Chapter 6

World Coal Quality Inventory: Peru

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Chapter 6 of

World Coal Quality Inventory: South America

Edited by Alex W. Karlsen, Susan J. Tewalt, Linda J. Bragg, 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 most of the world's coal-producing countries, has undertaken a project called the World Coal Quality Inventory (WoCQI). The WoCQI currently contains coal quality and ancillary information on samples obtained from major and minor coal-producing regions throughout the world (Finkelman and Lovern, 2001a, b). Sample collection and analytical methods for the WoCQI are described in the Executive Summary (Chapter 1, this volume).

This chapter focuses on the coals of Peru, but standard, representative samples of Peruvian coals were difficult to obtain and this study draws no final conclusions as to the chemical nature of the 16 coal samples collected.

Peru

Although coal occurrences are widely distributed in Peru (fig. 1), the country is not considered one of the region's major coal-producing or coal-using nations. In general, there is little information relating directly to Peruvian coals; most reports discuss the sedimentary environment of the coal-bearing stratigraphic sequences. In recent years, more reports on the coal composition and distribution have been published (Carrascal-Miranda and Suarez-Ruiz, 2004). Many publications still focus on describing isolated occurrences of coal.

These references cover various aspects of Peruvian coals from geology to annual production: Brooks and Kent (2000),Gurmendi (2001), INGEMMET (undated), Jessen (1989), Marquez (1992), Minero Peru (1986), and Mining Journal (2002).

Geology of Coal Areas

Coal is present in Paleozoic, Mesozoic, and Cenozoic basins (fig. 1). In the Paleozoic-Mesozoic basins, coal ranges in rank from bituminous to meta-anthracite in proximity to intrusive rocks. Coal rank ranges from lignite to sub-bituminous in the Cenozoic basins in the Amazon region and near Tumbes in northern Peru.

The number of coal-producing basins in Peru varies by author. For example: Olive (1978) lists seven coal-producing basins; Petersen (1978) lists four; Alvarado (1980) lists fifteen; Agramonte and Diaz (1983) list twelve; Yanque (1989) lists eight; Weaver and Wood (1994) list eight; Dunin-Borowski (1996) lists five; Carrascal and others (2000) list thirteen (fig. 1); and Lopes and Ferreira (2000) list three.

The wide range in the number of coal-producing areas in Peru is likely due to the definition of a basin or field by the individual authors. Data on Peruvian coalfields, reserves, and usage were also compiled by Weaver (1993). Carrascal and others (2000) provide the most recent and authoritative compilation that includes maps, locations, formations, ages, rank, reserves, and analytical data for 230 occurrences of coal. Table 1 summarizes Carrascal and others (2000) major coal bearing basins with the age and name of stratigraphic units and coal rank.

Historically, the best-known coal-producing area is the Goyllarisquizga coalfield in central Peru (fig. 1), which supplied coking coal to the copper smelters for the Cerro de Pasco Corporation. The coals occur in the Goyllarisquizga Group of Cretaceous age, which is predominantly composed of orthoquartzites. From 1903 to 1971, a privately owned mine produced a total of approximately 8,800,000 metric tons of coal, but the mine closed due to economic reasons in 1971 (Petersen, 1978). After nationalization in the late 1970's, the Goyllarisquizga mine was reopened and output from the mine declined from a maxiumum of 60,000 metric tons per year to about 45,000 metric tons per year in the 1990's. The Goyllarisquizga mine may, once again, be privatized in the foreseeable future (A. Gurmendi, USGS, oral communication, 2002).

The most extensive, and potentially most productive, coal-producing area in Peru is the Northern Anthracite Field in northern Peru (Petersen, 1978). This area is more commonly known as the Alto Chicama (fig.1) (Escudero, 1979). Northern Peru is subdivided into four sectors, each with numerous coal occurrences (Carrascal and others, 2000). Coal is hosted in folded and faulted rocks of the Cretaceous Goyllarisquizga Group that includes the sandstones of the Santa and Chimu Formations (Petersen, 1978). The coal beds are 1.0 to 2.5 meters in thickness (Carrascal and others, 2000). Average sulfur content and ash yield of Alto Chicama coal is 0.6 weight percent and 11.1 percent (as received), respectively (Carrascal and others, 2000). These averages are for 37 analyses; the analytical data from the anomalously high-sulfur coal (up to 23 weight percent) from Callacuyan were excluded (Carrascal and others, 2000). Gold exploration programs are also active in this region (Mining Journal, 2002).

Another important coal region in the Alto Chicama is the Santa Basin (fig. 1). Several mines including La Galgada, Cocobal, and La Limena, have been active in this area which is near the steel works at Chimbote. Carrascal and others (2000) also subdivide the Santa Basin into several sectors. Steeply dipping anticlines and synclines are the dominant structures and coal beds range from 0.3 to 3.5 meters in thickness. Average sulfur content and ash yield of Santa basin coal (17 analyses) is 0.48 weight percent and 15.2 percent (as received), respectively (Carrascal and others, 2000).

Coal Resources

Carrascal and others (2000, table 4.1.8) indicate resources of approximately 1 billion metric tons of coal of which 78.3 percent is from Mesozoic basins, 21.4 percent is from Cenozoic basins, and 0.3 percent is from Paleozoic occurrences. The Alto Chicama (1,520 km^2) is the most extensive, and potentially most productive of the four coal-producing areas in northern Peru that also include the Santa, Ojon, and Jatunhuasi basins. Alto Chicama reserves are estimated to be 223,700,000 metric tons (Escudero, 1979). There are numerous smaller coal occurrences in this area and resources are estimated to be 225,000,000 metric tons (Escudero, 1979).

Baruya and Clark (1996) estimate proven recoverable reserves of 11 million metric tons in Peru, ranking it 39th worldwide. Reserve figures for Peru have a low level of credibility according to the British Geological Survey (Burgess, 1985). Burgess (1985) indicates that no adequate estimate can be made of the total resources on a country-wide basis or of those reserves in the many small coalfields.

Coal Production

Some information on coal production from individual fields was covered in the section on geology. Information on total Peruvian coal production was compiled by country specialists Alfredo C. Gurmendi (2001) and Thomas R. Yager, U.S. Geological Survey Minerals Information Team (written communication, USGS, 2002) (Table 2).

In 1999 there were only two small mines operating in Peru, within the administrative district of the city of Lima (J. Miguel Angel Yepez, written communication, U.S. State Department, 2000). Production remains limited at this time, with coal often being delivered to local towns by truck (fig. 2).

Coal Uses

In Peru, coal was used during pre-Inca times for metallurgy (Agramonte and Diaz, 1983, p. 30) and decorative purposes such as highly-polished anthracite mirrors and necklaces (Petersen, 1970; Burger, 1992; Larco, 2001). According to Agramonte and Diaz (1983), the first large-scale industrial application of coal in Peru began around 1816, for steam generation at copper mines. By 1880 coal was used extensively in the copper and silver smelters in the region (Bargellini, 1992). Exploitation of coal intensified from 1880-1931, and in 1931 an 8 kilometer long cable system with a hauling capacity of 225 metric tons of coal per day was set up to transport coal from the mines at Callacuyan to the silver smelter at Shorey (Minero Peru, 1986), near Santiago de Chuco. Between 1943 and 1956, anthracite from northern Peru, mainly from La Galgada, Cocabal, and La Limeña mines, was exported to Argentina and France (Dunin -Borkowski, 1996; Carrascal and others, 2000).

Electricity in Peru is mainly produced from hydroelectric power. Because the coals from Peru have a reputation of having high sulfur content, coal is currently imported from Indonesia, Colombia, and Venezuela for power generation in the copper mining operations of southern Peru (Bowen, 2001). In Peru, coal has been used in rural ovens for cooking, and for general domestic use (see fig. 3), and a variety of industrial applications that include brick-making, coal briquettes, metallurgy, filters, and cement production (Mucho, 1992).

Coal Trade

Anthracite from northern Peru was exported to Argentina and France between 1943-56 (Dunin-Borkowski, 1996; Carrascal and others, 2000). Some coal is imported from Indonesia, Colombia, and Venezuela for power generation in southern Peru (Bowen, 2001) however, no data were provided on the quantity of the coal imported.

Coal Quality

Proximate and ultimate coal data are available for Peruvian coal (Agramonte and Diaz, 1983; Dunin-Borkowski, 1996; Carrascal and others, 2000) and some trace element data are also available (Ojeda and Mendoza, 1996; Carrascal and others, 2000). However, data on elements of environmental concern, such as As and Hg, are not available. Therefore, as part of the World Coal Quality Inventory, coal samples from Peru were analyzed by the USGS for major oxide and major-, minor-, and trace-element contents. Proximate and ultimate analyses and sulfur-form data were also obtained from a commercial coal laboratory. These coal quality parameters, which are significant for environmental impact, technological behavior, and economic byproduct recovery (Finkelman and others, 2001) are an integral part of the World Coal Quality Inventory.

Samples of coal from the Alto Chicama were obtained by one author (Brooks) from site visits or through counterpart contacts in Peru. Brief sample descriptions and geologic settings are given in Appendix 1. A total of 16 samples were obtained from a variety of sources (outcrop, grab, run-of-mine, briquette, etc.). The limited number of samples and the absence of geologic information for some samples preclude any detailed discussion of geologic controls on coal quality or any statistical treatment of the analytical data. Only general comments are provided.

Analytical results for the limited suite of Peruvian coal samples are compiled in Table 3 (proximate-ultimate data), Table 4 (major oxides), and Table 5 (major- minor-, and trace-elements).

The moisture content of the Peruvian coal samples is generally low (Table 3), most samples having around 5 weight percent moisture. The sole exception is sample BP0108 with almost 16 weight percent moisture. Ash yields range from near 2 weight percent for a run-of-the mine sample from Mina La Victoria (BP2500) to nearly 30 weight percent for several of the anthracite samples from Alto Chicama. One grab sample (BP3200) had almost 62 weight percent ash. Sulfur contents are generally low, with only one sample (BP0108) having more than 1 weight percent total sulfur. Pyritic sulfur was also low with only one sample having more than 0.1 weight percent. Gross calorific value (dry basis) ranged from 4,060 Btu/lb to more than 13,000 Btu/lb for several samples from the Santa and Alto Chicama basins.

Table 4 shows results for major oxides. For 12 of the 16 samples the oxide sums are between 90 and 102 weight percent. The dominant oxides for most samples are silica and alumina. Iron oxides are generally about 5 weight percent, except for sample BP0108 (10.4 weight percent). The sum of SiO_2 and Al_2O_3 in the briquette sample (BP2700) is 84.6 weight percent indicating that clay was used as the binding agent. For most of the oxides (Na_2O, CaO, K_2O, MgO, P_2O_5, and TiO_2) the samples have low to modest concentrations within a narrow range of values.

Table 5 contains information on the trace elements on a dry, whole coal basis. The briquette (BP2700) had the highest Hg value (0.63 ppm). Arsenic is low, all samples having less than 19 ppm, except for sample BP0108 with 975 ppm – perhaps related to the nearby metal occurrences. Several samples (BP3200 and BP0108) have relatively high (>160 ppm) B contents. Sample BP0108 appears to be the only sample to have undergone mineralization. This sample has the highest S content (1.5 weight percent—though mostly organic sulfur) and the highest or nearly the highest concentrations of Co, Cu, Mn, Ni, Zn, B, Ag, As, Bi, Cd, Pb, Sb, Sn, and Te.

Coal Utilization Impacts

The Na_2O content of sample BP108 is nearly 5 weight percent – sodium contents at this level are known to cause fouling in coal-fired boilers (Vaninetti and Busch, 1982). Because of the relatively low concentrations of most elements, these Peruvian coal samples do not appear to present any potential environmental or health problems (except for sample BP0108) nor do they have any economic byproduct potential. The As concentration (975 ppm) of sample BP0108 is reason for concern, if the sample is representative of the area. Combined with the high concentrations of Pb (339 ppm), Cu (141 ppm), Cd (6.4 ppm), Sb (5.3 ppm), and Te (0.9 ppm), combustion of this sample or the handling of the combustion byproducts presents a potential hazard to human health. Coals from this location are close to metallurgic deposits (see Appendix 1).

Coalbed Methane

No information was found on coalbed methane resources or production in Peru.

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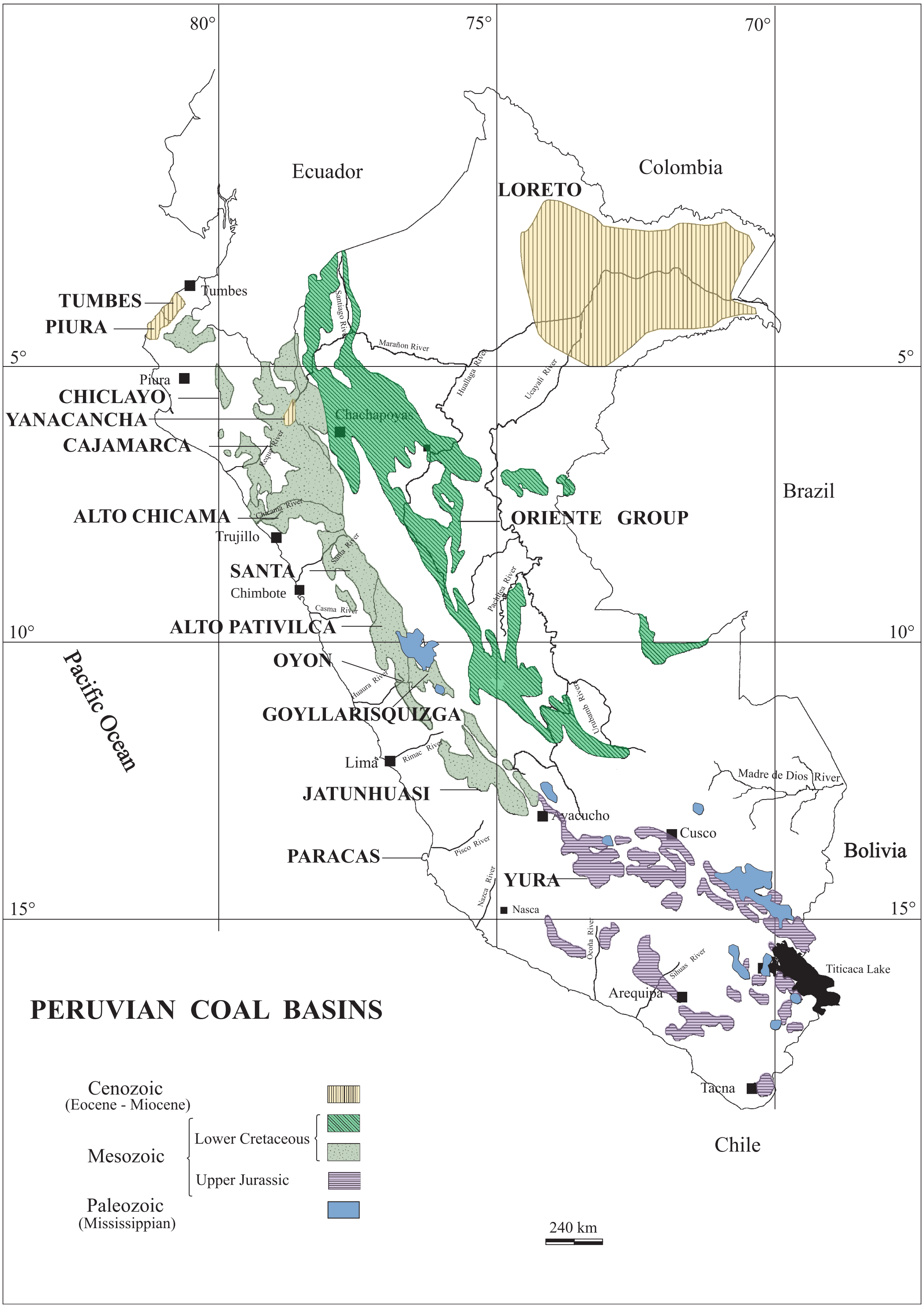

Figure 1. Coal basins in Peru (Carrascal and others, 2000).

Figure 2. Coal from Mina La Victoria brought to public market in Quiruvilca, northern Peru.

Figure 3a. Rural use of a coal briquette burner, town of Chao, northern Peru.

Figure 3b. Domestic use of coal in Quiruvilca, northern Peru.

List of Tables

Table 1. Major coal bearing basins and units of Peru (see figure 1) from Carrascal and others (2000). Abbreviations: subbit = subbituminous, bit = bituminous, hi-vol = high volatile bituminous, med-vol = medium volatile bituminous, semi-anth = semi-anthracite, anth = anthracite, meta-anth = meta-anthracite, Fm = Formation, Gp = Group

Basin name	Stratigraphic unit	Age	Rank of coal
Loreto	Debas Fm	Miocene	peat, brown lignite
Tumbes	Mancora Fm	Oligocene	lignite
	Zorritos Fm	Miocene	lignite
Piura	Ostrea Fm	Middle Eocene	lignite
Yanacocha	Porculla Fm	Lower-Middle Tertiary	subbit/hi-vol bit
Jatunhuasi	Goyllarisquizga Gp	Neocomian (Mesozoic)	bit/semi-anth
Goyllarisquiza	Goyllarisquizga Gp	Neocomian (Mesozoic)	subbit (debated)
Alto Chicama	Chimu Fm (Goyllarisquizga Gp)	Lower Valanginian	anth/meta-anth
Santa	Oyon Fm	Tithonian-Berriasian	anth/meta-anth
Oyon	Oyon Fm	Tithonian-Berriasian	med-vol bit /meta-anth
Yura	Labra Fm, Gramadal Fm, Hualhuani Fm	?	bit/semi-anth/anth
Paracas	Ambo Group	Mississippian	anth to lignite
Cordillera Oriental	Ambo Group	Mississippian	anth to lignite

Table 2. Estimated recent Peruvian coal production (in metric tons).

Rank	1998	1999	2000
anthracite	7,000	1,000	17,000
bituminous	45,000	45,000	45,000
total	52,000	46,000	62,000

Table 3. Proximate,ultimate, and forms of sulfur analyses for select samples on an as-received basis for 14 Peruvian coal samples.

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

	Proximate Analyses				Ultimate Analyses							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 (%)
BP2400	5.07	2.72	86.35	5.86	1.08	86.00	0.56	0.27	1.16	13,070	30	0.01	0.01	0.25
BP2500	5.77	1.65	90.41	2.17	1.03	88.18	0.54	0.28	2.03	13,550	32	0.01	0.02	0.25
BP2900	3.22	4.12	83.93	8.73	0.79	82.90	0.32	0.44	3.60	12,180	28	0.15	0.03	0.26
BP3100	4.41	1.67	90.35	3.57	0.99	88.13	0.65	0.53	1.72	13,390	31	0.01	0.04	0.48
BP3200	2.12	12.37	23.94	61.57	1.97	24.99	0.73	0.67	7.95	4,060	9	0.26	0.09	0.32
BP0101	4.28	5.85	58.92	30.95	0.75	59.22	0.60	0.49	3.71	8,710	20	0.13	0.06	0.30
BP0102	7.02	7.87	56.24	28.87	0.48	55.96	0.45	0.67	6.55	8,010	19	0.41	0.09	0.17
BP0103	5.95	6.80	64.97	22.28	0.41	66.37	0.47	0.38	4.14	9,570	22	0.10	0.05	0.23
BP0104	4.37	3.38	82.18	10.07	0.83	81.45	0.71	0.34	2.23	12,210	28	0.02	0.01	0.31
BP0105	2.60	4.48	81.53	11.39	2.04	80.70	0.79	0.92	1.56	12,740	30	0.01	0.3	0.61
BP0106	5.09	3.40	65.74	25.77	0.91	63.93	0.67	0.44	3.19	9,600	22	0.02	0.03	0.39
BP0107	5.59	4.38	73.81	16.22	1.43	72.67	0.73	0.61	2.75	11,440	27	0.02	0.10	0.49
BP0108	15.78	12.55	44.95	26.72	0.31	46.84	0.62	1.50	8.23	6,620	15	0.02	0.09	1.39
BP0501	4.72	1.78	90.28	3.22	1.15	87.95	0.55	0.36	2.05	13,560	32	0.02	0.02	0.32

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

[Abbreviations: Ash = ash yield, %=weight percent, nd=not determined; °C= degrees Centigrade; Total = sum of oxides on an ash basis; nd=not determined. 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
BP2300	31.5	56.9	28.0	1.30	0.290	1.70	2.30	2.30	1.50	0.050	nd	94.3
BP2400	6.80	40.3	34.0	2.20	1.40	1.30	1.50	1.50	1.90	0.420	nd	84.5
BP2500	2.40	30.1	33.0	7.50	5.40	1.30	0.810	5.60	1.60	0.580	nd	85.9
BP2700	13.3	53.3	31.5	0.97	1.20	0.410	3.80	3.00	1.70	0.360	nd	96.2
BP2900	8.90	38.2	32.8	2.20	1.40	2.30	1.60	1.80	1.70	0.540	nd	82.5
BP3100	3.90	38.9	32.4	3.40	2.80	0.490	1.50	4.20	2.20	1.50	nd	87.4
BP3200	63.4	50.9	38.9	0.040	0.410	0.220	0.890	1.10	1.90	0.060	nd	94.4
BP0101	30.7	59.3	28.2	0.970	1.30	1.70	2.80	4.50	1.40	0.100	1.20	101.5
BP0102	31.1	61.8	24.6	1.20	0.870	1.90	4.50	5.60	1.10	0.020	2.00	103.6
BP0103	23.8	63.0	17.8	1.60	5.60	1.30	1.60	5.40	1.40	0.080	4.50	102.3
BP0104	10.4	69.7	18.5	0.690	0.930	2.00	1.60	4.60	1.10	0.160	1.10	100.4
BP0105	12.0	45.7	31.8	2.30	0.530	0.100	0.540	4.10	1.80	2.40	0.540	89.8
BP0106	27.5	62.2	25.9	0.380	0.900	0.480	3.20	3.50	1.60	0.340	0.820	99.3
BP0107	17.0	59.6	30.9	0.200	0.430	0.140	0.730	2.20	1.90	0.060	0.310	96.5
BP0108	29.0	45.1	18.6	1.20	5.70	4.80	5.40	10.4	1.10	0.690	9.10	102.1
BP0501	3.31	45.0	33.9	1.70	2.20	0.900	2.60	3.80	1.80	0.150	1.90	94.0

Table 5. Major-, minor-, and trace- element data for 16 Peruvian coal samples calculated to a dry, whole-coal basis. Sample BP2300 was weathered and BP2700 was a briquette.

[All values in micrograms per gram (µg/g) parts per million (ppm), except ash yield, Si, Al, Ca, Mg, Na, K, Fe, Ti, P and S which are in weight %. Ash=ash yield, %=weight percent, °C=degrees Centigrade, nd=not determined, <=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 (%)	S (%)
BP2300	33.4	8.89	4.96	0.311	0.0585	0.422	0.638	0.538	0.301	0.00730	nd
BP2400	6.90	1.30	1.24	0.109	0.0583	0.0666	0.086	0.0724	0.0786	0.0127	nd
BP2500	2.40	0.342	0.425	0.130	0.0792	0.0235	0.0164	0.0952	0.0233	0.00620	nd
BP2700	14.0	3.48	2.33	0.0967	0.101	0.0424	0.440	0.293	0.142	0.0219	nd
BP2900	9.10	1.63	1.58	0.143	0.0768	0.155	0.121	0.115	0.0927	0.0214	nd
BP3100	4.00	0.724	0.682	0.0967	0.0672	0.0145	0.0496	0.117	0.0525	0.0260	nd
BP3200	64.0	15.2	13.2	0.0183	0.158	0.105	0.473	0.493	0.729	0.0168	nd
BP0101	31.4	8.69	4.68	0.217	0.246	0.395	0.729	0.987	0.263	0.0137	0.525
BP0102	31.8	9.20	4.14	0.273	0.167	0.449	1.19	1.25	0.210	0.00280	0.766
BP0103	24.4	7.19	2.30	0.279	0.824	0.235	0.324	0.922	0.205	0.00850	0.391
BP0104	10.5	3.44	1.03	0.0520	0.0592	0.156	0.140	0.339	0.0696	0.00740	0.706
BP0105	12.1	2.58	2.03	0.198	0.0386	0.00900	0.0541	0.346	0.130	0.126	0.997
BP0106	27.7	8.06	3.80	0.0753	0.150	0.0987	0.736	0.679	0.266	0.0411	0.473
BP0107	17.1	4.77	2.80	0.0245	0.0444	0.0178	0.104	0.264	0.195	0.0045	0.666
BP0108	30.3	6.38	2.98	0.260	1.040	1.080	1.36	2.20	0.200	0.0911	1.82
BP0501	3.40	0.716	0.610	0.0413	0.0451	0.0227	0.0734	0.0904	0.0367	0.0022	0.410

Table 5. Major-, minor-, and trace- element data for 16 Peruvian coal samples calculated to a dry, whole-coal basis. Sample BP2300 was weathered and BP2700 was a briquette—continued.

Field Number	Ag (ppm)	As (µg/g)	Au (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)
BP2300	<0.34	17.0	<3.4	9.03	314.	2.01	0.254	0.181	0.0552	3.54	23.6
BP2400	<0.070	1.09	<0.70	7.46	43.7	0.697	0.0759	0.0759	<0.0160	3.36	10.4
BP2500	<0.025	0.588	<0.25	4.81	17.2	0.219	0.0389	0.0462	<0.0160	1.78	2.87
BP2700	<0.14	13.0	<1.4	5.26	83.2	0.600	0.109	0.516	0.119	5.72	8.32
BP2900	<0.092	7.67	<0.92	11.3	56.4	1.99	0.228	0.127	0.0184	11.0	25.5
BP3100	<0.040	0.497	<0.40	2.63	33.4	0.418	0.0637	0.0302	0.0235	2.78	5.61
BP3200	<0.65	2.75	<6.5	245.	150.	1.22	0.467	0.275	<0.0160	18.8	17.7
BP0101	<0.63	8.37	<3.2	75.6	120.	1.03	<0.0320	0.188	0.300	7.34	19.8
BP0102	<0.64	18.2	<3.2	44.2	369.	1.11	0.188	0.987	0.0542	7.39	11.6
BP0103	<0.49	4.76	<2.5	21.2	39.1	<0.250	<0.0250	0.293	0.0451	6.42	6.86
BP0104	<0.22	2.30	<1.1	8.58	114.	0.264	<0.0110	0.538	0.0264	1.86	6.81
BP0105	<0.25	4.06	<1.3	4.33	97.8	0.592	0.0604	0.0423	0.139	2.50	8.64
BP0106	<0.56	7.40	<2.8	22.7	106.	0.582	<0.028	2.02	0.106	6.29	19.1
BP0107	<0.35	15.0	<1.8	12.5	10.7	0.480	0.096	0.0651	<0.0160	13.2	12.5
BP0108	0.605	975.	<3.1	166.	125.	0.969	1.57	6.39	1.92	16.6	11.5
BP0501	<0.069	1.11	<0.35	4.42	18.1	0.218	0.0408	0.0116	0.125	2.21	4.59

Table 5. Major-, minor-, and trace- element data for 16 Peruvian coal samples calculated to a dry, whole-coal basis. Sample BP2300 was weathered and BP2700 was a briquette—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)	Pb (µg/g)
BP2300	5.22	32.3	11.3	1.20	0.042	10.8	12.5	7.36	2.21	4.31	46.8
BP2400	0.794	14.9	3.51	0.159	0.041	11.5	11.5	0.504	1.85	5.82	2.66
BP2500	0.0681	6.27	0.965	0.139	0.041	4.79	18.3	0.168	0.674	2.75	1.31
BP2700	4.66	17.3	5.71	0.600	0.63	9.21	29.3	0.475	2.57	8.16	6.06
BP2900	5.51	57.4	9.46	0.710	0.32	42.1	78.8	1.27	4.70	14.7	9.46
BP3100	0.191	3.38	1.94	0.354	0.13	7.44	10.4	0.438	1.49	7.36	1.83
BP3200	50.5	31.8	34.5	2.43	0.19	96.1	40.3	1.41	11.7	20.5	6.40
BP0101	7.40	24.8	10.8	0.564	0.21	31.7	93.4	1.69	4.48	16.4	9.69
BP0102	4.17	32.5	8.98	1.43	0.32	23.0	145.	1.59	3.34	10.1	44.6
BP0103	5.37	17.7	5.71	0.757	0.52	11.1	254.	1.54	3.08	7.03	34.7
BP0104	1.17	5.89	2.56	0.506	0.071	5.04	24.2	0.643	1.17	5.47	4.75
BP0105	1.68	82.0	5.46	0.362	0.27	26.1	4.97	0.386	0.954	5.87	20.3
BP0106	6.65	19.7	8.73	0.130	0.49	38.8	60.4	0.554	3.74	8.65	20.9
BP0107	3.56	35.0	7.11	0.943	0.45	24.0	6.94	1.77	3.63	9.46	12.1
BP0108	3.69	141.	9.41	0.787	0.25	12.0	209.	1.36	2.54	18.9	339.
BP0501	0.197	2.05	1.21	0.133	0.051	5.44	10.1	0.259	0.789	8.57	1.27

Table 5. Major-, minor-, and trace- element data for 16 Peruvian coal samples calculated to a dry, whole-coal basis. Sample BP2300 was weathered and BP2700 was a briquette—continued.

Field Number	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)	U (µg/g)
BP2300	44.1	3.51	14.3	2.8	6.12	107.	0.602	5.42	1.04	0.736
BP2400	5.53	0.269	4.17	<0.20	1.64	55.4	0.0476	2.78	0.0621	0.787
BP2500	0.657	0.160	1.18	<0.20	2.58	18.7	0.0608	0.790	0.00875	0.246
BP2700	16.6	1.48	4.03	0.67	1.49	72.4	0.107	2.12	0.209	0.586
BP2900	13.1	1.99	11.1	0.42	3.07	184.	0.282	6.29	0.118	1.61
BP3100	1.79	0.179	2.45	0.35	1.31	54.9	0.0915	1.58	0.0175	0.474
BP3200	39.0	0.704	8.52	3.1	7.56	138.	0.416	6.40	0.231	1.67
BP0101	40.1	1.13	7.53	1.0	3.61	108.	0.157	5.96	0.345	0.753
BP0102	47.1	3.47	5.67	0.83	3.31	92.3	0.382	4.71	0.637	0.764
BP0103	11.9	1.76	6.91	0.28	1.42	23.5	0.244	2.88	0.127	0.513
BP0104	5.6	0.359	1.93	0.27	1.36	25.3	0.148	1.16	0.0812	0.200
BP0105	2.78	0.193	4.58	1.7	0.459	243.	0.157	3.53	0.169	0.785
BP0106	32.7	2.05	6.51	0.54	1.86	112.	0.0527	3.24	0.360	0.582
BP0107	6.41	1.25	5.93	1.7	2.02	30.2	0.223	4.92	0.206	0.891
BP0108	73.9	5.33	7.78	0.98	8.6	132.	0.938	5.39	0.363	1.09
BP0501	2.78	0.0476	2.00	<0.20	0.405	16.4	0.0612	1.16	0.0330	0.340

Table 5. Major-, minor-, and trace- element data for 16 Peruvian coal samples calculated to a dry, whole-coal basis. Sample BP2300 was weathered and BP2700 was a briquette—continued.

Field Number	V (µg/g)	Y (µg/g)	Zn (µg/g)	Zr (µg/g)
BP2300	151.	6.32	17.6	101.
BP2400	32.9	4.53	11.8	22.6
BP2500	9.87	2.06	7.93	8.41
BP2700	32.2	2.72	4.77	61.3
BP2900	97.4	8.47	51.6	28.3
BP3100	20.3	3.64	8.24	18.3
BP3200	62.4	<0.650	52.1	251.
BP0101	67.4	5.61	28.3	129.
BP0102	46.2	3.60	69.4	170.
BP0103	45.9	6.62	22.0	95.4
BP0104	21.7	1.07	917.	23.1
BP0105	43.9	8.92	27.5	67.6
BP0106	59.6	2.61	99.5	114.
BP0107	80.5	4.18	14.3	129.
BP0108	43.3	8.57	327.	124.
BP0501	16.0	1.43	4.80	10.9

Appendix 1: sample descriptions

Mina San Juan/Baños de Chimu—Channel samples were taken from conchoidally fractured, shiny, anthracite (locally referred to as “cisco”) at Mina San Juan, which is also referred to as Banos de Chimu, from a steeply dipping 3 meter seam in the Cretaceous Chimu Formation. This coal is used locally for cooking and is transported 110 kilometers south to Trujillo for processing into briquettes (which are comprised of coal, clay, calcium carbonate, and water) for domestic use, brick making, and minor use as a heat source for the poultry industry.

Mina La Victoria—Channel samples were taken from conchoidally fractured, shiny, anthracite (locally referred to as “cisco”) at Mina La Victoria from an 800 meter adit that follows a 2 meter coal bed, offset by faults, in steeply dipping massive sandstones of the Cretaceous Chimu Formation. One or two trucks leave the mine two to three times a week and drop the coal near the public market (fig. 2) for domestic use (figs. 3a, 3b) in the silver mining town of Quiruvilca. Coal from La Victoria is used for cooking and heating in Quiruvilca and in the nearby mining town of Shorey. At Mina Callacuyan (Jessen, 1989), which is nearby, the combined effects of high sulfur content of the coal and terrorist activity shut down mining in 1992. Both La Victoria and Callacuyan are hosted in a northwest-trending breached anticline that is several kilometers long.

Sample List

BP2300 [78.830 deg W; 7.760 deg S], Alto Chicama, near town of Sausal, Mina La Posa, cisco. Rocks strike 25°/60°E, metasediments with quartz veins and ~3 meter by 500 meter coal seam, local use and occasionally sent to Trujillo. Mine is caved in and grown over due to 1998 effects of El Nino. Sample collected from outcrop.

BP2400 [no location], Alto Chicama, cisco coal sample collected fresh from Mina La Victoria delivery truck in Quiruvilca. Coal from the mine is used for cooking and heating in Quiruvilca.

BP2500 [78.547 deg W; 7.894 deg S], Alto Chicama, cisco coal from Mina La Victoria. Adit is about 800 meters long and is approximately 1.8 meters wide, worked by cart on rails by two or three miners, one to two trucks, two to three times a week from Quiruvilca. Host rock is gray fine-grained sandstone, 320°/70°NE dip. Cross faults offset the seam. Not a channel sample, but fresh from cart from the coal bed.

BP2700 [no location], briquette sample from sales yard approximately 8 kilometers from Huanchaco. Coal is brought in from Mina Huaranchal (Alto Chicama), anthracite/cisco, considered to be low sulfur by owner. Coal is mixed with clay, calcium carbonate, and water to form a briquette for domestic use, to heat chicken coops, and incubators, and to cure bricks. Briquettes used in small town restaurants to cook and keep water boiling for instant coffee or tea.

BP2900 [78.631 deg W; 5.510 deg S], Alto Chicama, Banos de Chimu, sample from within massive bedded 8°/25°E quartzite. Coal bed is approximately 2 meters wide for 750 meters. Mine has been worked since 1970's. Now 6 men move 12 tons daily. Hot springs are nearby, and mine is hot and smells of steam and sulfur.

BP3100, [no location], anthracite from Mina Huaranchal, Reserva del Estado, Alto Chicama, sample collected by Sr. Wellington Pacheco, coal dealer in Lima.

BP3200, [no location], bituminous coal from Mina Patron Santiago, Alto Chicama, sample collected by Sr. Wellington Pacheco, coal dealer in Lima.

BP0101, [no location], anthracite from Mina La Galgada, Alto Chicama/Santa Basin, sample collected by Sr. Oscar Medina, coal consultant in Lima.

BP0102, [no location], anthracite from Mina La Limena 2, Alto Chicama/Santa Basin, sample collected by Sr. Oscar Medina, coal consultant in Lima.

BP0103, [no location], anthracite from Mina La Limena 1, Alto Chicama/Santa Basin, sample collected by Sr. Oscar Medina, coal consultant in Lima.

BP0104, [no location], anthracite from Mina Cocobal, Alto Chicama/Santa Basin, sample collected by Sr. Oscar Medina, coal consultant in Lima.

BP0105, [no location], anthracite from Mina Villon, Alto Chicama/Santa Basin, sample collected by Sr. Oscar Medina, coal consultant in Lima.

BP0106, [no location], anthracite from Mina Caraz, Alto Chicama/Santa Basin, sample collected by Sr. Oscar Medina, coal consultant in Lima.

BP0107, [no location], anthracite from Mina San Roque, Alto Chicama/Santa Basin, sample collected by Sr. Oscar Medina, coal consultant in Lima.

BP0108, [no location], from Mina Sta. Julia, Alto Chicama/Santa Basin, sample collected by Sr. Oscar Medina, coal consultant in Lima. Base and precious metal occurrences are nearby.

BP0501, [no location], coal sample bought in the public market in Trujillo, Alto Chicama, specific mine unknown.