QUALITY OF COAL RESOURCES UNDERLYING SAND AND LOOKOUT MOUNTAINS GEORGIA AND ALABAMA

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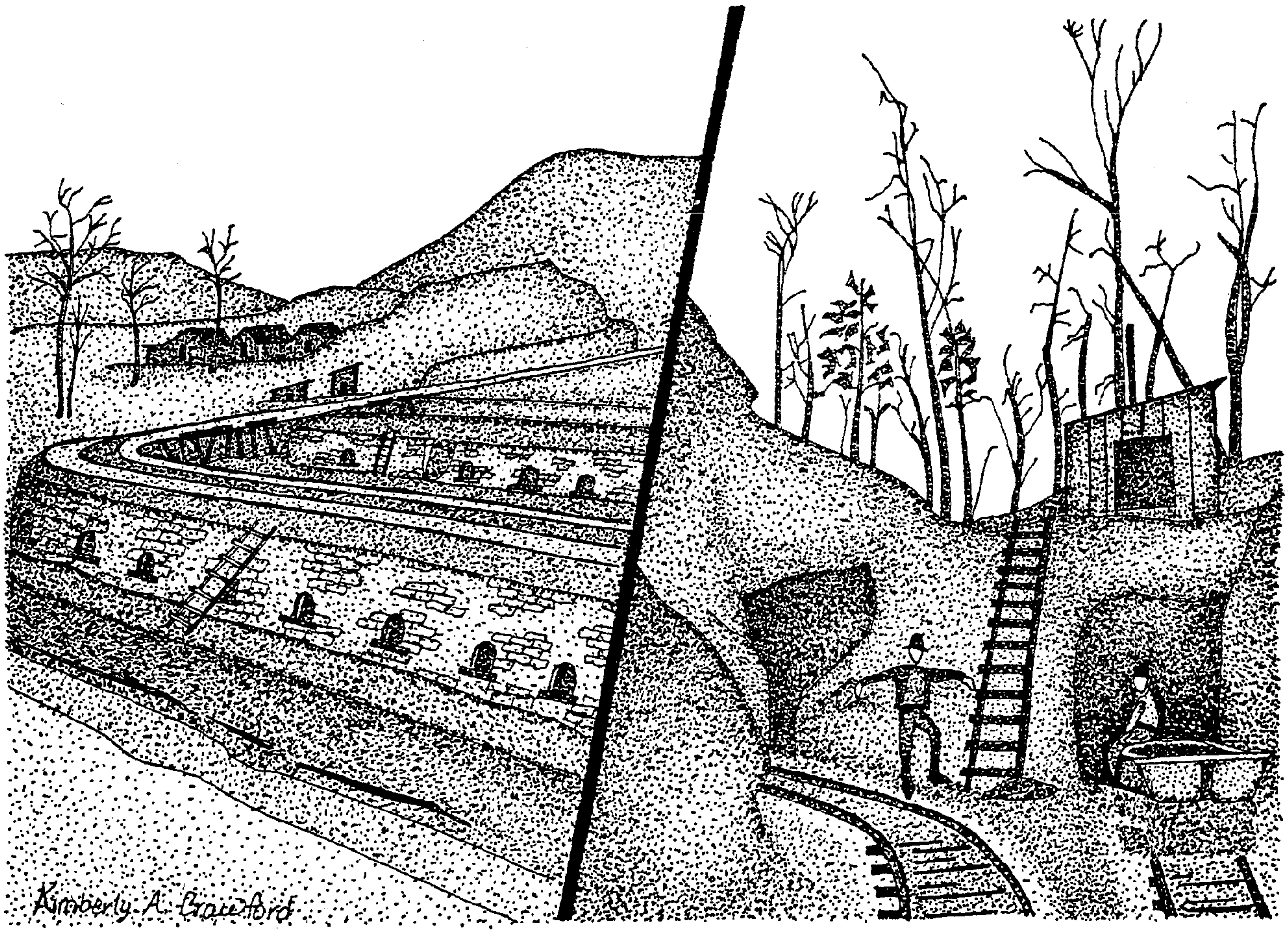
prepared in cooperation with the U.S.Geological Survey



Georgia Geologic Survey
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Drawings taken from photographs, Georgia Geologic Survey Bulletin 12, _Coal Deposits of Georgia_ (1904).

Left: Plate 13- Coke ovens of the Georgia Iron & Coal Company, Cole City, Dade County, Georgia

Right: Plate 10- Entrance to the Raccoon Coal Mine, Cole City, Dade County, Georgia

QUALITY OF COAL RESOURCES OF NORTHWEST GEORGIA

by

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U.S. Geological Survey

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ABSTRACT

Sand and Lookout Mountains are underlain by Pennsylvanian age coal-bearing rocks which crop out along, around, and on these mountains and which have been mined for more than 100 years. These coal deposits have been known for a long time to be of superior quality; however, little significant data have been gathered in a systematic manner and on a broad, regional scale. Beginning in 1977, efforts were initiated to systematically collect and to analyze coal samples from the more than 10 coal beds that underlie Sand and Lookout Mountains, to evaluate their quality. These efforts provided 47 coal samples which were analyzed for ultimate and proximate values, calorific value, forms-of-sulfur, ash-fusion temperatures, free-swelling index, and more than 60 major-, minor-, and trace-element concentrations. These samples were collected from both Sand and Lookout Mountains and from coal beds No. 1, 2, 3, 4, 5, 5A, 6, 8, 9, 9A, and 10.

Analytical results from these samples reveal the following conclusions concerning the quality of coal resources on Sand and Lookout Mountains. The rank of Sand and Lookout Mountains coal ranges from low- to medium-volatile bituminous. Most of the coal samples have less than one percent total sulfur and have very low pyritic and organic sulfur contents. The ash content is low with a geometric mean value of about eight percent. The calorific value for all samples has a mean value of just above 13,000 Btu per pound with some samples having values above 15,000 Btu per pound. The low-volatile and low-ash contents along with high free-swelling indices, for some samples, show the coal to be a high quality metallurgical or metallurgical-blend coal.

The overall geometric mean values for major lithophil oxides such as SiO_2 and Al_2O_3 do not differ very much in concentration when compared to coal samples from other parts of the Appalachian basin. In some individual coal beds, the concentration of CaO, Na_2O, P_2O_5, MgO, and chlorine show wide differences from the overall geometric mean for all the Sand and Lookout Mountains samples.

The geometric mean concentrations of minor- and trace-lithophil elements do not display large differences when compared to eastern United States bituminous coal samples.

Overall, trace chalcophil elements such as silver, arsenic, cobalt, mercury, selenium, and zinc display concentrations that are very similar to other eastern United States bituminous coal samples. However, antimony concentration in the Sand and Lookout Mountains samples is unusually higher than many other comparable bituminous coal samples; and coal beds No. 2, 8, 9A, and 10 contain higher than normal concentrations of arsenic, antimony, cadmium, mercury, lead, selenium, and zinc.

The depositional environments for the Sand and Lookout Mountains coal-bearing rock probably were similar to those described by Milici and various other workers and likely ranged from barrier-bar complexes to fluvial and alluvial systems.

INTRODUCTION

With the increased interest in coal during the 1970's came a renewed interest in mining Georgia coal, and strip mining operations were begun again on Lookout and Sand Mountains (fig. 1). The coal-bearing rocks of Georgia underlie a small area compared with other states; however, the quality of many of the coal beds makes the

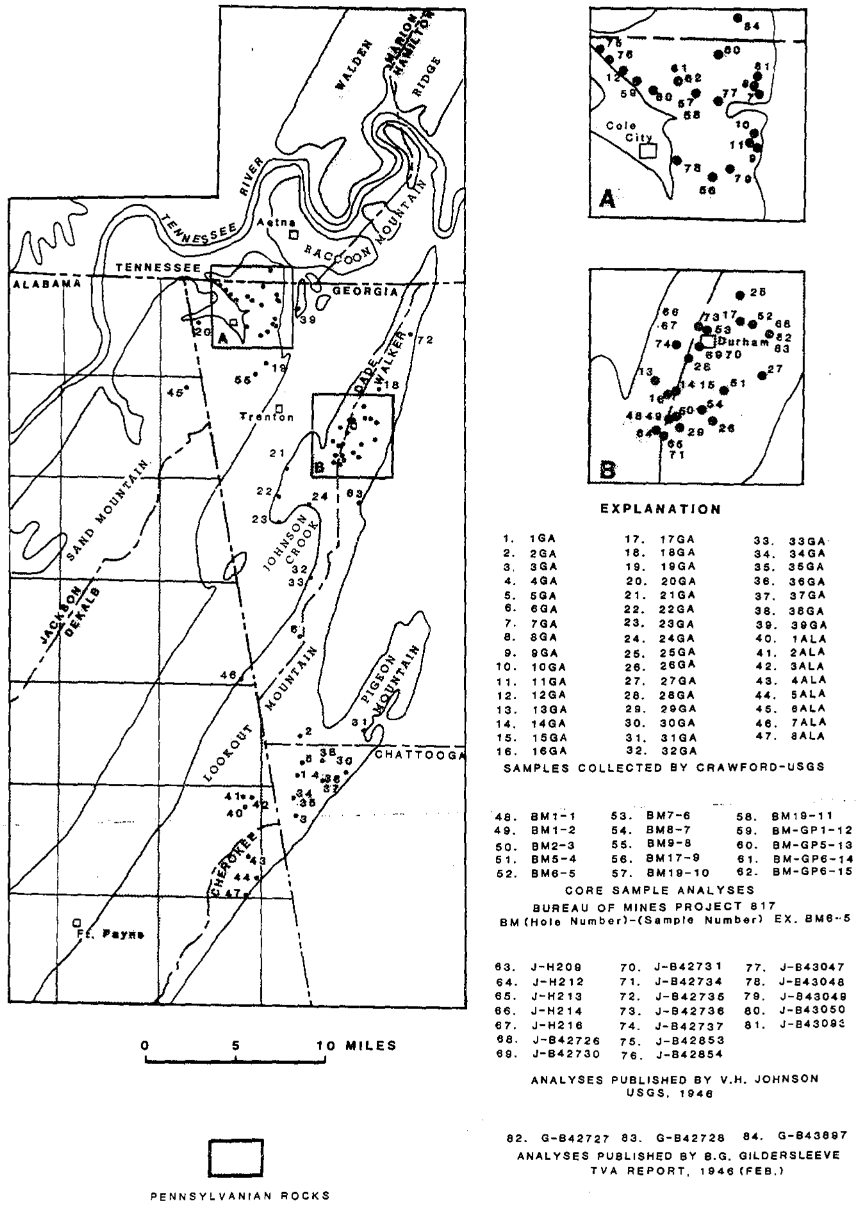

Figure 1. Coal-bearing Pennsylvanian rocks underlying Sand and Lookout Mountains, Georgia, Alabama, and Tennessee. Black dots locate coal samples collected and analyzed during the U. S. Bureau of Mines Project 817 (Troxell, 1946), and during investigations by Johnson (1946), and Gildersleeve (1946).

coal suitable for metallurgical uses, blending, and steam generation. The combined low-ash, low-sulfur and low-volatile content make this coal valuable.

This manuscript characterizes the quality of the coal beds underlying Sand and Lookout Mountains in Georgia and northeast Alabama. This characterization includes not only ultimate and proximate analyses, forms-of-sulfur, free-swelling index, and the heating value, but also the major-, minor-, and trace-element concentrations. By characterizing the coal using modern analytical methods, and combining the quality and quantity data, one can arrive at useful assessments of the coal resources of Georgia.

There are technological, environmental, and geological reasons for characterizing coal. The quality of coal determines its value and usage; properties such as ash and sulfur contents and the heating value are important in assessing the use of coal. Environmental concerns recently have been expressed over the release during combustion of suspected toxic amounts of elements such as arsenic, antimony, selenium, and sulfur. Thus, data on the concentration of these elements are important in environmental decisions and acid precipitation debates. Another reason for studying the quality and geochemistry of coal is for the application of coal quality characteristics to geologic interpretation and development of predictive coal quality models. Because of abrupt vertical and lateral changes in the coal-bearing rocks of Sand and Lookout Mountains and the proximity, or apparent nearness, of the coal deposits to the deposition centers during Pennsylvanian time, there is an opportunity to relate the coal geochemistry to the ancient depositional environments that existed at the time of Pennsylvanian peat accumulation. This is especially pertinent when one recognizes that the coal-bearing rocks of Sand and Lookout Mountains could represent contrasting types of depositional environments, such as barrier-bar and delta-plain environments. Combining geologic mapping, correlation frameworks, and formation distribution patterns with coal geochemistry can provide answers to various technological, environmental, and geological questions concerning the coal resources of Sand and Lookout Mountains and lead to predictive models applicable to other United States coal basins.

A review of the literature emphasizes the need for an integrated study of the coal and coal-bearing rocks of Georgia and Alabama. Each previous study of this area has contributed to an understanding of the stratigraphy, structure, depositional environment, paleontology, distribution of the coal beds, or coal quality. The past studies, however, have not provided adequate detailed or correlatable data to enable a reasonable assessment of the quantity, quality, or distribution of the coal resources of Sand and Lookout Mountains.

General Geologic Setting

The geology of the Paleozoic rocks of northwest Georgia and northeastern Alabama, which includes the Pennsylvanian coal-bearing strata of Georgia, was described by C.W. Hayes (1891, 1892, 1894, 1895, and 1902), Spencer (1893), McCallie (1904), Maynard (1912), Shearer (1912), Smith (1931), Croft (1964), Cressler (1964a, 1964b, 1970), McLemore and Hurst (1970), Chowns (1972), and Cramer (1979). One of the most detailed reports is that of Butts and Gildersleeve (1948).

Geologic Setting of Coal-Bearing Carboniferous Rocks

McCallie (1904) indicated that the most complete section of Carboniferous rocks in Georgia was best developed in Dade, Walker, and Chattooga Counties (fig. 1). McCallie also showed areas of Carboniferous rocks in Floyd, Gordon, Whitfield, and Catoosa Counties; several isolated occurrences were shown in western Polk County. Sections of McCallie's report describe the coal deposits and the coal mines in Dade, Walker, and Chattooga Counties. Discussions on the stratigraphic correlation of what McCallie calls the "lower coal measures" and the "upper coal measures" are also included. There are discussions and analyses of the chemical properties of Georgia coal, and coal samples are related to the coal mines active at the time of study.

Johnson (1946) conducted comprehensive mapping and stratigraphic studies of the coal deposits on Sand and Lookout Mountains and presented a map of the coal-bearing rocks in Dade and Walker Counties, lithologic sections of drill holes on Sand and Lookout Mountains, chemical data, and a description of the coal-bearing rocks and coal beds of economic importance. We shall refer more specifically to Johnson's work in a later part of this report.

Troxell's report (1946) is concerned with the exploration of coal deposits on Lookout and Sand Mountains in Dade and Walker Counties. Troxell stated that commercial coal mining in the Lookout Mountain area began in 1891, in the Durham area. Coal on Sand Mountain was first mined near Castle Rock and Cole City; these mines have long since been abandoned. Troxell reported that on Sand Mountain there were two, and locally three, coal-bearing horizons or coal beds in the shales which form the upper part of what is now called the Gizzard

Formation. The lower coal bed was designated Dade; the upper bed has been locally designated as the Aetna, Castle Rock, or Raccoon.

Butts and Gildersleeve (1948) reported that the coal deposits in Georgia were limited to Lookout, Sand, and Pigeon Mountains. In Dade County these coals crop out on the northern portion of Sand Mountain and the western part of Lookout Mountain. In Walker County, outcrops of coal-bearing rocks are found on Pigeon Mountain and the eastern part of Lookout Mountain, with the most important occurrences being on a part of Lookout Mountain known as Round Mountain, a somewhat circular feature approximately five miles in circumference. The Durham coal mining area is centered at Round Mountain. Butts and Gildersleeve found three workable coal beds in the Durham area; they were about 150 feet apart in elevation. These coal beds crop out in an irregular, circular pattern; the bottom (oldest) bed underlies the largest area and was named the No. 4; overlying the No. 4 bed was the Durham which was in turn overlain by the youngest, or "A", bed. The "A" bed underlies the smallest and most irregular area.

The coal-bearing rocks in Chattooga County are found in a very small area in the northwest corner of the county near the Alabama-Georgia state line. The coal beds are thin and irregular, and occur in pockets along the eastern side of Lookout Mountain. Their thickness ranges from 10 to 18 inches as reported from prospect adits. Taken together the total coal-bearing sequence of rocks underlie approximately 170 square miles in Georgia (Butts and Gildersleeve, 1948).

Butts and Gildersleeve said that there were more than a dozen coal beds in the Sand and Lookout Mountains area, but that only six beds had been extensively mined, including the Rattlesnake, Dade and Aetna coal beds. These coal beds occur in an alternating sequence of sandstones, shales, conglomerates, and underclays approximately 1500 feet thick.

Cressler (1970) reports that the Pennsylvanian System in Floyd County, Georgia, is represented by approximately 350 feet of sandstone, conglomerate, and shale. In addition, Cressler prepared reports on the geology and ground-water resources of Catoosa (1963), Chattooga (1964a), and Walker (1964b) Counties; he used Johnson's (1946) nomenclature and descriptions for rocks of the Pennsylvanian System.

Croft (1964), in his report on the geology and ground-water resources of Dade County, describes the Pennsylvanian rocks in that area and presents a table which shows the correlation of the equivalent Pennsylvanian formations of the Cumberland Plateau of Georgia and Tennessee. This was an attempt to show how the stratigraphic units of Johnson (1946) and Wilson, Jewell and Luther (1956) correlated between Georgia and Tennessee. Croft addresses the differences between Johnson and Wilson, Jewell and Luther's stratigraphic sequences. He describes the lithologies in general but does not mention the coal beds.

Structure

The general structure of the coal fields of northwest Georgia has been known for many years (McCallie, 1904; Butts and Gildersleeve, 1948; Johnson, 1946; Croft, 1964; and Cressler, 1963, 1964a).

The area is characterized by gently folded synclines and anticlines (fig. 2). The most prominent of these synclines are the Lookout Mountain and Sand Mountain synclines. The principal

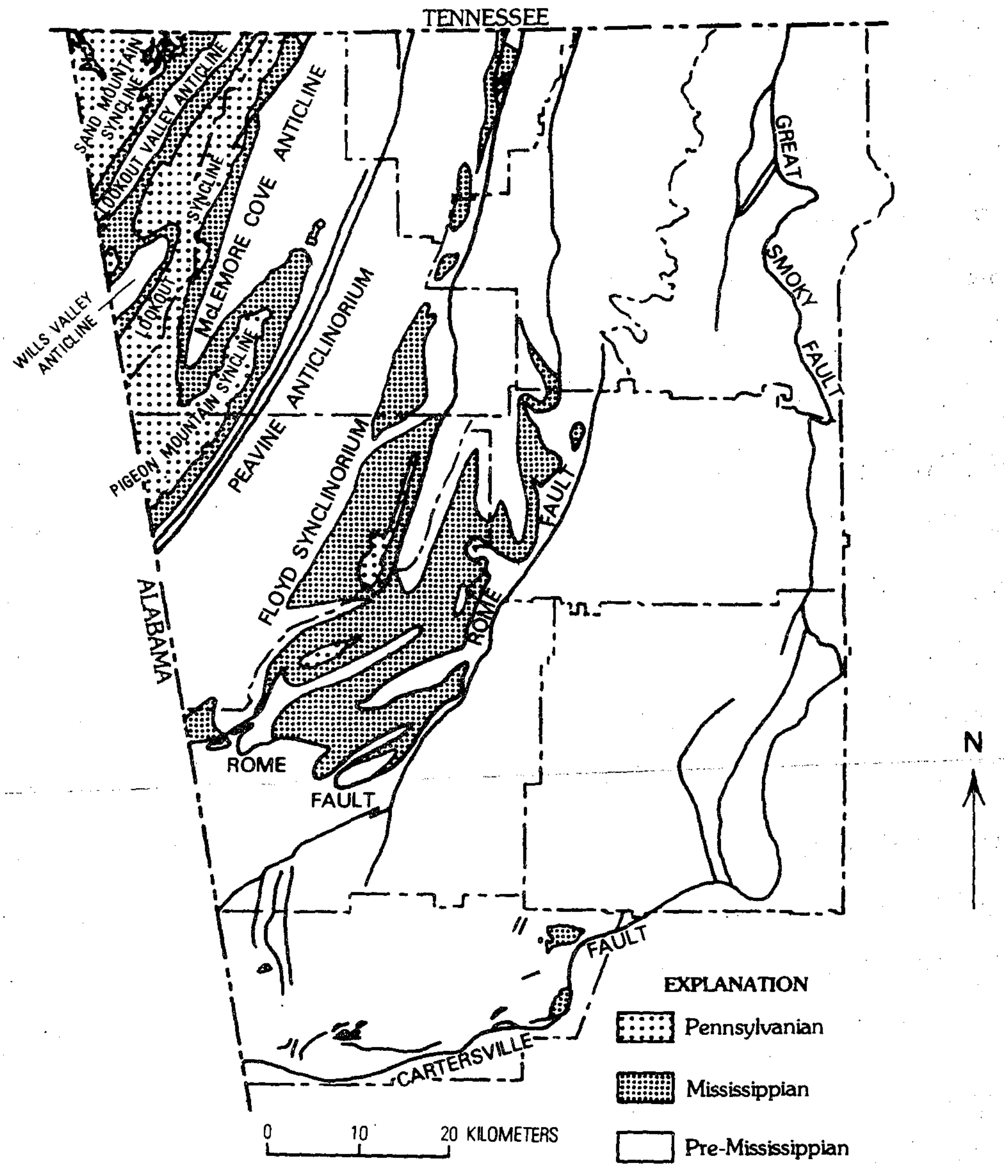

Figure 2. Major structural features and geologic setting of northwest Georgia (from Cramer, 1979).

anticlines are the Lookout Valley, Wills Valley, McLemore Cove and Peavine Anticlines. Lookout Mountain Syncline has its northern terminus in Tennessee (McCallie, 1904); the structure crosses the northwestern corner of Georgia and continues southwestward into Alabama. Its maximum width in Georgia is about 5 miles, near McLemore Cove. In Georgia, east of the McLemore Cove Anticline, another synclinal fold forms Pigeon Mountain. The rocks underlying Pigeon Mountain are the same as those underlying Lookout Mountain. In general, these synclinal and anticlinal structures trend northeast-southwest. The Lookout Valley Anticline, west of Lookout Mountain and separating the Lookout Mountain Syncline from the Sand Mountain Syncline, is an asymmetrical fold with dips on the eastern flank ranging from 12 to 59 degrees and those on the western flank ranging from 2 to 21 degrees (Croft, 1964). Lookout Mountain is a structural trough about 800 ft deep on which minor folds, which trend at angles of 15 to 20 degrees to the axis of the synclinal trough, distort the major synclinal structure (Johnson, 1946). The plunge near Durham is approximately 1 degree to the northeast. West of the Lookout Valley Anticline is the Sand Mountain Syncline.

The Sand Mountain Syncline is a structural trough approximately 200 feet deep. The structural character of Sand Mountain closely approximates that of the Cumberland Plateau (Johnson, 1946), from which it is separated by the narrow valley of the Tennessee River.

Coal deposits in the area are restricted to synclinal mountains called Pigeon Mountain, Lookout Mountain and Sand Mountain. The intensity of structural deformation decreases from east to west.

Environments of Deposition

The depositional setting of the coal-bearing Pennsylvanian rocks of Sand and Lookout Mountains has been studied by many workers. Wanless (1946) interpreted the lithologic units such as the Warren Point Member of the Gizzard Formation, the Sewanee and Newton Sandstone Members of the Crab Orchard Mountains Formation, and the Herbert and Rockcastle Sandstones as all being basal members of cyclothemic sequences. Wanless further speculated that the sediments all appeared to have formed in aqueous environments in piedmont, valley flat, marsh, lake, delta, lagoon, and shallow sea floor areas. He concluded that a network of delta lakes, marshes and lagoons received sediment from shifting stream channels which ultimately discharged their lithic materials into the sea and that the great thicknesses of lithologic units accumulated in a very short time. He used the textures, structures, sorting, and distribution of rocks such as the bluff-forming sandstones on Sand Mountain and the northern part of Lookout Mountain as examples.

Wanless' work has been followed by many other studies which describe different types of depositional environments for this sequence of rocks. Renshaw (1951) suggested deltaic and beach sedimentation. Allen (1955) and Albrighton (1955) modeled tidal flat sedimentation. Shotts (1957) postulated that the southern part of Lookout Mountain was orginally a series of discrete basins which were separated from each other by variations in deltaic sedimentation during Pennsylvanian time. Schlee (1963) studied cross-bedding in the sandstones of the sequence in Georgia, Tennessee, and Alabama, and concluded that the predominant transport direction was toward the southwest. Schlee suggested that the sandstones represent detrital material which was deposited in a fluvial environment and that the sandstones are sheets of "...overlapping anastomosing channel sands ...grown together into one unit." Chen and Goodell (1964) suggested that regional direction of transport of the sand was to the southwest, but suggested a paludal or marginal continental depositional environment for the bluff-forming sandstones.

McKee and others (1975) concluded that the source of the sediments was to the east and northwest. They further stated that the Pennsylvanian sea transgressed periodically from the southwest, resulting in cyclic sedimentation but under less than uniform cyclothemic conditions.

Cramer (1979) wrote that there were possibly several episodes of erosion in the Applachians during Pennsylvanian time. However, it was not possible to determine whether the alternation between the conglomeratic sandstones and clay and coal beds resulted from intermittent renewal of tectonism or from climatic changes that may have occurred at that time.

Cramer (1979) also interpreted the depositional environment of the coal-bearing sequence in northwest Georgia as an environment between the marine and terrestrial. Cramer suggests, from his review and interpretation of the literature, that this environment was one of littoral zone, barrier-island complex, and lower delta plain.

Stearns and Mitchum (1962) believed that the regional lithofacies of the Pennsylvanian in the southeastern United States are several subparallel patterns which resulted from barrier island complexes. Further, they considered that these lithofacies patterns developed parallel to paleoshore lines. Supporting this interpretation are the bluff-forming quartzose sandstones which are massively bedded, cross-bedded, conglomeratic, and contain channel-form deposits. Cross-bedding in the channels and planar cross-bedding and troughlike cross-bedding were interpreted as being indicative of a barrier-island complex environment. Cramer (1979) stated that where the bluff-forming sandstones are not massive or conglomeratic, they may be remnants of other parts of the barrier-island complex such as tidal deltas, washover fans, or dunes. The shales and thinner-bedded sandstones which accompany the more massive sandstones could be interpreted as representing either barrier island marshes which were occasionally invaded by the sea, or washover fans or tidal fans from the seaward side, or terrestrial detritus brought in from the landward side of the barrier island complexes. This environment would explain the irregular distribution of the coal and the associated sandstones, and the mixture of sandstones and shales.

Milici (1974) and Ferm and others (1972) suggested that these rocks originated in littoral environments. They postulated that the Raccoon Mountain Member of the Gizzard Formation, which underlies the bluff-forming sandstones of the Warren Point Member of the same formation, formed in a lagoon complex behind barrier bars. Further, they believed that rocks they interpreted as beach deposits, washover fans, and tidal deltas were part of the lagoonal complex and that the sandstones interfingered as facies with the coal-bearing, shaly, lagoonal deposits. Moreover, the shifting of the strand line resulted in the deposition of "blanket-like deposits" of sand, as the bars migrated over the marsh deposits. The resulting process would be equivalent to the transgressive migration of the sea over those marsh deposits lying behind the barrier island complex or barrier bar complex. Milici named the Raccoon Mountain basin as the depositional center for the thick section of rocks underlying the sandstones on Sand Mountain.

Milici's interpretation could explain the abrupt changes, both laterally and vertically, of the various lithologic units and the difficulty in the correlation of the coal beds in Lookout and Sand Mountains. The interfingering of the various lithologic units, including the coal beds, is also explained by Milici's interpretation. Such a depositional process could lead to the intercalation of lithologic units of both marine and non-marine origin, and the transgressive-regressive fluctuations of the coastal area. Thomas (1972) thought that, during Mississippian and Pennsylvanian time, this part of the southeastern United States was under the influence of a southwestward prograding clastic system.

Cramer (1979), quoting studies by Hayes (1892) and Wanless (1961), states that on the northern part of Lookout Mountain the lithologic units above the bluff-forming sandstones are different from those below. Moreover, Cramer felt that the coal beds, enclosing shales, and sandstones above the bluff-forming sandstones had more lateral continuity, reflected deposition over a greater geographic area, and represented rock units that were deposited in a more stable environment over a longer period of time than those below the sandstones. Further, Cramer stated that the greater thicknesses of coal beds in the coal-bearing sequence overlying the bluff-forming sandstones indicate a much more stable depositional environment than existed during deposition of the sequence below the sandstones. Cramer concluded that the depositional environments of the coal-bearing rocks overlying the bluff-forming sandstones were more akin to a delta plain type of environment. He speculated a littoral offshore bar environment for those coal beds and rock units below the sandstones on the northern part of Lookout Mountain and on Sand Mountain: "...if the tectonic-sedimentation regime which began in the Mississippian with deltaic progradation over a carbonate sequence, were to have continued into the Pennsylvanian, the resulting vertical sequence of rocks to be expected over the open-marine rocks would be prodelta and delta-front clastic rocks, which in turn would be overlain by deposits of barrier-bar complexes and bar-marsh deposits, which in turn would be overlain by delta-plain deposits in which the coal seams would be thicker and more widespread."

Stratigraphic Nomenclature Of The Pennsylvanian Rocks Of Northwest Georgia

Culbertson (1963) clarified the stratigraphic nomenclature of the Pennsylvanian System of Georgia, and made the nomenclature consistent from Tennessee into Georgia and from Georgia into Alabama. Close scrutiny of Figure 3 and Figure 4, which are taken from Culbertson, illustrate the historical trend of the stratigraphic nomenclature in northwest Georgia and southern Tennessee. Culbertson basically adopted the nomeclature established in southern Tennessee by Wilson and others (1956). There is, however, one important distinction between Culbertson´s proposed stratigraphy and nomenclature and that devised for southern Tennessee by Wilson and others (1956). Wilson and others divided the Pennsylvanian rocks into the Gizzard and the Crab Orchard Mountains Groups, with formations broken out in each of these groups. Culbertson´s nomenclature for northwest Georgia assigns formation ranking to the group units established in southern Tennessee. For example, in Georgia, Culbertson changed the Gizzard

System	Series	Aetna (Etna) mines, Tenn. (Safford, 1869, p. 383-384; 1893)	Northwest Georgia, northeast Alabama, and south Tennessee (Hayes, 1892, p. 49)	South Tennessee (Nelson, 1925, p. 39)	Geologic map of Georgia (Georgia Div. of Mines, Mining, and Geology, 1939)	Northwest Georgia, Chart 6 of Pennsylvanian Subcommittee (Moore, 1944)	Northwest Georgia (Johnson, 1946)	South Tennessee (Wilson and others, 1956, p. 1)	Northwest Georgia (this article)
CARBONIFEROUS	PENNSYLVANIAN	(Unit missing)	(Unit missing)	Lee group: Rockcastle conglomerate	(Unit missing)	(Unit missing)	(Unit missing)	Crab Orchard Mountains group: Rockcastle conglomerate	(Unit missing)
		Upper Coal Measures	Walden sandstone	Vandever shale	Pottsville formation	Walden formation	Rockcastle sandstone	Vandever formation	Crab Orchard Mountains Formation: Vandever Member
				Newton sandstone				Newton sandstone	Newton Sandstone Member
				Eastland shale lentil [1]					
				Herbert conglomerate [1]					
				Whitwell shale			Vandever shale	Whitwell shale	Whitwell Shale Member
		Upper Conglomerate (Sewanee conglomerate)		Sewanee conglomerate		Lookout formation: Upper conglomerate	Bonair sandstone	Sewanee conglomerate	Sewanee Member
		Unnamed unit		Gizzard formation: Unnamed member		Unnamed member	Whitwell Shale	Gizzard group: Signal Point shale	Gizzard Formation: Signal Point Shale Member
		Lower Conglomerate (Cliff Rock)	Lookout sandstone	Warren Point sandstone		Lower conglomerate	Lookout sandstone: Sewanee member	Warren Point sandstone	Warren Point Member
		Lower Coal Measures		Unnamed member		Unnamed member	Gizzard member	Raccoon Mountain formation	Raccoon Mountain Member
	MISSISSIPPIAN			Pennington formation	Pennington shale	Pennington formation	Pennington shale	Pennington formation	Pennington Shale
		Mountain limestone	Bangor limestone	Bangor limestone	Bangor limestone	Not shown	Bangor limestone	Not shown	Bangor Limestone

[1] According to Wilson and others (1956, p. 4) the Eastland Shale Lentil and Herbert Conglomerate of Nelson are equivalent to the Whitwell Shale and Newton Sandstone of Nelson, so the names Eastland and Herbert are discarded.

Figure 3. History of stratigraphic nomenclature of Pennsylvanian rocks in northwest Georgia and southern Tennessee (Culbertson, 1963).

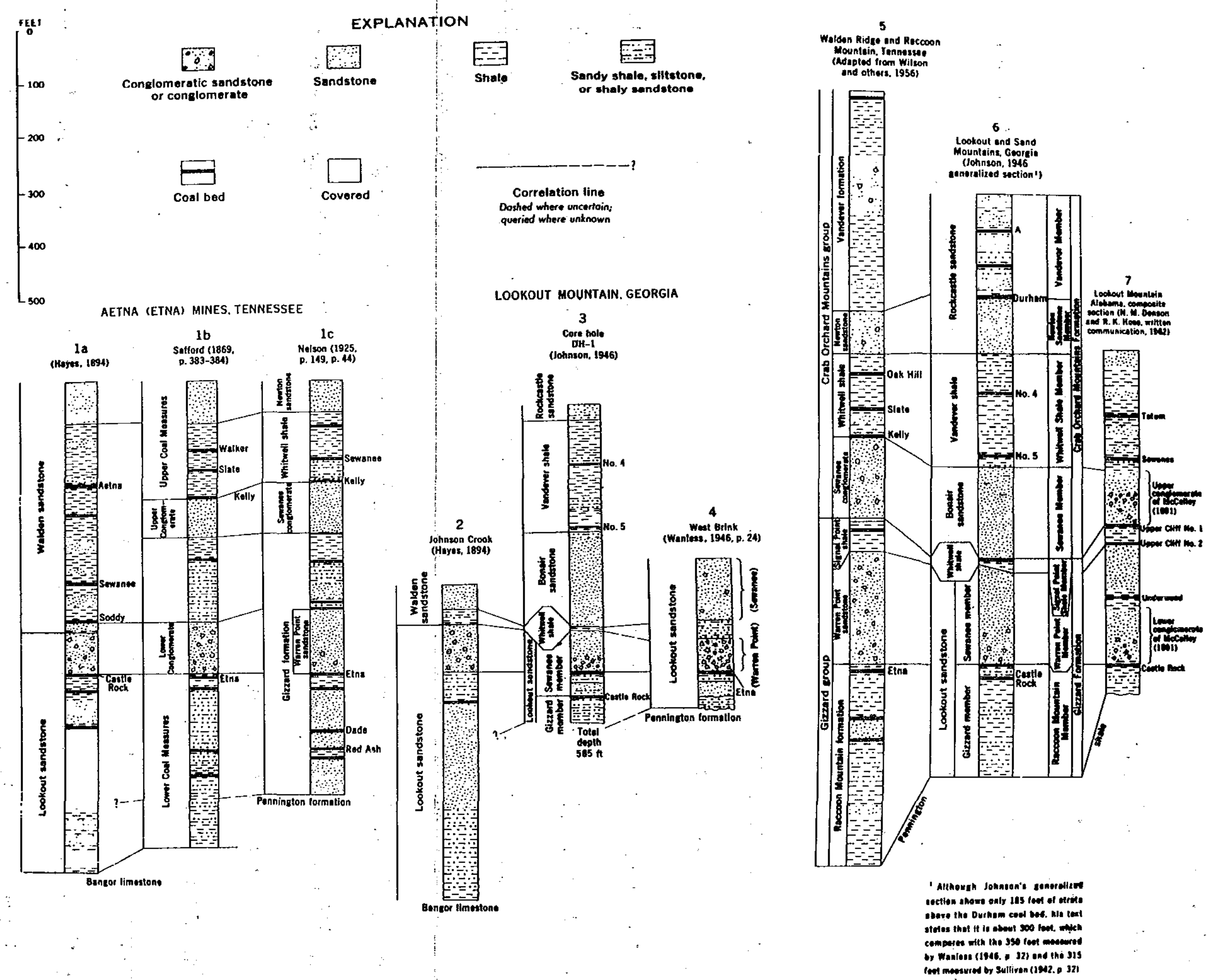

Figure 4. Columnar sections of Pennsylvanian strata in Georgia, Alabama, and Tennessee (reproduced from Culbertson, 1963). Stratigraphic names of each author shown on left side of column, coal bed names on right except where labeled otherwise. Stratigraphic names assigned by Culbertson are to the right of Column 6.

Group of Wilson and others (1956) to the Gizzard Formation and broke out three members within the Gizzard Formation: the Raccoon Mountain, the Warren Point and the Signal Point Shale.

The Raccoon Mountain Member of the Gizzard Formation overlies the Upper Mississippian Pennington Formation. It consists of a sequence of shale, sandstone and siltstone, and discontinuous coal beds. The thickness of this sequence ranges from about 50 feet on Lookout Mountain, Alabama, to 353 ft on the north end of Sand Mountain (Culbertson, 1963). The Aetna, Cliff, or Castle Rock coal bed occurs at or near the top of this member.

The Warren Point Member, which is a cliff-forming conglomeratic sandstone and forms the main cliff face on Sand and Lookout Mountains, ranges from 50 to 100 feet in thickness. On Lookout Mountain in Alabama, the Warren Point Member is from 100 to 150 feet thick (Culbertson (1963). Shale layers are common in the upper part of this unit. Culbertson places the Underwood coal bed and associated shale in the Warren Point Member.

The Signal Point Shale Member of the Gizzard Formation ranges from 6 to 50 feet in thickness in northwest Georgia, and consists of gray shale with locally a thin coal bed and thin beds of sandstone. Two coal beds have been mined locally from this member.

The Sewanee Member of the Crab Orchard Mountains Formation is equivalent to Johnson's Bon Air sandstone and ranges from 150 to 200 feet in thickness. Johnson (1946) describes the lithology of the Sewanee Member as being similar to that of the Warren Point Member but with the exception that the Sewanee does not contain pebbles and weathers more readily than the Warren Point Member. At other localities the Sewanee Member is described as forming the surface rocks on much of Lookout Mountain, Georgia.

Overlying the Sewanee is the Whitwell Shale Member of the Crab Orchard Mountains Formation. This member is a shale and sandy shale sequence which ranges from 100 to 150 feet in thickness and underlies the central portion of Lookout Mountain, Georgia (Culbertson, 1963). The No. 4 and No. 5 coal beds occur in the Whitwell Shale Member; on Lookout Mountain, Alabama, the thin Sewanee and Tatum coal beds are present.

The Whitwell Shale Member is overlain by the Newton Sandstone Member which is a coarse-grained, cross-bedded, bench-forming sandstone that is approximately 110 feet thick (Culbertson, 1963). Coal beds are not known to occur in this member.

The uppermost and youngest member of the Crab Orchard Mountains Formation in northwest Georgia is the Vandever Member. This member consists of 300 feet or more of interlayered shale and sandstone and is correlative with the Vandever Shale in Cumberland County, Tennessee. This member contains the thick Durham coal bed at its base. In describing and discussing the results of the present studies we have chosen to adopt Culbertson's formation and member nomenclature, but we have chosen to use and to modify Johnson's coal bed numbering system.

Present Work

Stratigraphic and structural interpretations based on the current study have been used in constructing the coal bed correlations indicated herein. However, details of the stratigraphy and structure used in this study are not included here, but will be published separately as part of Georgia Geological Survey Bulletin 103 and Geologic Atlas 2.

COAL PRODUCTION AND RESOURCE ESTIMATES

Coal production in Georgia commenced in the early 1860's. Coal mined in the Durham area of Lookout Mountain was processed in coke ovens nearby, and by 1894 nearly 1000 tons daily were being produced (Troxell, 1946). In the Sand Mountain area, coal has been mined intermittently since before the Civil War; 6,500,000 tons of coal were produced through 1946 (Troxell, 1946). Cramer's (1979) coal production figures are shown in Figure 5.

Cramer (1979) shows reserve and resource estimates for Georgia (Table 1). Johnson's (1946) estimates are shown in Table 2, and Butts and Gildersleeve (1948) estimates are given in Table 3. Averitt (1975) and the U.S. Bureau of Mines (1977) showed the demonstrated reserve base for Georgia to be approximately 1 million short tons.

A more recent estimate of the demonstrated reserve base for Georgia can be found in the U.S. Department of Energy's (1981) report. According to this report, Georgia has 1.90 million short tons of remaining underground reserves base coal, 1.75 million short tons of surface mineable reserve base coal, and a total of 3.65 million short tons for the demonstrated reserve base in Georgia as of January 1, 1979. For an explanation of the methodology used in determining these tonnages and for a listing of the references used to arrive at these tonnages, it is recommended that the Department of Energy publication be consulted.

COAL SAMPLING AND ANALYTICAL PROCEDURES

Many of the samples collected in this study were full-channel samples obtained by methods similar to those described by Swanson and

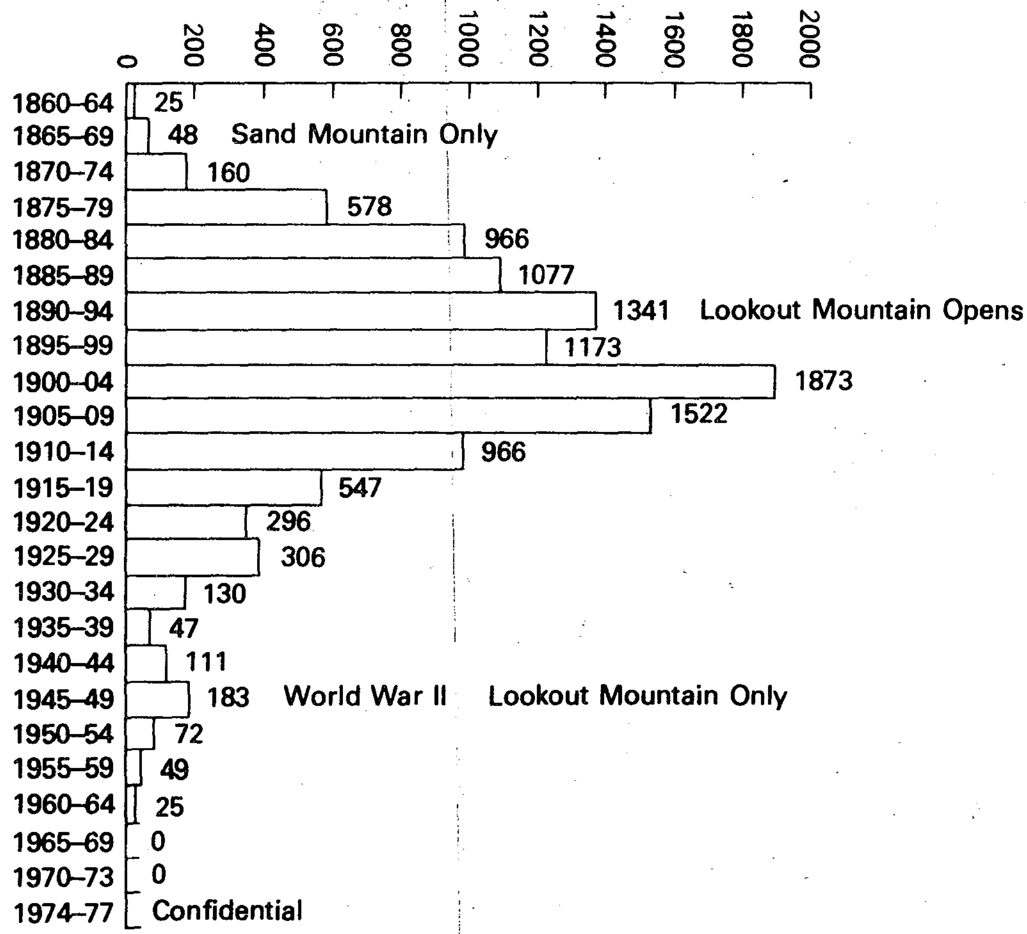

Figure 5. Graph showing coal production (in thousands of short tons) in Georgia from 1860-1977 (modified from Cramer, 1979).

Table 1 - Coal Reserve estimates for Georgia, 1907-1974 (from Cramer, 1979).

Date	Source	Original reserves (millions of short tons)	Remaining reserves (millions of short tons)	Remarks
1907--	Campbell, 1908	933	921	
1942--	Peyton, 1942	---	400	Unpublished data
1942--	Sullivan, 1942	188	184	Sand Mountain only
1946--	Johnson, 1946	24	---	
1948--	Gildersleeve, 1948	206	120	In Butts and Gildersleeve, 1948
1948--	Peyton, 1948	---	115	Unpublished data
1960--	Averitt, 1961	100	76	Average of others
1967--	Averitt, 1969	24	18	
1974--	Averitt, 1975	84	78	Includes hypothetical possibilities
1974--	Averitt, 1975	---	1	Demonstrated reserve base.

Table 2. Coal reserve estimates[1/] for northwest Georgia (from Johnson, 1946).

Bed	Thicker than 2 feet		Thicker than 17 inches inclusive		Total Coal 2/		Comment
	Tons	Average thickness (feet)	Tons	Average thickness (feet)	Tons	Average thickness (feet)	
Lookout Mountain A 2/	<300,000	2.2	<500,000	1.5	<1,000,000	1.3+	2-ft+ coal is very limited. 17-in.+ coal partly depleted by mining.
Durham	500,000±	3.3	500,000±	3.2			All under Round Mountain originally 1,000 acres. Largely depleted.
No. 4 Bed	1,500,000	2.3	2,900,000	1.7	10,000,000	1.5	
Sand Mountain Bed No. 8	840,000	2.3	2,700,000	1.8	12,000,000	1.4	2-ft+ coal. Reserves limited to area around holes Nos. G4, G5, G6, G8, near Tennessee line (see Johnson, 1946)
No. 8	50,000	2.2	100,000	1.6			Around Bailey mine and drill hole No. 9 (see Johnson, 1946)
No. 9	50,000	3.0	100,000	2.0	200,000		Widely scattered in small pockets of a few thousand tons each.

1/ Estimated coal in the ground with minimum and average thickness as shown. These reserves are not necessarily recoverable.

2/ Total coal without regard to thickness or grade.

< Less than.

Table 3. Coal reserve estimates for northwest Georgia (from Butts and Gildersleeve, 1948)

Area and Coal Bed	Average thickness in inches	Acreage underlain by bed	Percent of Area worked out	Percent of Area unworkable
Sand Mountain Area				
Aetna	24	1380	10	25
Dade	40	13800	20	20
Rattlesnake	36	13800	15	30
Durham Area				
"A"	32	670	5	20
No. 5	38	1500	70	15
No. 4	24	7700	1	15

Huffman (1976). A more detailed explanation of full-channel samples is found in Coleman and others (1985).

Figure 6 is a flow diagram which illustrates the plan by which all coal samples are processed by the U.S. Geological Survey. As this figure shows, the coal samples are analyzed by a variety of analytical methods. These include wet chemical analysis, semi-quantitative emission specroscopy, x-ray fluorescence (XRF), flame atomic absorption spectroscopy (AAS), graphite furnace atomic absorption spectroscopy, and instrumental neutron activation analysis (INNA). Samples are analyzed on a whole-coal or coal-ash basis depending on the analytical method and volatility of the element being determined. A discussion of the precision and accuracy of each of these analytical methods is given in Coleman and others (1985).

The standard ultimate and proximate analyses follow analytical standards described in U.S. Bureau of Mines Bulletin 638 (1967). These analyses are important from both a technological and an economic viewpoint, especially the calorific value and the ash and sulfur contents.

Statistical terms used in this bulletin are described in Georgia Information Circular 75 (Coleman and others, 1985). These terms are those used by Connor and others (1976), Miesch (1967), and Cohen (1959).

RESULTS OF ANALYSES

Previous Analyses

Most previous chemical determinations of Sand and Lookout Mountains coal have been proximate analysis and analyses of coke derived from several coal beds. Some of these analyses are given by

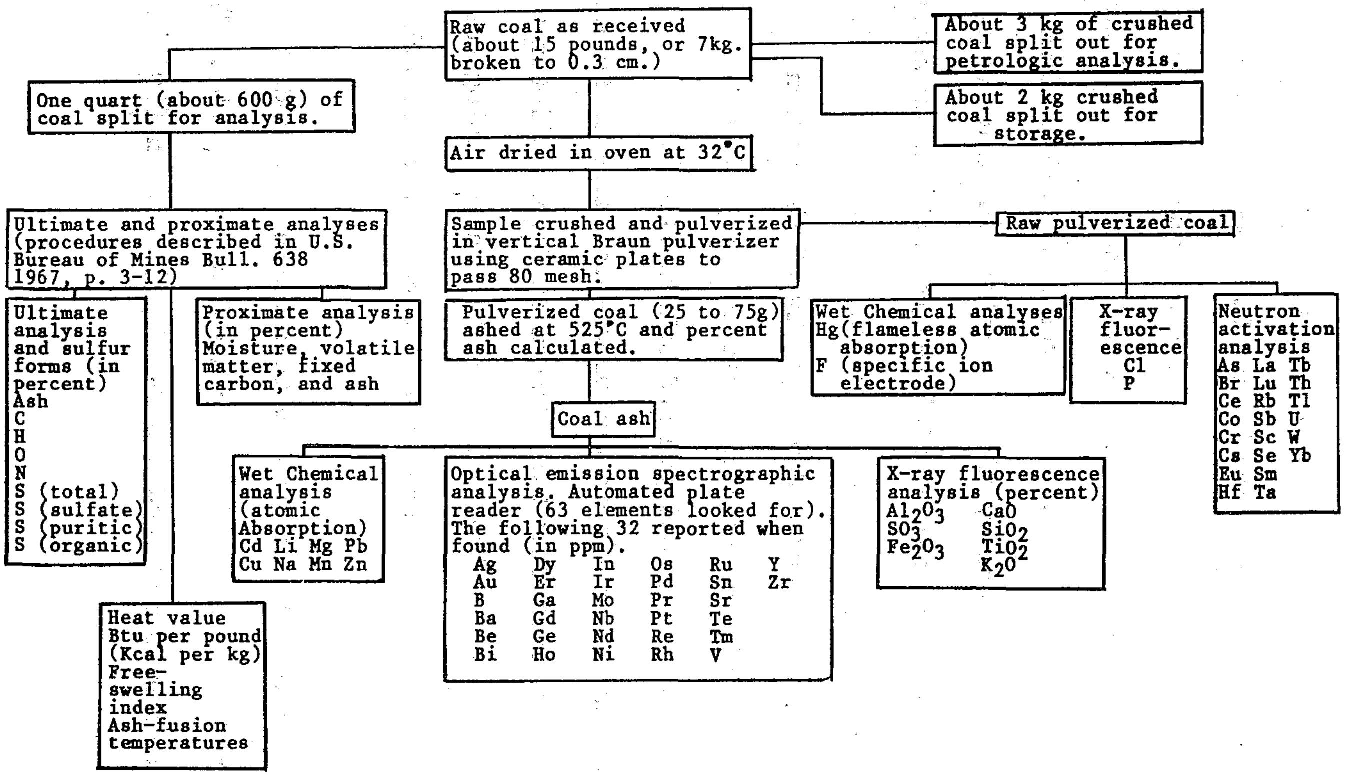

Figure 6. Flow diagram for coal sample analysis by the U. S. Geological Survey

Johnson (1946), Cramer (1979), McCallie (1904), and Butts (1948). The uncertainty of coal bed correlations, differences in sampling methods, and questions concerning the reliability of analytical laboratories make it difficult to evaluate data in the literature and describe specific coal quality for any one coal bed on Sand and Lookout Mountains. However, for completeness, we have tabulated chemical data for Georgia coal as reported by various workers. Table 4 lists data compiled by Cramer (1979); Table 5 displays data from McCallie (1904); Table 6 summarizes chemical data taken from the Keystone Coal Manual (1980); and Table 7 lists data presented by Johnson (1946), Gildersleeve (1946), and Nelson (1945). Data presented in Table 7 will be used extensively as a basis for comparison in later sections of this report. Our use of data presented variously by Johnson (1946), Gildersleeve (1946), and Nelson (1945) is determined by our ability to relocate the drill holes, test pits, adits, and mines from which they collected their samples.

The most recent analyses before this study are from the Keystone Coal Manual (Table 6). Analyses, but no locations, are given for the Etna and Dade coal beds. The Etna is a medium-volatile, low-sulfur, low-ash, metallurgical grade coal. The analysis shows an ash content of 2.4 percent and a sulfur content of 0.79 percent for the Etna; a free-swelling index of 9.0, a pyritic sulfur content of 0.41 percent and an organic sulfur content of 0.38 percent. The Dade is a medium-volatile, low-sulfur, low-ash, metallurgical grade coal, which commonly has a shale roof. It contains 4.7 percent ash and 0.76 percent sulfur. The pyritic sulfur content is also 0.38 percent. The free-swelling index is 9.0 and the calorific value is 14,398 Btu per pound on an as-received basis. This compares with 14,628 Btu per

Table 4. Proximate analyses and sulfur content of Georgia coal, in percent (from Cramer, 1979). Analyses taken exactly from Cramer and do not sum to 100 percent.

Coal Bed	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur
Cliff-------------	1.7	21.1	70.5	8.1	2.0
Dade--------------	2.5	23.9	63.4	11.4	.9
Red Ash-----------	4.8	23.9	70.2	4.4	1.3
Etna--------------	2.6	26.3	66.8	5.3	1.8
Rattlesnake-------	3.8	24.6	65.0	9.3	1.1
Durham 4----------	2.8	20.2	72.1	5.4	.7
Durham 5----------	2.4	20.0	72.5	5.5	.9
A-----------------	2.6	20.2	61.6	18.1	2.1
Sewanee-----------	2.9	18.1	65.6	13.5	1.0

Table 5. Coal analyses from northwest Georgia coal fields (from McCallie, 1904). Values in percent. Analyses reproduced exactly from source and do not sum to 100 percent.

Coal Bed	Source	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Phosphorus	Total
Raccoon	p. 90	1.15	24.85	60.12	13.88	1.51	--	101.51
Dade	p. 89		27.15	61.69	10.59	0.58	--	100.01
Rattlesnake	p. 89		28.64	66.55	4.41	1.04	--	100.64
Unnamed	p. 46	0.60	19.12	76.98	3.30	0.93	--	100.93
Unnamed	p. 42	1.020	20.850	75.980	1.440	0.760	0.007	100.057
Durham	p. 38		16.030	79.100	4.810	0.360	0.007	100.307
Durham	p. 38	0.615	21.011	75.956	1.940	0.047	--	99.567

Table 6. Analyses of coal samples from the Etna and Dade Coal Seams in northwest Georgia (from 1980 Keystone Coal Manual, p. 495).

<u>Etna Coal Bed</u>

Moisture (%)	3.49
Ash (%)	2.45
Volatile matter (%)	28.90
Fixed Carbon (%)	65.16
B.T.U.	14,628
Sulfur (%)	.79
Fusion temperature	2,000°F
F.S.I.	9.0
Grindability index	81.1
Maximum fluidity (DDPM)	13,100
Initial softening temperature (1 DDPM) °C	396
Maximum fluid temperature, °C	453
Temperature range, °C	96
Pyritic sulfur (%)	.41
Sulfate sulfur (%)	.00
Organic sulfur (%)	.38

<u>Dade Coal Bed</u>

Moisture (%)	3.07
Ash (%)	4.70
Volatile matter (%)	27.60
Fixed Carbon (%)	64.63
B.T.U.	14,398
Sulfur (%)	.76
Fusion temperature	2,000°F
F.S.I.	9.0
Grindability index	71.2
Maximum fluidity (DDPM)	21,100
Initial softening temperature (1 DDPM) °C	396
Maximum fluid temperature, °C	453
Solidification temperature, °C	495
Temperature range, °C	99
Pyritic sulfur (%)	.38
Sulfate sulfur (%)	.00
Organic sulfur (%)	.38

Table 7. Proximate analyses of Georgia coal deposits [1](Johnson, 1946; Gildersleeve, 1946; Nelson, 1945).

Coal bed	Mine	Sample No. 2/	Map No.	Thickness Bed	Thickness Sample	H_2O	Volatile matter	Fixed carbon	Ash	Sulfur	B.T.U./ lb.	Comments (by Johnson)
No. 1	Adit	H214	104	26	26	0.9	20.9	66.5	11.7	3.0	13540	
	Strip pit	H216	104	54	54	1.1	19.9	52.2	26.8	1.5	11010	
	Adit	B42737	104	39	33	3.4	19.1	60.5	17.0	1.6	12270	Weathered coal from drift mine.
No. 3	Durham	B42736	105?	69	52	2.7	20.4	73.0	3.9	0.9	14640	Abandoned drift.
	"	B42726	103?	19	19	3.4	20.3	73.7	2.6	0.6	14770	Durham mine, present operations.
	"	B42730	103	64	29	3.1	19.7	72.5	4.7	1.5	14500	Upper bench, Durham mine.
	"	B42731	103	?	23	3.1	19.1	68.3	9.5	0.8	13660	Lower bench.
No. 4	Drill hole	--	DH-2	35	35	1.3	19.5	71.8	7.4	0.5	14260	
4	Gillen No. 3	H212	97		24	2.1	21.9	74.0	2.0	0.6	14830	Near Gillen No. 4
4	Gillen No. 1	H213	98	38	38	1.2	19.7	65.6	13.5	0.5	13310	
4	Drift	B42734	--	41	31	4.4	18.7	66.5	10.4	1.1	13210	Believed to be Gillen No. 1.
4	Durham	B42727	--	20	20	2.9	19.8	72.9	4.4	0.6	14570	
4	Durham	B42728	--	20	20	3.2	19.7	73.2	3.9	0.7	14560	
No. 6	Drift 3/	H208	107	40	40	5.8	18.4	41.8	34.0	0.4	7880	Description fits No. 6 bed. Not located.
No. 6A*	Test pit	B42735	77	39	24	2.6	20.7	54.4	22.3	1.2	11520	Test pit by road near Lula Lake. Not located.
No. 8	Green	B43049	33	28	28	3.2	25.4	65.4	6.0	1.4	14230	
8	Murphy	B43093	27	23	23	2.9	26.8	63.4	6.9	3.2	14040	100 ft. in drift.
8	O'Brien	B42853	1	24	24	3.5	27.2	64.0	5.3	1.0	14250	200 ft. in drift.
No. 9	Ferndale	B43047	30	56	36	4.4	23.2	63.1	9.3	0.9	13240	200 ft. from portal.
9	Dade	B43048	16	52	47	2.8	23.2	60.6	13.4	0.4	12830	50 ft. from portal.
9	Tatum Gulch	B43050	9	47	46	3.3	23.9	59.3	13.5	0.9	12710	500 ft. in from air shaft, New Camp mine.
No.10*	Prospect	H209	75		47	15.4	26.4	51.7	6.5	0.6	9170	
10	Test pit	B42854	--	20	20	4.8	26.5	63.9	4.8	1.5	13930	Listed as Red Ash (?) bed.
No.11	Scratch Ankle Hollow	B43897	--	46	42	3.3	24.3	62.0	10.4	1.5	13200	

1/Hudson, Unpublished report: U.S. Bureau of Mines
Nelson, W.A., Analyses of Tennessee coals (including Georgia): U.S. Bureau of Mines Tech. Paper No. 671, 1945. Samples taken in 1939. All analyses are on an as-received basis.

2/Samples numbers beginning with H are samples by Hudson, courtesy U.S. Bureau of Mines. "B" indicates samples quoted from technical paper No. 671, U.S. Bureau of Mines, 1945.

3/See descriptions of exposures in Johnson (1946).

*Correlation of these coal beds have been changed by present authors from those originally presented by Johnson.

pound for the Aetna coal. The Dade has been mined on Sand Mountain; the Aetna bed has been mined on the north end of Sand Mountain in Georgia and Tennessee.

Current Analytical Results

Previous sections of this bulletin have described the geologic setting, stratigraphy, coal resources, and coal production. This section describes the distribution, occurrence, thickness and stratigraphic position of the coal beds on a bed-by-bed basis; discusses analytical data reported by Johnson (1946), Gildersleeve (1946), and Nelson (1945); presents new analytical data for most of the coal beds; describes the calculated rank for many of the coal beds; discusses the major-, minor-, and trace-element/oxide concentrations in coal samples for many of the coal beds; and compares the analytical results with other eastern U.S. bituminous coal samples.

All tabular geologic and analytical data for the 47 coal samples which we collected and analyzed are presented in Information Circular 75 (Coleman and others, 1985). Also, Information Circular 75 contains maps of the location and elevation of each sample; information about collection sites; and the stratigraphic section, where feasible, at each collection site.

To provide a stratigraphic guide to the location of each sample and to provide a way for correlation between Johnson's (1946) and Culbertson's (1963) stratigraphic frameworks, Figure 7 should be consulted. The coal bed numbers referred to in the following pages are Johnson's.

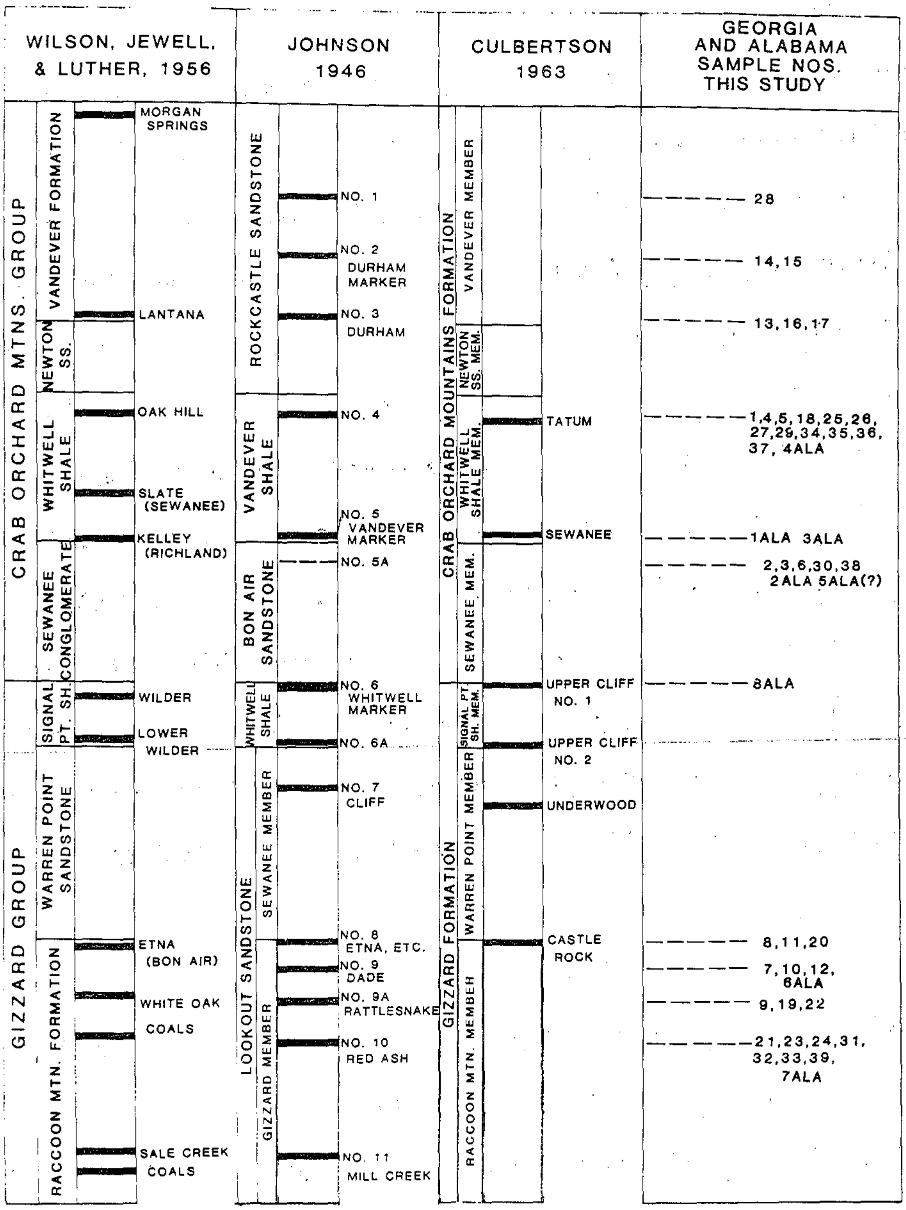

Figure 7. Coal bed correlation diagram depicting nomenclature of Wilson and others (1956), Johnson (1946), and Culbertson (1963). Also shown are Georgia and Alabama coal bed sample numbers related to coal bed nomenclature. (The spelling of Aetna is often given as Etna. Also, it is assumed that a typographical error in Johnson's manuscript changed the Red Ash seam to the Red Seam, and the Mill Creek seam to the Ash Creek seam.)

Coal Bed No. 11

The oldest coal bed recognized so far in the Georgia coal fields is the No. 11. This bed occurs near the bottom of the Raccoon Mountain Member of the Gizzard Formation. It is thought by us to be present on both Sand and Lookout Mountains and may be equivalent to Johnson's Mill Creek coal bed. Johnson (1946) reported that the (Ash) Mill Creek bed was 0 to 10 inches thick and that it and a coal bed, which he designated the Red Seam occurred in shales near the base of his Gizzard Member below the "...saccharoidal sandstone beds." He reported that these two coal beds were "thin and erratic." We observed, but neither collected nor measured, this coal bed.

Nelson (1945) reported an analysis for one sample from this coal bed. This sample was collected from Scratch Ankle Hollow, Sand Mountain, along the Georgia-Tennessee state line. This sample contained 10.4 percent ash; 1.5 percent total sulfur; and had a calorific value of 13,200 Btu per pound. Its calculated rank using the Parr formula (Parr, 1928) is medium-volatile bituminous.

Coal Bed No. 10

Coal bed No. 10 occurs on both Sand and Lookout Mountains in the Raccoon Mountain Member of the Gizzard Formation. We collected eight samples (21GA, 23GA, 24GA, 31GA, 32GA, 33GA, 39GA, and 7ALA) from this bed; all are from Lookout Mountain. This bed may be equivalent to Johnson's Red (Red Ash) seam.

Samples 23GA and 32GA are not complete channel samples. Sample 23GA is from the upper 19 inches of the bed with a total thickness of 21 inches; sample 32GA represents the upper 31 inches of a bed with a total thickness of 45 inches. However, 33GA is from the same location as 32GA and represents the entire 45 inches of the No. 10 coal bed at this location.

The roof rock for samples 21GA, 24GA, 32GA, 33GA, and 39GA is sandstone, conglomeratic sandstone or siltstone; the floor rock is underclay. Samples 23GA, 31GA, and 7ALA have a shale roof and an underclay floor rock.

Johnson (1946) reported analytical results from one sample from this coal bed (Table 7). However, based on our studies we believe that Johnson's sample number H209 is equivalent to the No. 10 coal bed and we, thus, include its analysis under coal bed No. 10 in table 7. The ash content for the two samples ranges from 4.8 to 6.5 percent; total sulfur from 0.6 to 1.5 percent; and calorific value from 9,170 to 13,930 Btu per pound.

We report modern chemical data from eight samples. These data show the following composition ranges and geometric means (in parentheses):

Ash	12.3 to 34.2 (17.8) percent
Total Sulfur	0.7 to 5.3 (1.44) percent
Pyritic Sulfur	0.05 to 3.5 (0.36) percent
Organic Sulfur	0.51 to 1.39 (0.73) percent
Free-Swelling Index	1.0 to 8.5 (4.0)
Calorific Value	9,404 to 13,270 (11,818) Btu per pound

Rank calculations reveal that all samples that we collected are medium-volatile bituminous. The calculated rank for the two samples reported by Johnson (1946) from this coal bed indicates that the one sample from Sand Mountain is medium-volatile bituminous; the other, from a coal prospect on Lookout Mountain, is high-volatile A bituminous.

Coal Bed No. 9A

This coal bed occurs in the Raccoon Mountain Member of the Gizzard Formation. Based on our field studies, we interpret this coal bed to be equivalent to the Rattlesnake coal bed.

Gildersleeve (1946) reported that the Rattlesnake coal bed contains a shale parting; he stated that the total thickness of the coal bed averages about 56 inches at the Ferndale mine. Gildersleeve (1946) wrote that because of rapid changes in the thickness and the character of the sandstone top, this bed may change in thickness over a short distance.

We collected three samples of the No. 9A coal bed: 9GA, 19GA, and 22GA, all from Sand Mountain. The coal ranges from 22 to 54 inches in thickness at these sites . Sample number 9GA is a bench sample from the upper 20 inches of coal where the bed is 54 inches thick.

At sampling sites 9GA and 22GA, this coal has a shale roof and shale and underclay floor rock. At site 19GA the coal is overlain by interlayered siltstone and sandstone with a shale floor.

Analytical data from the current study yield the following compositional ranges (geometric mean in parentheses).

Ash	7.8 to 31.3 (18.5) percent
Total Sulfur	0.5 to 0.9 (0.71) percent
Pyritic Sulfur	0.08 to 0.21 (0.13) percent
Organic Sulfur	0.3 to 0.79 (0.55) percent
Free-Swelling Index	5.0 to 6.0 (5.5)
Calorific Value	9,930 to 11,650 (10,750) Btu per pound

Calculation of the coal rank reveals that all samples are medium-volatile bituminous.

Coal Bed No. 9

Johnson (1946) designated the No. 9 coal bed as being equivalent to what was locally known as the Dade, Rattlesnake?, and Bluff coal beds. It is in the upper part of the Raccoon Mountain Member of the Gizzard Formation.

Johnson (1946) reported that coal lenses, locally reaching a thickness of 72 inches, were present in this coal horizon. He stated that the names Dade and Rattlesnake were applied to locations on Sand Mountain and that the Bluff name was applicable on Lookout Mountain. Johnson described this coal bed as generally crushed and dirty and reported that the shale roof made it difficult to mine. He further noted that the tendency of the coal bed to swell and pinch in short distances made it expensive to develop. Johnson believed that this coal had been mined out.

Gildersleeve (1946) suggested that the Dade (No. 9) coal bed has its greatest development in the area east and southeast of Cole City, Dade County, Georgia. Its thickness is variable, but the bed is extensive and more persistent than any of the lower coal beds. He stated that the coal ranges from 36 to 40 inches in thickness and has a shale top and a smooth shale bottom. There is a fire clay parting near the middle of the bed.

We collected coal from four sites (7GA, 10GA, 12GA, and 6ALA). Sample 7GA is a composite sample from a coal test pit. Sample 10GA is a channel sample of the upper 41 inches where the coal is 48 inches thick. Samples 7GA, 10GA, and 12GA are all are from Sand Mountain and sample 6ALA is from Lookout Mountain.

The thickness of this coal at the sampling sites ranges from 17 to 48 inches. Three of the samples (7GA, 12GA, and 6ALA) are from sampling sites where the roof rock is shale; samples 7GA and 6ALA have sandstone floor rock; sample 12GA has an underclay floor rock. Sample 10GA has interlayered shale and siltstone for both the roof and floor rock.

Analytical results from three samples of the No. 9 coal bed are reported by Johnson (1946). The ash content ranges from 9.3 to 13.5 percent; total sulfur content is 0.4 to 0.9 percent; and calorific value is 12,710 to 13,240 Btu per pound.

Chemical data for our four samples of the No. 9 coal bed reveal the following ranges and geometric means (in parentheses).

Ash	2.5 to 11.7 (7.2) percent
Total Sulfur	0.5 to 0.9 (0.63) percent
Pyritic Sulfur	0.04 to 0.67 (0.12) percent
Organic Sulfur	0.25 to 0.50 (0.40) percent
Free-Swelling Index	7.5 to 9.0 (8.5)
Calorific Value	11,150 to 14,960 (13,275) Btu per pound

The calculated rank for all samples collected from this coal bed during the current study is medium-volatile bituminous. The calculated rank for the three samples reported in Table 7, all from Sand Mountain, are also medium-volatile bituminous.

Coal Bed No. 8

This coal bed is at the top of the Raccoon Mountain member of the Gizzard Formation. Johnson notes that this coal bed is known locally as the Etna and that in various places it is designated as the

Castlerock, Raccoon, Bluff, and Lower Cliff. Johnson described this bed as reaching a thickness of 48 inches, but being discontinuous and lenticular. Because of its lenticular nature, the Castlerock, Raccoon, Bluff, and Lower Cliff coal beds may not have formed at the same time and they may represent a series of individual coal beds in a very narrow stratigraphic interval.

Gildersleeve (1946) states that the Etna (Aetna) coal bed is best developed in the vicinity of Whiteside, Tennessee, and Nickajack Cove in northwest Dade County, Georgia. He believed that this bed was one of the most persistent ones in the area and that it usually crops out near the bluff line on both Sand and Lookout Mountains. The coal thickness averages about 24 inches, and ranges in thickness from just a few inches to 48 inches.

We collected three samples, 8GA, 11GA, and 20GA, of the No. 8 coal bed from Sand Mountain. Sample 8GA is a composite sample from a coal test pit; the other samples are channel samples. At the collection sites, this bed ranges from 18 to 30 inches thick. The roof rock at the collection sites is either sandstone or conglomeratic sandstone. The floor rock is either interlayered shale and siltstone or underclay.

Chemical analyses from three samples from the No. 8 coal are reported by Johnson (1946) and are shown in Table 7. These analyses reveal that this coal has a range in ash content from 5.3 to 6.9 percent; total sulfur content from 1.0 to 3.2 percent; and calorific value from 14,040 to 14,250 Btu per pound.

During the present study three samples were analyzed from this coal. The analytical results are given below with the range in chemical and physical properties followed by the geometric mean in parentheses.

Ash	5.8 to 16.4 (8.97) percent
Total Sulfur	0.5 to 4.6 (1.92) percent
Pyritic Sulfur	0.11 to 4.02 (1.07) percent
Organic Sulfur	0.32 to 0.61 (0.43) percent
Free-Swelling Index	2.0 to 9.0 (5.5)
Calorific Value	12,190 to 14,270 (13,420) Btu per pound

Calculation of rank reveals that the samples are medium-volatile bituminous.

Coal Bed No. 7

This coal bed is in the upper part of the Warren Point Member of the Gizzard Formation and was called the Underwood by Culbertson (1963). Johnson (1946) placed the No. 7 coal bed in the Sewanee Member of the Lookout Sandstone Formation and designated it the Cliff coal seam. It is in association with thin shales enclosed in massive blanket sandstones and conglomeratic sandstones. We neither collected the coal nor measured it because the occurrence of the coal is very sporadic.

Coal Bed No. 6A

This coal bed occurs near the base of the Signal Point Shale Member of the Gizzard Formation. The coal is associated with shales and is lenticular and very sporadic. We correlate the 6A bed with Culbertson's Upper Cliff No. 2 coal bed on the basis of our field studies. We neither collected nor measured the coal. This coal bed occurs only on Lookout Mountain.

Johnson (1946) reported that his sample number B42735 (Table 7) was from a test pit in the No. 6 coal. We have concluded that this sample and the test pit are in the No. 6A coal bed and have shown it this way in Table 7. The ash content of the sample is 22.3 percent; total sulfur content is 1.2 percent; and heating value is 11,520 Btu per pound.

A coal rank calculation, using the Parr Formula, on the analysis given by Johnson reveals that the sample is medium-volatile bituminous; the sample was collected on Lookout Mountain.

Coal Bed No. 6

The No. 6 coal bed occurs at the top of the Signal Point Shale Member of the Gizzard Formation. Culbertson (1963) referred to this bed as the Upper Cliff No. 1. Locally this coal bed has been designated as the Whitwell Marker. Johnson (1946) found that this coal bed ranges from 6 to 10 inches in thickness.

During the present study we collected one sample (8ALA) of this coal on Lookout Mountain. At the collection site, the bed is 24 inches thick. The roof rock is sandstone and the floor rock is shale.

Johnson provided chemical analysis for one sample from the No. 6 coal bed from Lookout Mountain (Table 7, Sample No. H208). This sample, from a mine drift, has 34.0 percent ash; 0.4 percent total sulfur; and a heating value of 7,880 Btu per pound.

Analytical results for our sample are given below:

Ash	3.7 percent
Total Sulfur	1.3 percent
Pyritic Sulfur	0.76 percent
Organic Sulfur	0.40 percent

Free-Swelling Index	8.0
Calorific Value	14,540 Btu per pound

The calculated rank of this sample is low-volatile bituminous. The analysis of the sample collected by Johnson indicates a calculated rank of medium-volatile bituminous.

Coal Bed No. 5A

This coal bed is in the upper part of the Sewanee Member of the Crab Orchard Mountains Formation. Seven samples (2GA, 3GA, 6GA, 30GA, 38GA, 2ALA, and 5ALA) were collected and analyzed from this coal bed; all were collected from Lookout Mountain. At the collection sites the coal bed ranges from 7 to 22 inches in thickness. Samples 2GA, 6GA, 38GA, and 2ALA have shale roofs; they have both shale and underclay for floor rock. Samples 3GA, 30GA, and 5ALA have sandstone or conglomeratic sandstone roofs; both underclay and shale occur as floor rock.

Analytical results for the seven coal samples from No. 5A coal bed are given below as the range and geometeric mean (in parentheses).

Ash	5.3 to 12.6 (7.2) percent
Total Sulfur	0.5 to 2.5 (0.99) percent
Pyritic Sulfur	0.07 to 2.14 (0.32) percent
Organic Sulfur	0.33 to 0.60 (0.47) percent
Free-Swelling Index	1.0 to 9.0 (5.0)
Calorific Value	11,200 to 14,530 (13,520) Btu per pound

Calculated rank is medium-volatile bituminous.

Coal Bed No. 5

This coal bed is located near the bottom of the Whitwell Shale Member of the Crab Orchard Mountains Formation. Johnson (1946) called it the Vandever Marker because of its widespread distribution and Culbertson (1963) called it the Sewanee. Johnson believed that this coal bed was an excellent stratigraphic marker but that it is never thicker than 8 inches and is too thin to be of economic interest.

In the present study this coal bed is represented by two samples, 1ALA and 3ALA, which were collected on Lookout Mountain. The thickness of the bed at the sampling sites ranges from 9 to 10 inches. The roof and floor rocks are shale.

Chemical data from analyses of the two samples reveal the following ranges and geometric means (in parentheses).

Ash	2.0 to 3.8 (2.76) percent
Total Sulfur	0.6 to 0.90 (0.73) percent
Pyritic Sulfur	0.2 to 0.36 (0.27) percent
Organic Sulfur	0.41 to 0.49 (0.45) percent
Free-Swelling Index	4.5 to 8.5 (6.0)
Calorific Value	14,850 to 15,160 (15,000) Btu per pound

The calculated rank of these two samples is low-volatile bituminous.

Coal Bed No. 4

This coal bed is in the upper part of the Whitwell Shale Member of the Crab Orchard Mountains Formation and was called Tatum by Culbertson (1963). Johnson indicated that the No. 4 bed was present in two benches separated locally by shale and sandy shale ranging in thickness from a few inches to several tens of feet.

We collected thirteen coal samples (1GA, 4GA, 5GA, 18GA, 25GA, 26GA, 27GA, 29GA, 34GA, 35GA, 36GA, 37GA, and 4ALA) of this coal bed on Lookout Mountain. These samples are from locations where the coal is 9 to 23 inches thick. Sample 36GA represents the upper 13 inches of an 17-1/2 inches thick bed; sample 37 GA represents the entire 17-1/2 inches of this bed at this collection site.

We found the roof floor lithologies to be quite variable for samples of the No. 4 coal. For example, sample 26GA has a sandstone roof and underclay floor. Samples 1GA, 29GA, 34GA, 36GA, and 37GA have interlayered shale, siltstone, and sandstone roof rocks; the floor rock for these sites is mostly underclay. Sample numbers 4GA, 5GA, 18GA, 25GA, 27GA, 35GA, and 4ALA have shale for roof rock and underclay for a floor rock.

Table 7 lists the chemical analyses for six coal samples reported by Johnson (1946), Gildersleeve (1946), or Nelson (1945) for the No. 4 coal bed. The range in ash content is from 2.0 to 13.5 percent; total sulfur content is from 0.5 to 1.1 percent; and calorific value is from 13,210 to 14,830 Btu per pound.

Chemical data for our thirteen samples of the No. 4 coal are given below. The geometric means are in parentheses. Ultimate and proximate analyses were not performed on two of the samples (4GA and 36GA); however, U.S. Geological Survey analyses were made on all samples.

Ash	1.6 to 24.0 (4.17) percent
Total Sulfur	0.49 to 1.07 (0.67) percent
Pyritic Sulfur	0.01 to 0.41 (0.12) percent
Organic Sulfur	0.29 to 0.72 (0.44) percent

Free-Swelling Index	1.0 to 9.0 (6.0)
Calorific Value	11,340 to 15,190 (14,320) Btu per pound

Five analyses presented by Johnson (1946), Gildersleeve (1946) and Nelson (1945) for six samples from Lookout Mountain yield a calculated rank of low-volatile bituminous: one sample (H212) is medium-volatile bituminous.

All of our samples have a calculated rank of low-volatile bituminous, except 25GA; its calculated rank is medium-volatile bituminous.

Coal Bed No. 3

This coal bed is located near the bottom of the Vandever Member of the Crab Orchard Mountains Formation and in Georgia is found only in the vicinity of the Durham Mines on Lookout Mountain. Johnson stated that the No. 3 bed was the thickest coal bed on Lookout Mountain; that it had been the most consistent producer in northwest Georgia coal fields; and that it consisted of two coal benches separated by a shale parting.

We collected three coal samples of the No. 3 coal (13GA, 16GA, and 17GA) from Lookout Mountain. The range in thickness of the coal bed at the collection sites is from 13 1/2 to 22 inches. Both the roof and floor rock are shale except in one area where the floor rock is underclay.

Chemical data from Johnson (1946) for four samples from the No. 3 bed are shown in Table 7. These data show that the ash content ranges from 2.6 to 9.5 percent; total sulfur content from 0.6 to 1.5 percent; and calorific value from 13,660 to 14,770 Btu per pound.

Analytical data from three samples collected during the present study are given below. The range of values is followed by the geometric mean (in parentheses).

Ash	2.2 to 7.4 (3.70) percent
Total Sulfur	0.60 to 0.80 (0.70) percent
Pyritic Sulfur	0.09 to 0.23 (0.15) percent
Organic Sulfur	0.49 to 0.59 (0.52) percent
Free-Swelling Index	7.0 to 9.0 (8.0)
Calorific Value	14,150 to 15,170 (14,740) Btu per pound

Samples 13GA and 16GA have a calculated rank of low-volatile bituminous. The rank of the three samples presented by Johnson also is low-volatile bituminous.

Coal Bed No. 2

The No. 2 coal bed occurs approximately 56 feet above the No. 3 coal bed in the lower part of the Vandever Member of the Crab Orchard Mountains Formation. Johnson found this coal bed to be thin, dirty, erratic in occurrence, and generally less than one foot thick.

We collected two samples (14GA and 15GA) from this coal bed on Lookout Mountain. These samples are from the same site. The first sample, 14GA, represents the upper 9 inches of the No. 2 coal bed; the second sample, 15GA, is from the lower 6 inches of the bed; a 1 inch shale parting separates the samples. The total bed thickness, including the parting, is 16 inches. The floor and roof rocks are shale.

The range in chemical data and the geometric mean (in parentheses) for the two samples is given below. The two samples taken together represent the composite chemical composition of the No. 2 coal bed.

Ash	11.3 to 21.8 (15.7) percent
Total Sulfur	3.9 to 4.4 (4.14) percent
Pyritic Sulfur	3.38 to 3.39 (3.38) percent
Organic Sulfur	0.34 to 0.86 (0.54) percent
Free-Swelling Index	5.5 to 7.5 (6.5)
Calorific Value	11,350 to 13,140 (12,210) Btu per pound

Both samples have a calculated rank of low-volatile bituminous.

Coal Bed No. 1

Johnson (1946) stated that the No. 1 coal bed was approximately 60 feet above the No. 2 coal bed near the middle of the Vandever Member of the Crab Orchard Mountains Formation. Johnson found that the No. 1 coal bed is limited to the small horseshoe-shaped area on Round Mountain near Durham. He suggested that the coal is thin and generally is 18 to 20 inches thick; its maximum thickness is about 30 inches.

We collected one sample of this coal (28GA) on Lookout Mountain. The coal there is 25 inches thick; its roof rock is interlayered shale and siltstone; the floor rock is shale.

Johnson (Table 7) presents the analyses for three samples collected from this coal bed. These analyses reveal that the ash content ranges from 11.7 to 26.8 percent; total sulfur ranges from 1.5 to 3.0 percent; and calorific value ranges from 11,010 to 13,540 Btu per pound.

Analysis of our sample yielded the following compositional data.

Ash	9.8 percent
Total Sulfur	1.5 percent

Pyritic Sulfur	0.06 percent
Organic Sulfur	1.25 percent
Free-Swelling Index	9.0
Calorific Value	13,790 Btu per pound

The calculated rank for the single sample is medium-volatile bituminous. All of the samples collected and reported by Johnson indicate a calculated rank of medium-volatile bituminous.

Comparison of Quality of Sand and Lookout Mountains Coal with Other Coal

Goldschmidt (1954) characterized the behavior or geochemical affinity for elements into various subdivisions such as lithophil, chalcophil, and biophil. Lithophil elements are characteristically associated with the silicates (clays, feldspars, micas, quartz), carbonates, and various oxide minerals. For a complete listing and discussion of minerals identified in coal, the reader should consult O'Gorman and Walker (1972), Mackowsky (1982), Finkelman (1980), or Davis and others (1984).

Silicate, carbonate, and oxide minerals may occur in coal as disseminated grains, in layers, as nodules, or as coatings along cleat surfaces. Their origin may be detrital, diagenetic, post-diagenetic alteration, or simply epigenetic. The same occurrence and origin relationships exist for the chalcophil elements.

It is evident that any comparisons or discussion of geochemical trends, relative quality, and anomalous values are dependent on the representative nature of the coal samples, that is, the number, distribution, sampling methods, method of analysis, and quality of the analysis. For many of the coal beds only 1 or 2 samples were collected, and for these only preliminary and general conclusions can be drawn. The following discussions therefore are tentative; they offer a guide to Georgia coal resource characterization and to further research. In this bulletin, we use Goldschmidt's geochemical classification scheme to better understand the geologic and geochemical distribution and concentration of elements in coal at Sand and Lookout Mountains.

Table 8 lists the geometric mean for the lithophil elements as oxides in coal samples from Sand and Lookout Mountains. Also listed for discussion and comparison purposes are the geometric means for 968 bituminous coal samples from the eastern United States (Zubovic and others, 1980), 27 samples from Tennessee (Zubovic and others, 1979), and 20 samples from Alabama (Zubovic and others, 1979). Examination of the concentration values in this table reveals little difference among the SiO_2, Al_2O_3, MgO, K_2O, Fe_2O_3, MnO, and TiO_2 values. There are differences in the CaO and Na_2O, and P_2O_5 contents for some of the samples, especially between those of this study and Alabama. The CaO concentration in samples of this study and Tennessee samples is notably higher than for bituminous coal samples from the eastern United States and those samples from Alabama.

Higher CaO values are present in the No. 6, No. 5, No. 4, and No. 3 coal beds. The Fe_2O_3 content for coal beds No. 8, No. 6, and No. 2 is also higher than the overall geometric mean for the Sand and Lookout Mountains samples. The P_2O_5 concentration for the No. 9, No. 6, No. 2, and No. 1 coal beds is unusually high when compared with the overall geometric mean for the Sand and Lookout Mountains samples.

Table 8. Geometric means for lithophil elements (as oxides) in bituminous coal samples from Sand and Lookout Mountains, eastern U.S. , Tennessee, and Alabama. All values in weight percent of coal-ash. Some values have been rounded.

Oxide	Sand and Lookout Mountains 47 samples	968 samples Eastern U.S. (Zubovic and others, 1980)	27 samples Tennessee (Zubovic and others, 1979)	20 samples Alabama (Zubovic and others, 1979)
SiO_2	38.	41.	39.	48.
Al_2O_3	24.	23.	25.	30.
CaO	1.61	1.2	2.8	0.97
MgO	0.92	0.76	0.71	0.83
Na_2O	0.24	0.38	0.28	0.46
K_2O	1.77	1.6	1.7	1.7
Fe_2O_3	14.	12.	12.	11.
MnO	0.02	0.02	0.02	0.01
TiO_2	0.99	1.1	1.2	1.5
P_2O_5	0.21	0.03	0.43	0.51

Table 9 lists the mean content of minor and trace lithophil elements, on a whole-coal and as-received basis. Examination of this table provides the following relationships when the geometric means of bituminous coal samples from Sand and Lookout Mountains, eastern United States, Tennessee, and Alabama are compared:

* Beryllium, cerium, chrominum, europium, lanthanum, scandium, samerium, terbium, and yttrium have about the same concentrations in Sand and Lookout Mountains coal as in the eastern United States, Tennessee, and Alabama coal.
* The concentration of hafnium in Sand and Lookout Mountains coal is about the same as that in eastern United States bituminous and Tennessee coal. Hafnium concentration in the Alabama coal is about twice as much as in Sand and Lookout Mountains coal.
* Strontium is about three times higher in the Sand and Lookout Mountains samples than in eastern United States samples.
* Barium, uranium, and vanadium in the Sand and Lookout Mountains coal is about the same as in eastern United States and Tennessee samples.
* Cesium and lithium concentrations in the Sand and Lookout Mountains samples are about the same as in eastern United States samples; boron is about two times lower in the Sand and Lookout Mountains coal when compared to eastern United States coal samples.
* Cesium and lithium concentrations in Sand and Lookout Mountains samples are twice as high as in the Tennessee samples; neodymium is about the same in both the Sand and

Table 9. Geometric means for lithophil minor- and trace-elements in bituminous coal samples from Sand and Lookout Mountains, eastern U.S., Tennessee, and Alabama. All values in parts-per-million on whole-coal, as-received basis. Some values have been rounded.

Element	Sand and Lookout Mountains 47 samples	968 samples Eastern U.S. (Zubovic and others, 1980)	27 samples Tennessee (Zubovic and others, 1979)	20 samples Alabama (Zubovic and others, 1979)
B	8.	22.	35.	30.
Ba	50.	57.	36.	160.
Be	1.5	2.2	1.1	2.4
Ce	17.	12.	11.	25.
Cr	12.	14.	7.4	19.
Cs	0.8	0.64	0.42	1.4
Eu	0.35	0.24	0.22	0.46
Ge	1.3	0.83	0.86	2.6
Hf	0.5	0.42	0.47	1.1
La	9.	6.8	5.6	14.
Li	14.	14.	6.5	35.
Nd	9.	1.9	5.7	18.
Rb	19.	-	-	-
Sc	2.9	3.1	2.	4.6
Sm	1.6	0.94	1.1	2.1
Sr	164.	62.	47.	150.
Tb	0.28	0.20	0.18	0.31
Th	1.7	-	-	-
U	0.6	1.1	0.78	1.8
V	15.	18.	9.3	29.
W	0.09	-	-	-
Y	7.	7.5	5.	11.
Zr	15.	22.	9.9	49.

Lookout Mountains and Tennessee samples; and barium is three times lower in the Sand and Lookout Mountains samples than in Tennessee coal.

* Neodymium, cesium, germanium, lithium, vanadium, and uranium are two to three times lower in the Sand and Lookout Mountains sample than in Alabama samples.
* Strontium concentration is about the same in both the Alabama and the Sand and Lookout Mountains samples.
* Boron is four times lower in the Sand and Lookout Mountains samples than in Tennessee and Alabama samples.
* Zirconium concentration is about the same in Sand and Lookout Mountains and eastern United States samples; Tennessee coal contains slightly less than the Sand and Lookout Mountains coal; in Alabama the zirconium concentration is three times greater than in Sand and Lookout Mountains samples.

Table 10 lists the geometric means of some chalcophil elements. These elements normally occur in their greatest concentrations in sulfide minerals such as pyrite, marcasite, sphalerite, greigite, galena, chalcopyrite, and pyrrhotite; all these have been previously identified in coal. Examination of Table 10 reveals the following differences and similarities between the Sand and Lookout Mountains coal and those geometric means of samples of eastern United States, Tennessee, and Alabama coal (Zubovic and others, 1979):

* The concentration of silver, cobalt, copper, mercury, nickel, lead, and selenium in the Sand and Lookout Mountains samples is about the same as in eastern United States, Tennessee, and Alabama coal samples. Copper and

Table 10. Geometric means for chalcophil trace elements in bituminous coal samples from Sand and Lookout Mountains, eastern U.S., Tennessee, and Alabama. All values in part-per-million, whole-coal, as-received basis. Some values have been rounded.

Element	Sand and Lookout Mountains 47 samples	968 samples Eastern U.S. (Zubovic and others, 1980)	27 samples Tennessee (Zubovic and others, 1979)	20 samples Alabama (Zubovic and others, 1979)
Ag	0.05	0.02	0.03	0.08
As	13.	8.	7.4	17.
Cd	0.05	0.09	0.05	0.07
Co	8.	5.2	4.4	5.5
Cu	14.	14.	13.	21.
Ga	3.2	5.2	2.	6.9
Hg	0.14	0.10	0.08	0.18
Ni	15.	12.	6.9	11.
Pb	6.	6.8	4.	5.2
Sb	0.78	0.17	0.48	1.1
Se	2.3	2.9	2.	3.4
Zn	12.	13.	7.5	7.6

mercury contents are slightly higher in the Alabama samples than Sand and Lookout Mountains samples and the Tennessee samples contain slightly less.

* Arsenic concentration of the Sand and Lookout Mountains samples is slightly higher than in eastern United States and Tennessee samples and are about the same as Alabama samples.
* Cadmium content of Sand and Lookout Mountains, Tennessee, and Alabama samples is about the same; the eastern United States coal samples contain about twice as much cadmium as the Sand and Lookout Mountains samples.
* Gallium concentration is about the same in Sand and Lookout Mountains, Tennessee, and eastern United States coal samples; Sand and Lookout Mountains coal contain two times less gallium than does Alabama coal.
* Antimony content in Sand and Lookout Mountains coal is about four times greater than in eastern United States coal; about twice as much as Tennessee coal; and slightly less than Alabama coal.
* Zinc concentration in Sand and Lookout Mountains coal is about the same as in eastern United States coal; zinc in Tennessee and Alabama coal is slightly less than in Sand and Lookout Mountains coal.

A review of the tables in Information Circular 75 (Coleman and others, 1985) reveals what appear to be anomalously higher geometric mean concentrations, when compared to all samples from Sand and Lookout Mountains, of some lithophil and chalcophil elements, sulfur species, and ash contents for the following coal beds.

No. 1	SiO_2, CaO, MgO, P_2O_5, boron, barium, bromine, fluorine, strontium, zirconium, organic sulfur
No. 2	P_2O_5, silver, arsenic, barium, cadmium, copper, mercury, molybdenum, antimony, selenium, zinc, pyritic sulfur, and total sulfur
No. 4	CaO, chlorine
No. 5	CaO, chlorine
No. 5A	Molybdenum
No. 6	CaO, Fe_2O_3, chlorine and molybdenum
No. 8	Fe_2O_3, chlorine, arsenic, mercury, lead and strontium
No. 9A	Boron, barium, cadmium, cesium, fluorine, mercury, lanthanum, lithium, niobium, neodymium nickel, lead, rubidium, tin, tantalum, terbium, vanadium, tungsten, zinc, zirconium, ash, and organic sulfur
No.10	SiO_2, arsenic, boron, bromine, cerium, chromium, cesium, gallium, hafnium, mercury, lanthanum, lithium, niobium, lead, scandium, selenium, tin, tantalum, thorium, uranium, vanadium, zirconium

As more samples are collected and analyzed from these coal beds the anomalous chemical values are likely to change or disappear.

Coal Utilization Parameters

During the utilization of coal there are particular coal quality characteristics that are important. These include the alkali element content, concentration of chlorine, phosphorus, and sulfur,

No. 1	SiO_2, CaO, MgO, P_2O_5, boron, barium, bromine, fluorine, strontium, zirconium, organic sulfur
No. 2	P_2O_5, silver, arsenic, barium, cadmium, copper, mercury, molybdenum, antimony, selenium, zinc, pyritic sulfur, and total sulfur
No. 4	CaO, chlorine
No. 5	CaO, chlorine
No. 5A	Molybdenum
No. 6	CaO, Fe_2O_3, chlorine and molybdenum
No. 8	Fe_2O_3, chlorine, arsenic, mercury, lead, and strontium
No. 9A	Boron, barium, cadmium, cesium, fluorine, mercury, lanthanum, lithium, niobium, neodymium nickel, lead, rubidium, tin, tantalum, terbium, vanadium, tungsten, zinc, zirconium, ash, and organic sulfur
No. 10	SiO_2, arsenic, boron, bromine, cerium, chromium, cesium, gallium, hafnium, mercury, lanthanum, lithium, niobium, lead, scandium, selenium, tin, tantalum, thorium, uranium, vanadium, zirconium

As more samples are collected and analyzed from these coal beds, the anomalous chemical values are likely to change or disappear.

Coal Utilization Parameters

During the utilization of coal there are particular coal quality characteristics that are important. These include the alkali element content, concentrations of chlorine, phosphorus, and sulfur, forms-of-sulfur, ash content, calorific value, ash-fusion temperatures, free-swelling index, and the rank of the coal. In many cases these coal quality properties are mutually dependent on each other. In some cases their importance is governed by the planned end use of the coal and whether cleaning and blending are contemplated prior to use.

A voluminous literature exists on the role played by the alkali elements in coal ash in power plant combustion chambers. This literature will not be reviewed. Sodium and potassium are reported to cause fouling in power plant boilers and, if their concentration exceeds 6 percent, they contribute to slagging problems in the furnaces (Bryers and Taylor, 1976). The total alkali element concentration in the Sand and Lookout Mountains samples is about 2 percent. This is comparable to the values in samples from adjacent states and the eastern United States (Table 8), and it is much less than 6 percent.

Both chlorine and phosphorus have been reported to contribute to boiler deposits and corrosion associated with power plant combustion (Ely and Barnhardt, 1963; Crossley, 1952; Kear and Menzies, 1952). Crossley (1948) stated that coal containing less than 0.15 percent chlorine could be used with little combustion difficulty. Gluskoter (1967), in studies of the Illinois Basin Herrin (No. 6) coal bed, reported chlorine values which range from 0.00 to 0.65 percent. The geometric mean value for chlorine in the Sand and Lookout Mountains samples, on whole-coal basis, is 0.07 percent, much less than 0.15 percent given by Crossley. For phosphorus the geometric mean value, on coal-ash basis, is 0.21 percent in the Sand and Lookout Mountains samples.

Sand and Lookout Mountains coal is low-sulfur as indicated by the geometric mean value (0.98) for all samples studied in this investigation (Table 11). The total sulfur content ranges from 0.50 to 5.30 percent. This total sulfur content for Sand and Lookout Mountains coal is less than the total sulfur content for the eastern United States, Tennessee, and Alabama coal samples (Table 11).

The pyritic and organic sulfur contents of Sand and Lookout Mountains coal are also low. The geometric mean of pyritic sulfur content is 0.25 percent. When compared with other samples, only the pyritic sulfur content in Tennessee coal is slightly lower. Organic sulfur in Sand and Lookout Mountains coal is 0.51 percent and is less than in the other similar samples (Table 11).

The Sand and Lookout Mountains coal samples are characterized by a low ash content; the geometric mean is 7.53 percent. This is much lower than the eastern United States and Alabama coal samples. Tennessee coal contains slightly less ash. This low ash content is important because it determines the value of the coal and the selection of pulverizing and cleaning equipment.

The geometric mean calorific value for Sand and Lookout Mountains coal is 13,260 Btu per pound. Only the calorific value of some Tennessee samples is higher. There are some Sand and Lookout Mountains samples which contain more than 15,000 Btu per pound on an as-received basis. Those samples that have relatively low Btu per pound may represent samples collected in less than ideal circumstances.

Ash-fusion temperatures are important in assessing the clinkering tendencies of the ash of the coal. The ash-fusion temperature of the Sand and Lookout Mountains coal samples are similar to those of other

Table 11. Comparison of important coal-quality parameters (geometric mean)in coal utilization for bituminous coal samples from Sand and Lookout Mountains, eastern U.S., Tennessee, and Alabama. Values are on whole-coal, as received basis.

Coal-quality parameter	Sand and Lookout Mountains 45 samples	850 samples Eastern U.S. (Zubovic and others, 1980)	27 samples Tennessee (Zubovic and others, 1979)	20 samples Alabama (Zubovic and others, 1979)
Sulfur (percent)				
Total	0.98	1.6	1.2	1.4
Pyritic	0.25	0.71	0.24	0.66
Organic	0.51	0.79	0.73	0.67
Ash percent	7.53	9.3	5.2	11.8
Calorific value (Btu/pound)	13,260	12,560	13,510	12,660
Ash Fusion Temperatures:				
Deformation	1302°C	1240°C	1330°C	1260°C
Softening	1353	1270	1380	1340
Fluid	1380	1370	1420	1410
Free Swelling	6.0	4.5	5.0	5.0

Appalachian and eastern United States coal samples. These temperatures are listed for specific coal beds in Information Circular 75 (Coleman and others, 1985).

The free-swelling index of Sand and Lookout Mountains coal samples is about 6.0 (geometric mean). The range is 1.0 to 9.0. These values indicate that the Sand and Lookout Mountains samples have some of the highest free-swelling index values of any coal in the eastern United States, and thus are some of the highest quality metallurgical or metallurgical blend coals in the United States. This is especially relevant when the low-ash and low-sulfur contents are considered.

Table 12 shows the calculated rank of each coal bed on Sand and Lookout Mountains. Data are derived from our study and from Johnson (1946), Gildersleeve (1946), and Nelson (1945). This table reveals that all samples from Sand Mountain have a calculated coal rank of medium-volatile bituminous. Samples collected and analyzed from Lookout Mountain show that the youngest coal bed, No. 1, is medium-volatile bituminous in rank. Data from this study and from Johnson (1946), Gildersleeve (1946), and Nelson (1945) reveal that the predominant rank of the underlying No. 2, No. 3, No. 4, and No. 5 coal beds is low-volatile bituminous. The rank changes to medium-volatile bituminous in No. 5A and then changes back to low-volatile bituminous in our one sample of the No. 6 coal bed. Johnson, Gildersleeve, and Nelson's rank for the No. 6 is medium-volatile bituminous.

The rank for coal bed (No. 10) on Lookout Mountain is medium-volatile bituminous. This rank is substantiated by our study and by analyses from the previous workers. We conclude that the rank changes with stratigraphic (time) position within the coal-bearing

Table 12. Calculated rank of coal beds on Lookout and Sand Mountains, by coal bed. Numbers in parenthesis are the number of samples having that rank. Parr formula used in calculation. Abbreviations are Lvb = low-volatile bituminous, Mvb = medium-volatile bituminous, and HvAb = high-volatile A bituminous.

Coal Bed No.	Lookout Mountain: This Study	Lookout Mountain: Johnson, Gildersleeve, and Nelson	Sand Mountain: This Study	Sand Mountain: Johnson Gildersleeve, and Nelson
1	Mvb(1)	Mvb(3)	--	--
2	Lvb(1)	--	--	--
3	Lvb(2) Mvb(1)	Lvb(4)	--	--
4	Lvb(10) Mvb(1)	Lvb(5) Mvb(1)	--	--
5	Lvb(2)	--	--	--
5A	Mvb(7)	--	--	--
6	Lvb(1)	Mvb(1)	--	--
6A	--	Mvb(1)	--	--
7	--	--	--	--
8	--	--	Mvb(3)	Mvb(3)
9	Mvb(2)	--	Mvb(3)	Mvb(3)
9A	--	--	Mvb(3)	--
10	Mvb(6)	HvAb	Mvb(1)	Mvb(1)
11	--	--	--	Mvb(1)

sequence. The low-volatile bituminous coal beds are in the middle of the stratigraphic section on Lookout Mountain. More research is needed to confirm this relationship.

Coal Environmental Parameters

From an environmental viewpoint the most important coal quality characteristics are the sulfur and ash contents and the forms-of-sulfur. Recently, however, more attention has been focused on the trace elements in coal. These include such "environmentally sensitive" elements as arsenic, beryllium, cadmium, copper, mercury, nickel, lead, antimony, selenium, and zinc. Many of these elements have either chalcophil or organic affinities.

Dicussions about the concentrations of these elements in Sand and Lookout Mountains coal are covered previously in this bulletin. Possible explanations for the unusual concentrations of the "environmentally sensitive" elements in some coal beds are evident when one examines the number of coal samples represented by the analyses for a particular coal bed, the ash content, and the pyritic sulfur concentration. For example, the No. 2 coal bed contains unusually high values of most of the "environmentally sensitive" elements. This bed is represented by a single sample even though two analyses are reported. Moreover, the pyritic sulfur content of this coal bed is about 3.38 percent and the ash content is about 15 percent. These values are much higher than the geometric mean values for all samples analyzed in this study. There are eight samples and analyses representing the No. 10 coal bed. However, there are unusual concentrations of the "environmentally sensitive" chalcophil elements. The analyses in Information Circular 75 (Coleman and other, 1985) indicate that some of the samples have very high ash and pyritic sulfur values. As a first approximation, one could assume that the higher concentrations are related to the ash and pyritic sulfur contents. Coal bed No. 8 has higher than average concentrations of the chalcophil elements and also has some samples which are high in total sulfur and pyritic sulfur contents.

CONCLUSIONS

The following conclusions result from this investigation of the quality of coal underlying Sand and Lookout Mountains in Georgia and Alabama.

* Coal underlying Sand Mountain has a rank of medium-volatile bituminous.
* Coal underlying Lookout Mountain has a rank from medium-volatile to low-volatile bituminous.
* Coal underlying Sand and Lookout Mountains contains low sulfur. The pyritic and organic sulfur contents are very low for many of the coal beds and coal samples analyzed during the current study. Much of the pyritic sulfur might be removed in routine beneficiation processes, yielding a cleaner fuel.
* Sand and Lookout Mountains coal can be categorized as low in ash content. The geometric mean for all samples is less than 8 percent ash on an as-received basis.
* Sand and Lookout Mountains coal is some of the highest quality metallurgical or metallurgical blend coal in the Appalachian Basin and in the United States. This is supported by a free-swelling index which ranges from 1 to 9 with a geometric mean value of 6.

* The calorific value of Sand and Lookout Mountains coal is greater than 13,000 Btu per pound on an as-received basis. Some samples have calorific values of 14,000 to 15,000 Btu per pound indicating that some of this coal has the highest Btu per pound values in the United States.
* The major lithophil oxides such as SiO_2, Al_2O_3, MgO, K_2O, Fe_2O_3, MnO, TiO_2, and P_2O_5 in the Sand and Lookout Mountains samples show only slight differences in concentration when compared to values for eastern United States, Tennessee and Alabama.

The CaO concentration in Sand and Lookout Mountains and Tennessee samples is notably higher than in eastern United States and Alabama coal samples.

There are notable Na_2O and P_2O_5 concentration differences between Sand and Lookout Mountains samples and Alabama samples.

Differences in oxide and chlorine contents exist between individual coal beds on Sand and Lookout Mountains when compared to the mean for all Sand and Lookout Mountains samples. These coal beds and their anomalously different oxides and elements include:

No. 1--SiO_2, MgO and P_2O_5

No. 2--P_2O_5 and Fe_2O_3

No. 3--CaO

No. 4--CaO and chlorine

No. 5--CaO and chlorine

No. 6--CaO, Fe_2O_3 and P_2O_5

No. 8--Fe_2O_3

No. 9--P_2O_5

No. 10--SiO_2

The concentration of the minor and trace lithophil elements, when compared with elemental concentrations from eastern United States, Tennessee, and Alabama coal samples, have the following similarities and differences:

* Beryllium, cerium, chromium, cesium, europium, germanium, lanthanum, lutetium, scandium, samarium, terbium, yttrium, and ytterbium concentrations in Sand and Lookout Mountains coal samples are essentially the same as those in eastern United States, Tennessee, and Alabama samples. This suggests similar source area or depositional processes for the coal beds.
* The concentration of barium, gallium, germanium, hafnium, lithium, niobium, neodymium, uranium, and zirconium in Alabama coal is at least twice that in Sand and Lookout Mountains samples.
* Strontium concentration in Sand and Lookout Mountains coal samples is about the same as Alabama samples, but three times greater than in eastern United States and Tennessee samples.
* Boron concentration in eastern United States, Tennessee, and Alabama samples is more than twice the boron concentration in the Sand and Lookout Mountains samples.
* Fluorine concentration is about the same in Sand and Lookout Mountains, eastern United States, and Tennessee samples, but Alabama coal has almost twice as much fluorine as the Sand and Lookout Mountains coal.

The trace chalcophil elements in the Sand and Lookout Mountains samples show the following concentration patterns:

* The overall concentration of silver, arsenic, cobalt, mercury, nickel, lead, selenium, and zinc in Sand and Lookout Mountains samples is only slightly different from values in other coal from the eastern United States, Tennessee, and Alabama.
* Cadmium and gallium contents are about the same or less than reported values for similar coal in eastern United States, Tennessee, and Alabama.
* Antimony concentration is unusually high in the Sand and Lookout Mountains samples when compared to other bituminous coals.
* Coal beds No. 2, No. 8, No. 9A, and No. 10 contain high concentrations of the chalcophil elements when compared to the overall geometric mean for all Sand and Lookout Mountains samples. This is especially evident for the elements arsenic, antimony, cadmium, mercury, lead, selenium, and zinc.

Lastly, depositional environments in which Sand and Lookout Mountains coal accumulated likely changed through time as indicated by the variation of the lithologies which enclose them, by the presence of marine horizons, by the variable sulfur and ash contents, major, minor and trace element concentrations, and by the shape of the coal beds and enclosing lithologies.

It is probable that these environments were similar to those described by Milici and various other workers, and likely ranged from barrier bar complexes to fluvial and alluvial systems.

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