Chapter 5

World Coal Quality Inventory: Colombia

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World Coal Quality Inventory: South America

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Metric Conversion Factors

Imperial Units	SI conversion
acre	4,046.87 square meters
acre-foot	1,233.49 cubic meters
British thermal unit (Btu)	1,005.056 joules
British thermal unit / pound (Btu / lb)	2,326 joules / kilogram
Fahrenheit (ºF)	Centigrade (ºC) = [(ºF-32)x5]/9
foot (ft)	0.3048 meters
inch (in)	0.0254 meters
mile (mi)	1.609 kilometers
pound (lb)	0.4536 kilograms
short ton (ton)	0.9072 metric tons
short tons / acre-foot	0.7355 kilograms / cubic meter
square mile (mi^2)	2.59 square kilometers

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Introduction

The U.S. Geological Survey (USGS), in cooperation with many of the world's coal producing countries, has undertaken a project called the World Coal Quality Inventory (WoCQI). The WoCQI currently contains coal quality and ancillary information on samples obtained from major and minor coal-producing regions throughout the world (Finkelman and Lovern, 2001a, b). Sample collection and analytical procedures for the WoCQI are described in the Executive Summary (Chapter 1, this volume). As part of the WoCQI, 16 coal samples from Colombia were collected and analyzed.

Colombia

The Republic of Colombia is the fourth largest country in South America and has 32 administrative regions (called 'departments', fig. 1) plus the capital district of Bogotá, which is its own autonomous administrative region. The Ministry of Mines and Energy (MME) is the key governmental body involved in the energy sector in Colombia and is responsible for overall policy making and regulation of Colombian mining activity. MME regulates generation, transmission, trading, interconnection, and distribution, and approves generation and transmission programs. The ministry delegates supervisory authority over the electricity sector to a number of its agencies, specifically Comisión Reguladora de Energía y Gas (CREG) and Unidad de Planeación Minero Energética (the Mining Energetic Planning Unit, or UPME). The premier scientific agency for interdisciplinary geologic and environmental research is the Instituto de Investigación e Información Geocientífica, Minero-ambiental y Nuclear (INGEOMINAS), a collaborator on this project.

In Colombia, the state owns all hydrocarbon reserves, but private companies operate individual coal mines. While Colombia is South America's largest coal producer, in 2002 about 63 percent of the country's electric power came from hydroelectric sources (Energy Information Administration, 2004). However, the Colombian government has been troubled for decades by a rebel insurgency that has attacked crucial energy infrastructure, including oil and gas pipelines and transmission lines. In 2003, there were 329 attempts on the electric power transmission system (Ministerio de Minas y Energía, 2004, p. 366). These attacks cost the government $35.4 million ($98,275 million pesos).

Geology of Coal Areas

Figure 2 shows a general geologic map of Colombia. Surficial geology is being mapped by INGEOMINAS and published in quadrangles at a map scale of 1:200,000. Colombia is South America's main coal producer and exporter (Da Cunha Lopes and Ferreira, 2000) and the ages of the major coals range from Cretaceous to Tertiary (Maestrichtian-Paleocene to middle Oligocene). The rank of coals in the Andean highlands region has been increased by tectonism to bituminous and even meta-anthracite (Alvarado, 1980).

The two main coal provinces or basins (eastern and western, fig. 1) are part of larger sedimentary basins (Weaver and Wood, 1994). Subbasins, or coal fields, within these two areas are shown on figure 1 (Kottlowski and others, 1978). Not all of the subbasins, particularly in the eastern basin, have been studied in great detail. Although nomenclature varies widely within the literature, the eastern basin includes the subbasins: Tocaina-Guaduas, Bogotá area, Tunja area, Santander, Pamplona-Cucuta-Catatumbo, La Jagua de Ibirico, and El Cerrejón (Orndorff, 1985).

The most well-known subbasin is the El Cerrejón (sometimes referred to as Guajira) located in the La Guajira department/peninsula (fig. 1), bounded by the Sierra Nevada de Santa Marta on the west and the Perija Mountains on the east. The rocks are deltaic (marine-continental) in origin and contain up to 40 economic coal beds intercalated between shale and siltstone in a Paleogene-age sequence that averages 900 m (ranging up to 1,000 m) in thickness (Weaver, 1993; Suescun-Gómez, 1978). Coal ranks range from lignite to bituminous (Suescun-Gómez, 1978), although most mined beds are high volatile B bituminous (Weaver, 1993). The Cerrejón Formation has been divided into three groups (lower, middle, upper) based on the thickness and distribution of the coal beds. Overall coal bed thickness averages 3 m and ranges from 0.7 to 10 m (Weaver, 1993), although the thickest coal beds (1.4 to 10 m) are in the upper third of the formation. The Cerrejón coalfield is split into north, central, and southern zones; the north zone being the largest.

In addition to Cerrejón, the traditional coal mining districts in the Andean highlands include Cundinamarca, Boyacá, Norte de Santander, and Antioquia. The petrography of coals representative of the northern Cundinamarca subbasin were presented by Hiltmann (1988).

Coal subbasins around Bogotá and to the north-northeast form a more than 600-km long trending belt in Colombia’s East Cordillera (Hiltmann, 1988). On the Bogotá plateau, the coals are predominantly in the Cretaceous-age Guadas Formation (Olsson, 1956). Subbasins are oriented southwest-northeast in folds (synclines) formed during the Andean orogeny.

Coal Reserves and Mining

The Energy Information Administration (2003) reports that Colombia has proven recoverable coal reserves of 6.8 billion metric tons, of which more than 94 percent is anthracite and bituminous coal. Northern Colombia contains the majority of coal reserves, in César department and also on the Guajira (Cerrejón) peninsula. The Cerrejón Norte area alone is estimated to have 3 billion metric tons of potential resources (Engineering and Mining Journal, 1994). The Cerrejón coalfield north zone is home to the Cerrejón Zona Norte mine, the largest opencast coal mine in the world (fig. 3) and is the largest coal mining operation in Latin America. The Cerrejón Zona Norte mine has a very desirable low-ash (1 - 21 percent), low-sulfur (0.01 - 0.23 percent, as-received), non-caking bituminous coal of Tertiary age. Production from the mine was 18.4 million metric tons in 2000, about 19 million metric tons in 2001, about 15 million metric tons in 2002, and just over 16.4 million metric tons in 2003. The mine exports over 80% of its production to Europe.

The Patilla coal mine on the Guajira peninsula has 65 million metric tons of proven reserves of high quality coal (Energy Information Administration, 2003). The Pribbenow Mine is another major coal mine in Colombia, located near La Loma in César department, which has estimated reserves in excess of 534 million metric tons of high Btu, low-ash, low sulfur coal and is run by Drummond Ltd. At the El Descanso mine, reserves are reported to be 960 million metric tons, making it Colombia's second largest reserves after the country's main Cerrejón project (Energy Information Administration, 2003). Hiltmann (1988) calculated reserves for the central part of the Tibita area in northern Cundinamarca subbasin to be about 56 million metric tons.

Coal Production

In the 1940s, coal production in Colombia was around 595,000 metric tons. About half of the production came from the Cundinamarca-Boyacá region, with the other half coming from Antioquia and Valle del Cauca regions plus a modest amount from Norte de Santander and Caldas areas. Weaver and Wood (1994) listed 37 Colombian coal occurrences, including active mines and companies. Since 1986, Cerrejón Norte has been Colombia’s largest producing mine. The mine was originally owned by a partnership between Carbones de Colombia S.A. (CARBOCOL -the Colombia government coal company) and International Colombian Resources Corporation (INTERCOR), a subsidiary of Exxon.

Cerrejón Norte, which was the world's largest export open pit mining operation, changed ownership in 2002 when a joint venture among BHP Billiton plc., Anglo American plc., and Glencore International AG acquired 50% of the mine from INTERCOR. The BHP Billiton, Anglo American, and Glencore joint venture had purchased the other 50% of Cerrejón Norte 2000 from CARBOCOL. With the change in ownership, two companies (Cerrejón Zona Norte and Carbones del Cerrejón) became Carbones del Cerrejón LLC merging Cerrejón Zona Norte, Cerrejón Zona Central, Cerrejón Zona Sur, Patilla and Oreganal deposits. Coal production capacity of Carbones del Cerrejón is 25,000 million metric tons.

Another important mine in Colombia is La Loma mine, which was owned by Drummond Ltd., a subsidiary of Drummond Inc. of the United States. La Loma is located (in la Jaguana subbasin) in the department of César. Also in the César department, is La Jagua, a mine which was owned by Carbones del Caribe S.A. The company was planning to expand production capacity to 4 million metric tons by 2007.

In 2003, Colombia's coal production was 49.3 million metric tons (Table 1). This represents a 51% increase in production from that in 1999 and a 25% increase from that of 2002. The Ministerio de Minas y Energía (2004) reports the largest producing departments were, in decreasing order of output, La Guajira (22.6 million metric tons), and César (21.2 million metric tons). Other producing departments were Antioquia, Boyacá, Córdoba, Cundicamarca, Norte de Santander, and Valle del Cauca (5.5 million metric tons). The principal producing mines were Cerrejón Zona Norte, the largest component of Carbones del Cerrejón (16.5 million metric tons), La Loma, (with 16.4 million metric tons). Patilla, also part of Carbones del Cerrejón (2.4 million metric tons); and La Jagua (2.3 million metric tons).

In January 2004, the process of liquidation of the State mining company (Minercol Ltda.) began with the Presidential Decree 0295. With the completion of Minercol's liquidation, Colombia's coal mining sector became fully privatized.

Coal plays a small role in Colombia's electrical generating capacity. In 2002, Colombia was the largest exporter of coal to the United States with exports of primarily steam coal totaling 6.9 million metric tons. In 2003, Colombian coal exports went mainly to Europe (43%) and North America (32%). A summary from the Ministerio de Minas y Energía (2004) of recent coal production and consumption in Colombia is shown in Table 1. Production nearly doubled between 1990 and 2000.

Coal Uses

Colombia historically has been largely dependent on hydroelectric power, which in 2003 generated 76.4% of installed generating capacity. In recent years severe droughts have caused power shortages and forced rationing. As a result, Colombia has encouraged development of more non-hydroelectric electricity generation capacity, with a goal of at least 20% shares for both coal-fueled and gas-fueled power generation. Colombia is planning to increase its thermal generation capacity to 50% of its total capacity by 2010 (Energy Information Administration, 2003). About 92% of Colombia's coal production is exported.

Coal Trade (Exports)

Colombian coal exports in 2003 totaled 45.3 million metric tons (Ministerio de Minas y Energía, 2004). Carbones del Cerrejón exported 22.7 million metric tons in 2003. Of these, 67% went to Europe, 18% to North America, 6% to Central and South America, and 9% to other areas. Another important exporter was Drummond, which exported all of its production (16.4 million metric tons). As stated earlier, Colombia exports the majority of its production to Europe, the Caribbean, and the United States. Plans exist to construct three new port facilities on the Caribbean coast, at Bahía Concha, Santa Marta, and Ciénaga in the Magdalena department. Colombia's export ability would be enhanced by these ports, but until some environmental issues are resolved, the Colombian government is withholding final approval. In the César department, a new port is intended with a handling capacity of 13.6 million metric tons per year. Improvements are planned to enhance handling and transportation at Puerto Bolívar, the shipping terminal for Cerrejón Zona Norte and other nearby coal mines.The railroad from the mines to Puerto Bolívar can only currently handle 22.5 million metric tons per year. Improvements to ports would increase total output to more than 40.6 million metric tons per year from Cerrejón Zona Norte and the Cerrejón Central and Sur mines. Colombia's coal industry is aggressively seeking to expand its current exports to more than 63.5 million metric tons by 2010.

Coal Quality

The quality of coals in Colombia is quite high, as evidenced by the large quantities that are exported. Sixteen coal samples were provided by INGEOMINAS for analysis. The samples came from multiple coal areas and sample information is summarized in Table 2. The analytical results for 16 Colombian coal samples are compiled in Table 3 (proximate-ultimate and sulfur forms data), Table 4 (major oxides on the ash), and Table

5 (major-, minor-, and trace-elements). These coal quality parameters are an integral part of the WoCQI.

The moisture content of the Colombian coal samples is generally low (Table 3); two samples with more than 10 weight percent moisture were from the San Jorge coalfield in the department of Córdoba. Ash yields range from less than 1 to 21 percent, but average around 6 percent on an as-received basis. Sulfur contents are also low, most values are less than 1 percent. The sample of the Nivel 1 bed from the Guachinte Formation is an exception as it has over 5 percent sulfur. Gross calorific values were all over 10,000 Btu/lb on an as-received basis.

The majority of the ash oxides (Table 4) are silica and alumina. Iron oxides are highest in the Nivel 1 bed sample from the Guachinte Formation, which has high pyritic sulfur content. The mineral distribution in gravity fractions of two coals in the Guachinte and Golondrinas units from south west Colombia were studied by Barraza and others (1999). Quartz and kaolinite were the predominant minerals in both coals, but the Guachinte coal also contained pyrite, marcasite, hematite, and smectite, which were not significant in the Golondrinas coal. Additional quality data for these coals were presented by Rojas and others (1999) in the context of combustion reactivity, using the weighted mean activation energy as the measuring parameter. CaO is significantly higher than most samples in the Puerto Bolívar Coal - Cordoba sample, which also has a higher SO_3 value. SO_3 and Fe_2O_3 are also high in the Cauca coalfield - El Hoyo sample. Most of the other oxides in the samples analyzed for the WoCQI occur in low concentrations.

Table 5 contains major-, minor-, and trace-element concentrations for the 16 samples on a dry, whole-coal basis. The elements of most concern, potential hazardous air pollutants, include As and Hg. Concentrations of these elements are extremely low; nearly half of the Hg values are below detection limits.

Coal Utilization Impacts

Colombia was one of the first Latin American countries to implement legislation requiring environmental impact assessments (EIAs). The first of these programs was established in 1974 under Law 2811. The National Institute of Renewable Natural Resources and of the Environment (INDERENA), the first Colombian environmental protection agency, was responsible for administering the EIA requirements. The law required developers to prepare impact statements and environmental and ecological studies as a step to obtain environmental licenses. The purpose of licensing was to prepare an environmental plan that showcased activities aimed at mitigating environmental impact.

Because Colombia possesses abundant fossil fuel resources, the majority of carbon emissions are from consumption and flaring of these fuels. Over the past decade, Colombia's carbon dioxide (CO_2) emissions from fossil fuel consumption have increased by about 40% (Energy Information Administration,2003), although most of Colombia's CO_2 emissions are related to the use of petroleum.

Coalbed Methane

The first coalbed methane test wells were drilled by GeoMet Operating Company in two blocks of coal in El Cerrejón. The test well in the northeastern Cerrejón block was drilled to 910 m and intersected about 60 m of net coal, the thickest bed being about 15 m. The southwestern block (or La Loma/La Jagua) core encountered 27 m of net coal at depths between 300 and 550m, with more coal in sections not yet penetrated (Schagchow, 1997).

Coalbed gas should find markets in the Caribbean coast and the Colombian interior, as the natural gas industry is deregulated. The gas pipeline network will extend through much of the country when completed.

Conclusions

Colombia is the top coal producing country in South America. The coals are largely Cretaceous to Tertiary in age and are low in sulfur, ash, and potential hazardous air pollutants. By 2010, Colombia hopes to export 63 million metric tons of coal to Europe and the U.S. Resources of coalbed methane have potential for exploitation.

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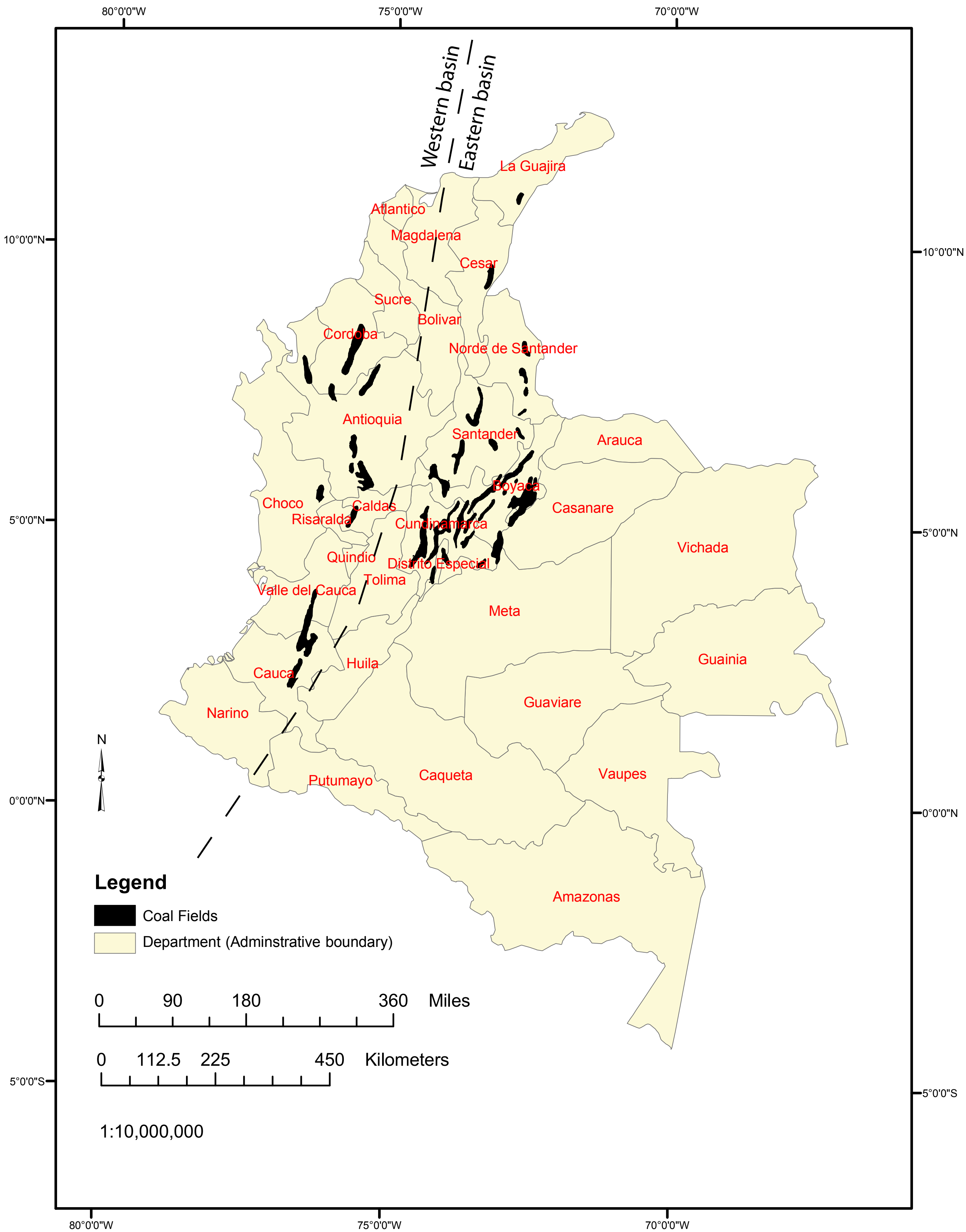

Figure 1. Location of Colombian coal basins, subbasins, and department boundaries. (source: Kottlowski and other, 1978).

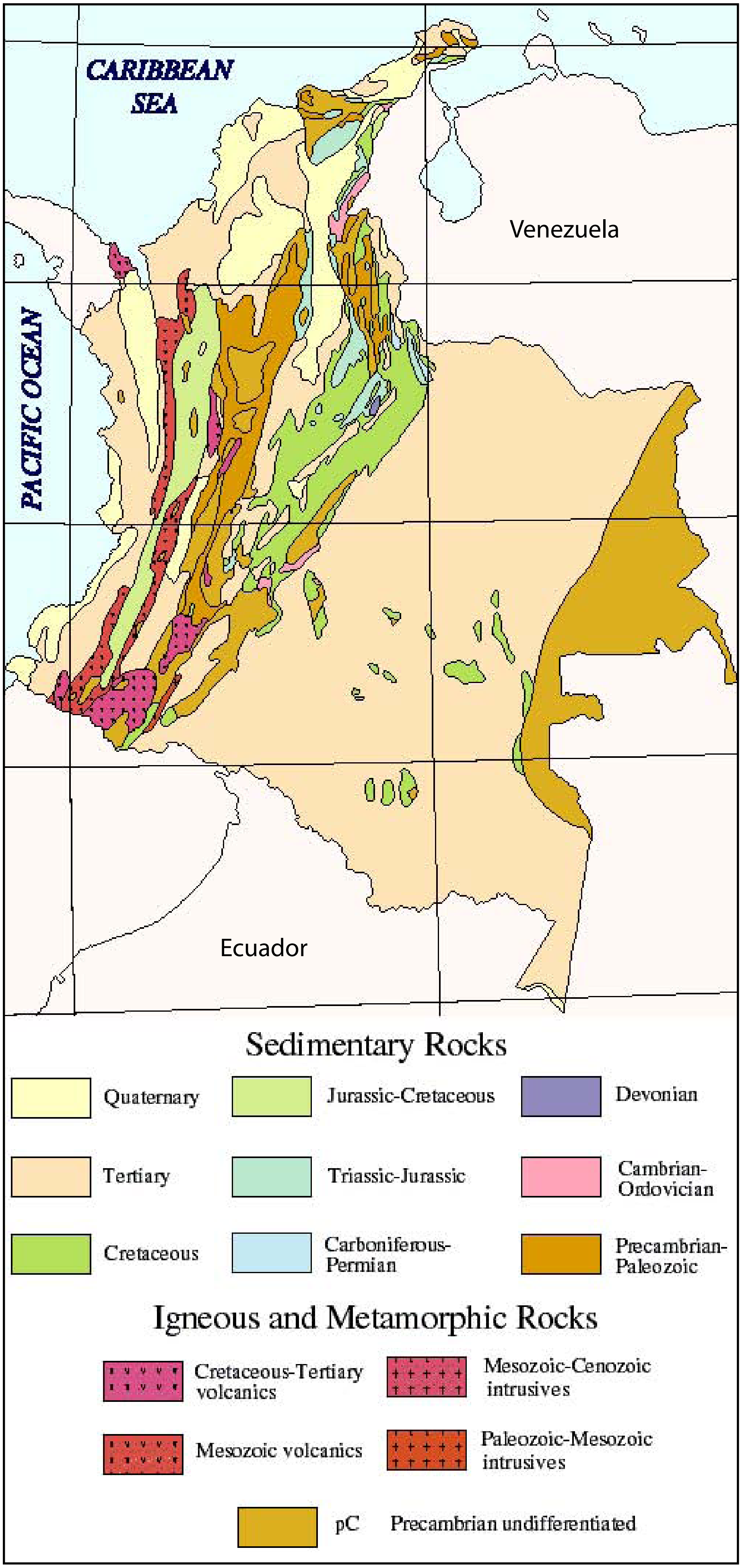

Figure 2. General geologic map of Colombia. (source:http://geology.about.com/library/bl/maps/blcolombiamap.htm)

Figure 3. The Cerrejón Zona Norte mine located in the La Guajira department (source: http://home.comcast.net/~nscolombia/index2.html - accessed 2004)

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Table 1: Coal production and consumption in Colombia, 1990-2003

(in millions of metric tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Production Total	20.5	20.0	23.8	21.22	22.67	25.87	29.56	32.74	33.75	32.75	38.14	43.44	39.53	49.32
Consumption	4.78	4.95	5.57	5.72	5.48	5.55	4.45	4.65	5.27	3.82	3.59	3.73	3.32	3.86

Source: Ministerio de Minas y Energía, 2004

Table 2. Sample Information for 16 coal samples from Colombia.

Field Number	Collector's Name	Date Collected	Country	Province Equivalent	Latitude (decimal degrees)	Longitude (decimal degrees)	Coal Province or equivalent	Formation	Bed	Mine name	Comments
Interlab 200	Lucy Barros	Dec-99	Colombia	Cauca	3.1500	-76.6511	Timba-Suzrez	Guachinte	Nivel 1		Interlab 0200
IGM 1084C	Lucy Barros	May-00	Colombia	Boyaca	5.4697	-76.6511	Suesca Abarracin	Guaduas	Piedra Gorda		Interlab 0300; bed thickness 1.5 m
IGM 1077	Lucy Barros	May-00	Colombia	Boyaca	5.9875	-72.4578	Sogamoso-Jerico	Guaduas		San Luis Paz del Rio	
IGM 1237	Elver Monterroza	Feb-00	Colombia	Cesar	9.5761	-73.4558	La Jagua de Ibirico	Los Cuervos		La Jagua de Ibirico	
IGM 1238	Elver Monterroza	Feb-00	Colombia	Cordoba	7.8497	-75.7403	San Jorge	Cerrito y Cienaga de Oro		Puerto Libertador	
IGM 1241	Orlando Pulido	May-00	Colombia	Norte de Santander	7.6847	-73.5250	Zulia-Chinacota	Los Cuervos	Cuatro	Maturin-Nivel4	
IGM 1242	Orlando Pulido	May-00	Colombia	Norte de Santander	7.9394	-72.6000	Tasajero	Los Cuervos	Superior	La Esmeralda	
IGM 1247	Orlando Pulido	Jun-00	Colombia	Norte de Santander	7.9875	-72.6244	Zulia-Tasajero	Los Cuervos	Veta Grande	Santa Cecilia	
IGM 0071C	Ricardo Barrantes	Feb-01	Colombia	Guajira	11.2742	-72.7122	Cerrejon Norte	Cerrejon	70		Manto 70
IGM 0073C	Ricardo Barrantes	Feb-01	Colombia	Guajira	11.2742	-72.7261	Cerrejon Norte	Cerrejon	75		Manto 75
IGM 0067C	Ricardo Barrantes	Feb-01	Colombia	Guajira	11.2742	-72.7261	Cerrejon Norte	Cerrejon	115		Manto 115
IGM 0074C	Ricardo Barrantes	Feb-01	Colombia	Guajira	11.2742	-72.7261	Cerrejon Norte	Cerrejon	130		Manto 130
IGM 0016	Maribel Barajas	Jun-00	Colombia	Norte de Santander	7.4544	-72.6311	Mutisca-Panplonita	Los Cuervos	Min. San Rafael		Interlab 0400
IGM 0032	Javier Becerra	Nov-00	Colombia	Cundinamarca	5.2694	-73.7369	Checua-Lenguazaque	Guaduas	Veta Grande		Interlab 0101
Interlab 201	Elver Monterroza	Feb-00	Colombia	Cordoba	7.8497	-72.7403	San Jorge	Cerrito y Cienaga de Oro	Inferior		Interlab 0201
IGM 0318	J.D. Perez	Jan-01	Colombia	Cauca	2.1914	-77.2753	Hoyo-Mosquera	Mosquera	H 3		Interlab 0301

Table 3. Proximate and ultimate analyses, gross calorific value, and forms of sulfur on an as-received basis for 16 Colombian coal samples.

[Abbreviations: Moist=moisture; %=weight percent; VM=volatile matter; FC=fixed carbon; Ash=ash yield; °C=degrees Centigrade; H=hydrogen; C=carbon; N=nitrogen; S=sulfur; O=oxygen; CV=gross calorific value; Btu/lb=British thermal units per pound; MJ/kg=Megajoules per kilogram; Sulf=sulfate sulfur; Pyr Sulf=pyritic sulfur; Org Sulf=organic sulfur.]

	Proximate Analyses				Ultimate Analyes							Forms of Sulfur		
Field Number	Moist (%)	VM (%)	FC (%)	Ash (%) (750°C)	H (%)	C (%)	N (%)	S (%)	O (%)	CV (Btu/lb)	CV (MJ/kg)	Sulf (%)	Pyr Sulf (%)	Org Sulf (%)
Interlab 200	1.70	37.67	39.29	21.34	4.45	60.16	1.05	5.12	6.18	11,150	26	0.23	3.46	1.43
IGM 1084C	1.03	31.38	59.06	8.53	4.85	78.04	1.57	0.93	5.05	14,000	33	0.01	0.12	0.80
IGM 1077	0.85	33.03	60.26	5.86	5.18	80.85	1.89	0.73	4.64	14,690	34	0.03	0.02	0.68
IGM 1237	4.55	37.08	53.97	4.40	4.88	74.61	1.46	0.59	9.51	13,200	31	0.06	0.07	0.46
IGM 1238	12.81	41.05	43.22	2.92	4.54	61.64	1.41	0.58	16.1	10,610	25	0.04	0.08	0.46
IGM 1241	1.67	38.17	54.66	5.50	5.28	78.46	1.57	0.62	6.90	14,080	33	0.03	0.09	0.50
IGM 1242	2.03	41.78	46.35	9.84	5.38	71.47	1.76	0.87	8.65	13,170	31	0.02	0.22	0.63
IGM 1247	1.16	34.23	59.66	4.95	5.19	81.04	1.52	0.60	5.54	14,570	34	0.06	0.01	0.53
IGM 0071C	3.09	36.79	58.73	1.39	5.18	78.72	1.52	0.39	9.71	13,850	32	0.06	0.01	0.32
IGM 0073C	3.66	46.18	49.15	1.01	5.33	77.70	1.73	0.47	10.10	13,770	32	0.03	0.01	0.43
IGM 0067C	3.89	39.82	55.76	0.53	5.20	75.91	1.70	0.63	12.14	13,520	31	0.01	0.09	0.53
IGM 0074C	3.99	38.72	53.02	4.27	5.13	73.82	1.15	0.33	11.31	12,900	30	0.01	0.06	0.26
IGM 0016	1.35	40.46	53.02	5.17	5.69	78.79	1.58	0.51	6.91	14,280	33	0.00	0.02	0.49
IGM 0032	2.09	39.30	47.20	11.41	5.29	70.15	1.58	1.57	7.91	12,690	30	0.03	0.53	1.01
Interlab 201	13.52	39.64	43.47	3.37	4.27	60.07	1.43	0.47	16.87	10,230	24	0.01	0.07	0.39
IGM 0318	5.53	40.73	48.16	5.58	4.83	66.92	1.59	1.13	14.42	11,670	27	0.17	0.07	0.89

Table 4. Analytical data (on an as-determined, ash basis) for ash yield and major- and minor- oxides for 16 Colombian coal samples.

[Abbreviations: Ash=ash yield; %=weight percent; °C=degrees Centigrade; Total=sum of oxides on an ash basis; nd=not determined; <=less than. Values were derived following methods described in Bullock and others (2002).]

Field Number	Ash (525°C) (%)	SiO_2 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)	Fe_2O_3 (%)	TiO_2 (%)	P_2O_5 (%)	SO_3 (%)	Total
Interlab 200	21.7	37.9	23.3	2.30	1.60	0.420	0.230	25.2	1.20	<0.020	nd	92.2
IGM 1084C	9.00	54.3	34.2	1.40	0.250	0.520	0.250	3.20	1.40	0.800	nd	96.3
IGM 1077	5.80	59.2	28.6	1.70	0.340	0.880	0.140	3.30	1.80	1.30	1.20	98.5
IGM 1237	4.40	55.8	23.3	1.10	0.580	0.460	1.30	6.70	0.970	0.660	2.00	92.9
IGM 1238	3.00	23.8	25.1	9.70	2.60	0.170	0.370	11.7	1.70	0.550	17.4	93.1
IGM 1241	5.40	56.6	27.8	2.30	0.420	0.330	0.950	4.30	1.50	0.030	1.40	95.6
IGM 1242	9.90	45.9	37.1	0.730	0.310	0.290	0.660	4.80	1.30	0.780	0.440	92.3
IGM 1247	4.90	59.5	32.9	0.660	0.320	0.110	0.490	4.80	1.30	<0.020	0.990	101.1
IGM 0071C	3.00	47.8	41.4	1.20	1.20	0.580	0.060	8.70	0.610	0.110	2.60	104.3
IGM 0073C	0.870	44.4	40.4	1.10	0.97	0.270	0.060	2.90	3.10	0.170	2.50	95.9
IGM 0067C	0.460	41.3	37.6	0.940	0.920	1.40	0.030	2.70	3.00	0.120	2.10	90.1
IGM 0074C	4.30	47.4	42.6	1.00	0.950	1.20	0.050	3.10	3.30	0.220	2.70	102.5
IGM 0016	5.20	72.6	20.3	0.380	0.350	0.260	1.30	2.30	2.30	<0.020	0.530	100.3
IGM 0032	11.5	59.6	33.0	0.350	0.280	0.200	0.690	8.20	1.40	0.310	0.580	104.6
Interlab 201	3.50	32.7	42.8	4.10	1.20	0.100	0.140	8.20	2.20	1.10	7.80	100.3
IGM 0318	6.10	32.7	30.4	5.00	3.60	0.280	0.820	16.6	0.990	0.12	13.1	103.6

Table 5. Major-, minor-, and trace- element data for 16 Colombian coal samples calculated to a dry, whole-coal basis.

[All values in µg/g (ppm), except ash yield, Si, Al, Ca, Mg, Na, K, Fe, Ti, P and S which are in weight percent. Ash=ash yield, %=weight percent, nd=not determined. Values were derived following methods described in Bullock and others (2002).]

Field Number	Ash (%) (525°C)	Si (%)	Al (%)	Ca (%)	Mg (%)	Na (%)	K (%)	Fe (%)	Ti (%)	P (%)	S (%)
Interlab 200	22.0	3.90	2.71	0.362	0.212	0.0686	0.0420	3.88	0.158	0.00192	nd
IGM 1084C	9.10	2.30	1.64	0.0908	0.0137	0.0350	0.0188	0.203	0.0761	0.0317	nd
IGM 1077	5.80	1.61	0.880	0.0706	0.0119	0.0379	0.00675	0.134	0.0627	0.0330	nd
IGM 1237	4.50	1.17	0.554	0.0353	0.0157	0.0153	0.0485	0.211	0.0261	0.0129	nd
IGM 1238	3.30	0.373	0.445	0.232	0.0525	0.00422	0.0103	0.274	0.0341	0.00804	nd
IGM 1241	5.40	1.44	0.800	0.0894	0.0138	0.0133	0.0429	0.164	0.0489	0.000712	nd
IGM 1242	10.0	2.15	1.96	0.0522	0.0187	0.0215	0.0548	0.336	0.0779	0.0340	nd
IGM 1247	4.90	1.37	0.856	0.0232	0.00948	0.00401	0.0200	0.165	0.0383	0.000429	nd
IGM 0071C	3.10	0.690	0.676	0.0265	0.0223	0.0133	0.00154	0.188	0.0113	0.00148	0.444
IGM 0073C	0.900	0.187	0.193	0.00709	0.00527	0.00181	0.000449	0.0183	0.0168	0.000669	0.516
IGM 0067C	0.500	0.0924	0.0953	0.00322	0.00266	0.00497	0.000119	0.00904	0.00861	0.000251	0.676
IGM 0074C	4.50	0.994	1.01	0.0320	0.0257	0.0399	0.00186	0.0972	0.0887	0.00430	0.332
IGM 0016	5.30	1.79	0.567	0.0143	0.0111	0.0102	0.0570	0.0849	0.0728	0.000461	0.552
IGM 0032	11.8	3.28	2.05	0.0294	0.0199	0.0174	0.0674	0.674	0.0987	0.0159	1.71
Interlab 201	4.00	0.617	0.914	0.118	0.0292	0.00299	0.00469	0.232	0.0532	0.0194	0.562
IGM 0318	6.50	0.989	1.04	0.231	0.140	0.0134	0.0440	0.751	0.0384	0.00339	1.25

Table 5. Major-, minor-, and trace- element data for 16 Colombian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	As (µg/g)	B (µg/g)	Ba (µg/g)	Be (µg/g)	Bi (µg/g)	Cd (µg/g)	Cl (µg/g)	Co (µg/g)	Cr (µg/g)	Cs (µg/g)
Interlab 200	1.50	65.1	46.2	1.43	0.0440	0.202	162	19.0	61.4	0.141
IGM 1084C	1.55	12.8	74.8	0.608	0.109	0.0998	103	2.88	7.35	0.136
IGM 1077	0.657	38.4	43.5	0.244	0.0511	0.0401	381	1.59	5.23	0.0337
IGM 1237	3.46	25.5	127	0.503	0.0261	0.135	<160	2.35	4.72	0.238
IGM 1238	2.21	60.3	173	0.429	0.0331	0.151	<170	4.22	3.52	0.0435
IGM 1241	0.653	16.9	266	2.12	0.0288	0.131	201	4.86	8.05	0.228
IGM 1242	1.16	33.3	73.2	1.34	0.0730	1.24	<160	5.52	28.2	0.380
IGM 1247	0.491	7.72	24.2	0.988	0.0192	0.157	<160	4.76	6.39	0.0885
IGM 0071C	0.327	61.1	17.0	0.0926	0.0225	0.0275	226	1.10	1.38	0.00617
IGM 0073C	0.0757	7.98	20.8	0.0514	0.00992	0.0135	404	0.392	0.483	0.00234
IGM 0067C	0.890	3.40	8.71	0.0249	0.00574	0.0124	323	0.350	0.438	0.00196
IGM 0074C	0.161	41.5	112	0.0852	0.0807	0.0179	292	1.72	11.7	0.0135
IGM 0016	0.201	14.2	39.8	1.31	0.0364	0.0845	<160	4.33	7.50	0.232
IGM 0032	5.74	52.9	80.7	0.976	0.0870	0.129	613	5.13	10.8	0.517
Interlab 201	2.24	55.3	157	0.440	0.0214	0.0444	196	7.19	4.60	0.0242
IGM 0318	7.83	34.7	217	0.291	0.0485	0.0712	<160	6.66	12.2	0.259

Table 5. Major-, minor-, and trace- element data for 16 Colombian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	Cu (µg/g)	Ga (µg/g)	Ge (µg/g)	Hg (µg/g)	Li (µg/g)	Mn (µg/g)	Mo (µg/g)	Nb (µg/g)	Ni (µg/g)	Pb (µg/g)
Interlab 200	60.1	6.67	1.87	0.10	36.3	46.9	0.858	1.25	27.3	0.572
IGM 1084C	13.4	3.24	0.517	0.081	24.6	2.97	3.14	2.01	5.29	5.85
IGM 1077	7.26	2.09	0.308	0.060	10.0	3.78	2.18	1.80	3.52	5.01
IGM 1237	8.76	1.72	2.81	0.061	6.74	10.1	2.61	0.544	6.92	1.52
IGM 1238	17.3	0.927	0.388	0.067	1.16	20.9	0.492	0.345	10.6	0.850
IGM 1241	9.95	5.93	10.2	0.040	5.10	1.91	4.37	1.07	13.6	1.76
IGM 1242	37.4	5.09	1.74	0.040	23.2	2.53	3.66	1.62	20.6	6.53
IGM 1247	8.16	4.53	1.68	0.020	3.80	2.31	4.42	0.703	12.3	2.13
IGM 0071C	9.78	1.33	1.60	<0.030	5.74	8.77	0.281	0.370	1.54	1.39
IGM 0073C	2.22	0.549	1.07	<0.030	1.36	2.01	0.487	0.111	0.724	0.757
IGM 0067C	1.49	0.242	0.546	<0.030	0.656	2.43	0.694	0.0493	0.446	0.376
IGM 0074C	5.07	1.91	0.0538	<0.030	24.6	8.16	0.426	0.574	5.60	4.66
IGM 0016	6.02	3.40	7.39	<0.030	2.72	2.07	0.412	1.39	11.1	3.02
IGM 0032	16.6	3.50	0.870	0.17	21.8	2.41	4.53	2.08	8.85	11.6
Interlab 201	17.5	1.47	0.315	<0.030	2.40	17.3	0.270	0.468	20.0	1.09
IGM 0318	38.1	2.09	2.06	0.053	4.04	2.50	0.944	0.505	18.7	1.87

Table 5. Major-, minor-, and trace- element data for 16 Colombian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	Rb (µg/g)	Sb (µg/g)	Sc (µg/g)	Se (µg/g)	Sn (µg/g)	Sr (µg/g)	Ta (µg/g)	Th (µg/g)	Tl (µg/g)	U (µg/g)
Interlab 200	1.96	0.134	24.2	3.4	1.21	121	0.101	<1.80	0.0924	0.528
IGM 1084C	1.43	0.463	2.30	8.8	0.953	73.9	0.0998	2.66	0.172	0.798
IGM 1077	0.343	0.337	1.58	6.6	0.825	86.6	0.0697	2.19	0.0180	0.581
IGM 1237	3.16	1.24	2.04	5.3	0.566	84.0	0.0427	0.387	0.148	0.404
IGM 1238	0.629	0.137	1.43	1.6	0.365	42.5	0.117	0.318	0.0402	0.124
IGM 1241	3.07	3.59	4.01	2.3	0.435	27.8	0.0402	1.06	0.103	1.01
IGM 1242	4.19	1.31	8.32	3.5	0.930	117	0.120	4.38	0.110	1.82
IGM 1247	1.19	0.762	2.24	2.7	0.315	22.3	0.0428	0.791	0.0265	0.413
IGM 0071C	0.0586	0.0772	0.562	4.2	0.460	20.6	0.0679	0.278	0.00957	0.454
IGM 0073C	0.0270	0.125	0.224	2.7	0.146	2.28	0.018	0.139	0.00288	0.112
IGM 0067C	0.0172	0.101	0.110	3.0	0.0656	1.79	0.012	0.0603	0.00766	0.0550
IGM 0074C	0.0986	0.148	0.910	6.4	0.659	19.5	0.0269	1.11	0.0386	0.556
IGM 0016	3.22	2.45	1.75	2.8	0.433	9.56	0.0449	1.66	0.0581	0.480
IGM 0032	4.59	0.988	3.30	6.4	0.882	74.0	0.129	4.17	0.929	1.46
Interlab 201	0.218	0.0606	2.43	1.7	0.283	63.0	0.0686	0.307	0.0444	0.178
IGM 0318	2.38	0.201	4.01	1.9	0.401	36.2	0.201	0.608	0.272	0.252

Table 5. Major-, minor-, and trace- element data for 16 Colombian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	V (µg/g)	Y (µg/g)	Zn (µg/g)	Zr (µg/g)
Interlab 200	120	19.1	37.0	27.7
IGM 1084C	20.2	3.42	3.30	31.4
IGM 1077	11.8	0.872	4.66	23.4
IGM 1237	14.6	2.07	29.9	10.2
IGM 1238	14.4	2.70	22.6	7.20
IGM 1241	25.3	12.8	13.8	13.7
IGM 1242	140	3.45	22.5	19.6
IGM 1247	17.1	11.1	26.4	12.6
IGM 0071C	2.59	0.636	3.18	7.19
IGM 0073C	1.68	0.204	1.24	4.52
IGM 0067C	0.670	0.110	1.01	2.37
IGM 0074C	12.5	<0.045	5.02	28.4
IGM 0016	13.3	4.53	5.81	46.2
IGM 0032	29.4	3.08	27.9	45.9
Interlab 201	21.1	3.12	28.4	15.3
IGM 0318	28.4	5.77	12.3	19.0