Chapter 7

World Coal Quality Inventory: Venezuela

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Chapter 7 of

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). As part of the WoCQI, 16 Venezuelan coal samples from Venezuela were collected and analyzed. Sample collection and analytical procedures for the WoCQI are described in the Executive Summary (Chapter 1, this volume).

Venezuela

Venezuela hosts potential resources of approximately ten billion metric tons of coal (Ministerio de Energía y Minas, 1996), making the country second to Colombia in South America in terms of coal resources (Fossil Energy International, 2002a). Coal deposits of Paleogene-Neogene age constitute approximately one-half of all coals in South America and over 55 percent of Paleogene-Neogene South American coal deposits occur in Venezuela (Weaver and Wood, 1994). Coal deposits are widely distributed in the foothills of the Coastal Ranges and Andean Cordillera and in the Maracaibo Basin of northern Venezuela (fig. 1). Due to the abundance of oil and natural gas in Venezuela (Fossil Energy International, 2002a), coal has been relatively undeveloped as a resource despite the presence of reserves of almost 500 million metric tons (Energy Information Administration, 2002). However, in the last decade, Venezuelan coal production for export has increased almost 400 percent to nine million tons per year, principally due to the development of the Guasare basin deposits at the Paso Diablo and Minas Norte mines (fig. 8) (International Energy Agency (IEA) Coal Research, 1996; Fossil Energy International, 2002a; Energy Information Administration, 2002). Currently, commercial coal mines operate in the States of Anzoátegui, Falcón, Táchira, Mérida, and Zulia (fig. 2)

(Chaves, 1997).

Much of the background material presented in this report was derived from "Carbón: una nueva alternativa de inversión en Venezuela", a comprehensive 1996 treatise on the coal industry in Venezuela. The reader is referred to this reference, written in Español by the Venezuelan Ministerio de Energía y Minas, for further information on coal in Venezuela.

Geology of Coal Areas

All currently mined coal in Venezuela occurs in Paleogene-Neogene sedimentary strata north of the Orinoco River (fig. 1). The following summary of the geology of coal areas is arranged in alphabetical order by State.

Anzoátegui: Historically, the first known coal deposits in Venezuela were from the State of Anzoátegui (fig. 3), where the Naricual deposit was developed in the early nineteenth century (González, 1938; International Energy Agency Coal Research, 1996). Liddle (1946) described six lignite to bituminous coal beds that were exploited from underground mines in the Naricual Formation in the valley of the Río Naricual. The coals were mined from beds one to three m thick interbedded with gray, micaceous, sandy, carbonaceous shales and thinly-bedded, gray sandstone. The extremely friable nature of the coals resulted in their crumbling to a fine powder which was made into briquettes for commercial sale. The coal seams in the Río Naricual valley commonly dip 70 to 85 degrees from horizontal due to intense folding of the strata, and historically, the coals have been mined from inclined shafts that followed the dip of the beds (Liddle, 1946). Coals of both the Naricual and Fila Maestra deposits are hosted in the upper Oligocene to lower Miocene Naricual Formation of the Merecure Group, described by Kiser (1997a).

Aragua: The State of Aragua, in north-central Venezuela (fig. 4), is the location of several coal deposits, and their evaluation for commercial production still is in the exploratory phases (Chaves, 1997). Important coal occurrences include El Corozo, Taguay, El Peñón, and Parapara (fig. 4) (Weaver and Wood, 1994). Coal deposits primarily occur in the upper Oligocene to lower Miocene Quebradon Formation, a lateral correlative of the Naricual Formation (Kiser, 1997a). Studies of the coal in the Taguay deposit indicate that vitrinite is the dominant coal maceral, and that the coals are higher in sulfur content and ash yield, and lower in fixed carbon and calorific value relative to other Venezuelan coals (Rodríguez, 1987; Ministerio de Energía y Minas, 1996). Weaver and Wood (1994) indicated that the rank of the Taguay coals is subbituminous and that at least two coal beds are present in the mine workings.

Falcón: The State of Falcón, in northwestern Venezuela (fig. 5), is the location of several important coal deposits, including the Cerro Pelado-Pedregal coal field located to the north of the city of Pedregal in the northern part of the State. This deposit currently is being developed by open-pit methods (Chaves, 1997). Coals of the Cerro Pelado-Pedregal deposit are hosted in the lower Miocene Cerro Pelado Formation, described by Díaz de Gamero (1989).

Mérida: The State of Mérida in western Venezuela is host to important coal deposits in the Franja Nororiental and Río Muyapá areas (fig. 6) (Ministerio de Energía y Minas, 1996).

The Franja Nororiental field encompasses an area of approximately 520 square km in western Mérida, where coals are hosted in the Paleocene Los Cuervos Formation (described by Jam, 1997a) and the Eocene-Oligocene Carbonera Formation (Savian, 1997). Active open-pit coal mines are located at El Palmital, Las Dantas-La Vega, and Río Escalante.

Coals of the Río Muyapá area currently are mined from the open-pit Palmichosa mine in the Miocene Palmar Formation, which is described by Sutton (1946) and Kiser (1997b). Coal beds of bituminous rank are found to vary in thickness from 0.3-1.65 m (Ministerio de Energía y Minas, 1996)

Táchira: The State of Táchira, in western Venezuela, is one of the major coal-producing regions of Venezuela and is host to six important Paleogene-Neogene coal fields; including Franja Nororiental (a southern continuation of the Franja Nororiental field in Mérida described above), San Félix-Río Guaramito, Franja Centro-Occidental, Rubio, Franja de Las Delicias, and Santa Domingo (fig. 7) (Ministerio de Energía y Minas, 1996). Important coal mines include Las Mesas (Río Pajitas and Finca Familia Arellano) in the Franja Nororiental coal field, Caliche in the San Felix-Río Guaramito coal field, Hato de la Virgen and Lobatera in the Franja Centro-Occidental coal field, Las Adjuntas and Cerro Capote in the Rubio coal field and Santo Domingo in the Santo Domingo coal field (Weaver and Wood, 1994; Ministerio de Energía y Minas, 1996; Martínez and others, 2001).

Coal deposits of Táchira are hosted in the Paleocene Los Cuervos Formation and the Eocene-Oligocene Carbonera Formation (Martínez and others, 2001). The Carbonera was mentioned in the preceding description of the coal deposits of Mérida. The Paleocene Los Cuervos Formation of the Orocue Group was described by Notestein and others (1944).

Zulia: The State of Zulia, in western Venezuela, contains over 80 percent of the coal resources of Venezuela in two main districts; Guasare in the north and Santa Rosa-Catatumbo in the southern part of the State (fig. 8) (Rodríguez, 1995). The Guasare district is host to five mines and/or known coal deposits, including the Paso Diablo, Socuy, Minas Norte, Cachirí, and Riecito Palmar localities. All coals in the Guasare coal field occur in the Paleocene Marcelina Formation (Sutton, 1946; Jam, 1997b). Ruíz (1983) reported that the Marcelina Formation hosted 25-30 coal beds ranging in thickness from 1-13 m.

The open-pit Paso Diablo mine, located about 85 km northwest of Maracaibo, contains 22 coal beds occurring over an interval of approximately 400 m (Ministerio de Energía y Minas, 1996). The total thickness of coal averages 60 m (Ministerio de Energía y Minas, 1996). The coals are consistent in thickness and lateral continuity across the mine area, where the beds dip 5-15 degrees to the southeast (Ministerio de Energía y Minas, 1996). The mine is operated by Carbones del Guasare, a subsidiary of Petróleos de Venezuela (Petróleos de Venezuela, 2001a). Sixteen coal beds, ranging between 0.5-13 m in thickness, currently are produced in the Paso Diablo mine (Petróleos de Venezuela, 2001b).

The Socuy deposit is located several kilometers south-southwest of the Paso Diablo mine. More strain is recorded here in the strata than to the north and the coal beds have steeper dips, ranging from 20-30 degrees from horizontal (Ministerio de Energía y Minas, 1996).

Minas Norte hosts 33 coal beds of bituminous rank, of which 21 are thicker than one meter (Ministerio de Energía y Minas, 1996). At this locality, a 533 m section in the Marcelina Formation contains 62.5 m total thickness of coal (Ministerio de Energía y Minas, 1996). Carbones de la Guajira, a subsidiary of Petroleos de Venezuela, has been producing coal from the Norte deposit since 1996 (Petróleos de Venezuela, 2001c).

The Cachirí and Riecito Palmar deposits of the Guasare basin currently are in the exploration phase. Approximately forty meters of total coal occur within the 20 beds at the Cachirí deposit. Seven beds of coal are present at the Riecito Palmar deposit (Ministerio de Energía y Minas, 1996).

The Santa Rosa-Catatumbo district in southern Zulia contains coals hosted in the Carbonera and Los Cuervos Formations, described above in the sections on the States of Mérida and Táchira. The Tocuco-Aricuaisá deposit of this district is being developed by CORPOZULIA, a State development corporation (Ministerio Energía y Minas, 1996).

Coal Resource Assessments

Coal resource estimates for Venezuela predictably vary according to the source and date of the information. The U.S. Department of Energy estimates Venezuela's total potential coal resource to be as much as 8.25 billion metric tons, ranking the country second in South America behind only Colombia in terms of resources (Fossil Energy International, 2002a). The Venezuelan Ministerio de Energía y Minas (1996) lists potential coal resources as slightly more than ten billion metric tons (Table 1), of which 8.65 billion metric tons are contained in the coal fields of Zulia, representing over eighty percent of the country's total coal resources. Total reserves of Venezuela are estimated by the U.S. Department of Energy to be on the order of 480 million metric tons (Fossil Energy International, 2002a; Energy Information Administration, 2002). In the Guasare Basin (fig. 8), approximately 70 percent of the reserves can be extracted by open-pit mining methods (Petróleos de Venezuela, 2001a). Reserves of the Paso Diablo deposit (fig. 8) are estimated at 180 (Ministerio de Energía y Minas, 1996) to 200 million metric tons (Petróleos de Venezuela, 2001b) and are entirely recoverable through open-pit mining methods. Reserves recoverable through open-pit methods in the Socuy deposit (fig. 8) are estimated at 215 (Petróleos de Venezuela, 2001a) to 226 million metric tons (Ministerio de Energía y Minas, 1996).

Elsewhere in Venezuela, potential resources of the Fila Maestra deposit in Anzoátegui (fig. 3) are about 50 million metric tons, and measured and inferred reserves are 4.4 million metric tons (Ministerio de Energía y Minas, 1996). Total resources in Anzoátegui are estimated to be 150 million metric tons (Ministerio de Energía y Minas, 1996). Weaver (1993) reported that coal resources in northern Aragua (fig. 4) were in the range of 20-30 million metric tons and the Ministerio de Energía y Minas (1996) estimates Aragua's resources at 34 million metric tons. In Falcón (fig. 5), remaining resources of the Coro deposit are 4 million metric tons at less than 150 m depth, and 1.4 million metric tons at the El Isiro deposit at less than 150 m depth (Ministerio de Energía y Minas, 1996). Coal resources in total for Falcón are estimated to be 46 million metric tons (Ministerio de Energía y Minas, 1996). Potential resources in the concessions of Cerro Pelado (fig. 5), occurring over an area of about 400 square kilometers at less than 150 m depth, are about 27.5 million metric tons and identified reserves in this same area are 14.8 million metric tons (Ministerio de Energía y Minas, 1996). Guarico (see fig. 2) contains resources of 50 million metric tons; Mérida (fig. 6) contains resources of approximately 9 million metric tons; and coal resources for Táchira (fig. 7) in total are estimated to be between 1.0-1.5 billion metric tons (Weaver, 1993; Ministerio de Energía y Minas, 1996).

Coal Production

Venezuela currently is the third largest coal-producing nation in Latin America, following Colombia and Brazil (Fossil Energy International, 2002a). Prior to 1988 and the development of the Guasare basin coal fields in

Zulia (fig. 8), annual production averaged around only 100,000 metric tons (IEA Coal Research, 1996). In 2000, Venezuelan coal production was over 7.9 million metric tons (table 2), of which almost all was exported to other countries including other South American nations, the eastern United States, and Europe (Energy Information Administration, 2002). In the mid-1990s, approximately 98 percent of the produced Venezuelan coal was exported (International Energy Agency Coal Research, 1996).

Anzoátegui: Coal has been mined in Venezuela for over a century (International Energy Agency Coal Research, 1996), and coal deposits were first exploited in Anzoátegui from the Naricual locality (fig. 3) (González, 1938; Chaves, 1997). The last major exploitation phase of the Naricual deposit began in 1970 and production had reached annual volumes of about 270,000 metric tons from open-pit excavations before mining operations ceased in 1993 (Chaves, 1997). Cumulative production of the Fila Maestra deposit (fig. 3) in Anzoátegui was reported to total 1 million metric tons between 1987 and 1993, when mining operations also temporarily ceased here (Ministerio de Energía y Minas, 1996). Production recently has resumed at the Fila Maestra deposit under the management of the company GEOCONSA and coal is mined by both open-pit and underground operations (GEOCONSA, 2002). Coal from the mine was exported from the port of Guanta (fig. 3) beginning in August 2002 (GEOCONSA, 2002; PetroLatin, 2002).

Aragua: Small-scale production at the El Corozo deposit (fig. 4) in Aragua during the period 1937 to 1950 totaled approximately 30,000 metric tons (Ministerio de Energía y Minas, 1996). Four coal seams, the Peñón Este, La Compuerta, Media Luna, and El Tigre, were exploited in underground mines. The Taguay coal deposit (fig. 4) was produced prior to 1949 (Ministerio de Energía y Minas, 1996).

Falcón: Coal has been produced in Falcón (fig. 5) since at least 1904 (Liddle, 1946). Annual coal production was on the order of 0.4 million metric tons in the mid-1990s (International Energy Agency Coal Research, 1996), and large-scale development of the coal fields in the Cerro Pelado-Pedregal region (fig. 5) was reported to be in the planning stages in the late 1990s (El Universal, 1997). Production for late 1998 and 1999 was forecast to be on the order of 200,000 metric tons of coal per month (El Universal, 1997). The

Cerro Pelado mines are operated by CORPOFALCON, a State-owned company responsible for the development of the deposit.

Mérida: Relatively little information is available regarding current or historical coal production in the state of Mérida (fig. 6). The Ministerio de Energía y Minas (1996) reported that the discovery of important coal deposits in the state was relatively recent compared to other regions in Venezuela.

Táchira: Coal in Táchira (fig. 7) is produced by a number of relatively small mining companies including Exmivenca, Copemin, Capote, and Asocoque, under the auspices of Carbones del Suroeste, a State agency responsible for the development and promotion of the coal industry (Chaves, 1997). Coal is exported from Táchira to the United States and Caribbean region through the port of Ceiba (fig. 7) on Lake Maracaibo (International Energy Agency Coal Research, 1996). Production from the largest mining cooperative of the region, Exmivenca, was 0.7 million metric tons in the mid-1990s (World Coal, 1995), and production for the Táchira region was forecast to increase to 2.7 million metric tons per year by 2010 (International Energy Agency Coal Research, 1996).

Zulia: The most important current coal production in Venezuela today occurs in the State of Zulia (fig. 8) where coal has been mined since at least 1917 (Liddle, 1946). The Paso Diablo mine is worked by approximately 1,200 men who produce about 6.5 million metric tons of coal annually from two beds in the open-pit mine (Chaves, 1997; Petróleos de Venezuela, 2001b).

Production from the Norte mine is approximately 1.2 million metric tons per year (Petróleos de Venezuela, 2001c). The coal from the Guasare mines is transported by trucks to a shipping terminal in Santa Cruz de Mara (fig. 8), a distance of approximately 85 km from the coal fields (Petróleos de Venezuela, 2001d). Coal then is loaded onto barges by a conveyor system with a loading capacity of approximately 1000 metric tons per hour (Petróleos de Venezuela, 2001d). Loaded barges are escorted by tug boat to Maracaibo (fig. 8), where the coal is transferred onto ocean-going vessels for export (Petróleos de Venezuela, 2001d).

In addition to the coals produced from the Norte and Paso Diablo mine, planning estimates forecast a maximum annual output of ten million metric tons from the Socuy deposit (Petróleos de Venezuela, 2001d). All of the coal produced in the Guasare Basin from the Paso Diablo and Norte mines currently is exported (Petróleos de Venezuela, 2001d).

Coal production in Venezuela currently is limited by internal infrastructure and transportation constraints, though the Venezuelan government has announced plans to increase coal production to almost 20 million metric tons per year by 2008 (Energy Information Administration, 2002). In the summer of 2002, CARBOZULIA, responsible for the management of Carbones del Guasare and Carbones de Guajira in Zulia, announced that it would increase the output of the Paso Diablo and Norte mines to a total annual production of eight million metric tons (Fossil Energy International, 2002a). CARBOZULIA plans call for construction of a 70 km railroad line to link the Paso Diablo and, eventually, the Socuy mine with a deep-water port at Pararú (fig. 8) where coal would be loaded directly onto oceangoing vessels for export (International Energy Agency Coal Research, 1996).

Coal Uses

Production of the vast oil and natural gas resources of Venezuela has long exceeded national consumption, providing little incentive to develop coal as a domestic thermal energy source. Hydroelectric power also is a readily available, renewable natural resource in Venezuela, contributing 6.7 percent of the total energy produced in the nation in 1996 (Fossil Energy International, 2002b). In contrast, coal contributed only 1.1 percent of the total produced energy (Fossil Energy International, 2002b). Currently, there is no coal-fired electrical generation in Venezuela (Energy Information Administration, 2002). Annual domestic coal consumption since 1990 typically is less than 500,000 metric tons (Fossil Energy International, 2002a, b), and is restricted to industries such as cement production (International Energy Agency Coal Research, 1996). In 1999, 1.05 million metric tons were used for domestic consumption, declining to 0.41 million metric tons in 2000 (table 2) (Fossil Energy International, 2002a).

Coal Trade

Carbones del Guasare manages the Paso Diablo mine (fig. 8) and exports coal to the United States, Italy, France, Spain, Holland, and the United Kingdom. The product from the Norte mine is managed by Carbones de la Guajira, which exports coal to the United States and countries in South and Central America. In 1999, these agencies exported 6.4 million metric tons of coal, of which approximately 75 percent ultimately was used for thermal energy and 25 percent for metallurgical purposes (Petróleos de Venezuela, 2001c). Coal produced from the Paso Diablo mine is marketed by Carbones del Guasare as two separate products: 1) a standard coal and 2) a premium grade coal with a relatively higher energy content and lower ash and sulfur content (Petróleos de Venezuela, 2001c). A small quantity of coal is imported to Venezuela for metallurgical use; in 1995, 108,000 metric tons were imported, primarily from the United States and Colombia (Fossil Energy International, 2002b).

Coal Quality

Proximate and ultimate analytical data for Venezuelan coals can be found in the scientific literature and on the World Wide Web (Rodríguez, 1986; Weaver and Wood, 1994; Ministerio de Energía y Minas, 1996; Escobar and others, 1997; Petróleos de Venezuela, 2001a, 2001b). In addition, a limited amount of data on the trace element concentrations of Venezuelan coals is available (Martínez and others, 2001). However, data on concentrations of elements of environmental concern, particularly the potentially hazardous air pollutants (HAPs) identified in the United States Clean Air Act Amendments of 1990, are sparse or unavailable. In addition, the available data typically are in relatively obscure, Spanish-language publications, which do not consistently contain reference to the type of analytical scheme used or the basis on which the data are presented. Therefore, the USGS, in partnership with the Instituto Nacional de Geología y Minería of Venezuela (INGEOMIN), analyzed 16 coal samples from active mines in the States of Táchira, Mérida, and

Zulia, western Venezuela, as part of the WoCQI project.

The coal samples were collected from active mines by personnel of INGEOMIN and analyzed in contract laboratories following American Society for Testing and Materials (ASTM) methods and procedures (ASTM, 1998), and in USGS laboratories following the analytical methods described in Bullock and others (2002). Information pertaining to sample collection and location is compiled in Table 3. Coal quality parameters include proximate and ultimate analyses, forms-of-sulfur data, and major-, minor-, and trace-element concentration analyses (Tables 4-6).

The coal samples were collected from surface and underground mines developed in coal-bearing intervals of the Los Cuervos, Carbonera, and Palmar Formations in the States of Mérida (four samples) and Táchira (ten samples), and in the Marcelina Formation in the State of Zulia (two samples). The limited number (16) of samples from Venezuela precludes any rigorous statistical treatment of the analytical data and therefore only general comments are provided. In addition, samples from the Fila Maestra (Anzoátegui; fig. 3) and Cerro Pelado (Falcón; fig. 5) mines, which currently are active, were not obtained for this study due to access limitations.

Proximate analytical results (Table 4) indicate that, on an as-received basis, the Venezuelan samples have an average ash yield of 5.13 weight percent, ranging from 0.41-16.85 weight percent ash. Coal samples from the Paso Diablo and Norte mines in the Guasare basin of Zulia, which constitute the vast majority of Venezuela's currently-produced coal, have exceptionally low ash yields of 0.41 and 1.83 weight percent (as-received basis), respectively. The samples range in sulfur content from 0.27-6.21 weight percent and, as with ash yield, the Guasare basin samples are relatively low in sulfur; 0.36 weight percent for Paso Diablo and 0.4 weight percent for Norte.

Gross calorific values range from 10,840-16,010 British thermal units per pound (Btu/lb)] on a moist, mineral-matter-free basis, and average 14,300 Btu/lb. The coal samples range in apparent rank from subbituminous A (one sample) to high volatile bituminous A using the ASTM D388 classification (ASTM, 1998).

Concentrations of the potential hazardous air pollutants (HAPs) mercury and arsenic in coals are of concern, because release of these potentially toxic elements into the environment may cause health problems (Finkelman and others, 2002). Mercury concentrations in Venezuelan coals range from below detection limits to 2.1 ppm in the sample from the Las Mesas-Río Pajitas mine in the Franja Nororiental of Táchira (fig. 7), the sample with the highest pyritic sulfur content (Table 4). Mercury concentrations were below the detection limit (0.03 ppm) in both of the samples from the Guasare basin. Arsenic concentrations in Venezuelan coals range from less than 0.004 ppm to a maximum of 71 ppm in the high-pyrite Las Mesas-Río Pajitas sample. The high concentrations of arsenic and mercury in this particular sample may be the result of the leaching of these elements from overlying strata into the sampled coal bed (Manuel Martínez, University of Central Venezuela, Caracas, written communication, 2004). Arsenic concentrations in the Guasare basin samples are particularly low; below detection limits (0.004 ppm) in the Norte sample and 0.021 ppm in the Paso Diablo sample.

The Venezuelan coals are noteworthy because of the exceptionally low ash yield (generally less than five weight percent as-received), the extraordinarily low concentrations of elements such as Hg, As, Cd, Li, Rb, and the low concentrations of most other elements (Ni and Se being among the few exceptions), in many of the samples. Coals with such low ash yield are known from only a few other locations worldwide, such as Colombian coals to the west of Zulia and coals in New Zealand. It is likely that these low-ash coals formed in settings that were well-protected from detrital input, perhaps in a domed ombrogenous peat deposit in a stable deltaic environment.

Coalbed Methane

Coalbed methane potential has not been widely assessed in Venezuela but the Maracaibo and Oficino basins (fig. 1) potentially host large gas accumulations in the abundant shallow to moderate depth coal intervals. Limited data from conventional gas production in these basins suggest that there are abundant, gassy coals at less than 1500 m depth which may be thick enough to be exploited as coal bed methane reservoirs (Vasquez-Herrera and others, 1996).

Conclusions

Coal is an abundant natural energy resource in Venezuela, where resources are estimated to be on the order of ten billion metric tons, and measured reserves are over 450 million metric tons. Coal is widely distributed, occurring in the foothills of the Coast Ranges and Andes as well as in the Maracaibo Basin of northern Venezuela, with coal mines currently producing coal from Tertiary strata in the States of Anzoátegui, Falcón, Mérida, Táchira, and Zulia. Coal production has increased almost four-fold in the last decade due to the development of the Guasare basin coal fields in Zulia. Mines in this basin produce about eight million metric tons of coal per year with production forecasts of 20 million metric tons per year by 2005. Nearly all of the coal mined in Venezuela goes to the export market. The relatively low concentrations of sulfur, ash yield, mercury and arsenic in Venezuelan coals, particularly in samples from the Guasare basin, coupled with relatively high calorific values, make these coals particularly desirable for exploitation as an energy resource.

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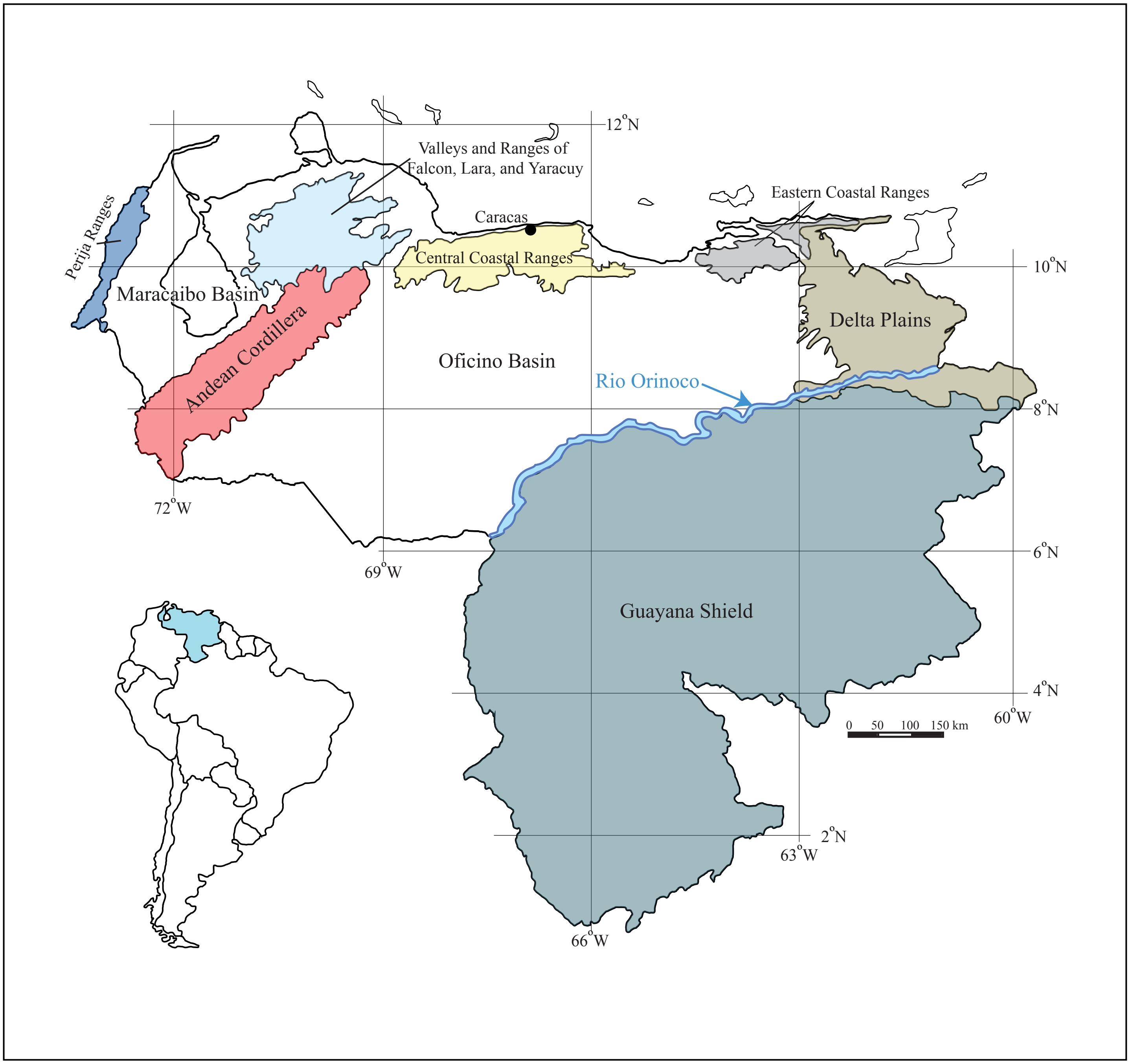
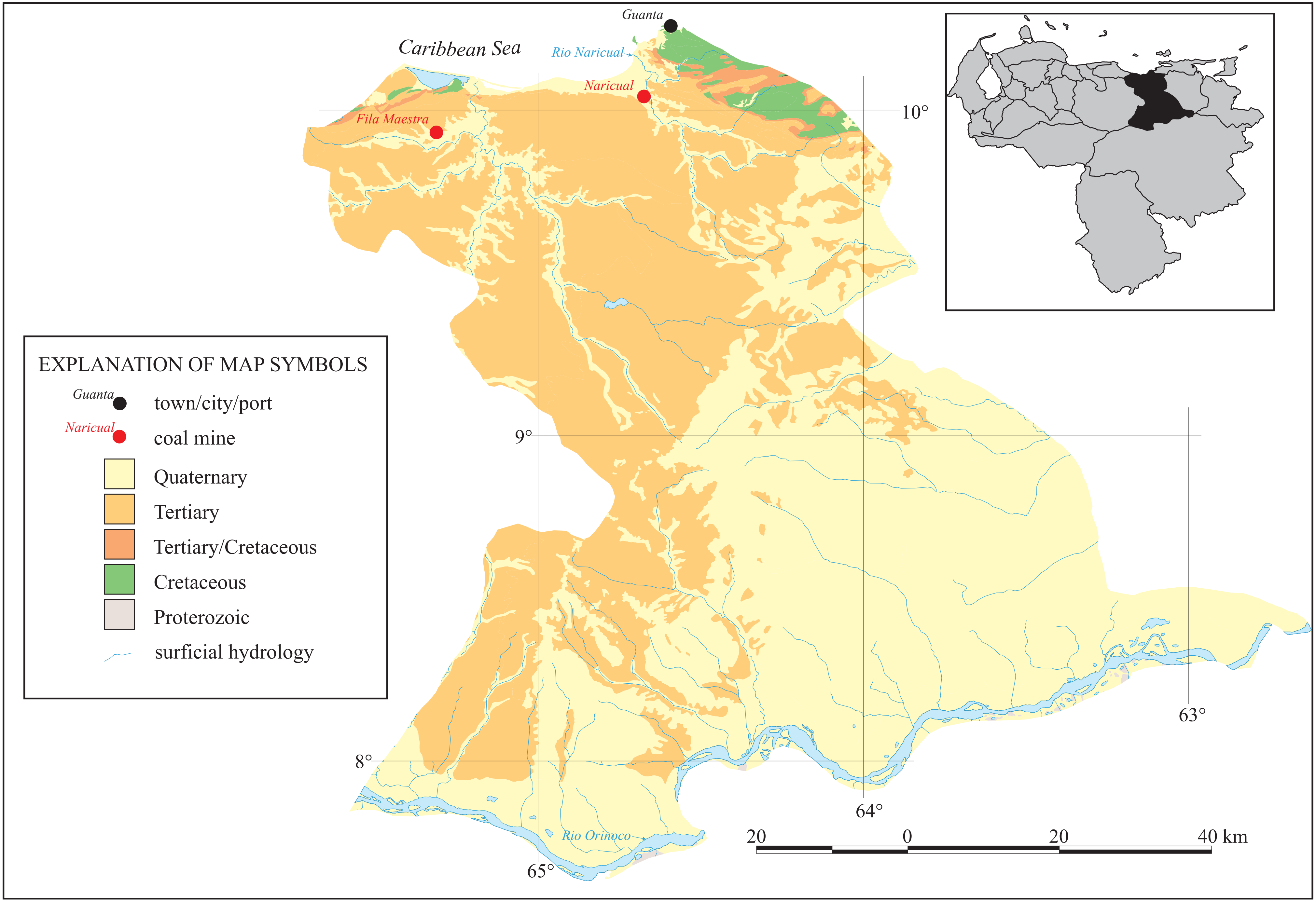


Figure 1. Map of Venezuela showing principal physiographic provinces. Venezuela is shaded blue in index map of South American continent. Physiographic province boundaries from Freile (1962).

Figure 2. Shaded relief map of Venezuela showing internal political boundaries and neighboring Caribbean and South American nations. Venezuela shaded blue in index map of South American continent. Shaded relief image from U.S. Geological Survey global 30-arc-second elevation data set (1996).



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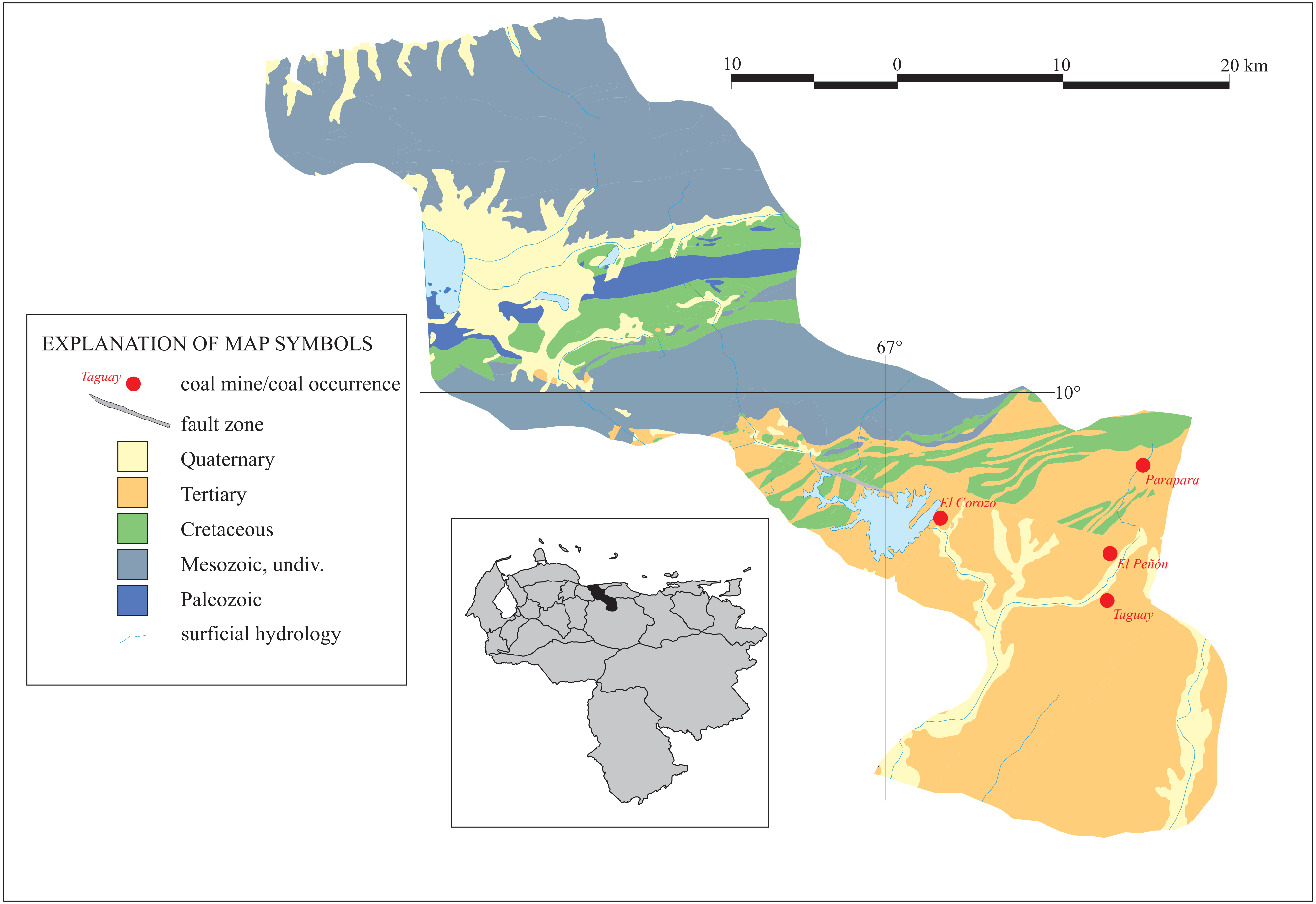

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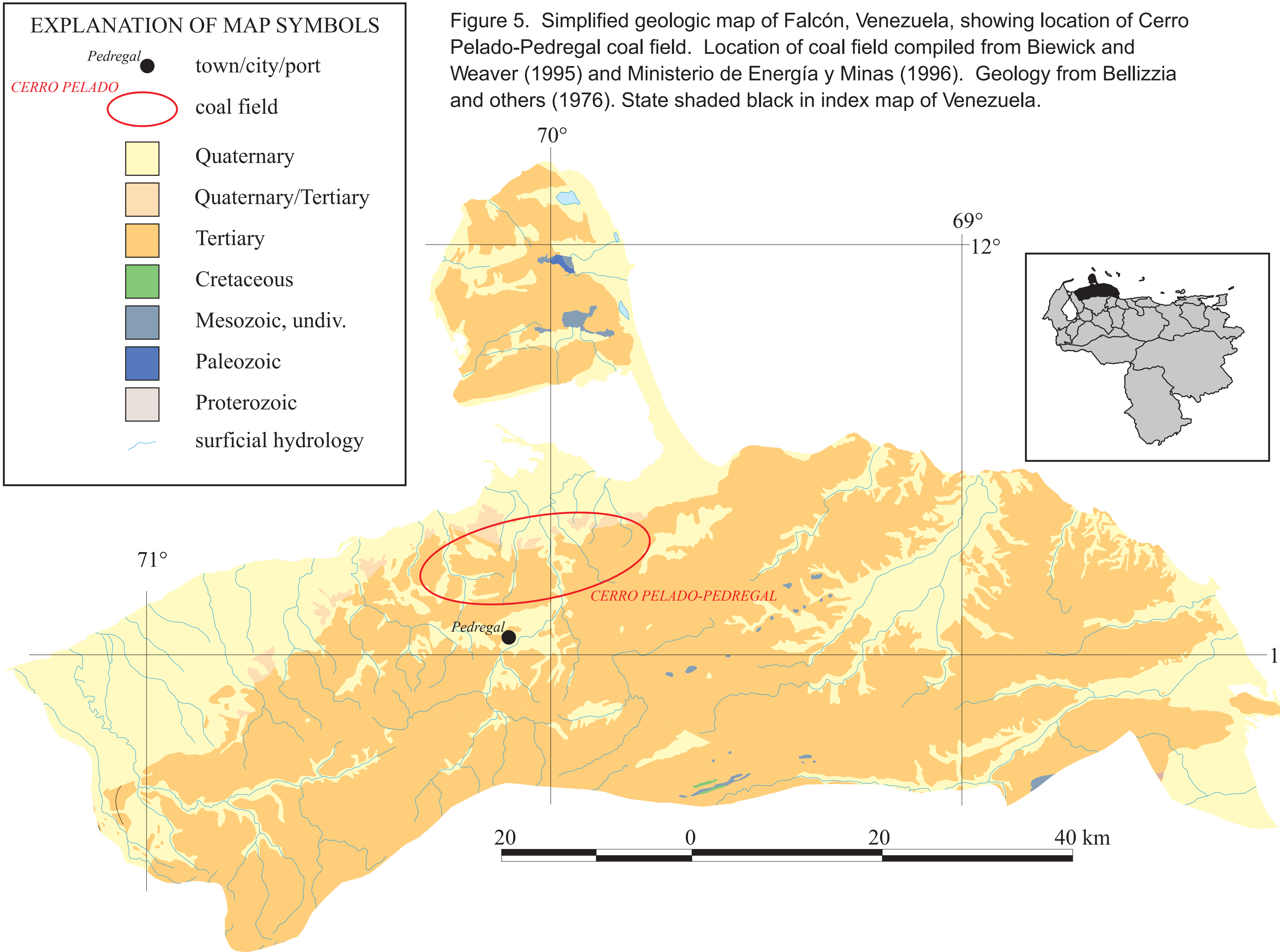

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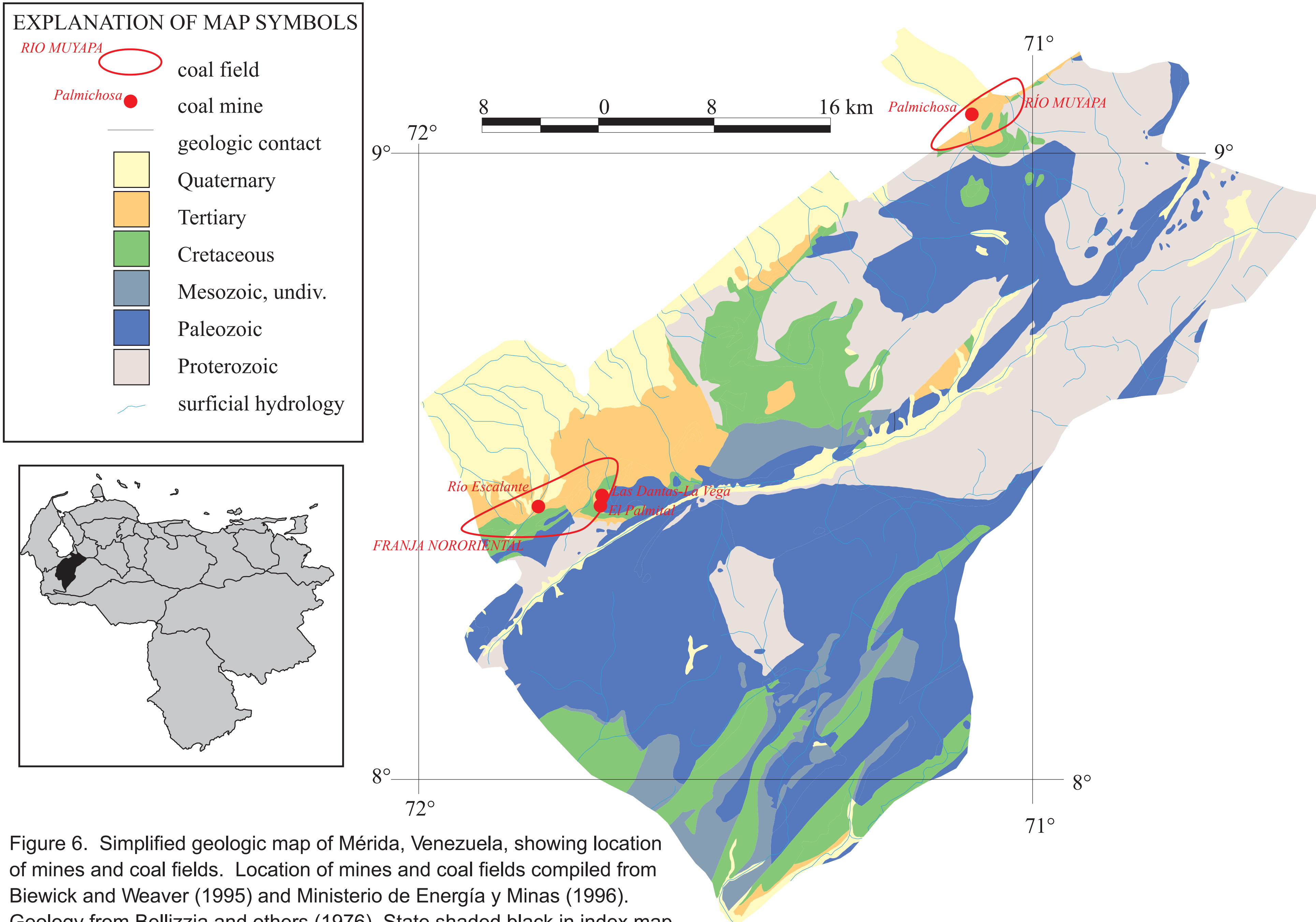

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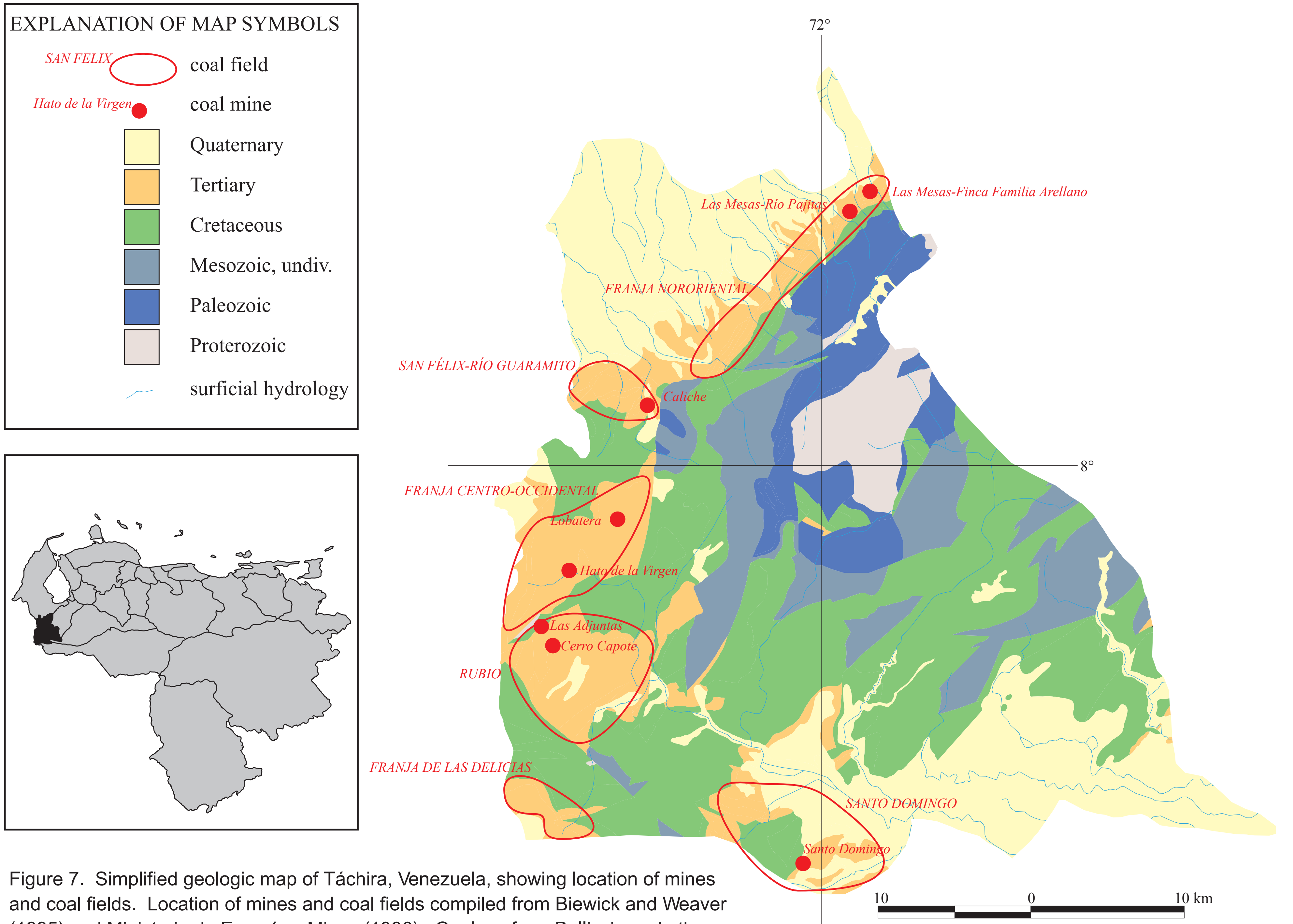

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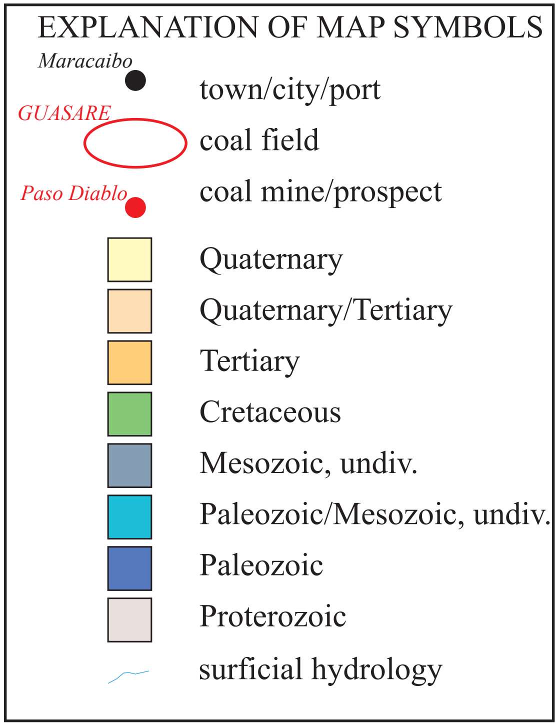

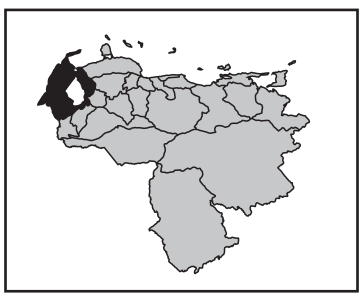

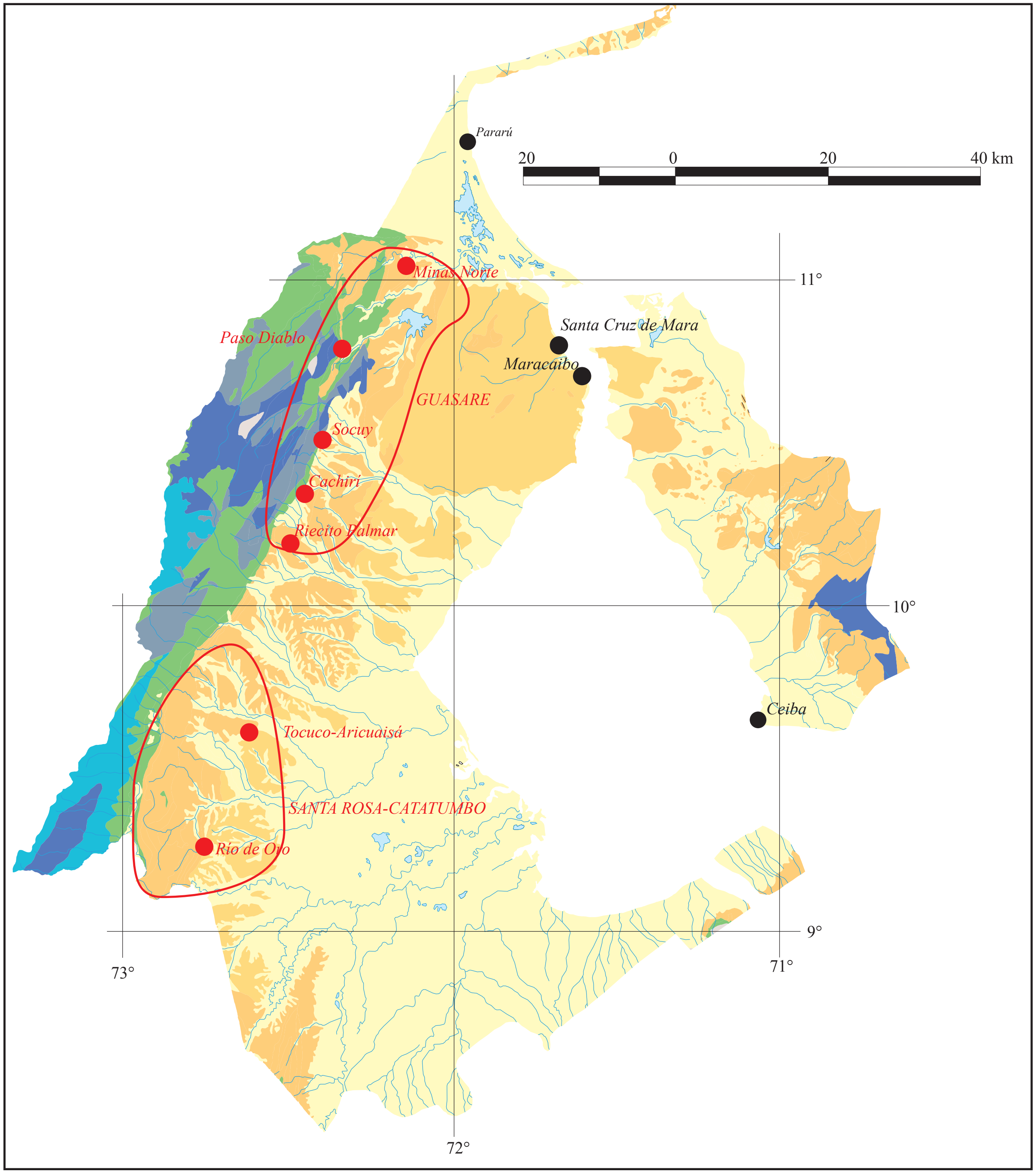

Figure 8. Simplified geologic map of Zulia showing locations of mines/prospects and coal fields. Locations of mines/prospects and coal fields compiled from Biewick and Weaver (1995) and Ministerio de Energía y Minas (1996). Geology from Bellizzia and others (1976). State shaded black in index map of Venezuela.

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Table 1. Coal mines of Venezuela with resource and reserve figures. Compiled from Ministerio de Energia y Minas (1996). Abbreviations: MMT = million metric tons, BMT = billion metric tons, * = recoverable through surface mining.

State	Coal District	Mine/Prospect	Potential Resources (MMT)	Measured and Inferred Reserves (MMT)
Anzoátegui		Fila Maestra	50.	4.4
		Naricual	100.	
Aragua			34.	
Falcón		Cerro Pelado	27.5	14.8
		Coro	4.	
		El Isiro	1.4	
Guarico			50.	
Mérida	Franja Nororiental		4.	
	Río Muyabá		5.	
Táchira	Franja Nororiental		200.	
	San Félix-Río Guaramito		172.	
	Franja Centro-Occidental			
		Lobatera		25.
		Hato de la Virgen		100.
	Rubio			
		Las Adjuntas	275.	
		Cerro Capote	22.	
	Franja de Las Delicias		5.	
	Santo Domingo		283.	
Zulia	Guasare			
		Minas Norte	1230.	59*
		Paso Diablo	2886.	180*
		Socuy	2910.	226*
		Cachirí	1463.	14*
		Riecito Palmar	83.	
	Catatumbo			
		Tocuco-Aricuaisá	3.	
		Casigua	74.	
		Total	**10 BMT**	

Table 2. Coal production and consumption in Venezuela in millions of metric tons, 1987-2001. From Fossil Energy International (2002a, b) and Torres (2002). Abbreviations: n.d. = no data.

Year	Production	Consumption
1987	0.06	0.24
1988	1.09	0.32
1989	2.12	0.34
1990	2.17	0.23
1991	2.18	0.00
1992	2.45	<0.01
1993	3.82	<0.04
1994	4.28	0.07
1995	4.06	<0.01
1996	3.64	0.21
1997	5.29	<0.05
1998	6.46	1.32
1999	6.59	1.05
2000	7.91	0.41
2001	7.69	n.d.

Table 3. Sample location and description information for Venezuelan coal samples. Latitude and longitude coordinates in decimal degrees obtained by GPS at time of sample collection.

	Sample ID	Latitude	Longitude	Locality	Name of Mine/Concession	Mine Type	Formation	Age
Mérida	M1-QP	8.441266548	-71.69080603	Quebreda El Palmital	El Palmital	Surface	Carbonera	Eocene-Oligocene
	M2-CDLV	8.448180187	-71.69061801	Carretera Las Dantas La Vega	Las Dantas-La Vega	Surface	Carbonera	Eocene-Oligocene
	M3-RE	8.43338877	-71.79267412	Río Escalante	Escalante	Surface	Carbonera	Eocene-Oligocene
	M4-QPA	9.069815739	-71.09390347	Quebreda Palmichosa	Palmichosa	Surface	Palmar	Middle Miocene
Táchira	M5-RP	8.392323201	-71.93938024	Río Pajitas	Las Mesas - Escalante 17	Surface	Carbonera	Eocene-Oligocene
	M6-FA	8.409814952	-71.90384841	Finca Familia Arellano	Las Mesas - Escalante 17	Surface	Carbonera	Eocene-Oligocene
	M7-LC	8.085782942	-72.23794753	Caliche	Cuchilla 3	Underground	Carbonera	Eocene-Oligocene
	M8-M1LA	7.761854265	-72.41608368	Las Adjuntas	Las Adjuntas	Surface	Los Cuervos	Upper Paleocene
	M8-M2LA	7.761854265	-72.41608368	Las Adjuntas	Las Adjuntas	Surface	Los Cuervos	Upper Paleocene
	M10-LC	7.40134303	-72.02840932	Campamento KOPEX	Santo Domingo	Surface	Los Cuervos	Upper Paleocene
	M11-HV	7.848697632	-72.36808288	Hato de la Virgen	Hato de la Virgen	Surface	Carbonera	Eocene-Oligocene
	M12-CA	7.922878177	-72.29072114	Casadero	Lobatera	Underground	Carbonera	Eocene-Oligocene
	M13-LP	7.737676949	-72.39907198	La Pajarita	-	Underground	Carbonera	Eocene-Oligocene
	M14-SC	7.737676949	-72.39907198	Cerro Capote	Silla de Capote	Underground	Carbonera	Eocene-Oligocene
Zulia	Guajira	11.04216	-72.27273	Paez	Minas Norte	Surface	Marcelina	Upper Paleocene
	Guasare	11.05000	-72.17000	Paez	Paso Diablo	Surface	Marcelina	Upper Paleocene

Table 4. Proximate and ultimate analyses, gross calorific value, and forms of sulfur on an as-received basis for 16 Venezuelan 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; m, mmf=moist, mineral matter free; MJ/kg=Megajoules per kilogram; Sulf=sulfate sulfur; Pyr Sulf=pyritic sulfur; Org Sulf=organic sulfur.]

	Proximate Analyses				Ultimate Analyses								Forms of Sulfur		
Field Number	Moist (%)	VM (%)	FC (%)	Ash (%) (750°C)	H (%)	C (%)	N (%)	S (%)	O (%)	CV (Btu/lb)	CV m, mmf (Btu/lb)	CV (MJ/kg)	Sulf (%)	Pyr Sulf (%)	Org Sulf (%)
M1-QP	3.49	43.75	50.89	1.87	6.07	76.82	1.72	0.84	9.19	14,060	14,320	33	0.02	0.07	0.75
M2-CDLV	2.03	44.23	36.89	16.85	5.41	62.29	1.31	6.21	5.90	12,030	14,910	28	0.15	3.55	2.51
M3-RE	6.75	45.04	44.75	3.46	5.63	69.61	1.39	0.91	12.25	12,600	13,060	29	0.02	0.05	0.84
M4-QPA	11.25	39.45	44.44	4.86	4.61	62.95	1.43	3.42	11.48	11,290	11,910	26	0.04	2.37	1.01
M5-RP	1.46	39.40	43.72	15.42	5.01	65.94	1.22	5.97	4.98	12,380	15,090	29	0.06	5.16	0.75
M6-FA	4.47	52.74	35.12	7.67	6.60	69.98	1.24	0.43	9.61	13,320	14,500	31	0.02	0.09	0.32
M7-LC	0.93	42.68	51.84	4.55	6.09	79.33	1.47	2.61	5.02	14,640	15,480	34	0.03	1.76	0.82
M8-M1LA	6.48	33.69	58.40	1.43	4.60	73.78	1.67	0.62	11.42	12,820	13,020	30	0.04	0.03	0.55
M8-M2LA	3.82	34.93	59.45	1.80	5.15	78.35	1.59	0.59	8.70	13,830	14,110	32	0.02	0.02	0.55
M10-LC	16.66	39.59	42.84	0.91	4.35	62.40	1.30	0.27	14.11	10,730	10,820	25	0.03	0.01	0.23
M11-HV	1.10	51.65	45.32	1.93	7.10	81.99	1.61	0.08	5.47	15,500	15,830	36	0.04	0.11	0.65
M12-CA	0.69	49.43	37.14	12.74	6.55	72.47	1.06	0.47	6.02	13,780	15,990	32	0.01	0.08	0.38
M13-LP	0.72	60.47	35.20	3.61	8.00	79.68	1.53	0.57	5.89	15,320	15,940	36	0.01	0.03	0.53
M14-SC	4.61	47.74	44.82	2.83	5.91	74.88	1.13	1.15	9.49	13,740	14,200	32	0.10	0.14	0.91
Guajira	2.78	37.22	58.17	1.83	5.45	80.02	1.47	0.40	8.05	14,350	14,650	33	0.02	0.01	0.37
Guasare	3.04	38.69	57.86	0.41	5.49	80.89	1.55	0.36	8.26	14,500	14,570	34	0.03	0.01	0.32

Table 5. Analytical data (on an as-determined, ash basis) for ash yield and major- and minor- oxides for 16 Venezuelan 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
M1-QP	2.17	23.4	20.9	8.40	2.70	3.90	0.940	13.6	0.840	0.140	17.2	92.0
M2-CDLV	17.50	35.5	22.7	0.610	0.540	0.200	1.20	24.3	0.840	0.0700	1.20	87.2
M3-RE	3.83	38.0	28.5	6.10	1.30	1.50	0.350	8.20	0.620	0.0400	9.8	94.4
M4-QPA	5.42	8.30	10.9	4.30	1.10	<0.030	0.340	63.1	0.220	0.0800	8.50	96.9
M5-RP	15.9	29.5	22.5	0.160	0.030	0.0600	0.310	37.9	0.640	0.220	0.130	91.4
M6-FA	8.01	57.1	17.9	2.40	0.310	0.160	0.200	4.10	3.30	0.110	2.50	88.1
M7-LC	4.67	18.2	14.3	0.390	1.60	0.0500	0.0500	47.2	0.290	0.0400	1.10	83.2
M8-M1LA	1.61	40.3	34.6	1.90	1.80	0.820	0.130	8.10	0.880	0.0300	4.90	93.5
M8-M2LA	1.90	42.4	25.8	3.60	1.00	0.640	0.480	9.90	1.00	0.0200	5.40	90.2
M10-LC	1.11	19.2	25.1	10.4	0.970	0.130	0.330	12.3	2.90	0.0500	16.6	88.0
M11-HV	1.99	27.2	27.1	7.30	0.940	1.30	0.160	22.3	0.670	0.0600	8.90	95.9
M12-CA	13.00	53.3	30.5	0.690	0.990	0.120	0.810	5.20	1.60	0.0300	0.490	93.7
M13-LP	3.61	39.6	33.3	4.50	0.750	0.260	0.270	6.90	1.20	1.60	3.10	91.5
M14-SC	2.99	36.6	34.4	0.504	0.280	0.0600	0.0820	19.1	1.41	0.0960	0.942	93.5
Guajira	1.87	51.9	38.2	0.702	0.294	0.480	0.0480	1.67	1.46	0.370	0.518	95.6
Guasare	0.377	50.0	30.6	1.70	1.10	3.10	0.0500	3.70	1.50	0.290	2.00	94.0

Table 6. Major-, minor-, and trace- element data for 16 Venezuelan 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, and P which are in weight percent. Ash=ash yield, %=weight percent, °C=degrees Centigrade, <=less than. 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 (%)
M1-QP	2.21	0.241	0.244	0.133	0.0359	0.0639	0.0172	0.210	0.0111	0.00135
M2-CDLV	17.68	2.93	2.12	0.0771	0.0576	0.0262	0.176	3.01	0.0891	0.00540
M3-RE	3.95	0.702	0.596	0.172	0.0310	0.0440	0.0115	0.227	0.0147	0.000690
M4-QPA	5.72	0.222	0.330	0.176	0.0380	0.00127	0.0162	2.53	0.00755	0.00200
M5-RP	16.01	2.21	1.91	0.0183	0.0029	0.00713	0.0412	4.24	0.0614	0.0154
M6-FA	8.14	2.17	0.771	0.140	0.0152	0.00966	0.0135	0.233	0.161	0.00391
M7-LC	4.69	0.399	0.355	0.0131	0.0453	0.00174	0.00195	1.55	0.00816	0.000819
M8-M1LA	1.66	0.312	0.304	0.0225	0.0180	0.0101	0.00179	0.0939	0.00875	0.000217
M8-M2LA	1.93	0.383	0.264	0.0498	0.0117	0.00918	0.00771	0.134	0.0116	0.000169
M10-LC	1.19	0.107	0.158	0.0884	0.00696	0.00115	0.00326	0.102	0.0207	0.000260
M11-HV	1.99	0.253	0.286	0.104	0.0113	0.0192	0.00265	0.311	0.00801	0.000522
M12-CA	13.03	3.25	2.10	0.0642	0.0778	0.0116	0.0876	0.474	0.125	0.00171
M13-LP	3.63	0.672	0.639	0.117	0.0164	0.00700	0.00813	0.175	0.0261	0.0253
M14-SC	3.03	0.519	0.552	0.0109	0.00512	0.00135	0.00206	0.405	0.0256	0.00127
Guajira	1.89	0.458	0.382	0.00948	0.00335	0.00673	0.000753	0.0221	0.0165	0.00305
Guasare	0.381	0.089	0.0617	0.00463	0.00253	0.00876	0.000158	0.00985	0.00342	0.000482

Table 6. Major-, minor-, and trace- element data for 16 Venezuelan coal samples calculated to a dry, whole-coal basis—continued.

Field Number	Ag (ppm)	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)
M1-QP	<0.0450	2.78	53.6	83.2	0.236	<0.00230	0.0662	346.	1.43	4.64
M2-CDLV	<0.360	10.1	48.8	302.	2.67	<0.0180	1.50	202.	19.6	49.7
M3-RE	<0.0800	0.815	35.5	166.	0.961	<0.00400	0.186	237.	1.93	10.9
M4-QPA	<0.120	18.9	69.8	95.6	1.81	0.0561	0.0859	<160	4.79	6.01
M5-RP	<0.330	71.3	15.7	30.7	2.53	0.240	1.99	232.	14.1	28.0
M6-FA	<0.170	1.89	12.0	256.	1.69	0.0643	2.42	<160	7.70	22.3
M7-LC	<0.0940	3.39	8.54	4.00	0.117	0.0155	0.0610	201.	1.36	2.27
M8-M1LA	<0.0340	0.255	7.35	28.7	1.18	0.0159	0.453	443.	2.30	1.46
M8-M2LA	<0.0390	0.395	7.18	45.3	1.74	0.0164	0.106	254.	2.82	2.36
M10-LC	0.0238	0.832	42.7	81.4	0.339	0.0178	0.0452	300.	5.00	1.30
M11-HV	<0.0400	0.415	18.4	58.2	0.480	0.0175	0.403	180.	3.59	10.5
M12-CA	<0.270	0.0651	3.60	71.1	3.24	0.0925	0.313	<160	4.08	17.2
M13-LP	<0.0730	0.388	13.2	114.	0.682	0.0207	0.385	201.	2.90	12.5
M14-SC	<0.0610	0.176	7.85	7.52	0.227	0.0197	0.594	355.	3.46	4.58
Guajira	<0.0380	<0.00380	21.3	3.51	0.0944	0.0189	0.00982	384.	0.510	1.19
Guasare	<0.00770	0.0213	17.9	1.21	0.0110	0.00495	0.00647	323.	0.110	0.179

Table 6. Major-, minor-, and trace- element data for 16 Venezuelan coal samples calculated to a dry, whole-coal basis—continued.

Field Number	Cs (µg/g)	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)
M1-QP	0.0949	3.31	1.19	0.821	0.051	1.76	5.23	0.949	0.225	3.53
M2-CDLV	1.36	58.0	6.33	3.20	0.200	19.1	18.0	10.1	1.64	63.1
M3-RE	0.0593	10.8	4.39	20.2	<0.0300	3.31	24.8	0.324	0.336	4.43
M4-QPA	0.126	5.15	0.853	0.217	0.170	2.64	15.9	5.29	0.155	35.0
M5-RP	0.109	16.0	6.50	5.12	2.10	16.5	4.04	21.5	1.18	66.3
M6-FA	0.0521	33.1	4.38	9.84	0.061	5.39	36.0	1.02	2.94	24.2
M7-LC	0.0113	2.35	0.877	0.296	0.280	2.43	25.9	0.835	0.211	5.58
M8-M1LA	0.0153	2.32	4.46	4.73	0.100	1.30	2.67	3.35	0.222	11.5
M8-M2LA	0.0387	4.16	3.93	6.15	0.110	1.03	2.24	1.41	0.269	8.94
M10-LC	0.0286	4.68	0.897	0.169	<0.0300	0.457	3.88	2.48	0.559	23.3
M11-HV	0.00738	10.5	0.514	0.124	0.0300	1.38	3.27	1.70	0.207	7.28
M12-CA	0.547	11.7	7.16	2.77	0.0300	12.4	42.5	0.860	3.44	4.99
M13-LP	0.0435	20.9	1.43	0.334	0.0300	3.74	5.01	1.59	0.464	13.1
M14-SC	0.0106	4.85	1.96	0.704	<0.0300	1.57	26.8	0.267	0.552	7.52
Guajira	0.00416	2.83	1.09	0.274	<0.0300	4.91	0.672	0.068	0.383	0.765
Guasare	0.00190	0.838	0.0735	0.0567	<0.0300	0.419	0.373	0.464	0.0400	0.224

Table 6. Major-, minor-, and trace- element data for 16 Venezuelan coal samples calculated to a dry, whole-coal basis—continued.

Field Number	Pb (µg/g)	Rb (µg/g)	Sb (µg/g)	Sc (µg/g)	Se (µg/g)	Sn (µg/g)	Sr (µg/g)	Te (µg/g)	Th (µg/g)	Tl (µg/g)
M1-QP	0.614	1.17	0.163	1.55	1.6	0.179	44.8	0.00684	0.711	0.0706
M2-CDLV	8.01	14.9	1.41	13.4	0.25	1.01	54.5	0.0654	3.54	0.902
M3-RE	1.27	0.648	0.285	3.31	1.9	0.411	34.8	0.0178	1.48	0.0233
M4-QPA	1.41	1.36	0.315	0.939	2.7	1.26	9.44	0.0572	1.14	2.11
M5-RP	16.0	2.19	33.8	6.13	5.5	4.39	14.5	0.110	3.20	13.7
M6-FA	4.86	0.765	3.16	9.19	0.47	3.84	42.1	0.0374	4.35	0.228
M7-LC	1.50	0.131	0.136	0.783	7.3	<0.150	0.812	0.0206	<0.470	0.676
M8-M1LA	1.15	0.126	1.82	0.642	1.6	0.0663	11.1	0.0124	0.529	0.0298
M8-M2LA	1.10	0.520	1.78	1.19	2.4	0.998	27.1	0.00909	0.596	0.0232
M10-LC	0.896	0.302	0.255	0.453	7.5	0.339	32.6	0.0155	0.443	0.211
M11-HV	0.762	0.0917	0.277	3.35	2.3	0.0837	27.3	0.0478	1.89	0.0134
M12-CA	5.22	7.20	0.612	4.55	4.5	3.60	18.2	0.0638	5.39	<0.014
M13-LP	2.01	0.613	0.323	5.22	2.9	1.98	99.8	0.0435	4.39	0.00363
M14-SC	1.32	0.103	0.243	1.63	2.2	2.18	3.97	0.0158	0.910	0.0576
Guajira	0.873	0.0359	0.0529	0.440	4.4	0.134	40.8	0.0176	0.378	<0.00190
Guasare	0.267	0.0118	0.00990	0.0563	3.4	0.203	5.44	0.00647	0.0381	<0.000390

Table 6. Major-, minor-, and trace- element data for 16 Venezuelan coal samples calculated a dry, whole-coal basis—continued.

Field Number	U (µg/g)	V (µg/g)	Y (µg/g)	Zn (µg/g)	Zr (µg/g)
M1-QP	0.300	13.8	1.91	2.56	2.54
M2-CDLV	3.18	154.	31.8	139.	14.4
M3-RE	0.360	18.7	10.0	4.74	4.43
M4-QPA	0.595	12.5	5.28	13.5	2.64
M5-RP	2.93	269.	18.7	15.9	16.7
M6-FA	1.11	49.8	16.3	33.2	37.8
M7-LC	0.117	6.38	2.07	4.39	1.79
M8-M1LA	0.259	5.80	5.87	9.22	3.33
M8-M2LA	0.228	6.19	8.43	3.09	3.44
M10-LC	0.140	9.03	1.61	13.1	8.96
M11-HV	0.600	28.9	7.58	6.18	3.53
M12-CA	0.573	44.8	23.2	13.9	23.7
M13-LP	0.755	47.9	11.5	2.13	7.84
M14-SC	0.246	12.9	2.34	19.4	5.85
Guajira	0.176	3.59	0.455	0.393	5.02
Guasare	0.0179	0.388	0.0914	2.14	1.11