Lignite and Peat in Northwestern Puerto Rico

By

Jean N. Weaver

U.S. Geological Survey

Table of Contents

Previous studies

Deposits of lignite have long been known to be present in Puerto Rico, but definitive information about the quantity and quality of the resource has been lacking. The earliest reports of lignite being present in Puerto Rico date back to the Spanish regime, when lignite was extracted from a site near Moca to act as a fuel for a Spanish boat returning to Spain (Bureau of Mines, 1941). Subsequent investigations in the late 1800's (Nitze, 1899; Hill, 1899) reported that lignite containing iron pyrites was present in western Puerto Rico. Some of these locations are near the towns of Utuado, Moca, Lares, and San Sebastian (fig. 1).

The largest reported seam was 6 in. thick and the average seam varied between 1 and 2 in. These lignites were high in ash and sulfur contents. Mitchell-Thorre (1954) noted that "... so much pyrite is present that the coal crumbles to powder upon exposure to the atmosphere. Further, the lignites have a high sulfur content and a very low carbon content, so that often the lignite cannot be kept burning. However, in other localities, the lignite contains much less pyrite, more carbon and in places the seams reach a width of 18 in."

In 1980, a project was initiated to assess the oil and gas source rock potential of the North Coast Tertiary basin of the island (Ueng and Larue, 1988) (fig. 2). Drill holes along the north coast and samples from the San Sebastian Formation were collected for analysis. Through Rock Eval pyrolysis, the samples were examined to determine the amount of organic carbon. One interesting aspect of the results was that thin lignite beds appeared much farther east than previously reported (KEWANEE 4CPR well, fig. 2 and 3).

Peat and other organic-rich sedimentary deposits have been previously mentioned in reports and maps. Roberts (1942) delineated peat, muck, and other organic-rich soil units and showed them on maps. Recent mapping of the geologic quadrangles of northwestern Puerto Rico resulted in discriminating organic-rich and peaty sediments as swamp deposits (Monroe, 1963, 1967,1969; Briggs, 1965, 1968). Morris and others (1990) recently stated that noncommercial lignite and peat deposits are present in Puerto Rico.

In 1960, Kewanee Interamerican Oil Company drilled a deep test well (No. 4CPR) that penetrated the post-Eocene strata in northern Puerto Rico. Coal beds were found in the San Sebastian Formation at approximately 4,640 ft, commonly interbedded with calcareous claystones (Briggs, 1961).

In 1980, North American Exploration, Inc, a private drilling company from Charlottesville, Va., initiated an extensive drilling project. Forty-four holes were drilled within the San Sebastian Formation targeting lignite deposits. Results indicated approximately 10 locations where lignite or coaly fragments appeared in the cuttings. A sample collected by North American Exploration, Inc., from an outcrop near Lares showed the following characteristics:

As received:

moisture	33.04 percent
ash	11.72 percent
volatile matter	25.93 percent
fixed carbon	29.31 percent
sulfur	0.63 percent
Btu/lb	5,817

Dry:

Btu/lb	8,687

These data were obtained from, and published with, the consent of Dr. Ramon Alonso Harris, Division de Geología, Departamento de Recursos Naturales, San Juan, Puerto Rico.

Present study

Field investigations guided by available information were conducted in northwestern Puerto Rico along the outcrop belt of the San Sebastian Formation (fig. 4). Coal, coaly claystone, and coaly sandstone were found primarily in roadcut exposures along Puerto Rico route 111. Route 111 generally coincides with the outcrop belt of the San Sebastian in the Utuado, Bayaney, San Sebastian, Central La Plata, and Moca 1:20,000-scale quadrangles. Exposures of coaly material were found at nine different locations along the San Sebastian outcrop belt, but most of the exposures were too weathered to allow detailed, confident interpretation of lithology and thickness or meaningful sample collection. One sample for coal analysis was collected in the Moca quadrangle, and eighteen samples were collected at exposures in an area near the town of Lares, in the San Sebastian and Bayaney quadrangles.

During collection and summation of available information about coaly materials it was found that other organic-rich sediments were also present. Variously termed muck, peat, peat-like, organic-rich, or simply swamp deposits, sedimentary deposits of peaty character had been observed and mapped by both geologists and soil scientists. As an incidental part of the present study, three swamp deposits were visited and samples were collected for analysis.

Geologic setting

The coal-bearing San Sebastian Formation and its partial lateral-equivalent, the Lares Limestone, are within the North Coast Tertiary basin of northwestern Puerto Rico. The San Sebastian and the Lares are of Oligocene age and are overlain by Tertiary and Quaternary sedimentary units, both unconformably overlie folded and faulted rocks of Cretaceous, Paleocene, and Eocene age.

The North Coast Tertiary basin is bounded on the south by the central mountainous spine of the island, which is largely composed of volcanic rocks of Eocene age and older. Sedimentary rocks of equivalent age to the San Sebastian and Lares were deposited south of the central spine but have not been reported to contain coaly materials.

Coal deposits

All of the coal deposits reported on Puerto Rico fall within the San Sebastian Formation. A total of nine locations where coaly and carbonaceous materials could be observed were visited during the field-checking database acquisition part of this study. Most of the locations had been previously reported, but some exposures have been destroyed by construction and agriculture activities and new exposures created by the same type of earth-moving activities. Recent construction of buildings and highways in the area including the town of Lares, for example, created the best, and freshest, exposures of the coal-bearing segments of the San Sebastian.

San Sebastian Formation

The San Sebastian Formation crops out as a narrow band from west of the town of Moca eastward to just south of San Juan (fig. 4). From Moca to the Rio Grande de Arecibo, the San Sebastian Formation is present in an apparently uniform thickness of approximately 738 ft. Subsurface thicknesses from drill holes indicate that the formation increases in thickness to as much as 1,090 ft farther north. Near the Rio Grande de Arecibo, it is locally missing where the Lares Limestone and Cibao Formation have scoured it out. In places between the towns of San Sebastian and Moca, the overlying Lares Limestone intertongues with clastic rocks indistinguishable from the San Sebastian Formation.

Hubbard (1923) described the San Sebastian Formation: "... although it is predominantly shale, it consists in large part of dark bluish clay carrying seams of lignite and pyrite and marcasite, conglomerate and pebble beds, red calcareous sand or lime sand, green marl, and impure limestone." Monroe (1980) elaborated on this description by adding that "... locally the San Sebastian Formation consists of conglomerate, composed of particles ranging from pebbles to boulders, and contains beds of lignite or carbonaceous shale."

Peat and organic-rich sediments

Peat has previously been reported as present on Puerto Rico. During recent geologic quadrangle mapping, many deposits of organic-rich sediments were identified in areas adjacent to the present-day north coast of Puerto Rico. Several of these organic-rich deposits were visited and sampled during this study.

Modern coastal sediments

Deposits of organic-rich sediments mapped as swamp deposits are shown on geologic maps along the coast of northwestern Puerto Rico. The swamp deposits have been variously described as "... nearly black carbonaceous muck, muck of which rests on a layer of black stringy peat..." (Monroe, 1962); and "... sandy, organic muck and peat associated with mangrove swamps..." (Monroe, 1967). Briggs (1965 and 1968) recognized two types of swamp deposits: "Clay, sandy clay, and silty clay--commonly with high organic content--" and "... peat and peaty muck..." and discriminated the two types in mapped units.

Three different soil units discriminated by Roberts (1942) were sampled as an incidental part of the present study. All three sample localities are in areas mapped as swamp deposits by Monroe (1963, 1967, 1969). All three samples were collected in mangrove swamps, two of that are landward of barrier sand dunes. The other sample locality is in a mangrove swamp on a river flood plain.

Coal

Coal is a solid fossil fuel formed from plant-derived organic remains along with nonorganic minerals. The organic components of coal constitute the combustible part. In order to consider this material coal and not rock, the organic components should constitute more than 50 percent dry weight and 70 percent by volume of the rock.

Grossling (1981) classed solid fossil fuels by the amount of fixed carbon present, ranging from peat (29 percent), lignite, subituminous coal, bituminous coal, to anthracite (95 percent). This increase of the fixed carbon, which happens during coalification, is one basis for characterizing rank.

Coalification implies the increasing of the fixed carbon content, generally increasing the calorific value and is associated with a decrease in the volatile matter and the hydrogen and oxygen content. The calorific value increase of a coal is of particular interest and importance when one views coal as a source of fuel. Although the source vegetable matter across the seam may vary, the coalification process leads to essentially coal of one rank throughout the seam.

Field work

Field studies were conducted during February 1991. Coaly materials were found at nine different locations along the outcrop belt of the San Sebastian Formation between the towns of Lares and Moca (table 1, fig. 2).

Samples were collected at one locality near Moca and four locations in the town of Lares. A total of nineteen samples were collected and submitted for standard coal analyses, and for major, minor, and trace element analyses (tables 2 and 3). Samples were not collected at the other four localities because the coaly materials were too thin and (or) too badly weathered and oxidized.

Figure 4 shows the areal relations of the localities where samples were collected to the outcrop belt of the San Sebastian Formation. In most places in the outcrop belt, the softer, more easily weathered parts of the San Sebastian are weathered, concealed by vegetation, and covered by slumped younger roc in most areas the lateral extent, lithologic character, geometric characteristics, and correlation of coal-bearing segments are unclear or undetermined.

Figure 5 shows the sequence of rocks of the San Sebastian Formation exposed in the Lares area. As the diagram shows, individual thin beds of coal are not laterally continuous. However, sequences of coaly rocks herein designated as zones 1, 2, and 3 are correlated between the four localities. The maximum zone thickness shown is 4.5 ft, and the thickest coal bed within any zone is 1.3 ft. The exposures shown in figure 5 owe their condition to recent construction activities and are the freshest found during this study. Figure 6 presents a more detailed view of the coal zones found in the Lares area and indicates graphically the sequence represented by different samples that were collected for analysis.

Analytical results

The standard coal analyses and other related determinations were performed by Geochemical Testing, Inc., of Somerset, Penn., under contract to the USGS. The results for northwestern Puerto Rico are presented in table 2. The standard coal analyses include proximate and ultimate analyses, heat of combustion, forms of sulfur, free-swelling index, ash-fusion temperature and Hardgrove grindability index determinations. Proximate analysis data for coal (moisture, ash, volatile matter, fixed carbon) are used as indicators of coal quality, to classify coal, to determine the market value of the coal, and as a guide to furnace design (Schweinfurth and others, 1990). The ultimate analysis determines the hydrogen, carbon, nitrogen, oxygen, and sulfur contents of the coal. The major, minor, and trace-element analyses were performed by USGS analytical laboratories in Reston, Va. (table 3). Major elements are defined as those present in concentrations exceeding 0.5 percent (5,000 ppm), minor elements in concentrations from 0.02 to 0.5 percent, and trace elements as less than 0.02 percent (200 ppm). Table 4 summarizes the proximate and ultimate analyses statistically for 19 coal samples. The results of proximate and ultimate analyses indicate ranges of physical and chemical characteristics that are useful in making broad estimates of the behavior of coal in mining, preparation, and utilization (American Society for Testing and Materials, 1986, 1988, 1992).

Classification of coals by rank, that is according to their degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite, is necessary for gross predictions of potential for utilization and for informed planning for extraction, transport, storage, preparation, and use. In low-rank coals, such as those in Puerto Rico, classification by rank is based on the moist, mineral-matter-free heat value stated in British thermal units (Btu) per pound. The apparent rank of the Puerto Rico coals is lignite B.

Classification of coals by grade is based upon the amount of recognized noncombustible constituents present in the coal. A high moisture content compromises the cost benefits of using such coals as a fuel because part of the heat is used to evaporate the moisture. The Puerto Rican coal samples range from 1.1 to 30.3 percent in moisture, the content averaging about 29 percent. The ash content of Puerto Rican coal samples ranges from 1.2 to 48.8 percent and averages about 43 percent. Coals containing more than 15 percent ash are categorized as having a high ash content (Wood and others, 1983). High-ash coals require considerations such as particular boiler designs and ash-disposal plans. The sulfur content of the Puerto Rican coal samples ranges from 0.87 to 5.7 percent and averages about 4.2 percent. Such coals are categorized as high sulfur content and require special handling and technology to prevent atmospheric pollution during combustion by release of sulfur oxides.

The arsenic analyses were performed on a whole-coal basis by neutron activation analysis. Average arsenic value (500 ppm) and selenium (3.9 ppm) contents of the Puerto Rican coals exceed the average amount of these elements (13 and 0.6 ppm, respectively) in the average shale of the world (Turekian and Wedepohl, 1961). In comparison, lignitic coals of Texas and Louisiana contain as little as 4 ppm of arsenic and 5 ppm selenium (Oman and Meissner, 1987). Many of the elements present in major and minor concentrations are largely found in the inorganic residue (mineral matter or ash) produced during combustion of the coaly material. These elements are by custom reported as oxides (table 5). The oxide composition of coal ash may be used in conjunction with tests such as ash-fusibility determinations to assist in predicting the slagging and fouling behaviour of coals during combustion. They are important environmentally also; for example, the amount of CaO in a coal determines the amount of limestone required in a fluidized bed combustion system to reduce sulfur emissions.

In common practice, the ash remaining after controlled combustion of coal samples is analyzed by standard chemical methods for as many as 47 elements (Turekian and Wedepohl, 1961). The elements Si, Al, Ca, Mg, Na, Fe, Ti, P, and S are reported on the oxide basis in percent. The remainder of the determined elements are reported in parts per million.

The reported oxide composition of the ash could be used in conjunction with such tests as ash-fusibility determinations and with a wide variety of largely empirical formulas to assist in explaining and predicting the behavior of coals during combustion and conversion. Regarding the composition of whole coal, as many as 25 minor trace elements are determined in the whole coal and, as previously stated, are reported on a whole-coal basis. Some are determined in this manner because of the particular analytical technique in use. Vast amounts of research have been done on the elemental assemblage of coals, especially on the forms in which the elements are present and the relationship of the resulting information to problems during utilization and (or) the possibilities of recovery of valuable byproducts (Gluskoter and others, 1981).

Resource estimates

Knowledge of a Nation's coal resources is important in planning for the exportation and importation of fuel. A detailed resource classification accomplishes the following factors: (1) identifies deposits of coal based on location, (2) distance from points of information, (3) thickness of coal and overburden, (4) rank and quality, and finally, (5) estimates of quantity (Wood and others, 1983).

The estimates of coal resources presented here were made in accordance with procedures presented by Wood and others (1983), in USGS Circular 891 "Coal Resource Classification System of the U.S. Geological Survey." Criteria used to calculate the resources of the Lares coal area are as shown in table 6.

Figure 4 shows the location of Lares 1, 2, 3, and 4 measured sections (figs. 5-7) along with the drill holes from the North American Exploration, Inc., drill program of 1980. Table 7 shows the areas that were delineated and the classification of those areas according to bed thickness, estimation reliability, and overburden thickness used in the calculations. Measured and indicated estimates appear in table 8, and inferred estimates are in table 9. Total resource estimates are summarized in table 10.

Depositional interpretation

The San Sebastian Formation is conformably overlain by the Lares Limestone at most places and is laterally equivalent in part to the Lares in some areas. The coal zones in the Lares coal area are closely associated with beds containing marine fossils (figs. 5 and 6). Marine fossils are found in most of the sandstone units associated with the coal beds in the Lares area. In some cases, borings made by marine organisms are visible within the sandstone units. These associated sandstone bodies, which are very fine grained and friable, closely resemble sand deposits of a modern beach or offshore bar. In contrast, most of the part of the San Sebastian Formation below the coal zones in the Lares area is nonmarine. The thick red-bed sequence at the base of Lares #1 exposure represents an alluvial plain that filled some of the lowlands eroded on the Cretaceous through Eocene basement rock (Frost and others, 1983). These outcrops are good examples of the transition from nonmarine to marine environments (fig. 8).

The presence of marine fossils associated with coal zones, coupled with burrowed sandstone units, infers that the lignites were deposited in low-lying, brackish-paralic environments on the broad coastal shelf of the island. The low-lying areas developed into swamps, commonly brackish in nature due to periodic rise of sea level. Palynology of the coals indicates the presence of Rhysophor-type (mangrove) pollen, and fungal spores (Habib, 1971).

The mangrove swamps probably never existed undisturbed for a sufficient period of time to result in bodies of peat thick enough to create thick coal beds. The thin, cyclic, poorly developed coals of the San Sebastian in the Lares area reflect the transient nature of the paralic environments in which they were deposited. Coals having high ash and sulfur contents are common in the depositional environment just described. For example, many of the coals in the lower portion of the Dakota Sandstone in southwestern Colorado, northwestern New Mexico, and northeastern Arizona are high-ash, high-sulfur coals. The high ash is usually due to the interfingering of organic-rich and organic-poor layers. Coals having high sulfur contents have commonly been subjected to marine influences (Landis, oral commun., 1992).

Peat

Peat is an inorganic material that develops as a result of the incomplete decomposition of wetland vegetation under conditions of excess moisture and oxygen deficiency. Organic matter accumulates when the rate of production exceeds that of degradation. Peat is defined as having 25 percent or less of ash and more than 75 percent of organic matter on a dry basis (fig. 9; Andrejko and others, 1983). Peat has long been used in the horticulture and agriculture sectors. The accumulation of organic matter is sometimes large, implying economic reserves that can be utilized for energy and agriculture (Chateauneuf and others, 1991).

Field work

Eight samples of peaty, organic-rich sediment were collected at three mangrove sites along the north coast of the island (fig. 4). All three sites are in present-day mangrove swamps. The Isabela and Punta Maracayo locations are both back-barrier beach deposits; the Quebradillas location could be considered an open (?) coastal estuary. The geologic maps that include the sample sites (Monroe, 1963, 1967, 1969) show the mapped swamp deposits to be as much as 5 m thick. Because collection of peaty materials was prior to initiation of fieldwork, samples were collected in a primitive fashion, using a 15-in. piece of 2-in. PVC tubing. Consequently, all samples represent only the uppermost part of the swamp deposits at each site.

Sample descriptions:

Isabela #1.

Sampled 3 in. from water edge; 12-in. core; sandy and dark brown; strong H_2S (?) odor.

Isabela #2.

Sampled 4 ft from Isabela #1; water 3 in. deep at sample locality; sandy, dark brown; strong H_2S odor.

Isabela #3.

Sampled 100 m west of Isabela #2; 4 ft into the swamp; 6 in. core. Water is brownish-red but clear. Sample was sandy and dark brown.

Isabela #4.

Sampled 15 ft from Isabela #2; 10 ft farther into swamp from Isabela #2. Water is 6 in. deep, and area is clear of roots. Sample was sandy and contains soft wood fragments; more organic material was present than in previous three samples.

Quebradillas #1.

Sampled 3 ft from shoreline. 6-in. core in 3 in. of brackish water. Sample was very sandy.

Quebradillas #2.

Sampled 2 ft from shore near mangroves. 3-in. in 1 ft of water. Sample was sandy, snails and shells were present along with twigs, rootlets, and woody material. Sample was darker in color than in previous Quebradillas #1 sample.

Punta Maracayo #1.

Sampled in red mangrove swamp; 4-in. sandy core, organic-rich. Strong H_2S odor.

Punta Maracayo #2.

Sampled in red mangrove swamp; 8-in. sandy, dark-brown, clayey, organic-rich (twigs, stems).

Sample analyses

From each sample bag, enough material was taken to obtain >20 g of wet sample. The wet samples were dried in evaporation dishes for 24 hours at 105? C. Moisture was calculated as weight in percent (that is, weight lost during drying/weight of wet sample).

The dry samples were converted to ash in a muffle furnace by raising the temperature to 550? C over 3 hours and maintaining at 550? C for 16 hours. Ash yield was then calculated as weight percent of sample after ashing/weight of dry sample before ashing.

Results of moisture and ash determinations are shown in figure 10 and table 11. The samples all had significant quantities of mineral matter, apparent to the touch when the sample was rubbed between the fingers. The moisture content ranged from 25 to 54 percent (fig. 10). The ash percentage ranged from 85 to 96 percent. After ashing, the samples appeared to be fairly coarse reddish sediments and several contained shells and shell fragments (Neuzil, S., written commun., 1991).

As expected, because of the type of available sampling equipment, none of the samples represented more than the surficial layers of the swamp deposits. None of the samples qualified as peat because of the large percentage of inorganic material, and no other characteristics, such as heat value, were determined. Both the observed depositional settings of the samples and available literature indicate that peat could be present under some, or many, of the present-day swampy areas in Puerto Rico. The purpose of the analyses presented here is to introduce the procedures used (in simplistic terms) and to emphasize that peat should still be considered as a potential resource for energy and other purposes. Further investigations and sampling programs would be needed to properly assess the peat resource potential of Puerto Rico.

The deposits accumulating now in and around mangrove swamps along the north coast of Puerto Rico are in many ways present-day analogs to the coaly sequences in the San Sebastian Formation. The size and shape of the coals and carbonaceous shale beds, the lithology and minor characteristics of the associated sandstone and finer clastic beds, and the type of plant debris accumulated to form organic-rich sediments are similar.

Conclusions

Coals and closely related rocks such as coaly shale, coaly sandstone, and carbonaceous shale and sandstone are present in the San Sebastian Formation of Oligocene age in many places in northwestern Puerto Rico.

The San Sebastian is the basal unit of a generally transgressive rock sequence of middle and late Tertiary age that occupies the North Coast Tertiary structural basin. The rocks included in the San Sebastian were deposited in near-shore fluvial, paralic, and shallow-water marine environments. The different environments impinged upon and replaced each other in short-term transitions typical of those observable under present-day coastal conditions. The coaly deposits in the San Sebastian reflect their depositional history in their external size and shape and their internal physical and chemical characteristics.

Coaly sequences were examined at nine different locations and sampled at five locations. However, only four of the locations could be used to derive a representative understanding of the resource. All four locations are recent exposures of the coaly part of the San Sebastian in an area that includes the town of Lares. Information gathered in the present study was supplemented by data from five previously drilled exploration wells. Resource estimates for coal beds more than 0.3 m thick, almost all overlaid by less than 150 m of overburden, total about 1.5 million tons. All of the resources fall in the subeconomic class because they are too thin to be economically mined at present. The coal is of lignite B rank and is classed as high-ash and high-sulfur grade. The potential for peat deposits in Puerto Rico cannot be evaluated with presently available information.

References Cited

American Society for Testing and Materials, 1986, Annual Book of ASTM Standards, Vol. 05.05, Gaseous Fuels, Coal and Coke: ASTM, Philadelphia, Pa., 565 p.

____,1988, Annual Book of ASTM Standards, Vol. 05.05., Gaseous Fuels, Coal and Coke:ASTM, Philadelphia, Pa., 444 p.

____,1992, Annual Book of ASTM Standards, Vol. 0.5.05, Gaseous Fuels, Coal and Coke: ASTM, Philadelphia, Pa., 506 p.

Andrejko, M.F., Fiene, F., and Cohen, A.D., 1983, Comparison of Ashing Techniques for Determination of the Inorganic Content of Peats. in Testing of peats and organic Soils, ASTM STP 820, Jarrett, P.M., ed., American Society for Testing and Materials, p. 5-20.

Briggs, R.P., 1961, Geology of Kewanee Interamerican Oil Company test Well Number 4CPR, northern Puerto Rico, in Oil and Gas Possibilities of northern Puerto Rico: San Juan, Puerto Rico Mining Commission, p.1-23.

____, 1965, Geologic map of the Barceloneta quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-421, scale 1:20,000.

____,1968, Geologic map of the Arecibo quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-551, scale 1:20,000.

Bureau of Mines, 1941, Report of the Bureau of Mines on the Mineral Resources of Puerto Rico: U.S. Bureau of Mines, p. 51.

Chateauneuf, J-J., Farjanel, G., Laggoun-Defarge, F., Pezeril, G., and Bikwemu, G., 1991, Petrological and physico-chemical properties of some Afrcian peats in relation to their suitablility for Carbonization. Bulletin Soc. Geol., France. Vol. 162, No. 2, p.423-435.

Frost, S.H., Harbor, J.L., Beach, D.K., Realini, M.J., and Harris, P.M., 1983, Oligocene Reef Tract Development-southwestern Puerto Rico. Sedimenta IX, University of Miami, Miami, Florida, 144 p.

Gluskoter, H.J., Shimp, N.F., and Ruch, R.R., 1981. Coal Analyses, Trace Elements, and Mineral Matter in Elliott, M.A., ed., Chemistry of Coal, A Supplementary Volume. A Wiley-Interscience Publication, John Wiley and Sons, New York, p. 369-424.

Grossling, B.F., 1981, World Coal Resources, Second Edition. Financial Times Business Information, Ltd., London, England, 166 p.

Habib, D., 1971, Palynology of the San Sebastian Coal (Oligocene) of Puerto Rico, (abs.), Fifth Caribbean Geologic Conference Transactions, Queens College, Department of Geology, Geologic Bulletin, No. 5, p. 141, 1971.

Hill, R.T., 1899, The mineral resources of Porto Rico, in 20th Annual report of the USGS, part VI-Mineral resources of the United States. 1898-99, Nonmetallic products except coal and coke, p. 771-778.

Hubbard, B., 1923, The geology of the Lares District, Porto Rico. New York Academy of Sciences, Scientific Survey Porto Rico and Virgin Islands, Vol. 2, Part 1, p. 1-115.

Mitchell-Thorre, R.C., 1954. A Survey of the Geology of Puerto Rico: Puerto Rico University, Agricultural Experimental Station Technology Paper 13, 167 p.

Monroe, W.H., 1962, Geology of the Manati quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-334, scale 1:20,000.

____, 1963, Geologic map of Camuy, Puerto Rico: U.S. Geological Survey Geologic Quadrangle Map GQ-197, scale 1;20,000.

____, 1967, Geologic Map of Quebradillas, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-498, scale 1:20,000.

,1969, Geologic map of the Moca and Isabella Quadrangles, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations map I-565, scale 1:20,000.

____,1980, Geology of the Middle Tertiary Formations of Puerto Rico: U.S. Geological Survey Professional Paper 953, 93 p.

Morris, A.E.L., Meyerhoff, A.A., Taner, I., Bueno-Salazar, R., and Young, G.A., 1990, Energy Resources of the Caribbean, in Dengo, G., and Case, J.E., eds., The Caribbean Region: Boulder, Colorado, Geological Society of America, The Geology of North America, p. 483-506.

Nitze, H.B.C., 1899, Some of the mineral resources of Porto Rico: in 20th Annual Report to the USGS, Part VI-Mineral Resources of the United States, 1899-99. Nonmetallic products except coal and coke, p. 779-787.

Oman, C.L., and Meissner, Jr., C.R., 1987, Chemical Analysis of Gulf Coast Lignite Samples with Significant Comparisons and Interpretations of Results in Finkelman, R.B., Casagrande, D.J., and Benson, S.A., eds., Gulf Coast Lignite Geology, Environmental and Coal Associates, Reston, Virginia, p. 211-223.

Roberts, R.C.,1942, Soil Survey of Puerto Rico: U.S. Department of Agriculture, Soil Survey Report, Series 1936, No. 8, 503 p.
Schweinfurth, S.P., San Filipo, J.R., Landis, E.R., Khan, R.A., and Shah, A.A., 1990, Coal resources of the Lakhra and Sonda coal fields, southern Sindh Province, Pakistan. A progress report. Part 1-Executive Summary: U.S. Geological Survey Open-File Report 90-59, 33 p.
Turekian, K.K., and Wedepohl, K.H., 1961, Distribution of the elements in some major units of the earth's crust: Geological Society of America Bulletin, Vol. 72, No. 2, p. 175-192.
Ueng, C.W.L., and Larue, D.K., 1988, North Coast Tertiary Basin, Puerto Rico: Studies of Source Rock Potential and Maturation. Submitted to the Puerto Rican Electric Power Authority October 1, 1988. 26 p.
Wood, G.H., Jr., Kehn, T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resources classification systems of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.