THE COALS OF BRAZIL

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The coal commission of Brazil was created by an act of the Brazilian Congress in 1903. On July 1, 1904, the writer was appointed chief of the Brazilian coal commission by Dr. Lauro Severiano Müller, the present distinguished Brazilian minister of foreign affairs, who was then serving his nation so efficiently as minister of industry, highways and public works.

The field examinations of the commission were carried on during August, September, October, and November of 1904, and were resumed again in July, 1905, to be concluded in January, 1906. The results of these studies in which the writer was aided by a staff of Brazilian engineers, including Dr. Francisco Paulo Oliveira, first engineer; Dr. Esdras do Prado Seixas, second engineer; Dr. Benedicto dos Santos, assistant engineer; Dr. Cicero Campos, assistant engineer; and Mr. Carlos Moreira, secretary, were submitted to Dr. Müller for publication under date of September 1, 1906, and the printed quarto volume of 517 pages, including 14 plates of fossil plants, 4 plates of fossil animals, two maps, and many illustrations in the text, was published at Rio de Janeiro by the Imprensa Nacional in 1908. The edition was necessarily limited, but it has been distributed in North America through the agency of the Smithsonian Institution to the libraries of the principal universities and colleges, and a like distribution was made by it and other agencies to the great libraries of Europe. The present paper is a brief summary of the results embodied in this formal report of the Brazilian coal commission, with the hope that if published it may secure a wider distribution than was possible with the limited edition of the bulky quarto volume.

LOCATION.

So far as exploited, the principal coal deposits of Brazil lie in the extreme southern portion of the country, in the States of Rio Grande do Sul, Santa Catharina and Parana. Not even an approximate estimate of the area covered by the coals in question can be given, owing to the absence of accurate maps, but the formation which holds the coal deposits certainly covers several hundred square miles in these three States.

Thin coal seams have also been reported from the State of Sao Paulo, and Dr. Ganzaga de Campos has recently discovered a considerable area of lignitic coals in north Brazil on tributaries of the Amazon, in the States of Para and Amazonas, to which reference will later be made.

The map accompanying the quarto report of the coal commission exhibits in a general way the distribution of these Brazilian Coal Measures which the writer has studied in South Brazil.

AGE OF THE COALS.

The fossil plants and animals found in the South Brazilian Coal Measures sediments prove conclusively that they belong to the closing stages of Carboniferous time, viz., in the Permian or at least not younger than the Permo-Carboniferous, or Artinskan beds of Russia. From an exhaustive study of the fossil plant remains collected by the coal commission, the eminent paleobotanist, Dr. David White, now chief geologist of the United States Geological Survey, and whose interesting memoir forms

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Part III of the Brazilian coal commission's report, reached the conclusion that the Brazilian Coal Measures belonged at the base of the Permian. The reptilian fossil remains discovered in the next higher series and described by Dr. McGregor in Part II of the same volume as *Mesosaurus brasiliensis*, are so nearly identical with *Mesosaurus tenuidens* of the South African Permian that they can with difficulty be separated. In the opinion of the writer, the Rio Tubarão series would correlate with the Dunkard series of Pennsylvania, Ohio, West Virginia, and Maryland, and thus with the Permo-Carboniferous or closing stage of the Pennsylvanian and the beginning of the true Permian. Curiously enough the principal coal bed of the Dunkard series, viz., the Washington coal, has a composition very similar to that of the coals in the Tubarão series of Brazil.

CLASSIFICATION AND CORRELATION OF THE BRAZILIAN COAL MEASURES AND THEIR OVERLYING BEDS.

On page 33 of the coal commission's report already mentioned is given the following classification of the Santa Catharina system of rocks in south Brazil which holds the coal measures as its basal member:

	Meters.
Santa Catharina system:	
São Bento series—	
Serra Geral eruptives	600
São Bento Sandstones, great cliffs of red, gray, and cream-colored sandstones	200
Rio do Rasto red beds, with fossil reptiles (*Scaphonyx*) and fossil trees	100
	900
Passa Dois series—	
Rocinha limestone	3
Estrada Nova gray and variegated shales with cherty concretions and sandy beds	150
Iraty black shale, *Mesosaurus* and *Stereosternum*	70
	223
Tubarão series—	
Palermo shales	90
Rio Bonito shales and sandstones, *coal measures*, and *Glossopteris* (*Gangamopteris*) flora	158
Orleans conglomerate	5
Yellow sandstones and shales to granite floor	27
	280

How completely this Santa Catherina system correlates with the Karroo system of South Africa in general features may be seen by comparison of the former with the following classification scheme of Drs. Hatch and Corstorphine, the eminent South African geologists:

Karroo system:

- Upper Karroo or Stormberg Series—
  - Volcanic beds, cave sandstone, Red beds, Molteno beds, zone of the *Zanclodonts*.
- Middle Karroo or Beaufort series—
  - Zone of the specialized *Theriodonts*, sandstones and shales with *Dicynodon*, sandstones and shales with *Pareiasaurus*.
- Lower Karroo or Ecca series—
  - Upper sandstones and shales, Dwyka conglomerates, Lower sandstones, and shales, zone of the *Mesosaurus*.

A comparison of these two systems will disclose the close parallelism in both the character of the sediments and the included fossil remains, since both the upper Karroo, and the lower Karroo are the exact counterparts of the São Bento and Tubarão series, respectively, with the latter extended upward to include the Iraty black shale with its Mesosaurus and Stereosternum remains.

Whether the middle Karroo is absent in Brazil, or whether its rocks may be represented in the upper portion of the Passa Dois or the lower portion of the São Bento series is not yet known.

The probabilities, however, are that the Beaufort series may not yet have been discovered in Brazil, since its abundant reptilian fauna of such bizarre types could hardly have escaped the trained eyes of Dr. Orville A. Derby, who has so long and carefully studied the geology of the State of São Paulo.

This close identity not only of the fossils of the Santa Catharina and Karroo systems, but also the general resemblance of the stratigraphic and lithologic features found in the two systems as well as in the Gondwana system of India so far as the lower and upper members are concerned, certainly lends great plausibility to the view that the southern continents must have been united in Permian and Triassic time by a great land connection now submerged which Suess has termed "Gondwana land."

The detailed character of the lower portion of the Santa Catharina system which holds the coal beds beginning with the Iraty black shale above is as follows, as measured with spirit level by Dr. Seixas along the Estrada nova in descending to Lauro Müller Station (formerly Minas) in Santa Catharina:

Iraty black shale		70
Palermo shales		90
Gray sandstone and sandy beds		6.096
Coal, Treviso bed:		
Coal	0.152	
Clay	0.254	
Coal	0.254	
		0.660
Concealed and sandstone, Upper Barro Branco		6.62
Coal, Barro Branco:		
Coal, slaty	0.25	
Clay, white	0.555	
Coal, slaty	0.305	
		1.11
Shales with fossil plants, *Glossopteris*, *Gangamopteris*, *Noeggerathiopsis*, *Cardiocarpon*		0.15
Sandstone, massive, white, Lower Barro Branco		9.14
Slaty coal (Irapua), fossil plant fragments		0.15
Soft creamy brown shales with thin layers of sandstone		9.14
Sandstone, grayish white		6.10
Shales		3.05
Sandstone		3.05
Brown shales, quite fossiliferous in lower portion, *Glossopteris*, *Sphenopteris*, *Noeggerathiopsis*, *Sigillaria*, *Equisetites*, *Cardiocarpon*, etc		6.10
Sandstone, gray		3.05
Coal, Ponte Alta		0.15
Shales		2.13
Sandstone, massive, Upper Bonito		12.20
Coal, Bonito Rider		0.455
Clay and coaly shale		0.555
Bonito coal bed (coal and slate)		2.13

Fire clay and light-colored shales	4.57
Sandstone, massive, pebbly, Lower Bonito	10.67
Shales, often weathering reddish, and concealed	22.86
Sandstone, massive, pebbly	15.24
Shales, weathering reddish and yellow above, but light gray at base	7.62
Light gray sandy micaceous shale, very full of *Glossopteris*, *Gangamopteris*, *Noeggerathiopsis*, *Phyllotheca*, *Derbyella*, *Hastimima*, *Rosellinites*, *Hysterites*, *Arberia*, *Cardiocarpon*, etc., together with many others, a full list of which is given in another part of this report	0.305
Sandy shale, gray	3.05
Sandstone	6.10
Blue shales, quite dark at base	3.05
Sandstone and concealed to mouth of boring at 197.2 meters above tide	12.20
Orleans conglomerate in boring	5.35
Shales and sandstone alternating, to granite	27.00
Total	350.051

QUALITY OF THE BRAZILIAN COAL.

Of these coal beds in the Rio Bonito group, the Barra Branco appears to be the best and most widely persistent, although locally the Bonito seam is thicker than the former on the waters of Rio Tubarão, Santa Catharina. Both of these coal beds in the Rio Bonito region, as also all the South Brazilizn coals, whether in other portions of Santa Catharina or in the States of Parana and Rio Grande do Sul, are quite impure, the thin layers of good coal always alternating with layers of bituminous slate in such manner that it is impossible to separate them in ordinary mining operations.

The average amount of ash in the raw coal from Santa Catharina and also from the State of Rio Grande do Sul is about 35 per cent of which approximately 6 per cent is sulphur in the form of nuggets of iron pyrites.

By crushing and washing operations, however, conducted in the Humboldt Engineering Works at Kalk, Germany, just across the Rhine from Cologne, by Lieut. Esser and the writer, it was learned that in practically 33 per cent of the coal the ash could be reduced to about 14 per cent, and the sulphur to six-tenths of 1 per cent, from which most excellent briquettes could be manufactured, having more heat units than much of the "Anchor" brand of Cardiff briquettes imported to Brazil in large quantities, while in about 42 per cent of the product, the ash could be reduced to 25 per cent, and the excess sulphur also eliminated, thus yielding a fair grade of slack coal, the remaining 25 per cent being waste material from which the large amount (5 to 6 per cent) of iron pyrites could readily be recovered in a practically pure condition for the manufacture of sulphuric acid as a by-product.

Many analyses and reports on Brazilian coal have been published in the past. In most of these reports, the samples appear to have been selected from the purest portions of the coal beds in question instead of from average samples which would include the entire bed. By this method of sampling, very contradictory results were obtained when the same coals were submitted to test of actual commercial use. The analyses published led many people to hope that a purer coal would eventually be found in good quantity, something that would in its natural state displace Cardiff coal in Brazilian industry. The result of the work of the coal commission during the year 1904 (which was fully confirmed by the further studies in 1905–6) was to abandon hope of finding beds of pure coal of explorable thickness in Brazil, since it was only too apparent at every outcrop and exploitation visited that the coal was everywhere of practically the same quality; that while some fairly pure coal existed in every bed, it was so interstratified and ingrained with bituminous shale or slate as to render the separation by ordinary mining methods impossible.

Samples of coal from all the points visited in Santa Catharina, Rio Grande do Sul, and Parana, where exploitations had been made, were collected. These samples were taken entirely across the face of each seam, and were analyzed under the supervision of Prof. B. H. Hite, chemist of the West Virginia Geological Survey. Prof. Hite was aided in this work by Messrs. Frank F. Grout, Leicester Patton, and C. S. Forkum, the assistant chemists of the geological survey and experiment station.

All of the samples, except those from the mines of the S. Jeronymo Co. in Rio Grande do Sul, were taken from near the crop of the coal and hence were in a more or less weathered condition, thus increasing the percentage of ash impurities.

The following tables give the results of the analyses of Brazilian coal from samples collected in the field under the direct supervision of the chief of the commission.

TABLE 1.—*Proximate analyses.*

Sample No.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.	B.t.u.
1	1.64	14.25	38.17	54.94	3.05	0.019	8,731
2	1.25	19.46	39.59	39.42	5.49	.019	10,083
3	1.24	19.98	44.34	34.44	3.60	.018	10,296
4	1.05	19.17	35.45	44.33	3.34	.015	9,351
5	.79	17.50	32.55	49.16	5.49	.019	8,281
6	1.18	17.45	33.08	48.29	2.68	.021	8,483
7	1.34	25.76	38.87	34.03	12.99	.019	9,893
8	1.44	24.84	35.34	38.38	10.49	.018	9,599
9	1.02	25.22	38.98	34.78	2.28	.015	10,420
10	1.01	15.80	50.94	32.25	11.42	.014	9,862
11	1.21	26.00	47.88	24.88	6.41	.020	11,970
12	1.06	7.64	54.63	36.67	1.58	.030	9,397
13	5.34	29.63	38.71	26.23	3.90	.025	9,692
14	.46	25.73	41.27	32.54	8.90	.023	10,157
15	3.43	27.28	37.52	31.77	12.96	.053	10,095
16	4.87	27.89	44.20	23.04	.60	.014	11,117
17	6.05	29.09	41.33	23.53	4.00	.057	10,715
18	2.62	29.54	38.62	29.22	11.80	.012	10,420
19	2.40	32.95	43.86	20.79	8.66	.020	10,808
20	7.68	17.62	48.94	25.76	3.14	.002	8,003
21	2.37	15 83	58.66	23.14	7.95	.060	10,711

NAMES OF MINES.

Sample No. 1. Middle and upper benches, Bonito No. 1, Santa Catharina.
2. Lower bench, Bonito No. 1, Santa Catharina.
3. From pile of coal in shed, Bonito No. 1, Santa Catharina.
4. Bonito No. 2, Santa Catharina.
5. Bonita No. 3, Santa Catharina.
6. Bonito bed, Tres Saltos, Santa Catharina.
7. Bonito Rider, coal on Estrada Nova, Santa Catharina.
8. Top and bottom (75 meters), Barro Branco Velho mine, Santa Catharina.
9. From pile in coal house, Barro Branco Velho mine, Santa Catharina.
10. Barro Branco at Passa Dois under basalt, Santa Catharina.
11. Barro Branco seam at Rocinha, Santa Catharina.
12. Barro Branco seam at Rio Carvao, near Urussanga, Santa Catharina.
13. Ponte Alta, Santa Catharina.

Sample No. 14. Treviso coal, near Treviso, Santa Catharina.
15. Upper bench, S. Jeronymo, Rio Grande do Sul.
16. Lower bench, S. Jeronymo, Rio Grande do Sul.
17. Upper and lower benches, S. Jeronymo, Rio Grande do Sul.
18. Coal at Col. Macedo's (Cedro), Parana.
19. Coal from the fazenda of Messrs. Leonel Heliodoro da Luz and Fernando Gil Born, near Quebra Dentes.
20. Coal from Imbausinho, collected by Dr. Cicero Campos.
21. Coal from Salto Apparado, collected by Dr. Cicero Campos.

TABLE 2.—*Ultimate analyses.*

Sample No.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.
1	41.93	2.96	0.39	3.05	6.87	44.80
2	46.31	3.33	.40	5.49	7.11	37.36
3	51.78	3.43	.52	3.60	7.58	33.09
15	46.00	4.05	.29	12.99	9.27	27.40
16	57.09	3.57	.39	.60	15.54	22.81
19	58.15	4.31	1.14	5.40	10.21	20.79
20	50.60	3.11	.80	2.00	17.73	25.76
21	60.00	3.78	.95	4.95	7.18	23.14

As already stated, several tons of Brazilian coal both from the outcrops near Lauro Müller Station in Santa Catharina, and also from the mines of the Companhia Estrada de Ferro e Minas de São Jeronymo, on Arroio dos Ratos, State of Rio Grande do Sul, were shipped to the Humboldt Engineering Works at Kalk, Germany, and there tested under the supervision of Lieut. Esser whose report to the writer giving the results obtained is as follows:

Test No 1.—For this test equal quantities of the two varieties of S. Jeronymo coal (top and bottom members) were taken. Average samples of these contained 34.9 per cent of ash. The object of the tests was to determine the method by which to obtain a coal containing 10 to 15 per cent of ash. As the coal was streaked with a considerable amount of bituminous shale, it appeared at first impossible to obtain a coal with the required percentage of ash without preliminary crushing. Small preliminary tests showed that crushing to below 6 m. was necessary. The whole of the material was therefore crushed on a bell mill down to under 6 mm. and then washed on a fine washer having a feldspar bottom. The resulting products were: Coal No. 1, Coal No. 2, and shale with pyrites. The slimes were collected in two neighboring settling tanks, and we thus have: Slime No. 1 and Slime No. 2. The results obtained in this test are collected in the accompanying table. All weights are the weights of the dry material per cent of stuff worked-up.

TABLE 1.—*Weighed out 4,279 kilograms of coal, S. Jeronymo bottom and S. Jeronymo top—100 per cent by weight. Average sample No. 0 contains 34.9 per cent of ash.*

No.	Products.	Per cent weight.	Per cent ash.	Per cent Sulphur.
1	Coal No. 1	32.45	13.7	0.6
2	Coal No. 2	42.10	20.7	
3	Shale and pyrites	13.81	50.4	
4	Slime No. 1	5.13	18.0	
5	Slime No. 2	6.51	26.6	
	Total	100.00		

As will be seen from this table, this test yielded 32.45 per cent of coal No. 1, containing 13.7 per cent of ash and 0.6 per cent of sulphur. Further, 42.10 per cent of coal No. 2, with 26.7 per cent of ash, were ultimately jigged, as well as 13.81 per cent of shale with pyrites containing 50.4 per cent of ash. Slime No. 1, of which there was 5.13 per cent, contained 18 per cent of ash and could be added to coal No. 2. Slime No. 2 contained 26.6 per cent of ash and could be added to coal No. 2 as well. The shale with pyrites was made to undergo a separate test in order to obtain pure pyrites. Calling the quantity of shale and pyrites 100, it is possible to obtain therefrom 78.22 per cent of shale and 21.78 per cent of pyrites by jigging. One-fifth of this product can therefore be obtained as pure pyrites.

BRIQUETTING TEST WITH COAL NO. 1 FROM TEST NO. 1.

The whole of the coal No. 1, mentioned in table No. 1, was used for making a test at the Altstaden mine, in order, as far as possible, to obtain results similar to those that would be obtained in practice. The coal was briquetted after adding 5.5 per cent of pitch. The briquets look well and burn satisfactorily. While burning they do not fall to dust, but break up into fair-sized pieces. It appears that a fineness of 0 to 6 millimeters is not so advantageous for briquetting as one of 0 to 4 millimeters. For this reason, it would be advisable in practice to crush the coal down to 4 millimeters in a disintegrator before briquetting, whereby it is quite possible that a smaller quantity of pitch than that previously stated would be sufficient to turn out good briquets.

TEST NO. 2 ON COAL MARKED BARRO BRANCO BED.

The appearance of this coal is far better than that in test No. 1, as the pure coal appears to the greater extent in lumps. It was, therefore, evident that the coal did not require such fine crushing as that in test No. 1, but one could assume that it could be treated straightaway in a coarse condition. After washing away first of all the clay, which, however, could in practice be kept away from the coal, the material was passed through a 10-millimeter screen. Both the coal above and that below 10-millimeter size was then washed in a two-compartment washer. From the coal above 10-millimeter size were obtained 52.31 per cent of coal and 22.96 per cent of shale. From the coal under 10 millimeters, 15.15 per cent of coal and 9.54 per cent of shale; total, 67.50 per cent of coal and 32.50 per cent of shale. On determining the percentage of ash in the coal above 10 millimeters (18.7 per cent) it was found that it was too high to enable the coal to be immediately utilized. Later tests showed that a sufficiently pure coal can not be obtained when crushed firstly to below 20 millimeters, in consequence of which the test was therefore started afresh, and the whole of the coal screened off with 20 millimeters and the coarse coal above 20 millimeters crushed down to below 20 millimeters. All crushed coal was then screened off with 10 millimeters, and the sizes 20 to 10 millimeters and below 10 millimeters each treated separately on washers.

In size 20 to 10 millimeters was obtained:

Coal I..No. 1
Coal II...No. 3
Shale...No. 5

Of the coal below 10 millimeters we have:

Coal I..No. 2
Coal II...No. 4
Dirt..No. 6

The results are given in the following table, in which the sludge from the washers is marked No. 7. All weights are dry weights, and given in weight per cent of the quantity of the raw material treated.

TABLE 2.

Classification.	Separation.								
	Coal I.			Coal II.			Shale.		
Sizes.	No.	Weight per cent.	Per cent ash.	No.	Weight per cent.	Per cent ash.	No.	Weight per cent.	Per cent ash.
20 to 10 millimeters....	1	10.57	16.6	3	25.50	27.03	5	4.54	52.5
Below 10 millimeters..	2	28.08	13.0	4	16.71	28.07	6	8.10	50.9
Sludge................	......	....	....	......	....	....	7	6.80	51.2
Total..............	......	38.65	13.98	......	42.21	27.70	......	19.44	54.38

From test No. 2 we therefore have 38.65 per cent of coal No. 1, averaging 13.98 per cent of ash. Further, 42.21 per cent of coal No. 2, averaging 27.70 per cent of ash, and 19.44 per cent of shale and sludge, averaging 51.38 per cent of ash. The pyrites are chiefly contained in the shale.

TEST NO. 3—COAL MARKED BONITO BED.

This was again a case of a considerably streaked coal, which apparently would require to be crushed in order to be able to obtain coal at all. The whole of the coal was therefore crushed to under 6 millimeters and treated in a fine coal washer.

The results of this test are collected in the following table. All weights are dry weights, and are given in weight per cent of the quantity of the raw material treated:

TABLE 3.

[Bonito coal equals 100 per cent by weight and 49.4 per cent ash.]

No.	Products.	Weight per cent.	Ash per cent.
1	Coal No. 1	16.24	25.4
2	Coal No. 2	49.46	48.1
3	Shale	21.50	68.6
4	Sludge	12.80	41.8
	Total	100.00	....

The results show that even when crushing down to under 6 millmeters only 16.24 per cent of coal, containing 25.4 per cent of ash, is obtainable; therefore treating this coal would not pay.

In order to check the determinations of Lieut. Esser, samples of the different grades of coal, slate, slimes, etc., into which the coal from Santa Catharina and Rio Grande do Sul had been separated at Kalk, were collected and transmitted to Prof. B. H. Hite at Morgantown, W. Va., in whose laboratory these samples were analyzed, with the following results:

TABLE 1.—*Analyses of separation products made at Kalk from S. Jeronymo coal.*

Proximate analyses.	S. Jeronymo, raw, unwashed, top and bottom portions mixed.	S. Jeronymo, first quality, washed, top and bottom portions mixed, 32 per cent of whole.	S. Jeronymo, second quality, washed, top and bottom portions mixed, 42 per cent of whole.
Moisture	6.42	6.37	4.710
Volatile matter	26.72	32.70	25.520
Fixed carbon	39.47	47.15	39.770
Ash	27.39	13.78	30.000
Total	100.00	100.00	100.000
Sulphur	3.35	0.54	0.640
Phosphorus	0.03	0.04	0.025
Ultimate analyses:			
Carbon	47.03	61.23	50.490
Hydrogen	4.03	5.17	3.540
Oxygen	20.36	19.23	15.540
Nitrogen	0.35	0.45	0.270
Sulphur	3.35	0.54	0.640
Ash (corrected for sulphur)	24.88	13.38	29.520
Total	100.00	100.00	100.000

The coal from the Bonito bed of Santa Catharina treated at Kalk gave the following results on analysis after treatment:

Analyses of Bonito coal, near Minas, Santa Catharina, Brazil.

Proximate.	No. 1. Unwashed.	No. 2. No. 1 washed (16.24 per cent of whole).	No. 3. No. 2 washed (49.46 per cent of whole).	No. 4. Refuse or waste (34.3 per cent of whole).
Moisture	2.15	1.950	1.940	6.350
Volatile matter	16.42	17.350	14.540	14.550
Fixed carbon	36.58	44.140	40.230	21.520
Ash	41.85	36.560	43.200	57.580
Total	100.00	100.000	100.000	100.000
Sulphur	3.71	2.580	2.050	8.550
Phosphorus	0.06	0.006	0.009	0.008
Ultimate:				
Carbon	41.58	48.550	40.910	21.550
Hydrogen	2.14	3.660	2.440	2.500
Oxygen	8.47	8.800	11.370	12.660
Nitrogen	0.66	0.830	0.690	0.360
Sulphur	2.30	1.600	1.300	5.350
Ash	44.85	36.560	43.290	57.580
Total	100.00	100.000	100.000	100.000
Calculated B. t. u	6,867	8,760	7,031	4,051
Calorimeter B. t. u	6,846	8,870	7,020	3,775

Analyses of separation products made at Kalk from Barro Branco coal, Santa Catharina.

Proximate.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Moisture	2.38	1.2500	2.280	1.330	3.620	3.850
Volatile matter	33.64	29.7000	32.320	27.250	22.500	22.470
Fixed carbon	50.72	44.6300	51.040	41.530	28.930	30.380
Ash	13.26	24.4200	14.360	29.890	44.950	43.300
Total	100.00	100.0000	100.000	100.000	100.000	100.000
Sulphur	2.18	1.9200	1.700	2.630	11.520	9.570
Phosphorus	0.01	0.0078	0.007	0.003	0.004	0.007
Ultimate:						
Carbon	70.64	61.2300	71.180	54.820	30.680	32.750
Hydrogen	4.89	4.4400	5.000	4.220	3.130	3.350
Oxygen	8.57	7.6800	7.220	8.550	13.520	14.120
Nitrogen	1.29	1.0300	1.230	0.870	0.520	0.530
Sulphur	1.35	1.2000	1.010	1.650	7.200	5.950
Ash	13.26	24.4200	14.360	29.890	44.950	43.300
Total	100.00	100.0000	100.000	100.000	100.000	100.000
Calculated B. t. u	12,732	11,142	12,966	10,051	5,822	6,194
Calorimeter B. t. u	12,989	11,097	12,774	10,009	5,767	6,411

The classification, percentage of quantity, size, etc., of above Barro Branco coal are given in the following table:

Sample.	Trade.	Size.	Per cent of whole.
		Millimeters.	
No. 1	First quality, washed, nut.	10.20	10.57
No. 2	Second quality, washed, nut.	10.20	25.50
No. 3	First quality, washed.	−10.00	28.08
No. 4	Second quality, washed.	−10.00	16.71
No. 5	Refuse shale	10.20	4.54
No. 6	Dirt and sludge washings.	....	14.90

BRIQUETTES.

The briquettes made at Kalk from Brazilian coal were also analyzed under the supervision of Prof. Hite, as also two grades of Cardiff briquettes taken from stock supplies in Brazil for comparison. Analyses were also made of two old briquettes manufactured at S. Jeronymo many years ago. All these briquette analyses made at Morgantown, as well as two made at St. Louis by the United States Geological Survey Fuel Testing Laboratory, are collected in the following table:

Proximate analyses.

Sample.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.	Calorimeter, B. t. u.
1, Barro Branco	1.43	29.75	59.83	8.99	1.56	0.003	13,427
2, Barro Branco	1.48	32.70	56.75	9.05	1.16	.003	13,669
3, Barro Branco, first grade, washed [1]	1.76	32.52	53.61	12.11	1.31	....	13,090
4, S. Jeronymo	5.03	33.42	50.77	10.78	.61	.033	12,496
5, S. Jeronymo, second grade, washed [1]	9.49	28.48	42.02	20.01	.62	....	9,479
6, Cardiff (Crown)	1.18	13.18	78.39	7.25	.66	.040	14,306
7, Cardiff (Crown)	1.28	15.38	73.87	9.47	.78	.040	13,931
8, Cardiff (Anchor)	0.70	14.42	70.21	14.67	.74	.050	13,080
9, old S. Jeronymo	9.00	25.43	45.25	20.32	.55	.006	9,302
10, old S. Jeronymo	7.38	26.72	45.52	20.38	.76	.006	9,707

Ultimate analyses.

Sample No.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Calculated B. t. u.
1, Barro Branco	77.45	3.89	7.49	1.20	0.98	8.99	13,156
2, Barro Branco	78.27	4.99	5.68	1.28	.73	9.05	13,903
3, Barro Branco, first grade, washed [1]	73.35	4.68	7.18	1.27	1.31	12.11	13,065
4, S. Jeronymo	70.16	5.16	13.68	.55	.61	9.84	....
5, S. Jeronymo, second grade, washed [1]	55.38	4.24	18.93	.82	.62	20.01	9,239
6, Cardiff (Crown)	84.55	4.00	2.80	.99	.41	7.25	14,589
7, Cardiff (Crown)	81.13	3.89	3.96	1.07	.48	9.47	14,934
8, Cardiff (Anchor)	75.27	3.56	1.12	4.98	.40	14.67	12,802
9, old S. Jeronymo	56.45	3.94	18.24	.70	.35	20.32	9,076
10, old S. Jeronymo	57.27	4.11	16.89	.87	.48	20.38	9,599

[1] Analysis made by United States Geological Survey.

These analyses of briquettes made from the purified Brazilian coal show that while their fuel values are slightly inferior to the best grade (Crown) of Cardiff briquette, yet they are equal or even superior to the Anchor brand, large quantities of which are used in Brazil.

The low results in sulphur found in the old S. Jeronymo briquette are due to the fact that the sulphur had been leached out during several years of exposure to the elements.

These analyses are given to show the high per cent of ash left in the coal by the old methods of briquetting.

Through the courtesy of Dr. C. D. Walcott, then Director of the United States Geological Survey, another sample of the coal from S. Jeronymo amounting to twenty-odd tons was shipped to St. Louis for testing in the fuel testing plant of the United States Geological Survey. This latter sample was selected by Mr. Otto Spalding, superintendent of the S. Jeronymo Co., who was instructed to send a general average sample of the coal he ships to Porto Alegre, Pelotas, Margem do Taquary, and elsewhere for industrial purposes. The United States Geological Survey report on the test of this 20-ton sample of S. Jeronymo coal is as follows:

[United States Geological Survey coal-testing plant. Chemical laboratory report.]

Analysis of Brazilian coal.

Proximate:	
Moisture	11.52
Volatile combustible	26.75
Fixed carbon	40.00
Ash	21.93
Ultimate:	
Ash	21.93
Sulphur	2.72
Carbon	52.29
Hydrogen	4.68
Nitrogen	0.88
Oxygen	17.50
Calorific value determined:	
Calories	5,135
British thermal units	9,243
Calorific value calculated from ultimate analysis:	
Calories	5,146
British thermal units	9,263

The following tables represent the results obtained by the United States Geological Survey at St. Louis in testing the fuel value of the carload of the S. Jeronymo coal.

Boiler test No. 172.

Brazil No. 1.—Duration of test, 3.35 hours; kind of coal, mine run; size of coal (average diameter), 1.42 inches; kind of grate, plain.

British thermal units per pound dry coal	10,028
Per cent of rated horsepower of boiler	73.38
Per cent of efficiency	58.83
Water evaporated per pound of coal as fired ... Pounds	4.48
Equivalent water evaporated—	
Per pound of coal as fired ... Pounds	5.16
Per pound dry coal ... Pounds	5.80
Per pound combustible ... Pounds	8.43
Furnace temperature, °F	1,900
Equivalent pounds of coal used per indicated horsepower at steam engine:	
Dry	4.88
As fired	5.48
Equivalent pounds of coal used per electric horsepower-hour developed at switchboard:	
Dry	6.02
As fired	6.77

Analyses.

Proximate:	Per cent.	Ultimate (figured from car sample):	Per cent.
Fixed carbon	37.49	Carbon	56.70
Volatile matter	27.06	Hydrogen	3.71
Moisture	10.92	Oxygen	8.08
Ash	24.53	Nitrogen	0.95
Sulphur separately determined	2.69	Sulphur	3.02
		Ash	27.54

Boiler test No. 173.

Brazil No. 1.—Duration of test, 5.6 hours; kind of coal, mine run; size of coal (average diameter), 1.26 inches; kind of grate, plain.

British thermal units per pound of dry coal		9, 830
Per cent of rated horsepower of boiler		85. 00
Per cent of efficiency		63. 38
Water evaporated per pound coal as fired	Pounds..	4. 67
Equivalent water evaporated—		
Per pound of coal as fired	Pounds..	5. 43
Per pound dry coal	Pounds..	6. 09
Per pound combustible	Pounds..	8. 94
Furnace temperature, °F		1, 858
Equivalent pounds of coal used per indicated horsepower-hour at steam engine:		
Dry		4. 64
As fired		5. 21
Equivalent pounds of coal used per electric horsepower-hour developed at switchboard:		
Dry		5. 73
As fired		6. 43

Analyses.

Proximate:

	Per cent.
Fixed carbon	38. 32
Volatile matter	26. 00
Moisture	10. 87
Ash	24. 81
Sulphur separately determined	4. 04

Ultimate (figured from car sample):

	Per cent.
Carbon	55. 23
Hydrogen	3. 61
Oxygen	7. 86
Nitrogen	0. 93
Sulphur	4. 5
Ash	27. 84

The S. Jeronymo coal was also tested in the St. Louis plant of the United States Geological Survey in the manufacture of producer gas for the gas engine, the results being entirely satisfactory, and showing much more horsepower developed per pound of coal than can be obtained by the best grades of Pocahontas or New River coal when used in connection with the steam engine. This gas-producer test gave the following results:

Gas-producer test No. 44.

Brazil No. 1.—Duration of test, 24 hours; kind of coal, mine run.

	Coal per horsepower-hour.		
	As fired.	Dry.	Combustible.
Pounds consumed in producer per electric horsepower available for outside purposes	2.63	2.35	1.73
Pounds consumed in producer per electric horsepower developed at switchboard	2.38	2.12	1.56
Pounds consumed in producer per brake horsepower available for outside purposes	2.24	1.99	1.47
Pounds consumed in producer per brake horsepower developed at engine	2.02	1.80	1.33
Equivalent pounds used by producer plant per electric horsepower available for outside purposes	2.88	2.56	1.89
Equivalent pounds used by producer per electric horsepower developed at switchboard	2.60	2.32	1.71
Equivalent pounds used by producer plant per brake horsepower available for outside purposes	2.45	2.18	1.61
Equivalent pounds used by producer plant per brake horsepower developed at engine	2.21	1.97	1.45

Average electrical horsepower	141.8
Average British thermal units gas per cubic foot	130.9
Total coal fired	8,100

Analyses.

	Per cent.
Average composition of coal:	
Moisture	10.96
Volatile matter	26.78
Fixed carbon	38.82
Ash	23.44
Sulphur	2.94
Average composition of gas volume:	
Carbon dioxide (CO_2)	11.5
Carbon monoxide (CO)	15.9
Hydrogen (H_2)	10.8
Methane (CH_4)	2.9
Nitrogen (N_2)	58.8
Oxygen (O_2)	0.1

The net results of the purification tests at Kalk, and the analyses made there and elsewhere may be summarized as follows:

First. All Brazilian coal mined in a commercial way will be high in both ash and sulphur. containing a total of 20 to 35 per cent of impurities, of which 2 to 8 per cent is sulphur.

Second. The sulphur occurs mostly in nuggets of iron pyrites, which can nearly all be removed from the coal by modern processes of crushing and washing, and the recovered pyrites utilized in the manufacture of sulphuric acid.

Third. From the coal of S. Jeronymo, in Rio Grande do Sul, two grades of purified fuel can be obtained; grade No. 1, 32 per cent of the amount treated, having less than 14 per cent of ash, and very low (0.6 per cent) in sulphur, while grade No. 2, amounting to 42 per cent of the whole, will have a little less than 27 per cent of ash and very little sulphur.

Fourth. From the Barro Branco coal of Santa Catharina two grades of coal can also be obtained, the first grade, 38 per cent of the whole, having 14 per cent of ash, while the second grade, 42 per cent of the whole, will have 28 per cent of ash, both grades containing only a little over 1 per cent of sulphur. It is also possible to secure a fair grade of "nut" coal from the Barro Branco bed that can be used without briquetting.

Fifth. From the coal of first grade both in Santa Catharina and Rio Grande do Sul, briquettes can be manufactured which compare favorably with those imported from Cardiff, Wales, being but little inferior in heating value to the Crown brand, and equal to or superior to the Anchor brand of Cardiff briquettes, while the second grade of coal can be used successfully either as a general fuel for power purposes, like the fine or slack coal from mines, or it can be utilized in the manufacture of producer gas for gas engines.

Sixth. The coal samples sent to Kalk from the Bonito bed of Santa Catharina were necessarily taken from the very much weathered crop coal, and Lieut. Esser's conclusions are that it contains so much ashy refuse that its treatment would prove unprofitable in a coal purification plant. It could be utilized, however, in the manufacture of producer gas for gas engines, and it is probable that deeper down in the basin the coal would hold much less ash than the surface samples, since Dr. Oliveira, the first engineer of the coal commission, reports the bed as 5 meters thick in the boring recently made at Barro Branco Velho, 3 meters of which, he says, is fairly pure coal, at a depth of only 65 meters below the surface.

Seventh. One of the capital discoveries made by the coal-testing plant of the United States Geological Survey at St. Louis was that impure coals, very high in both ash and sulphur, can be utilized in the manufacture of producer gas for the gas engine (the sulphur having no deleterious effect), and when so used, coals of very inferior quality give a greater efficiency in the production of power than the best grades of Cardiff or Pocahontas coal when utilized through the steam engine. That even refuse and waste production of mines, when converted into producer gas, yield large returns in power.

These conclusions would seem to render it very probable, in view of the high price of imported coal everywhere in Brazil, that the coals of Santa Catharina and Rio Grande do Sul can be successfully marketed in competition with foreign coal if properly prepared by modern methods of purification.

The estimate of cost for such a plant, which would crush, wash, and briquette 300 tons of coal daily, as designed by the Humboldt Engineering Works of Kalk, Germany, was about $57,000 f. o. b. Antwerp, in 1905.

LIGNITIC COALS OF NORTH BRAZIL.

In a paper read before the Engineers Club of Rio de Janeiro on the 4th of May, 1915, by Cesar de Campos, it is stated that Dr. Gonzaga de Campos has discovered some valuable beds of lignitic coal on several tributaries of the upper Amazon in the States of Para and Amazonas. The outcrops of these lignites have been observed along the Javary, the Solimoes, and also along the Ica and Japura. In a résumé of this discovery printed in the Journal do Commercio of May 11, 1915, an analysis of this lignite is published as made by the Servico Geologico do Brasil. The sample, which was collected from Igarape de Santo Antonio, near Tabatinga, latitude 4° 8′ south and longitude 70° west of Greenwich, gave the following results:

	Per cent.
Moisture	18.60
Volatile combustible	40.90
Fixed carbon	33.20
Ash	7.30
Total	100.00
B. t. u. per pound	10,103

This would appear to compare favorably in heating power with the best lignites or subbituminous coals of the western United Sataes, and hence, when further explored, may prove to be a valuable addition to the fuel resources of Brazil. These lignites according to Dr. Campos occur either in the Cretaceous or Eocene, and hence may be contemporaneous with the great lignitic series of deposits in North America.

WATER POWERS.

Any résumé of the fuel resources of Brazil should not fail to mention its wonderfu riches in waterfalls available for the generation of electric current, or "white coal." The great outflows of basaltic lavas and other igneous rocks which took place during Mesozoic time in Brazil, as well as in other regions of the world, have of course profoundly modified its physical geography, probably changing the courses of many of its pre-Mesozoic rivers, and making that wonderful system of cascades and vertical falls which characterize so many Brazilian rivers, thus causing them to tumble down with rapid descent from the high mountain plateaus until they arrive within a few miles of the sea coast. This is true of nearly all the rivers of Brazil south from the great Amazon and the other streams of north Brazil, where the rapids and falls occur in their upper reaches next to the Andean Plateau.

The great cataracts, like the Seven Falls (Sete Quedas) of the Parana, and the numererous falls and rapids of the Uruguayan and other rivers within the zone of the Carboniferous and Triassic formations, are practically all caused by these dikes and sills of eruptive rocks. Thus, while these and other igneous agencies have given rise to conditions which forbid a large inland commerce on the rivers of south Brazil, they have at the same time provided such great resources for the cheap generation of electric power as to compensate largely for possible deficiencies in navigable rivers and coal deposits in populous communities, since Brazil has enough water power to operate all her present railways and factories with the electric current and leave an enormous surplus for any future developments. The recent utilization of waterfalls on the Rio Tieté for light and power in the city of S. Paulo, and also of the falls of Ribeirão das Lages to furnish light and power for the large city of Rio de Janeiro, is only the beginning of the development of the enormous possibilities afforded by the great cascades and rapids of the rivers of southern Brazil.

It may even be possible thus to utilize the immense iron ore deposits of Minas Geraes and other Brazilian States through the developments and improvements yet to be made in the electric furnace, so that a large iron and steel industry may finally be developed in Brazil without the necessity of transporting coke thereto from other countries. The age of "white coal," as the electric current has been appropriately named, is yet only in its infancy, and when its full development is attained our sister Republic of Brazil will not be found wanting in power to carry on industries rivaling or even surpassing many of the nations much more highly favored with deposits of coal, petroleum, and natural gas.

The total Permian flora, so far as yet discovered, is included in the following list of the fossil plants from the coal fields of Brazil:

Reinschia australis Bert. & Ren. var. brasiliensis n. var.
Rosellinites gangamopteris n. sp.
Hysterites brasiliensis n. sp.
Equisetites calamitinoides n. sp.
Schizoneura? sp.
Phyllotheca griesbachi Zeill.
Phyllotheca muelleriana n. sp.
Phyllotheca (?) sp.
Lycopodiopsis derbyi Ren.
Lepidodendron pedroanum (Carr.) Zeill.
Lepidophloios laricinus Sternb.
Sigillaria brardii Brongn.
Sigillaria australis n. sp.
Sigillaria sp.
Sigillaria (?) *muralis* n. sp.
Sphenopteris hastata McCoy?
Sphenopteris sp.
Psaronius brasiliensis Brongn. (Not represented in the collections.)
Neuropteridium plantianum (Carr.) D. W. (Not represented in the collections.)
Glossopteris browniana Brongn.
Glossopteris indica (Brongn.) Schimp.
Glossopteris ampla Dana.
Glossopteris occidentalis n. sp.
Glossopteris sp.
Vertebraria sp.
Gangamopteris obovata (Carr.) D. W.
Ottokaria ovalis n. sp.
Arberia minasica n. g., n. sp.
Derbyella aurita n. g., n. sp.
Noeggerathiopsis hislopi (Bunb.) Feist.
Cardiocarpon seixasi n. sp.
Cardiocarpon moreiranum n. sp.
Cardiocarpon oliveiranum n. sp.
Cardiocarpon barcellosum n. sp.
Voltzia? sp.
Dadoylon pedroi Zeill.
Dadoxylon nummularium n. sp.
Dadoxylon meridionale n. sp.
Carpolithus? sp.
Hastimima whitei n. g., n. sp. (*Eurypterid*).

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The great cataracts, like the famed Falls (Salto Grande) of the Paraná, and the numerous falls and rapids of the Uruguay and other rivers within the zone of the Carboniferous and Triassic formations, are practically all caused by those dikes and sills of eruptive rocks. Thus, while these and other igneous agencies have given rise to conditions which forbid a large inland commerce on the rivers of south Brazil, they have at the same time provided such great resources for the cheap generation of electric power as to compensate largely for possible deficiencies in navigable rivers and coal deposits in populous communities, since Brazil has enough water power to operate all her present railways and factories with the electric current and leave an enormous surplus for any future developments. The recent utilization of waterfalls on the Rio Tieté for light and power in the city of S. Paulo, and also of the falls of Ribeirão das Lages to furnish light and power for the large city of Rio de Janeiro is only the beginning of the development of the enormous possibilities afforded by the great cascades and rapids of the rivers of southern Brazil.

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The total Permian flora, so far as yet discovered, is included in the following list of the fossil plants from the coal fields of Brazil:

Psilotum? sp. ...

Kelseia australis Bertr. & Ren. var. *brasiliensis* n. var.
Rhacilinites gonyamopteris n. sp.
Hyphelia brasiliensis n. sp.
Annularites calamitoides n. sp.
Schizoneura sp.
Phyllotheca griesbachi Zeill.
Phyllotheca muelleriana n. sp.
Phyllotheca (?) sp.
Lycopodiopsis derbyi Ren.
Lepidodendron pedroanum (Carr.) Zeill.
Lepidophloios laricinus Sternb.
Sigillaria brardi Brongn.
Sigillaria muralis n. sp.
Sigillaria sp.
Sigillaria (?) *mussoi* n. sp.
Sphenopteris lobata McCoy?
Sphenopteris sp.
Pecopteris brasiliensis Brongn. (Not represented in the collections.)
Neuropteridium plantianum (Carr.) D. W. (Not represented in the collections.)
Glossopteris browniana Brongn.
Glossopteris indica (Brongn.) Schimp.
Glossopteris angusta Dana.
Glossopteris occidentalis n. sp.
Glossopteris sp.
Bertrandia sp.
Gangamopteris obovata (Carr.) D. W.
Ottokaria ovalis n. sp.
Arberia minasica n. g., n. sp.
Dadoxylon nummularium n. sp.
Noeggerathiopsis hislopi (Bunb.) Feistm.
Cardiocarpon seixasi n. sp.
Cardiocarpon moreirianum n. sp.
Cardiocarpon eilerianum n. sp.
Cardiocarpon barcellosum n. sp.
Holdenia? sp.
Dadoxylon pedroi Zeill.
Dadoxylon nummularium n. sp.
Dadoxylon marianum n. sp.
Carpolithus? sp.
Kaoliniana arborea n. g., n. sp. (Euryphyllum).