so that they produce AMD in different stratas of the Lenguazaque sincline.

It was suggested (INGEOMINAS, 1985) the ankerite occurrence ($CaCO_3$ (Mg,Fe,Mn)CO_3), as mineral that would contribute to neutralize part of the acidity produced by pyrite oxidation. The above-mentioned is quite probable since it has been proven that besides framboidal pyrite, in some paleoenvironments it has accumulated calcareous material that contributes to neutralize the produced acidity (Wildeman, 1991). The concentration of neutralizing agents in the coal seams is not enough to neutralize the generated acidity, resulting in acid mine drainages in this zone.

Results showed that the carboniferous Checua-Lenguazaque sincline have areas of high mineralogical variability, in such a way, there are areas where acid drainages are in high proportion, areas where the drainages are fundamentally neutral to basic, and areas where acid drainages occur in little extension.

According to a matrix presented by Wildeman (1991) for coal mine drainages, the water chemistry is quite predictable, if the environment generated a situation where the two constituents of the matrix have opposite abundances. However when the abundances of pyrite and carbonates are both high or low, the results are uncertain. In the latter case, the application of a prediction model (Figure 4) will require of: paleoenvironments studies; petrographic analysis (pyrite forms); sulfur speciation; surficial and underground water assessment; and analysis of alkalinity and carbonate species.

	Pyrite		
Carbonate	pH 3-4 $SO_4^=$ High HCO_3^- Low	Uncertain	Low
Carbonate	Uncertain	pH 7-8 $SO_4^=$ Low HCO_3^- High	High
	High	Low	

Figure 4. Matrix showing how abundances of calcareous material (carbonates) and framboidal pyrite can affect mine drainages chemistry (Wildeman, 1991, adapted from Caruccio (1979)).

In Cundinamarca's carboniferous area, given the spatial variability in the pyrite and carbonate concentration, the four-hydrogeochemical environments considered in the model (Figure 4) are presented indistinctly. Therefore it is necessary and urgent to carry out systematic studies on coal characterization, as basis for proposing management and remediation plans that consider appropriated AMD treatments in each particular area.

MITIGATION

In the carboniferous area have been carried out environmental campaigns that have given the construction of some sedimentation lagoons and reforestation programs, as a result.

In spite of these facts, and due to the lack of technical knowledge and to the absence of environmental education, those actions have not been effective. In such a way the lagoons are siltated and they have lost their efficiency totally, so they are contributing to magnify the impacts to the environment.

In Colombia and particularly in this carboniferous area, AMD characterization studies have not been carried out (sources, composition, geochemical behavior, sinks, and fate), neither treatment systems have been implemented. So most of these drainages are flowing directly to agricultural soils or to surficial streams that later on are used for consumption and cultivation watering.

CONCLUSIONS

Some mining activities produce highly significant affectations and imbalances on the environmental components. The main negative affectations have been classified as **Class 1.** They correspond to air and to water components and related to particulate matter contribution, gas emission and AMD generation. The effects on soils, morphology and landscape, of medium magnitude, were classified as **Class 2.** They are associated with organic layer removal, inadequate wastes management and erosion problems. The positive effects were classified as **Class 1.** They are centered in the socioeconomic components and represented in employment and royalties generation, and economic growth.

Using simple indicators, low costly and easy evaluation (pH and conductivity), it was proven AMD occurrence in the Checua-Lenguazaque sincline. The identified AMD are carriers of ions in solution; so they contain leached ions (carboniferous body), possibly heavy metals (toxic) that affect aquatic environment. As main responsible for AMD generation in this area, the pyrite (FeS_2), possibly framboidal, and diaspore ($AlO(OH)$) minerals were identified. These minerals are present in very variable concentrations in the coal seams.

For designing management plans and implementing treatment systems that mitigate the effects of these AMDs in coal exploitations, the development of systematic studies that characterize the coal deposit, as well as the drainages in this area, is recommended. For developing mitigation and rehabilitation plans, it becomes necessary to introduce technology in the exploitations, to increase the area knowledge (scientific and technological), and to bring environmental education, focused to consider the environment as a common wealth.

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REFERENCES

Carucio, F.T., 1979. The nature of acid mine drainage reactions and their relation to overburden analysis. In M.K. Wali, ed., Ecology and coal resource development, New York, Pergamon Press, pp 775-781.

Carucio, F.T., J.C. Ferm, J. Horne, G. Geidel and B. Baganz 1977. paleoenvironment of coal and its relation to drainage quality. U.S.E.P.A., Document No. EPA 600/7-77-067,107 p.

CERI, 1999. Scooping of a Sectorial Environmental Assessment, Colombia Hydrocarbon and Mining Sectors. Komex International Ltda. – CERI. Santafé de Bogotá.

ECOCARBON, 1996. Plan de Desarrollo del subsector carbón 1997-2005.

INGEOMINAS, 1999. Diagnóstico y asistencia Técnica, Explotación y Fomento de la minería en el Departamento, Inventario Minero de Cundinamarca, Fase II. Santa Fé de Bogotá, Ingeominas-Gobernación de Cundinamarca.

INGEOMINAS, 1997. Metodología del Inventario Minero ambiental Nacional – Formatos minero – geológico - ambiental e instructivo para diligenciamiento.

INGEOMINAS, 1997. Diagnóstico y asistencia Técnica, Explotación y Fomento de la minería en el Departamento, Inventario de Materiales de Construcción en la Sabana de Bogotá, Fase I. Santa Fé de Bogotá, Ingeominas-Gobernación de Cundinamarca.

INGEOMINAS, 1992. Proyecto de caracterización y Usos Tecnológicos de los Carbones Colombianos, Zona Cundinamarca – Boyacá. CV-286-40.

INGEOMINAS, 1985. Caracterización de carbones Colombianos, Zona Checua – Lenguazaque. INGEOMINAS. Bogotá. 388pp.

INGEOMINAS, 1981. Evaluación de Reservas de Carbón en Siete Zonas de Colombia. Santa Fé de Bogotá, Publicaciones Geológicas Especiales del Ingeominas, No.6, pp 1-134.

MINERCOL, 1998. Plan de Desarrollo del subsector carbón 1999-2010.

Sarmiento, P.G.A., ,1990. Estratigrafía y ambientes de la parte superior del Grupo Guadalupe y la Formación Guaduas en el Flanco W del Sinclinal Checua-Lenguazaque, Peñas del Boquerón de Sutatausa. Bogotá, INGEOMINAS. Informe 2133. 105 pp.

Skousen, J.G. and P.F. Ziemkiewicz, 1996. Acid Mine Drainage Control and Treatment. 2nd. Edition. NMLRC. West Virginia. USA.

Wildeman, T., 1991. Drainage from coal mines: Chemistry and Environmental Problems. Geology in Coal Resources Utilization, D.C. Peters, edi., Tech Books, Fairfax, VA. Pp 499-511.