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Chapter 3

World Coal Quality Inventory: Brazil

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Chapter 3 of

World Coal Quality Inventory: South America

Edited by Alex W. Karlsen, Susan J. Tewalt, Linda J. Bragg, and Robert B. Finkelman

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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 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, 57 coal samples from Brazil were collected and analyzed.

Brazil

All of Brazil's economically recoverable coal deposits are in the Rio Bonito Formation of the Paraná Basin, located in the southernmost region of Brazil (Machado, 1978; Weaver, 1993). It is comprised of the States of Paraná, Santa Catarina and Rio Grande do Sul (fig. 1) and has been known for its abundant and economically important coal beds since the beginning of the 20th century. There are eight large coal deposits associated with Permian sedimentary successions of the Paraná Basin. Seven of these deposits occur in the State of Rio Grande do Sul, and the remaining one in the State of Santa Catarina (fig.1). The majority of the total coal resources occur in Rio Grande do Sul (89 percent).

Brazil has the second largest recoverable coal reserves in the Western Hemisphere, totaling 11.9 billion metric tons (Energy Information Agency, 2004).

Geology of Coal Areas

The Paraná Basin, a large intracratonic basin (Milani and others 1994), is a tectonic unit which was part of southwestern Gondwana. This basin is located in the central-eastern part of the South-American Platform. The sedimentary fill of the basin is divided by Milani and others (1994) into six-second order depositional sequences from Ordovician-Silurian to Late Cretaceous ages. The coal-bearing Rio Bonito Formation, a fluvial to marine sandstone and shale-prone lithostratigraphic unit of Early Permian age (Artinskian/Kungurian), is located at the base of the Carboniferous/Early-Triassic Sequence (Milani and others 1994) which forms the thickest sedimentary sequence of the basin (2800 m). Coals in the Rio Bonito Formation were deposited in a back-barrier depositional setting, an interpretation based on regional sequence stratigraphy analysis (e.g. Holz, 1998) and tissue preservation and gelification indices derived from maceral analysis (e.g. Alves and Ade, 1996; Holz and Kalkrueth, 2000).

An overview of the general stratigraphy of the coal-bearing succession is given in figure 2, which shows the entire Early Permian interval in southernmost Brazil (Sakmarian to Kungurian/Ufimian). This interval comprises the lithostratigraphic units Itararé, Rio Bonito, Palermo and base of Irati, and records a second-order transgressive cycle, which began at the time of deposition of the topmost Itararé unit and has its maximum flooding surface within the Palermo Formation (e.g. Milani and others, 1994; Holz, 1999). This second-order cycle is punctuated by important third-order base level falls, with generation of several third-order depositional sequences. The two coal-bearing intervals of the Rio Bonito Formation are linked to third-order sequence 2 and the base of third-order sequence 3 (fig. 2). In the State of Rio Grande do Sul most of the coals occur within the transgressive systems tract of sequence 2, as detailed by Holz (1998) and Holz and others (2000), with the recognition of four main depositional systems - alluvial fan, delta, lagoonal estuary and barrier/shoreface. According to these studies the accumulation of the Permian peats were linked to swamps and marshes in a lagoonal estuary setting.

Coal Resource Estimates

Total coal reserves in Brazil are estimated to be in the range of 29 billion metric tons of lignite and subbituminous coals (Informative Annual da Industria Carbonffera, 1996). Recoverable reserves in 2002 were estimated at almost 11.9 billion metric tons of lignite and subbituminous coal (Energy Information Administration, 2004).

Coal Utilization Impacts

High ash yields (20.46 - 64.20 weight percent) and high sulfur values (0.31 - 11.46 weight percent) are typical of Brazilian coals. Mining of coals with high sulfur contents has led to acid mine drainage impacts for rivers in the Araranguá, Tubarão and Urussanga River basins in the Santa Catarina coal region. Cleaning of Brazilian coals helps to lower ash yield and sulfur.The WoCQI analytical data show an extremely high As value (568 ug/g) in sample 02-429, although other samples have more typical values. Cd content is over 1 ug/g in only two samples, with 20 percent of the values having Cd contents below the analytical detection limit. Se varies widely, ranging from 0.25 to 7.1 ug/g. Hg is less than 1 ug/g in all samples, but more than 50 percent of the samples have values over 0.20 ug/g for Hg, which is likely related to the sulfide concentration.

Coal Production, Uses, and Trade

Coal production in Brazil during 2002 was approximately 4.2 million metric tons (Energy Information Agency, 2004). In 2002, Brazil’s coal consumption was an estimated 20.1 million metric tons, which accounted for only 5.2% of the country’s total primary energy consumption for the year. Net coal imports in 2002 were 15.9 million metric tons (Energy Information Agency, 2004). Most of the domestic coal production in Brazil is used for power generation, while coal imports are used primarily for the country's steel industry.

Brazil is attempting to reverse its status as a net importer of coal. Brazil's national development bank, Banco Nacional de Desenvolvimento Economico e Social (BNDES) is developing a plan to expand the country's coal industry. BNDES hopes that the proposed program will make Brazil self-sufficient in coal by 2010 and eventually a net exporter of coal (Energy Information Agency, 2004).

Coal Quality

Fifty-seven coal samples from the three basins were analyzed for major, minor, and trace elements using the U.S. Geological Survey's analytical protocol. The analytical results are presented in Tables 1, 2 and 3. Locality data for 14 of the 57 coal samples analyzed are shown in Appendix 1.

In addition to the chemical analysis, several samples were selected for semi-quantitative X-ray diffraction (XRD) analysis of the low temperature ash (LTA) using the procedures described by Hosterman and Dulong (1985). Polished pellets of crushed coal less than 200 mesh were examined by scanning electron microscopy (SEM) with an energy dispersive X-ray analyzer (EDX).

A selective leaching procedure was used on one sample (WK-38-98) to semi-quantitatively determine the modes of occurrence of 45 elements. The sequential selective leaching procedure used was similar to that described by Palmer and others (1993), and modified from Finkelman and others (1990). Duplicate 5 grams coal samples were leached sequentially with 35 milliliters each of 1N ammonium acetate (CH_3COONH_4), 3N hydrochloric acid (HCl), concentrated hydrofluoric acid (48% HF) and 2N (1:7) nitric acid (HNO_3) in 50 milliliter polypropylene tubes. Each tube was shaken for 18 hrs using a motorized shaker. Due to the potential for gas formation during the leaching procedure, each tube was enclosed in double polyethylene bags, which allows gas to escape, but prevents the release of liquid. After each leaching step, the coal slurries were centrifuged and the resulting solutions were analyzed by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) and inductively coupled plasma-mass spectroscopy (ICP-MS). Each sample was washed at least five times with distilled water, using an ultrasonic cleaner to remove the solvent. After removing the solvent and drying the residual solid, about 0.5 grams of this material were removed from each tube for the determination of 28 elements by instrumental neutron activation analysis (INAA) and the determination of Hg by cold vapor atomic absorption analysis (CVAA).

Data for the leachates and residues were processed to derive the percentages of each element leached by each of the four leaching agents. The calculated percentages were then used as an indirect estimate of the modes of occurrence of 45 elements. We estimate an error of up to 20 percent for the leached percentages reported by comparing data for the residual fractions with data for the solutions.

Chemistry Results and Discussion

All of the samples had high ash yields with most yields greater than 35 percent (Table 2). The mean for all three coal fields was about 48.5 weight percent on an as-received basis with a range of 27.4 to 83.1 weight percent.

The oxide sums (Table 2) for all of the Brazil coal samples were near 100 percent. For two samples (99-182 and 99-190), adjustment of the oxide sums for SO_3 complexed by CaO and MgO was substantial. Proximate, ultimate and forms of sulfur data were obtained for 39 samples (Table 1). The range for total sulfur was 0.28 to 11.46 weight percent, with an average of 2.15 on an as-received basis. Most of the variation is due to pyritic sulfur that ranged from 0.05 to 10.5 weight percent with an average of 1.66 percent.

The SiO_2 content of the ash is remarkably uniform (60-75 weight percent), with only a couple of exceptions. Two samples (99-163 and 99-341) have low oxide sums (51.7 percent and 50.6 percent SiO_2, respectively). Samples 99-175 and 99-226 (47.6 percent and 54.3 percent, respectively) have high Fe_2O_3 concentrations and samples 99-182 and 99-190 (33.7 percent and 52.4 percent respectively) have high CaO and MgO concentrations. One sample 99-224 (50.5 percent) has high concentrations of Al_2O_3, CaO, and Fe_2O_3. The uniformly high SiO_2 concentrations and high SiO_2/Al_2O_3 ratios (Table 2) indicate that quartz is a major component of all of the coal samples. The XRD results (Table 4) of selected samples indicate quartz contents up to 60 percent of the LTA.

Major oxide totals for most samples were small percentages of the total ash yield. The percentage of Na_2O in the ash is very low, generally less than 0.4 weight percent (Table 2). Only six samples, all from the Santa Terezinha coalfield, have more than 0.42 weight percent Na_2O (Table 2). P_2O_5 content is also very low with only three samples having 0.1 weight percent or more (Table 2) CaO contents are low, less than 4 weight percent, with only three exceptions (samples 99-182, 99-190, and 99-223). K_2O, MgO and TiO_2 contents are also relatively low, with few exceptions (Table 2). Only Fe_2O_3 shows significant variation with a range of about 1 to more than 30 weight percent in the coals from Santa Terezinha and Leão and about 3 to 19 weight percent in the coals from Candiota (Table 2).

Scanning Electron Microscopy-Energy Dispersive X-ray analysis

Results from the SEM-EDX analysis of the polished pellets are broadly consistent with the bulk chemical and mineralogical analyses. The high ash yields were reflected in abundant mineral clusters and dispersed grains in the coal matrix (fig. 3b). Quartz and clays are common in all of the samples studied (fig. 3b). Texturally, most of the minerals appear to be detrital, although siderite (fig. 3a) and calcite nodules (fig. 3c) and kaolinite blebs are probably diagenetic (fig. 3c). Several epigenetic calcite vein fillings were observed in the polished blocks of sample WK-38-98. Both syngenetic and diagenetic pyrites were observed. No attempt was made to quantify the minerals or the elements detected in the sulfides and accessory mineral phases.

Six samples from the Leão coalfields were examined. All had abundant pyrite, some with detectable copper. Other minerals observed included zircon (some with Hf, Th or U), mica, sphalerite, the rare-earth phosphates monazite and xenotime, siderite (with Mn), calcite, ilmenite, rutile, feldspar, barite, chalcopyrite, and sylvite.

Five samples from the Candiota coalfield were studied. The minerals and accessory elements observed included siderite nodules containing traces of Mn, sphalerite containing traces of Cd, pyrite (some with traces of As), rare-earth phosphates containing traces of Th, zircon, apatite, galena, rutile, feldspar, chromite, chalcopyrite, and an unidentified tin oxide.

The minerals observed in four samples from the Santa Terezinha coalfield include rutile, siderite nodules containing traces of Mn, calcite, pyrite, feldspar, barite, rare-earth phosphates, zircon, chalcopyrite and clausthalite (PbSe).

Selective Leaching Results

Results from the selective leaching protocol on sample WK 38-98 showed good correlation with the mineralogical analyses. Results indicate that many elements (Li, Be, Mg, Al, K, Sc, V, Cr, Rb, Zr, Hf, Sn, and U) are primarily (>50 percent) leached by hydrofluoric acid and are probably associated with silicates such as clays. Other elements (Ti, Ta, W) leached by hydrofluoric acid are also likely to occur as oxides (Ti oxides were commonly observed with the SEM). Fe, Cu, Zn, As, Se, Sb, Tl, and Pb are primarily leached by the nitric acid and are undoubtedly associated with sulfides (pyrite and chalcopyrite were observed by SEM). Ca and Mn, leached by hydrochloric acid, are associated primarily with carbonate minerals (calcite and siderite were observed by SEM). Substantial amounts of several elements (Co, Ni, Mo, Ba, Sr, and Cs) were leached by several solvents indicating multiple associations. P, Th and most rare-earth elements were leached by hydrochloric acid indicating an association with phosphate minerals such as monazite and xenotime which were observed by SEM. Na was the only element that was primarily leached by the ammonium acetate, indicating that it is in ion-exchangeable sites. Table 5 contains the summary of the selective leaching results for sample WK 38-98.

Regional and Stratigraphic Variations

The coals from the Santa Terezinha area have the highest mean concentration of CaO, MgO, Mn, and Sr, reflecting the presence of carbonates. XRD analysis of the LTA from sample 99-182 (Table 2), the sample with the highest CaO (17.3 weight percent) and MgO (4.8 weight percent) values indicated the presence of at least 30 percent calcite, ankerite, and dolomite. The LTA from sample 99-175 contained 15 percent siderite, reflecting the high Fe_2O_3 (34.4 weight percent) content (Table 2). In contrast, sample 99-226 from the Leão coalfield had a similar Fe_2O_3 (33.0 weight percent) (Table 2) content, but in this coal the iron is present as pyrite (25 percent) rather than siderite (Table 3).

Fourteen samples (99-250 to 99-345) from the Candiota Coal Field are benches from a core and represent the full 12.4 meter thickness of the coal bed. There is little systematic vertical variation of major or trace elements in the coal bed. Only CaO and Fe_2O_3 appear to show a trend with higher values in the bottom half of the bed.

Coalbed Methane

The Chico Loma and Santa Terezinha coalfields within the Paraná Basin in Rio Grande do Sul are potential areas for development of coalbed methane resources. Preliminary results from coalbed methane exploration in the Santa Terezinha coalfield suggest that there may be up to 19 billion cubic meters of methane present (Kalkreuth and Holz, 2000).

Conclusions

Brazil has the second largest coal reserves in the Western Hemisphere. All of the commercially extractable coal in Brazil is distributed in the Paraná Basin, located in the central-eastern part of the South-American Platform, within the southern States of Paraná, Santa Catarina and Rio Grande do Sul. Most of the coals in the Paraná Basin are within the coal-bearing Rio Bonito Formation. Total coal reserves in Brazil are estimated to be in the range of 29 billion metric tons of lignite and subbituminous coals (Informative Anual da Industria Carbonfera, 1996). Recoverable reserves in 2002 were estimated at almost 11.9 billion metric tons of lignite and subbituminous coal (Energy Information Agency, 2004). Coal production in Brazil during 2002 was approximately 4.2 million metric tons (Energy Information Agency, 2004). Most of the domestic coal production in Brazil is used for power generation, while coal imports are used primarily for the country's steel making industry.

All of the 57 Brazilian coal samples analyzed had high ash yields with most yields greater than 35 percent (Table 2). Despite the high ash yields of the coal samples that were analyzed, the concentrations of most trace elements were well within the range typical for world coals (Swaine, 1990). The modes of occurrence of the elements in the Brazilian coal samples are consistent with most coals that have been analyzed using the USGS approach over the last 10 to 15 years (Finkelman, 1995).

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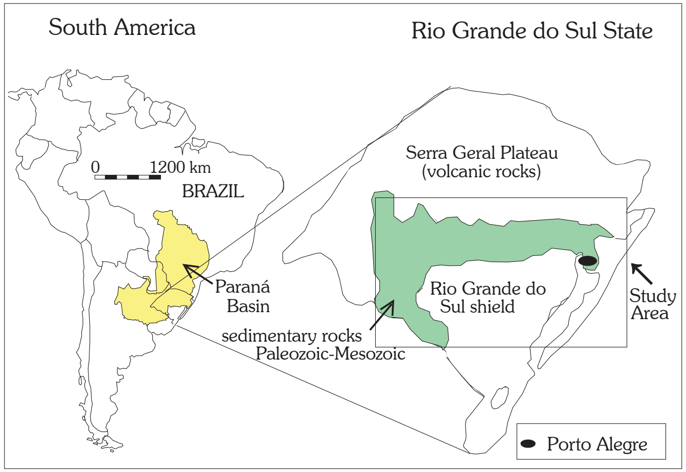

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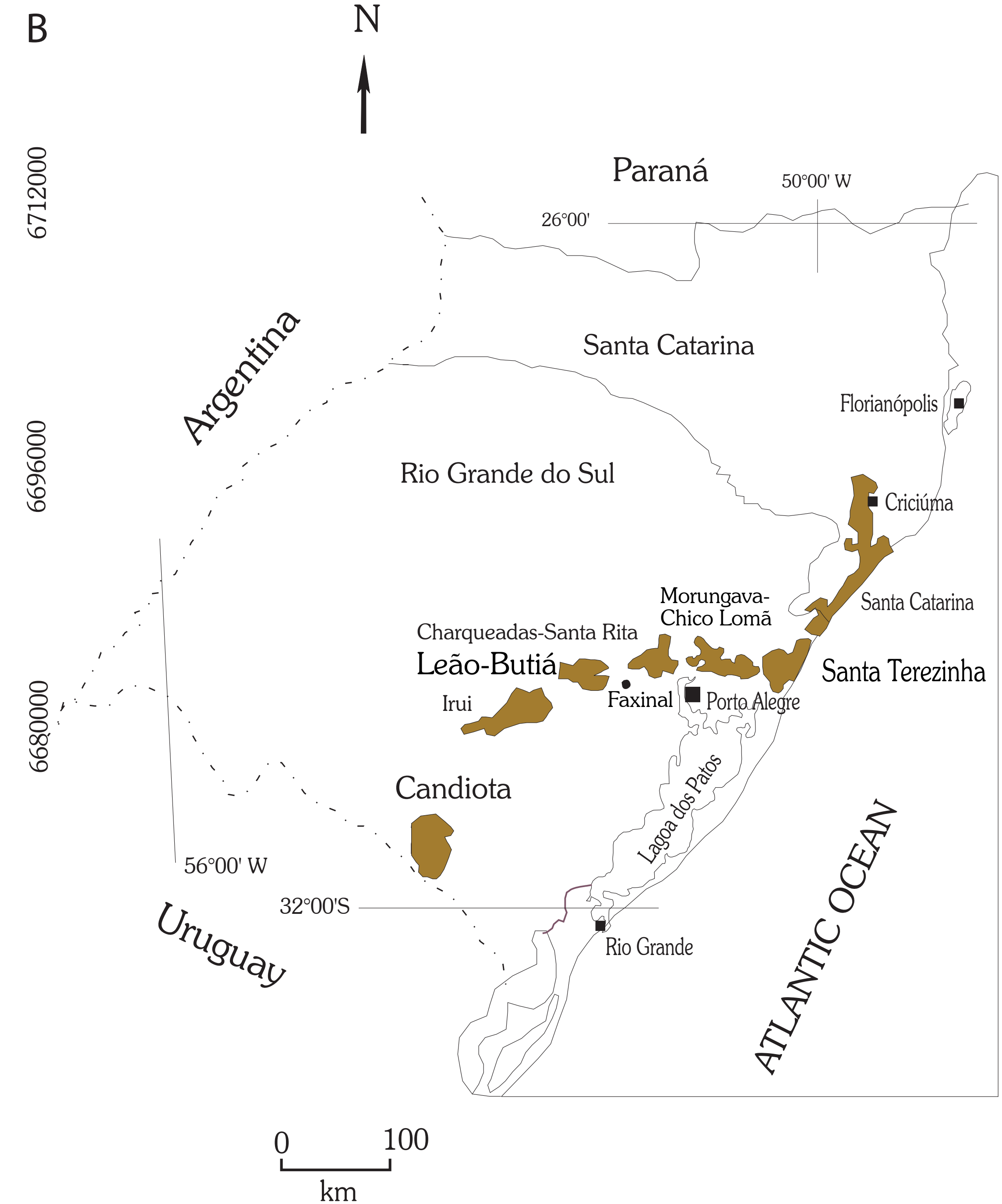

C

	Stage	Lithostratigraphy	
PERMIAN	KUNGURIAN	Passa Dois Gp.	Irati Formation
		Guatá Group	Palermo Formation
	ARTINSKIAN		Rio Bonito Formation
	SAKMARIAN	Itararé Group	Rio do Sul Formation

Figure 1. A) Map showing the study area, B) coal deposits, and C) a chart of regional stratigraphic nomenclature.

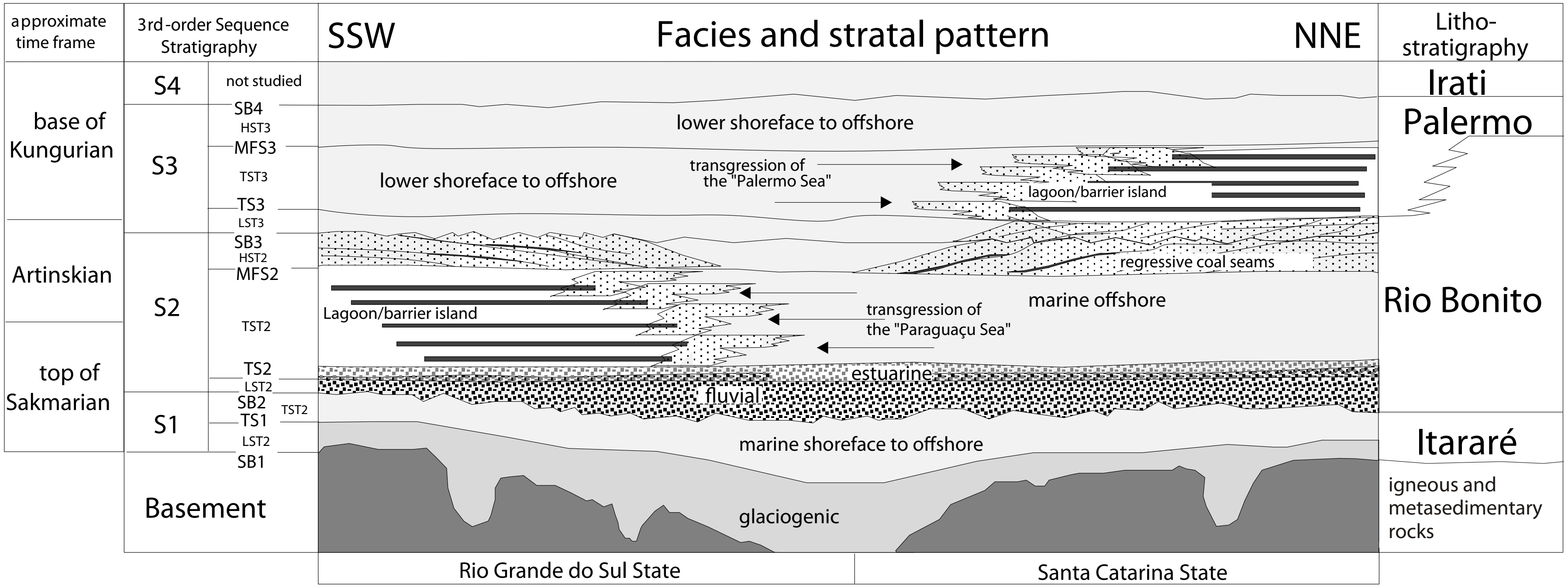

Figure 2. Generalized stratigraphic cross-section of the southern portion of the Paraná Basin, Brazil

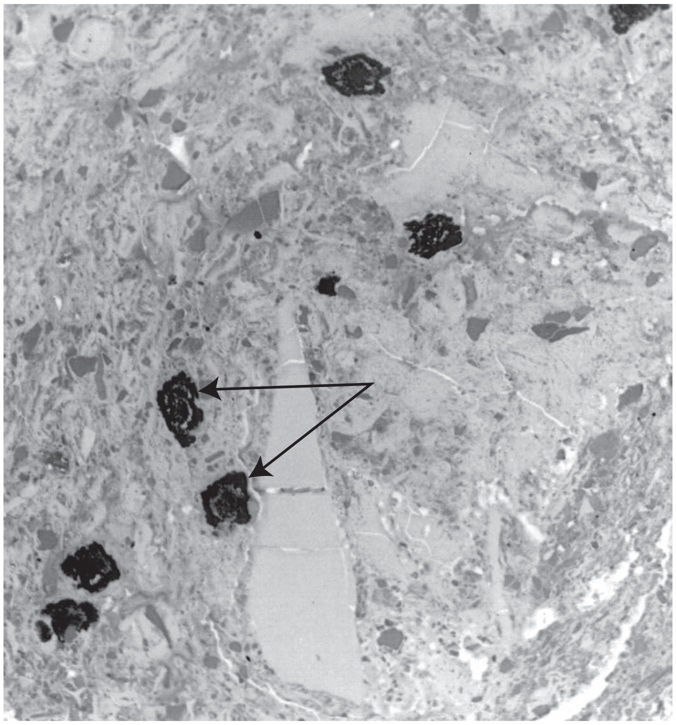

Figure 3a. Dark spots are siderite found in sample 99-036 from the Candiota Coal Field

Figure 3b. Inorganic content (dark colors) is very high in sample WK-38-98 from the Leão Coal Field. (Organic fraction is light)

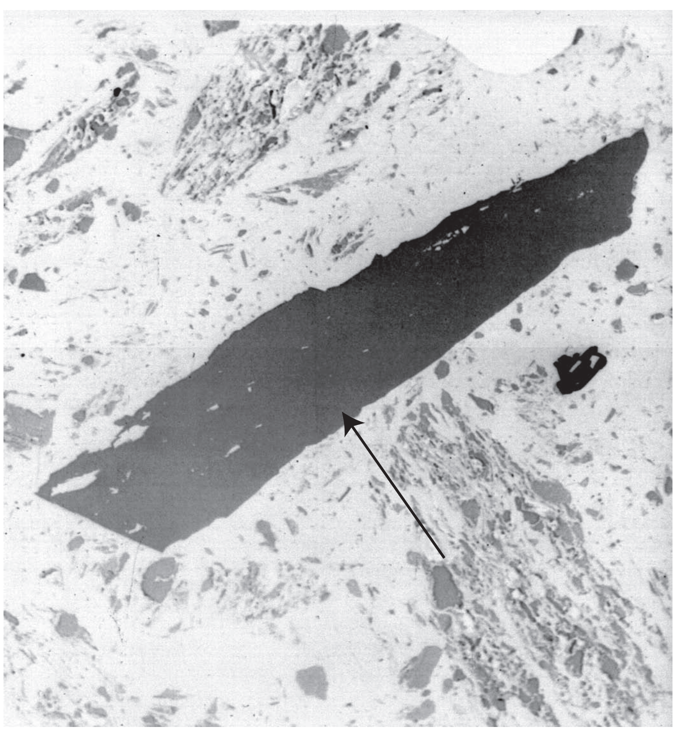

Figure 3c. Carbonate mineral found in sample 99-223 from the Leão Coal Field

Figure 3d. All of the dark spots are pyrite found in sample 99-226 from the Leão Coal Field

Figure 3. Scanning electron microscope photomicrographs of elements in selected coal samples from the Leão and Candiota Coalfields

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Table 1. Proximate and ultimate analyses, gross calorific value, and forms of sulfur on an as-received basis for 39 Brazilian coal samples. Carbonaceous shale samples with >50% ash yield are shown in bold.

[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; nd=not determined.]

	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 (%)
99-035	11.48	19.61	23.47	45.44	2.22	32.05	0.56	0.80	7.45	5,510	13	0.04	0.40	0.36
99-036	10.57	19.36	23.38	46.69	2.21	30.99	0.38	1.20	7.96	5,280	12	0.09	0.68	0.43
99-105	1.23	nd	nd	28.58	nd	nd	nd	1.52	nd	nd	nd	0.28	1.07	0.34
99-163	4.89	23.19	35.61	36.31	2.71	44.23	0.79	0.43	10.64	7,520	17	0.11	0.19	0.13
99-175	**0.76**	**30.03**	**15.11**	**54.10**	**1.95**	**33.17**	**0.62**	**0.35**	**9.05**	**5,420**	**13**	**0.05**	**0.14**	**0.16**
99-176	**1.23**	**18.37**	**21.03**	**59.37**	**1.96**	**29.85**	**0.62**	**1.15**	**5.82**	**5,170**	**12**	**0.42**	**0.48**	**0.25**
99-182	1.39	20.28	41.87	36.46	2.22	49.67	1.02	2.21	7.03	8,210	19	0.38	1.40	0.43
99-217	11.00	19.73	24.86	44.41	2.22	32.64	0.56	0.31	8.86	5,660	13	0.03	0.05	0.23
99-218	**10.38**	**16.91**	**16.85**	**55.86**	**1.64**	**23.79**	**0.95**	**4.93**	**2.45**	**4,470**	**10**	**0.32**	**4.37**	**0.24**
99-219	11.31	20.49	26.53	41.67	2.34	33.98	0.55	1.94	8.21	6,010	14	0.14	1.52	0.28
99-220	12.35	18.73	21.78	47.14	1.83	27.36	0.50	5.32	5.50	4,950	12	0.30	4.89	0.13
99-221	10.65	19.12	23.49	46.74	1.92	29.55	0.52	5.29	5.33	5,390	13	0.46	4.41	0.42
99-222	10.67	19.45	27.04	42.84	2.27	34.81	0.63	0.34	8.44	5,980	14	0.03	0.10	0.21
99-223	9.14	20.57	25.13	45.16	2.33	33.64	0.57	0.28	8.88	5,670	13	0.02	0.07	0.19
99-224	11.60	28.78	32.51	27.11	3.03	45.86	0.76	3.07	8.57	8,070	19	0.37	2.26	0.44
99-225	14.29	27.71	37.54	20.46	3.22	51.20	0.95	1.30	8.58	8,890	21	0.06	0.84	0.40
99-226	**9.33**	**18.92**	**21.29**	**50.46**	**1.53**	**24.78**	**0.44**	**11.46**	**2.00**	**4,850**	**11**	**0.54**	**10.50**	**0.42**
99-284	5.51	18.85	26.46	49.18	2.06	33.44	0.50	0.60	8.71	5,510	13	0.17	0.12	0.31
99-296	7.41	20.49	26.19	45.91	2.18	33.06	0.55	1.65	9.24	5,650	13	0.38	0.79	0.48
99-308	7.28	19.49	27.09	46.14	2.21	34.05	0.71	0.82	8.79	5,780	13	0.09	0.41	0.32

Table 1. Proximate and ultimate analyses, gross calorific value, and forms of sulfur on an as-received basis for 39 Brazilian coal samples. Carbonaceous shale samples with >50% ash yield are shown in bold—continued.

	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 (%)
99-326	**5.34**	**17.93**	**19.58**	**57.15**	**1.88**	**26.63**	**0.52**	**0.85**	**7.63**	**4,570**	**11**	**0.05**	**0.56**	**0.24**
00-23	9.13	20.18	27.63	43.06	2.76	35.45	0.55	0.48	8.57	6,050	14	0.09	0.18	0.21
02-292	**1.53**	**14.03**	**20.24**	**64.20**	**1.94**	**21.80**	**0.43**	**7.73**	**2.37**	**4,040**	**9.4**	**0.25**	**7.05**	**0.43**
02-295	**2.01**	**11.67**	**30.23**	**56.09**	**2.15**	**32.62**	**0.60**	**5.44**	**1.09**	**5,680**	**13**	**0.31**	**4.44**	**0.69**
02-296	2.10	12.68	37.32	47.90	2.57	42.09	0.75	2.53	2.06	7,310	17	0.21	1.37	0.95
02-297	**2.03**	**20.01**	**23.02**	**54.94**	**2.70**	**30.91**	**0.57**	**3.75**	**5.10**	**5,700**	**13**	**0.34**	**2.71**	**0.70**
02-298	1.52	23.55	29.63	45.30	3.20	42.64	0.80	2.17	4.37	7,600	18	0.10	1.32	0.75
02-299	**1.41**	**20.05**	**22.16**	**56.38**	**2.50**	**30.13**	**0.55**	**6.32**	**2.71**	**5,710**	**13**	**0.27**	**5.34**	**0.71**
02-300	1.22	28.95	42.05	27.78	3.78	55.99	1.02	9.22	0.99	10,440	24	0.26	7.37	1.59
02-301	**1.17**	**20.41**	**28.24**	**50.18**	**2.98**	**37.12**	**0.65**	**3.35**	**4.55**	**6,590**	**15**	**0.28**	**2.60**	**0.47**
02-302	1.48	27.62	46.44	24.46	4.19	60.99	1.10	2.18	5.60	10,980	26	0.10	1.30	0.78
02-303	**2.07**	**18.11**	**17.54**	**62.28**	**2.33**	**23.24**	**0.42**	**5.73**	**3.93**	**4,520**	**11**	**0.17**	**4.90**	**0.66**
02-304	1.53	25.18	32.81	40.48	3.61	45.19	0.89	2.19	6.11	8,310	19	0.10	1.41	0.68
02-305	**4.32**	**15.20**	**19.05**	**61.43**	**2.03**	**24.61**	**0.43**	**4.41**	**2.77**	**4,420**	**10**	**0.28**	**3.53**	**0.60**
02-419	**1.96**	**11.35**	**26.34**	**60.35**	**2.18**	**26.16**	**0.53**	**5.82**	**3.00**	**4,740**	**11**	**0.30**	**4.80**	**0.72**
02-420	1.28	13.44	46.01	39.27	3.11	49.77	1.02	1.61	3.94	8,640	20	0.08	0.84	0.69
02-421	**1.36**	**21.66**	**23.38**	**53.60**	**2.79**	**32.21**	**0.60**	**6.35**	**3.09**	**6,000**	**14**	**0.22**	**5.23**	**0.90**
02-422	**1.31**	**29.24**	**18.93**	**50.52**	**2.59**	**33.81**	**0.57**	**10.94**	**0.26**	**6,430**	**15**	**0.36**	**9.20**	**1.38**
02-429	4.13	27.95	42.20	25.72	3.81	54.49	1.07	5.17	5.61	9,800	23	0.25	3.27	1.65

Table 2. Analytical data (on an as-determined, ash basis) for ash yield and major- and minor- oxides for 55 Brazilian 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
99-036	50.0	68.4	19.7	0.81	0.70	0.130	1.80	5.70	0.700	0.050	nd	98.0
99-105	32.0	63.5	25.0	0.300	0.600	1.20	2.40	8.20	0.830	0.100	nd	102.1
99-115	37.3	67.7	8.10	6.00	0.470	0.510	0.860	12.5	0.350	0.090	nd	96.6
99-136	51.6	71.6	23.1	1.20	0.360	0.180	1.30	2.00	0.950	0.050	nd	100.7
99-144+146	29.7	59.8	29.4	0.660	0.190	0.190	1.40	1.50	1.100	0.070	nd	94.3
99-163	36.8	51.7	22.0	2.20	0.840	0.170	1.10	3.40	0.860	0.040	nd	82.3
99-167	54.7	64.6	21.7	2.70	0.840	0.680	2.00	5.30	0.940	0.040	nd	98.8
99-175	57.8	47.6	10.0	2.60	0.930	0.650	0.800	34.4	0.450	0.080	nd	97.5
99-176	62.1	68.4	14.2	1.70	0.810	1.30	1.20	10.9	0.620	0.070	nd	99.2
99-178	58.3	66.6	26.6	1.90	0.550	0.340	1.60	3.50	1.00	<0.020	nd	102.1
99-182	43.8	33.7	6.20	17.3	4.80	0.720	0.940	9.90	0.330	0.070	nd	74.0
99-187	83.1	69.2	27.2	0.230	0.500	0.320	1.50	1.90	1.10	<0.020	nd	102.0
99-190	35.3	52.4	17.7	9.8	2.30	0.240	0.850	7.60	0.640	0.050	nd	91.6
99-217	50.1	67.4	27.5	1.50	0.420	0.130	1.40	1.20	1.20	<0.020	nd	100.8
99-218	62.7	65.4	13.3	2.20	1.20	0.420	1.80	16.8	0.520	0.060	nd	101.7
99-219	62.1	62.0	27.1	1.50	0.460	0.120	1.30	6.70	1.00	<0.020	nd	100.2
99-220	54.4	62.0	14.3	3.00	0.820	0.340	1.50	17.2	0.520	0.090	nd	99.8
99-221	52.4	63.6	13.4	2.40	0.660	0.270	1.20	18.4	0.480	0.070	nd	100.5
99-222	47.5	68.5	26.7	1.20	0.400	0.130	1.00	1.30	1.20	0.020	nd	100.4
99-223	47.9	65.2	32.4	0.720	0.350	0.130	0.810	1.10	1.10	<0.020	nd	101.8

Table 2. Analytical data (on an as-determined, ash basis) for ash yield and major- and minor- oxides for 55 Brazilian coal samples—continued.

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
99-224	31.1	50.5	23.6	4.60	0.440	0.140	0.850	14.8	1.00	0.080	nd	96.0
99-225	23.8	58.6	22.8	3.70	0.440	0.180	1.10	6.50	1.20	0.300	nd	94.8
99-226	57.0	54.3	8.50	3.00	0.780	0.330	1.20	33.0	0.360	0.070	nd	101.5
99-250	45.3	69.3	23.5	0.700	1.00	0.390	2.40	2.80	0.98	<0.020	nd	101.1
99-255	58.0	70.2	21.1	0.650	0.930	0.300	2.00	4.00	0.840	0.030	nd	100.0
99-266	44.0	69.1	20.0	0.980	1.10	0.310	2.30	6.50	0.890	0.020	nd	101.2
99-270	52.1	66.6	25.6	0.910	0.860	0.160	1.70	5.30	0.900	0.190	nd	102.2
99-284	49.0	60.9	22.4	1.00	0.810	0.140	1.60	3.90	0.710	<0.020	nd	91.5
99-296	46.8	69.0	18.8	1.80	0.930	0.310	2.00	6.50	0.780	0.040	nd	100.2
99-308	47.1	72.1	19.1	1.10	0.950	0.360	1.90	3.70	0.670	<0.020	nd	99.9
99-313	60.2	78.9	15.2	1.10	0.760	0.330	1.50	3.40	0.600	0.030	nd	101.8
99-317	53.1	72.4	5.70	1.20	1.20	0.190	0.630	19.4	0.300	0.050	nd	101.1
99-326	58.0	74.1	18.4	1.00	0.760	0.340	1.70	3.30	0.650	0.050	nd	100.3
99-331	41.9	60.7	15.2	1.30	2.30	0.310	1.80	17.4	0.630	0.070	nd	99.7
99-336	48.3	63.8	18.9	1.70	0.840	0.310	2.10	10.6	0.840	0.050	nd	99.1
99-341	32.8	50.6	19.5	2.60	0.760	0.220	2.40	11.4	0.910	0.050	nd	88.4
99-345	47.3	61.6	20.2	0.880	0.640	0.250	2.60	7.2	0.960	0.040	nd	94.4
00-23	47.0	51.9	27.5	9.61	1.73	0.164	0.473	2.63	1.59	0.359	2.50	98.5
02-292	65.6	51.4	24.7	1.49	0.446	0.190	1.78	16.3	1.19	0.082	0.761	98.3
02-295	58.3	55.0	17.4	2.71	0.944	0.860	3.34	12.0	0.684	0.099	1.62	94.7

Table 2. Analytical data (on an as-determined, ash basis) for ash yield and major- and minor- oxides for 55 Brazilian coal samples—continued.

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
02-296	48.8	67.7	19.6	2.38	0.998	1.02	3.98	6.21	0.832	0.092	1.12	103.9
02-297	56.1	53.4	26.8	0.759	0.719	0.300	2.57	8.61	1.30	0.077	1.13	95.7
02-298	46.4	57.2	27.4	3.40	0.981	0.332	3.43	5.81	1.44	0.109	1.78	101.9
02-299	57.3	50.0	26.8	0.892	0.452	0.210	2.39	14.3	1.26	0.074	0.565	96.9
02-300	28.4	32.6	18.9	2.11	0.662	0.188	2.79	40.5	1.05	0.095	1.77	100.7
02-301	50.4	53.2	29.1	0.133	0.466	0.120	3.11	8.48	1.33	0.056	0.481	96.5
02-302	24.9	51.8	33.4	0.272	0.643	0.127	3.66	10.1	1.48	0.074	0.237	101.8
02-303	64.2	52.2	26.0	0.762	0.472	0.160	2.32	11.4	1.27	0.065	0.525	95.2
02-304	40.7	57.8	28.2	1.14	0.663	0.163	3.14	6.39	1.46	0.083	0.432	99.5
02-305	63.9	54.8	20.9	0.751	1.03	0.400	3.70	9.60	0.851	0.056	1.10	93.2
02-419	60.9	58.9	25.1	0.514	0.539	0.221	2.65	13.2	1.17	0.099	0.569	103.0
02-420	40.1	63.2	27.9	0.452	0.810	0.299	3.53	4.75	1.54	0.096	0.045	102.6
02-421	54.8	55.3	25.0	1.20	0.515	0.385	2.81	16.2	1.29	0.082	0.377	103.1
02-422	53.8	26.3	11.2	18.9	0.417	0.182	1.39	26.7	0.613	0.147	6.51	92.4
02-429	26.7	51.0	17.6	3.74	0.792	0.971	2.40	21.2	0.968	0.165	1.86	100.7

Table 3. Major-, minor-, and trace- element data for 57 Brazilian 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, °C=degrees Centigrade, 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 (%)
WK-38-98	41.9	10.8	6.21	0.868	0.101	0.140	0.522	2.78	0.301	0.00731	nd
99-035	52.5	16.8	5.47	0.304	0.221	0.0506	0.784	2.09	0.220	0.0114	nd
99-036	51.7	16.7	5.29	0.370	0.306	0.0768	0.859	2.10	0.220	0.0113	nd
99-105	32.5	9.63	4.29	0.0696	0.117	0.289	0.647	1.86	0.161	0.0142	nd
99-115	37.9	12.0	1.63	1.63	0.108	0.144	0.271	3.32	0.0796	0.0149	nd
99-136	52.4	17.5	6.40	0.449	0.114	0.070	0.565	0.733	0.298	0.0114	nd
99-144+146	30.1	8.40	4.68	0.142	0.0344	0.0424	0.349	0.315	0.198	0.00918	nd
99-163	38.5	9.29	4.48	0.605	0.195	0.0485	0.351	0.914	0.198	0.00671	nd
99-167	55.9	16.9	6.42	1.08	0.283	0.282	0.928	2.07	0.315	0.00975	nd
99-175	58.3	13.0	3.09	1.08	0.327	0.281	0.387	14.0	0.157	0.0204	nd
99-176	62.9	20.1	4.73	0.764	0.307	0.607	0.627	4.80	0.234	0.0192	nd
99-178	59.0	18.4	8.31	0.801	0.196	0.149	0.784	1.44	0.354	0.00515	nd
99-182	44.4	7.00	1.46	5.49	1.29	0.237	0.347	3.08	0.0879	0.0136	nd
99-187	84.5	27.3	12.2	0.139	0.255	0.200	1.05	1.12	0.557	0.00737	nd
99-190	36.4	8.91	3.41	2.55	0.504	0.0647	0.257	1.93	0.139	0.00793	nd
99-217	51.5	16.2	7.49	0.552	0.130	0.0497	0.598	0.432	0.370	0.00449	nd
99-218	64.4	19.7	4.54	1.01	0.466	0.201	0.963	7.57	0.201	0.0169	nd
99-219	63.8	18.5	9.14	0.684	0.177	0.0568	0.688	2.99	0.382	0.00556	nd
99-220	55.9	16.2	4.23	1.20	0.276	0.141	0.696	6.73	0.174	0.0220	nd
99-221	53.9	16.0	3.82	0.924	0.214	0.108	0.536	6.93	0.155	0.0165	nd

Table 3. Major-, minor-, and trace- element data for 57 Brazilian coal samples calculated to a dry, whole-coal basis—continued

Field Number	Ash (%) (525°C)	Si (%)	Al (%)	Ca (%)	Mg (%)	Na (%)	K (%)	Fe (%)	Ti (%)	P (%)	S (%)
99-222	48.7	15.6	6.88	0.418	0.118	0.0470	0.404	0.443	0.350	0.00425	nd
99-223	49.1	15.0	8.42	0.253	0.104	0.0473	0.330	0.378	0.324	0.00428	nd
99-224	32.1	7.58	4.01	1.06	0.0852	0.0333	0.226	3.32	0.192	0.0112	nd
99-225	24.6	6.74	2.97	0.650	0.0652	0.0328	0.225	1.12	0.177	0.0322	nd
99-226	58.4	14.8	2.63	1.25	0.275	0.143	0.582	13.5	0.126	0.0178	nd
99-250	48.3	15.6	6.01	0.242	0.291	0.140	0.962	0.946	0.284	0.00421	nd
99-255	61.3	20.1	6.85	0.285	0.344	0.136	1.02	1.72	0.309	0.00803	nd
99-266	48.6	15.7	5.15	0.341	0.323	0.112	0.928	2.21	0.259	0.00424	nd
99-270	55.5	17.3	7.52	0.361	0.288	0.0659	0.783	2.06	0.299	0.0460	nd
99-284	52.2	14.9	6.19	0.373	0.255	0.0543	0.694	1.42	0.222	0.00456	nd
99-296	50.2	16.2	4.99	0.645	0.281	0.115	0.833	2.28	0.235	0.00876	nd
99-308	50.6	17.1	5.12	0.398	0.290	0.135	0.799	1.31	0.203	0.00442	nd
99-313	63.4	23.4	5.10	0.499	0.291	0.155	0.790	1.51	0.228	0.0083	nd
99-317	56.1	19.0	1.69	0.481	0.406	0.079	0.293	7.61	0.101	0.0122	nd
99-326	61.1	21.1	5.95	0.436	0.280	0.154	0.862	1.41	0.238	0.0133	nd
99-331	45.0	12.8	3.62	0.418	0.624	0.103	0.672	5.47	0.170	0.0137	nd
99-336	51.5	15.4	5.15	0.626	0.261	0.118	0.898	3.82	0.259	0.0112	nd
99-341	35.8	8.47	3.70	0.665	0.164	0.0584	0.713	2.86	0.195	0.00781	nd
99-345	50.5	14.5	5.40	0.317	0.195	0.0936	1.09	2.54	0.291	0.00881	nd
00-23	47.7	11.6	6.94	3.27	0.497	0.0580	0.187	0.877	0.454	0.0747	0.56

Table 3. Major-, minor-, and trace- element data for 57 Brazilian coal samples calculated to a dry, whole-coal basis—continued

Field Number	Ash (%) (525°C)	Si (%)	Al (%)	Ca (%)	Mg (%)	Na (%)	K (%)	Fe (%)	Ti (%)	P (%)	S (%)
02-292	66.1	15.9	8.64	0.704	0.178	0.0932	0.977	7.53	0.471	0.0236	7.69
02-295	58.9	15.1	5.42	1.14	0.335	0.376	1.63	4.94	0.241	0.0254	5.58
02-296	49.1	15.5	5.09	0.835	0.296	0.372	1.62	2.13	0.245	0.0197	2.66
02-297	56.7	14.1	8.04	0.307	0.246	0.126	1.21	3.41	0.442	0.0190	3.72
02-298	46.6	12.5	6.76	1.13	0.276	0.115	1.33	1.90	0.403	0.0222	2.29
02-299	57.7	13.5	8.19	0.368	0.157	0.090	1.15	5.78	0.436	0.0186	6.02
02-300	28.5	4.34	2.85	0.430	0.114	0.0398	0.66	8.08	0.179	0.0118	9.73
02-301	51.1	12.7	7.87	0.0486	0.144	0.0455	1.32	3.03	0.407	0.0125	3.37
02-302	25.0	6.06	4.42	0.0486	0.097	0.0236	0.76	1.77	0.222	0.00808	2.44
02-303	64.8	15.8	8.92	0.353	0.184	0.0769	1.25	5.17	0.493	0.0184	5.44
02-304	40.9	11.1	6.11	0.333	0.164	0.0495	1.07	1.83	0.358	0.0148	2.38
02-305	64.9	16.6	7.18	0.349	0.403	0.193	1.99	4.36	0.331	0.0159	4.40
02-419	61.3	16.9	8.15	0.225	0.199	0.101	1.35	5.66	0.430	0.0265	6.17
02-420	40.3	11.9	5.95	0.130	0.197	0.0894	1.18	1.34	0.372	0.0169	1.77
02-421	55.0	14.2	7.28	0.472	0.171	0.157	1.28	6.24	0.426	0.0197	6.66
02-422	54.1	6.65	3.21	7.30	0.136	0.073	0.624	10.1	0.199	0.0347	11.1
02-429	27.0	6.45	2.52	0.723	0.129	0.195	0.539	4.01	0.157	0.0195	5.40

Table 3. Major-, minor-, and trace- element data for 57 Brazilian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	Ag (µg/g)	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)
WK-38-98	<0.84	21.4	<13.0	117	7.54	0.838	0.335	nd	15.1	40.2
99-035	<0.53	6.40	<11.0	160	0.630	0.735	0.0682	nd	16.1	22.2
99-036	<0.52	6.36	<11.0	143	0.673	0.414	0.222	nd	13.7	23.4
99-105	<0.33	35.1	52.6	87.0	3.70	0.454	0.844	274	19.2	31.4
99-115	<0.38	48.6	14.6	40.6	2.69	0.0987	0.645	326	14.8	29.9
99-136	<0.53	2.51	<11.0	571	6.86	0.445	<0.053	274	6.39	32.5
99-144+146	<0.31	6.67	12.1	55.3	5.05	0.571	0.153	324	10.2	31.3
99-163	<0.39	4.88	31.5	65.0	4.96	0.577	0.211	<160	7.11	37.9
99-167	<0.56	9.67	16.5	104	4.81	0.531	0.134	317	10.3	43.8
99-175	<0.59	3.09	43.6	52.8	5.60	0.332	<0.059	272	11.3	122.
99-176	<0.63	61.0	13.5	216	2.20	0.145	0.522	223	28.8	42.4
99-178	<0.60	1.89	<12.0	240	4.66	0.767	<0.060	273	6.9	43.6
99-182	<0.45	17.3	<8.9	44.9	2.84	0.222	0.227	203	17.0	29.8
99-187	<0.85	3.29	21.0	140	6.16	1.18	<0.085	<160	10.6	45.9
99-190	<0.37	19.5	36.2	34.5	6.87	0.436	<0.037	196	15.7	42.9
99-217	<0.52	2.47	35.6	147	5.51	0.824	0.149	<160	7.72	41.9
99-218	<0.65	31.8	65.7	158	3.29	0.303	0.271	<160	23.6	56.6
99-219	<0.64	21.2	79.7	178	5.80	0.893	0.108	<160	16.1	45.7
99-220	<0.56	34.8	90.0	132	3.13	0.397	0.950	<160	17.6	46.5
99-221	<0.54	51.4	67.3	104	3.66	0.323	0.162	<160	10.2	42.2

Table 3. Major-, minor-, and trace- element data for 57 Brazilian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	Ag (µg/g)	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)
99-222	<0.49	3.70	38.4	140	6.63	0.877	<0.0490	<160	7.26	37.3
99-223	<0.50	4.37	28.4	113	8.25	0.834	<0.0500	<160	7.41	34.0
99-224	<0.33	30.4	73.2	80.2	7.00	0.610	0.0770	165	24.8	31.9
99-225	<0.25	7.77	93.9	69.3	6.32	0.762	0.0565	<160	8.78	35.9
99-226	<0.59	88.8	94.0	102	2.69	0.181	0.199	164	25.2	75.9
99-250	<0.49	3.57	31.5	153	9.08	0.580	0.0580	<160	5.46	32.8
99-255	<0.62	7.48	16.0	164	5.40	0.552	0.0858	<160	19.4	41.9
99-266	<0.49	21.8	41.1	137	5.15	0.418	0.0729	<170	13.2	30.2
99-270	<0.56	2.66	24.7	116	6.10	0.555	0.189	<160	7.88	34.9
99-284	<0.53	5.59	27.1	110	5.38	0.444	<0.0530	<160	7.57	35.9
99-296	<0.51	7.12	60.7	141	3.01	0.381	<0.0510	<170	10.3	33.7
99-308	<0.51	1.92	49.1	120	3.29	0.314	<0.0510	<170	5.57	33.1
99-313	<0.64	24.1	18.4	128	5.01	0.292	<0.0640	<160	8.56	29.4
99-317	<0.57	23.4	83.5	66.2	3.20	0.146	<0.0570	<160	9.76	63.9
99-326	<0.62	2.81	33.6	150	4.76	0.488	0.0794	<160	7.39	40.6
99-331	<0.45	2.52	85.9	98.9	4.54	0.225	0.108	<170	4.86	42.8
99-336	<0.52	33.9	46.4	139	7.52	0.273	0.0721	<160	8.44	50.3
99-341	<0.36	9.56	83.8	116	20.0	0.243	0.0752	<170	7.88	42.6
99-345	<0.51	9.24	39.5	158	23.2	0.262	0.207	<170	11.8	47.9
00-23	<0.96	7.53	163	519	11.1	0.453	0.0524	<160	8.58	39.7

Table 3. Major-, minor-, and trace- element data for 57 Brazilian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	Ag (µg/g)	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)
02-292	<1.40	29.5	98.5	291	4.10	1.34	0.264	403	20.6	55.1
02-295	<1.20	23.9	64.8	93.6	2.83	0.560	0.118	242	10.2	34.3
02-296	<0.990	9.82	21.8	96.3	2.55	0.344	0.275	<160	8.15	34.8
02-297	<1.20	18.8	61.8	158	4.19	0.725	0.640	556	15.0	69.1
02-298	<0.940	12.6	21.5	256	3.79	0.606	0.695	<160	13.2	77.4
02-299	<1.20	47.2	71.0	397	4.39	0.716	0.277	322	21.4	64.7
02-300	0.713	49.6	8.50	119	3.08	0.282	9.04	214	15.4	28.1
02-301	<1.10	19.9	54.7	1610	3.58	0.618	0.0613	405	8.63	49.4
02-302	<0.510	8.80	16.4	295	3.23	0.408	0.118	288	5.48	30.8
02-303	<1.30	28.8	79.7	430	4.34	0.732	0.194	293	20.5	63.9
02-304	<0.820	13.6	28.4	225	4.58	0.593	0.417	<160	12.3	70.0
02-305	<1.30	30.1	67.5	237	3.96	0.487	0.0909	335	13.4	45.1
02-419	<1.30	20.7	24.4	277	3.32	0.540	0.135	218	15.6	54.5
02-420	<0.810	7.13	29.2	283	3.96	0.544	0.161	<160	12.3	83.4
02-421	<1.20	30.3	18.6	146	3.57	0.666	0.429	<160	15.4	61.7
02-422	<1.10	86.0	<11.0	1370	1.99	0.357	0.649	<160	11.1	38.9
02-429	<0.550	568	36.2	226	3.30	0.227	4.25	<160	9.06	33.0

Table 3. Major-, minor-, and trace- element data for 57 Brazilian 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)
WK-38-98	7.96	20.1	16.3	7.12	0.43	88.0	226.	11.7	12.6	28.9
99-035	2.47	<1.10	14.1	3.25	nd	21.5	319.	1.05	8.71	7.45
99-036	1.76	<1.10	12.6	2.38	nd	21.5	351.	5.80	7.30	5.17
99-105	10.8	16.4	12.3	10.7	0.041	98.7	50.3	2.40	3.54	49.0
99-115	2.43	21.4	4.71	32.6	0.42	18.5	138.	4.40	4.29	54.6
99-136	16.6	11.9	15.8	3.67	0.051	53.4	31.3	0.508	7.54	19.1
99-144+146	8.96	17.6	13.8	7.24	0.081	31.3	12.8	1.50	4.93	29.5
99-163	4.85	20.6	13.4	22.1	0.073	34.9	138.	0.808	6.23	23.4
99-167	12.1	17.8	17.6	7.65	0.23	43.0	320.	2.12	7.26	21.3
99-175	10.8	25.1	11.4	17.3	0.040	41.9	3780.	1.69	5.07	22.0
99-176	4.91	15.2	11.0	6.61	0.31	29.7	768.	25.5	6.10	61.2
99-178	11.7	20.1	18.2	2.18	0.040	64.9	179.	0.649	9.44	17.8
99-182	3.07	11.0	6.71	7.29	0.051	6.00	737.	2.93	5.29	30.3
99-187	11.3	33.7	26.9	2.20	0.051	81.7	25.8	0.929	16.2	22.5
99-190	3.74	23.7	10.4	9.31	0.14	20.6	158.	1.82	4.84	52.0
99-217	12.9	23.7	18.6	5.05	0.082	83.4	25.7	1.39	10.1	19.1
99-218	11.4	20.2	11.5	27.0	0.29	35.9	57.4	4.70	11.0	30.2
99-219	14.4	20.2	24.2	16.1	0.33	68.2	27.9	2.81	12.9	26.8
99-220	7.32	9.90	11.0	8.55	0.28	26.3	56.5	6.54	12.2	28.6
99-221	6.46	6.46	9.75	18.7	0.35	27.3	53.5	3.39	6.46	20.0

Table 3. Major-, minor-, and trace- element data for 57 Brazilian 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)
99-222	11.1	20.9	17.1	5.16	0.072	105.	18.9	1.41	9.06	17.1
99-223	8.88	25.7	18.0	5.06	0.15	156.	17.5	0.932	7.85	30.1
99-224	6.23	16.8	15.3	11.5	0.69	46.5	99.5	3.34	5.58	26.1
99-225	5.83	19.5	14.2	12.9	0.20	37.9	21.1	3.79	5.51	23.2
99-226	6.54	10.2	7.07	11.9	0.67	26.6	87.0	13.7	4.56	47.5
99-250	10.3	15.7	15.6	73.4	0.28	22.1	86.0	0.580	7.73	12.9
99-255	12.1	15.7	16.3	12.7	0.13	28.1	92.0	0.509	7.97	21.0
99-266	10.2	14.9	13.4	8.02	0.11	22.2	101.	1.12	6.66	16.4
99-270	6.71	17.7	16.0	15.1	0.085	25.4	462.	0.610	5.55	11.3
99-284	9.56	13.0	13.9	4.23	0.21	34.1	358.	0.836	7.16	12.6
99-296	8.08	12.7	12.4	2.71	0.26	22.6	102.	1.76	6.77	15.1
99-308	9.52	12.4	11.7	2.63	0.075	23.1	37.5	0.760	5.93	13.3
99-313	9.83	8.94	10.5	0.952	0.15	26.1	31.5	2.28	5.77	19.2
99-317	2.75	7.51	8.41	34.5	0.16	15.3	639.	2.58	6.73	31.6
99-326	8.30	10.1	13.5	6.17	0.095	24.0	102.	0.794	8.18	15.1
99-331	7.01	9.76	12.5	11.4	0.064	15.9	755.	0.944	4.63	13.5
99-336	9.58	14.4	12.6	4.38	0.32	20.4	111.	31.4	5.66	19.8
99-341	7.02	14.5	15.4	98.8	0.15	15.3	64.8	3.12	4.69	18.9
99-345	9.19	16.9	16.7	96.4	0.064	17.1	28.8	3.84	6.06	30.3
00-23	12.6	18.8	16.9	7.15	0.068	118	50.5	0.553	10.3	12.9

Table 3. Major-, minor-, and trace- element data for 57 Brazilian 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)
02-292	9.65	32.4	19.0	10.0	0.50	74.0	183.	3.84	11.0	41.6
02-295	20.0	18.0	12.0	6.36	0.26	23.2	311.	2.08	5.19	18.7
02-296	19.8	17.4	11.0	5.26	0.139	27.2	194	1.34	5.01	14.5
02-297	15.5	26.7	18.8	7.25	0.37	76.5	204.	2.39	10.7	25.7
02-298	11.8	19.4	16.8	7.28	0.202	63.0	374	2.53	10.1	21.0
02-299	11.3	34.0	19.2	7.28	0.62	78.5	92.4	3.14	11.2	44.9
02-300	6.73	15.6	9.29	16.5	0.939	33.1	107	4.45	4.90	31.6
02-301	12.0	11.8	19.8	8.38	0.45	50.4	18.5	1.67	10.4	15.1
02-302	8.10	3.8	12.1	14.3	0.238	26.3	12.7	1.15	6.10	7.80
02-303	13.2	42.6	21.8	7.71	0.76	82.3	80.4	2.67	12.1	44.1
02-304	11.7	17.1	16.8	13.6	0.371	54.0	62.2	1.54	9.37	23.4
02-305	17.0	15.6	16.9	5.27	0.27	31.0	135.	1.79	7.73	19.5
02-419	11.3	21.1	17.5	7.24	0.278	68.1	70.5	1.85	9.45	23.1
02-420	14.3	13.1	16.2	9.67	0.148	41.5	45.5	1.24	9.91	21.6
02-421	8.86	29.8	16.8	9.58	0.442	69.9	95.2	2.21	10.1	26.4
02-422	5.24	14.4	7.25	6.49	0.778	63.3	1740	3.94	4.75	26.8
02-429	2.11	18.7	6.00	25.2	0.658	40.0	186	16.7	3.89	21.1

Table 3. Major-, minor-, and trace- element data for 57 Brazilian 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)
WK-38-98	46.1	46.1	1.26	8.38	7.1	4.19	101.	<0.840	11.3	2.30
99-035	16.7	67.7	1.15	7.97	nd	7.35	61.9	0.0839	5.46	0.839
99-036	15.6	78.6	0.621	7.24	nd	3.31	71.4	0.0621	8.80	0.409
99-105	53.9	44.8	3.05	6.36	2.8	2.86	103.	0.357	5.26	4.74
99-115	32.1	23.1	8.65	5.58	1.6	1.29	126.	0.102	5.81	3.11
99-136	78.6	48.8	1.26	10.5	3.1	3.82	149.	0.267	12.5	0.576
99-144+146	13.2	27.1	0.902	8.78	2.3	2.86	171.	0.253	6.67	1.08
99-163	42.7	22.7	4.00	15.7	3.6	3.69	85.4	0.250	11.8	0.423
99-167	23.5	62.0	1.68	16.5	1.7	4.41	107.	0.363	19.8	0.782
99-175	32.1	54.0	5.60	9.86	2.5	5.02	533.	0.239	4.90	0.455
99-176	29.0	49.7	3.40	7.93	0.85	3.15	190.	0.132	5.35	2.52
99-178	38.5	52.2	0.708	15.2	2.1	5.02	126.	0.413	20.3	0.555
99-182	17.5	26.7	0.977	5.38	0.57	2.84	436.	0.080	9.68	2.13
99-187	21.8	59.3	0.659	15.7	1.9	9.97	301.	0.405	16.5	0.600
99-190	29.6	17.3	3.89	13.3	3.9	2.58	162.	0.269	6.11	0.545
99-217	17.1	43.2	0.927	13.9	3.4	5.25	147.	0.227	8.65	0.463
99-218	52.8	76.7	5.16	7.54	1.4	2.13	233.	0.412	7.22	2.90
99-219	53.9	52.2	1.47	12.8	2.7	6.63	115.	0.274	13.2	2.42
99-220	35.8	49.5	1.17	6.15	0.85	2.12	176.	0.0839	<4.50	2.57
99-221	49.8	42.3	1.02	5.17	0.83	2.05	100.	0.129	4.20	4.25

Table 3. Major-, minor-, and trace- element data for 57 Brazilian 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)
99-222	20.3	29.0	1.07	13.3	3.5	4.68	109.	0.268	6.63	0.487
99-223	14.6	25.4	0.687	10.6	2.6	5.06	146.	0.186	5.40	0.314
99-224	100.	19.3	1.22	7.77	5.3	2.73	117.	0.212	4.27	3.27
99-225	52.4	17.1	1.99	12.4	1.9	2.83	56.3	0.295	4.65	0.861
99-226	40.8	42.6	2.10	5.08	1.6	<1.80	209.	0.117	<4.70	12.6
99-250	7.63	73.9	1.01	11.6	1.0	4.68	94.2	0.222	6.57	0.676
99-255	19.9	78.5	0.509	13.1	2.1	4.66	174.	0.147	7.85	0.920
99-266	13.2	69.5	0.729	9.04	2.4	3.70	57.4	0.0972	8.27	0.681
99-270	5.66	58.3	0.777	13.1	0.38	3.61	77.7	0.111	16.3	0.344
99-284	13.0	49.5	0.522	10.4	3.0	3.87	64.3	0.157	11.9	0.319
99-296	13.0	56.7	0.552	9.58	1.7	3.01	78.3	0.0752	7.22	0.803
99-308	9.27	64.8	0.436	8.91	0.43	2.99	104.	0.0506	11.6	0.289
99-313	24.9	53.5	1.27	9.26	1.8	2.22	74.9	<0.0640	11.6	0.393
99-317	30.4	23.1	2.47	7.07	0.39	<1.70	70.7	<0.0570	<4.50	2.41
99-326	17.0	61.7	0.855	9.65	0.64	4.09	66.5	0.0733	10.1	0.733
99-331	10.9	43.9	1.17	12.1	0.25	2.29	110.	0.0450	6.47	0.719
99-336	17.1	60.2	0.669	11.6	1.5	2.11	75.7	0.0927	10.8	2.52
99-341	11.9	53.4	0.752	10.7	0.80	1.97	88.4	0.104	8.74	3.08
99-345	11.7	90.4	1.41	10.7	1.1	3.13	73.2	0.116	6.16	1.36
00-23	17.6	52.4	1.37	13.5	nd	5.72	64.8	0.214	15.6	0.925

Table 3. Major-, minor-, and trace- element data for 57 Brazilian 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)
02-292	66.8	55.0	1.87	16.4	5.1	9.91	76.7	0.773	19.2	5.96
02-295	28.3	99.5	0.954	8.54	2.6	4.62	87.2	0.253	9.89	4.25
02-296	15.9	92.3	0.648	9.04	nd	3.23	86.4	0.118	9.68	1.66
02-297	34.7	66.3	0.839	20.6	4.1	7.42	54.7	0.289	25.9	4.21
02-298	21.4	67.2	0.644	19.9	nd	7.46	70.9	0.300	17.7	2.07
02-299	105.	65.2	1.93	14.7	5.0	8.14	85.5	0.312	11.0	4.80
02-300	136	34.8	2.16	5.93	nd	3.96	30.5	0.200	<2.30	6.16
02-301	79.7	70.5	1.54	10.6	1.7	6.85	49.8	0.184	11.7	2.19
02-302	38.8	44.8	1.18	6.15	nd	3.13	30.3	0.163	5.50	1.19
02-303	56.0	71.3	1.14	15.4	4.1	7.26	83.0	0.285	14.3	7.58
02-304	26.9	61.4	0.769	14.4	nd	5.48	59.3	0.262	16.2	3.04
02-305	40.0	124.0	0.870	11.8	2.4	9.74	37.8	0.123	11.6	3.47
02-419	28.4	65.0	0.699	12.0	nd	5.18	47.8	0.276	10.7	5.30
02-420	14.0	71.7	0.608	16.0	nd	6.81	42.7	0.310	17.3	2.52
02-421	39.1	58.9	1.01	12.1	nd	5.83	64.4	0.286	7.27	5.24
02-422	29.0	30.0	0.995	11.8	nd	3.06	134	0.178	<4.40	9.46
02-429	116	23.8	3.00	9.33	nd	2.42	116	0.0973	4.38	15.1

Table 3. Major-, minor-, and trace- element data for 57 Brazilian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	U (µg/g)	V (µg/g)	Y (µg/g)	Zn (µg/g)	Zr (µg/g)
WK-38-98	4.11	67.0	19.7	31.8	88.0
99-035	4.35	48.9	28.6	42.7	144.
99-036	3.36	44.6	22.7	32.5	86.4
99-105	1.72	78.9	14.0	138.	60.0
99-115	5.16	71.3	33.8	244.	101.
99-136	46.6	128.	128.	23.2	195.
99-144+146	2.56	74.6	14.9	33.7	73.9
99-163	18.9	110.	57.7	50.0	142.
99-167	15.8	109.	74.3	188.	268.
99-175	3.03	105.	37.8	58.9	67.7
99-176	2.64	54.7	22.5	243.	113.
99-178	9.15	92.6	40.1	18.8	140.
99-182	19.3	89.7	47.1	101.	232.
99-187	6.42	70.1	24.7	7.09	157.
99-190	5.24	120.	66.9	15.6	235.
99-217	5.35	112.	23.9	63.8	191.
99-218	5.93	67.7	46.8	65.1	107.
99-219	7.14	86.7	33.5	27.2	160.
99-220	5.65	55.9	24.9	258.	139.
99-221	3.18	43.0	30.5	60.3	84.6

Table 3. Major-, minor-, and trace- element data for 57 Brazilian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	U (µg/g)	V (µg/g)	Y (µg/g)	Zn (µg/g)	Zr (µg/g)
99-222	5.65	119.	26.5	13.3	139.
99-223	3.83	86.4	21.1	18.5	128.
99-224	3.37	48.1	19.9	21.2	77.7
99-225	7.33	99.3	39.6	22.5	147.
99-226	4.44	58.2	31.2	44.3	74.2
99-250	6.13	72.9	58.0	113.	297.
99-255	6.62	65.0	44.2	87.1	183.
99-266	5.30	52.5	25.3	55.9	107.
99-270	9.32	93.2	78.8	187.	259.
99-284	3.13	58.0	27.4	46.4	76.8
99-296	3.61	48.5	28.9	46.7	129.
99-308	3.24	44.4	21.8	39.5	102.
99-313	2.60	49.0	19.3	31.1	105.
99-317	3.48	51.4	22.7	155.	325.
99-326	5.01	47.4	31.3	73.3	176.
99-331	6.16	62.5	37.9	109.	217.
99-336	2.94	59.2	24.4	66.4	137.
99-341	2.76	64.5	27.5	59.8	115.
99-345	3.08	91.4	27.3	140.	202.
00-23	5.15	79.1	31.8	29.4	211

Table 3. Major-, minor-, and trace- element data for 57 Brazilian coal samples calculated to a dry, whole-coal basis—continued.

Field Number	U (µg/g)	V (µg/g)	Y (µg/g)	Zn (µg/g)	Zr (µg/g)
02-292	8.06	91.9	19.2	70.7	244.
02-295	4.42	74.2	16.8	45.6	105.
02-296	3.54	71.7	16.2	141	158
02-297	13.1	125.	28.3	298.	325.
02-298	14.2	132	33.6	256	454
02-299	12.4	121.	24.1	60.6	427.
02-300	28.4	44.8	23.6	2140	1200
02-301	4.48	89.4	16.2	45.8	221.
02-302	2.95	60.8	11.1	40.0	188
02-303	5.00	110.	20.3	50.6	231.
02-304	4.38	121	22.3	154	264
02-305	5.20	83.8	18.6	23.4	138.
02-419	3.37	90.8	17.6	28.7	286
02-420	4.35	140	21.2	54.0	319
02-421	8.92	101	24.3	146	462
02-422	19.4	64.9	39.7	249	537
02-429	113	71.9	47.6	506	354

Table 4. Semi-quantitative X-ray diffraction mineralogy. All values in percent of the low temperature ash yield.

Sample #	Quartz	Feldspar	Calcite	Ankerite	Dolomite	Siderite	Illite	Kaolinite	Pyrite
WK-38-98	21	T	T			R	6	64	6
99-115	60	T	T				15	10	M
99-175	40	T	T			15	M	30	
99-182	45	T	15	15	T	R	M	T	M
99-187	30	T				R	10	60	
99-226	45	T	T			R	M	10	25

Sample #	Sphalerite	Bassanite	Apatite	Anatase	Rutile	Hematite	Corundum	SumMajorPhase (>10%)
WK-38-98	T	T	R		R	T		97
99-115						R	T	85
99-175	T		T		R	T		85
99-182	R	T	R			R		75
99-187	R	T	T		T			100
99-226			T	R	R	T	T	80

Notes: T= trace amount <= 5%, M= minor amount >5 and <10%, R= rejected.

Table 5. Fraction leached from sample WK-38-98 (weight percent)

Element	NH_4Ac	HCl	HF	HNO_3	Total
Li	0%	<20%	80%	<15	80-100%
Be	0%	20%	55%	0%	75%
Na	70%	5%	20%	0%	95%
Mg	5%	10%	50%	10%	75%
Al	0%	0%	85%	0%	85%
P	0%	65%	35%	0%	100%
K	5%	0%	90%	0%	95%
Ca	40%	40%	0%	0%	80%
Sc	0%	25%	60%	0%	85%
Ti	0%	5%	70%	0%	75%
V	0%	25%	50%	0%	75%
Cr	0%	0%	65%	0%	65%
Mn	15%	75%	5%	5%	100%
Fe	0%	10%	10%	80%	100%
Co	5%	40%	10%	25%	80%
Ni	0%	20%	15%	40%	75%
Cu	0%	10%	10%	50%	70%
Zn	0%	20%	15%	45%	80%
As	0%	20%	10%	65%	95%
Se	0%	0%	5%	75%	80%
Br	15%	0%	15%	10%	40%
Rb	5%	0%	65%	20%	90%
Sr	40%	10%	20%	5%	75%
Y	0%	30%	55%	15%	100%
Zr	0%	5%	75%	5%	85%
Mo	20%	0%	20%	25%	65%
Sn	0%	10%	80%	0%	90%
Sb	0%	0%	15%	45%	60%
Cs	15%	5%	45%	30%	95%
Ba	10%	10%	60%	5%	85%
La	0%	55%	15%	20%	90%
Ce	0%	60%	15%	15%	90%
Sm	0%	65%	15%	10%	90%
Eu	5%	60%	15%	10%	90%
Tb	0%	45%	25%	10%	80%
Yb	0%	10%	45%	10%	65%
Lu	0%	10%	45%	10%	65%
Hf	0%	5%	60%	0%	65%
Ta	0%	0%	40%	10%	50%
W	0%	10%	45%	10%	65%
Au	0%	10%	20%	20%	50%
Tl	5%	10%	15%	45%	75%
Pb	0%	15%	5%	50%	70%
Th	0%	50%	25%	10%	85%
U	5%	20%	55%	5%	85%

Appendix 1. Locality information for 14 Brazilian coal samples. Please note that the latitude and longitude coordinates for each sample were determined from the best available information and may not be accurate. There was insufficient sample locality information available to determine the latitude/longitude coordinates for the remaining 43 Brazil coal samples.
[Abbreviations: ERT=Energy Resources Team, Labid=laboratory identification number, Fieldid=field identification number]

ERT Fieldid	ERT Labid	Sample source	Latitude	Longitude	State	Coal Field	Mine	Bed	Thickness (m)	Thick (ft)
99-105	E-167728	Core	-29.96	-49.99	Rio Grande do Sul	Santa Terezinha	TG-95	B	0.48	1.58
99-115	E-167729	Core	-29.84	-49.94	Rio Grande do Sul	Santa Terezinha	TG-94	Leito 5	0.15	0.50
99-136	E-167730	Core	-29.79	-49.95	Rio Grande do Sul	Santa Terezinha	TG-65	F	0.66	2.18
99-144+146	E-167731	Core	-29.85	-50.04	Rio Grande do Sul	Santa Terezinha	TG-10	A	0.65	2.15
99-153	NONE	Core	-29.75	-49.60	Rio Grande do Sul	Santa Terezinha	TG-02	CL3	0.51	1.68
99-163	E-167732	Core	-29.79	-49.49	Rio Grande do Sul	Santa Terezinha	TG-130	C	0.07	0.23
99-167	E-167733	Core	-29.83	-49.77	Rio Grande do Sul	Santa Terezinha	TG-49	E	0.4	1.32
99-175	E-167734	Core	-29.91	-49.96	Rio Grande do Sul	Santa Terezinha	TG-59	Inferior	0.30	0.99
99-176	E-167735	Core	-29.91	-49.96	Rio Grande do Sul	Santa Terezinha	TG-59	G	0.42	1.39
99-178	E-167736	Core	-29.91	-49.96	Rio Grande do Sul	Santa Terezinha	TG-59	F	0.5	1.65
99-182	E-167737	Core	-29.77	-49.72	Rio Grande do Sul	Santa Terezinha	TG-83	D	0.28	0.92
99-187	E-167738	Core	-29.73	-49.67	Rio Grande do Sul	Santa Terezinha	TG-51	G	0.2	0.66
99-190	E-167739	Core	-29.73	-49.67	Rio Grande do Sul	Santa Terezinha	TG-51	G	0.04	0.13