UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# Geology, Coal resources, and chemical analyses of coal from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, New Mexico

by
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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards

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# ABSTRACT

The Kimbeto EMRIA study site, an area of about 20 square miles (52 $km^2$), is located on the south margin of the San Juan Basin on the gently northward-dipping strata of the Upper Cretaceous Fruitland Formation and the Kirtland Shale. The coal beds are mainly in the lower 150 feet (45 m) of the Fruitland Formation.

Coal resources--measured, indicated, and inferred--with less than 400 feet (120 m) of overburden in the site are 69,085,000 short tons (62,660,100 metric tons), 369,078,000 short tons (334,754,000 metric tons), and 177,803,000 short tons (161,267,000 metric tons) respectively. About 68 percent of these resources are overlain by 200 feet (60 m) or less of overburden.

The apparent rank of the coal ranges from subbituminous B to subbituminous A. The average Btu/lb value of 14 core samples from the site on the as-received basis is 8,240 (4580 Kcal/kg), average ash content is 23.4 percent, and average sulfur content is 0.5 percent.

Analyses of coal from the Kimbeto EMRIA study site show significantly higher ash content and significantly lower contents of volatile matter, fixed carbon, carbon, and a significantly lower heat of combustion when compared with other coal analyses from the Rocky Mountain province.

## INTRODUCTION

This report was prepared as a contribution to the study of the reclamation potential of the Kimbeto EMRIA study site in the south-central part of the San Juan Basin in northwest New Mexico. The area was selected by the U.S. Bureau of Land Management to be included in the EMRIA (Energy Minerals Rehabilitation Inventory and Analysis) program in order to evaluate reclamation potential of sediments from the Fruitland Formation in this part of the basin.

The Kimbeto EMRIA study site is an area of about 20 square miles (52 $km^2$) just north of Escavada Wash, a tributary of the Chaco River. The site is within the Pueblo Bonito, Pueblo Bonito NW, Sargent Ranch, and Kimbeto 7 1/2 -minute quadrangles. Ten holes were cored by the Bureau of Reclamation (fig. 1).

## ACKNOWLEDGMENTS

Fundamental to this paper is the contribution of chemists in the U.S. Geological Survey under the direction of Joseph H. Christie: James W. Baker, Celeste M. Ellis, John C. Hamilton, Roy J. Knight, Cynthia McFee, Robert E. McGregor, Violet M. Merritt, Hugh T. Millard, Jr., Harriet G. Neiman, Gaylord D. Shipley, James A. Thomas, Michele L. Tuttle, Richard E. Van Loenen, and James S. Wahlberg. The invaluable contribution of the chemists in the Coal Analysis section (Forrest E. Walker, Chemist-in-Charge), Department of Energy, Pittsburgh, Pa., is also greatly appreciated.

## GEOLOGIC SETTING

The coal evaluated for this study comprises a series of as many as 5 major lenticular beds up to 41 feet thick (fig. 2). Most of the coal is in the lower 150 feet of the Fruitland Formation. Maximum overburden on the uppermost minable coal is 260 feet.

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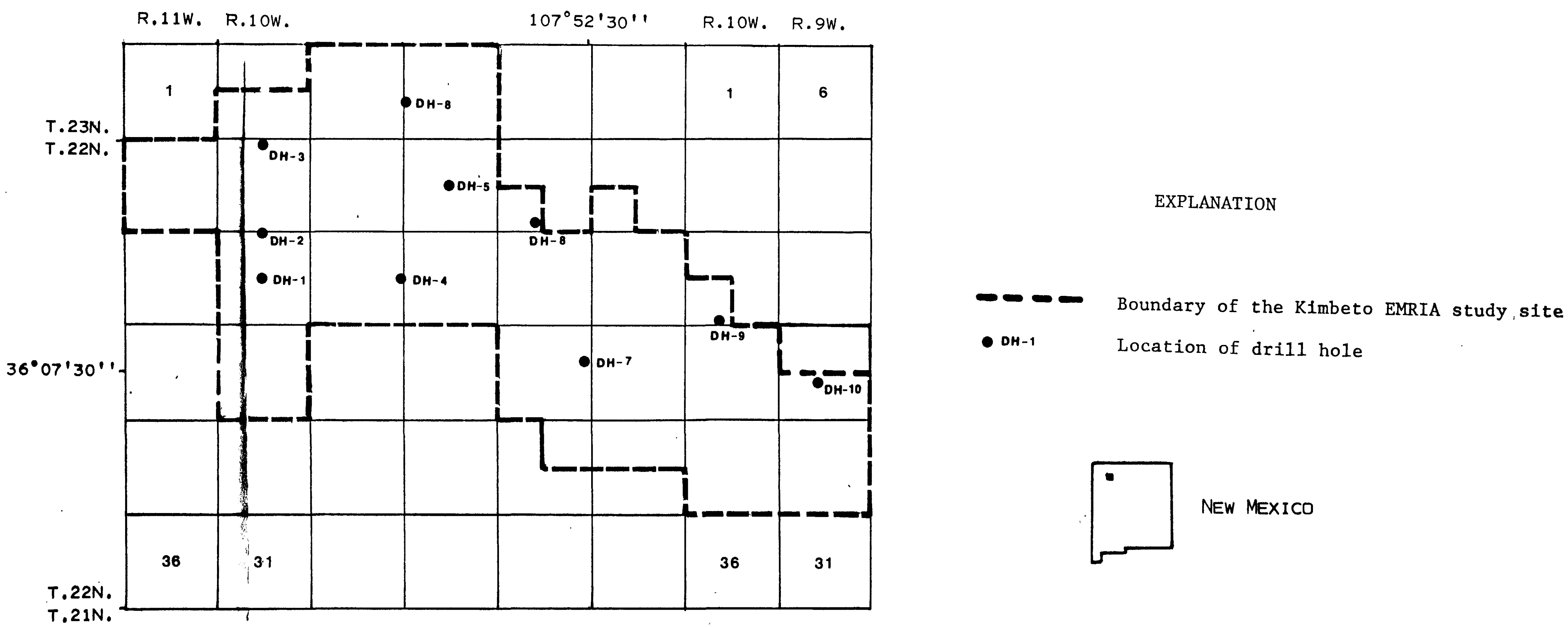


FIGURE 1.--INDEX MAP OF THE KIMBETO EMRIA SITE, SAN JUAN COUNTY, NEW MEXICO

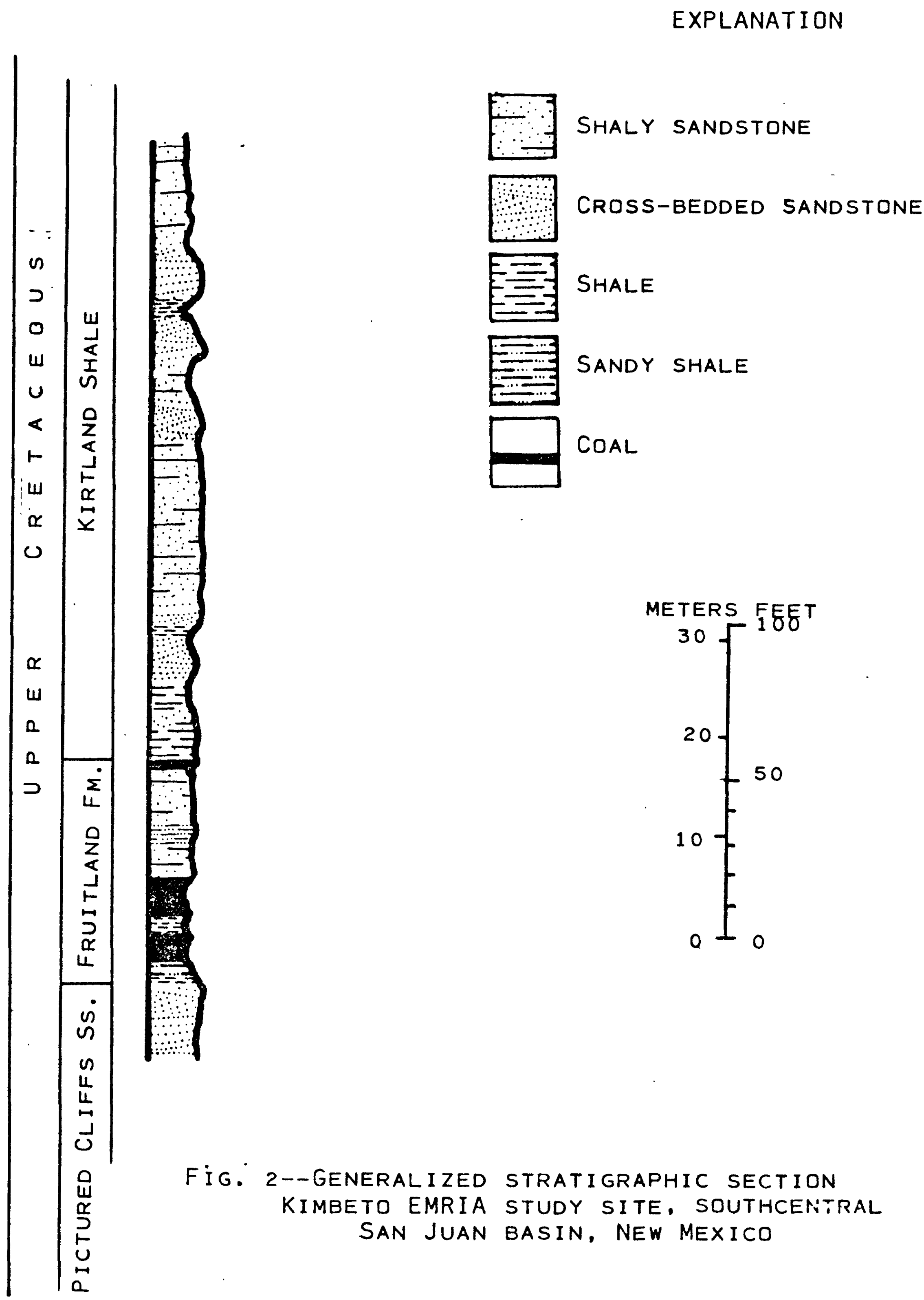


FIG. 2--GENERALIZED STRATIGRAPHIC SECTION KIMBETO EMRIA STUDY SITE, SOUTHCENTRAL SAN JUAN BASIN, NEW MEXICO

The Fruitland Formation consists of a highly variable sequence of interbedded lenticular non-marine claystone, silty and sandy shale, cross-bedded sandstone, and coal; the overlying Kirtland Shale is of similar lithology but lacks commercial coal. The Fruitland is underlain by, and intertongues with, the marine Pictured Cliffs Sandstone, also of Late Cretaceous age. Coal-bearing rocks below the Pictured Cliffs were not evaluated in this study. The geology of the study site area was mapped at a scale of 1:24,000 (Schneider, 1978).

## COAL

### Origin

Coal has been defined as "a readily combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous material, formed from compaction or induration of variously altered plant remains similar to those of peaty deposits. Differences in the kinds of plant materials (type), in degree of metamorphism (rank), and range of impurity (grade) are characteristics of the varieties of coal" (Schopf, 1966, p. 588). Inherent in the definition is the specification that the coal originated as a mixture of organic plant remains and inorganic mineral matter that accumulated in a manner similar to that in which modern-day peat deposits are formed. The peat underwent a long, complex process called "coalification", during which diverse physical and chemical changes occurred as the peat changed to coal and as the coal assumed the characteristics by which members of the series are differentiated from each other. The factors that affect the composition of coals have been summarized by Francis (1961, p. 2) as follows:

1) The mode of accumulation and burial of the plant debris forming the deposit.
2) The age of the deposits and their geographical distribution.
3) The structure of the coal-forming plants, particularly details of structure that affect chemical composition or resistance to decay.
4) The chemical composition of the coal-forming debris and its resistance to decay.
5) The nature and intensity of the plant-decaying agencies.
6) The subsequent geological history of the residual products of decay of the plant debris forming the deposits.

These factors, are discussed in greater detail by Moore (1940), Lowry (1945), Tomkeieff (1954), Francis (1961), and Lowry (1963).

## Classification

Coals are classified in many ways (Tomkeieff, 1954, p. 9; Moore, 1940, p. 113,; Francis, 1961, p. 361), but the classification by rank, that is, by degree of metamorphism in the progressive series that begins with peat and ends with graphocite (Schopf, 1966), is the most commonly used system. Classification by types of plant materials is commonly used as a descriptive adjunct to rank classification when sufficient megascopic and microscopic information is available, and classification by type and quantity of impurities (grade) is also frequently used when utilization of the coal is being considered. Other categorizations are possible and are commonly employed in discussion of coal resources. Factors such as weight of the coal, thickness and areal extent of individual coal beds, and the thickness of overburden are generally considered.

## Rank of coal

The position of a coal within the metamorphic series, which begins with peat and ends with graphocite, is dependent upon the temperature and pressure to which the coal has been subjected and the duration of time of subjection. Because it is, by definition, largely derived from plant material, coal is mostly composed of carbon, hydrogen, and oxygen, along with smaller quantities of nitrogen, sulfur, and other elements. The increase in rank of coal as it undergoes progressive metamorphism is indicated by changes in the proportions of the coal constitutients, e.g., the higher rank coals have more carbon and less hydrogen than the lower rank coals.

Two standardized forms of coal analyses--the proximate analysis and the ultimate analysis--are generally used, though sometimes only the less complicated and less expensive proximate analysis is made. The analyses are described as follows (U.S. Bureau of Mines, 1965, p. 121-122):

> The proximate analysis of coal involves the determination of four constituents: (1) water, called moisture; (2) mineral impurity, called ash, left when the coal is completely burned; (3) volatile matter, consisting of gases or vapors driven out when coal is heated to certain temperatures; and (4) fixed carbon, the solid or cokelike residue that burns at higher temperatures after volatile matter has been driven off. Ultimate analysis involves the determination of carbon and hydrogen as found in the gaseous products of combustion, the determination of sulfur, nitrogen, and ash in the material as a whole, and the estimation of oxygen by difference.

Most coals are burned to produce heat energy so the heating value of the coal is an important property. The heating value (calorific value) is commonly expressed in British thermal units (Btu) per pound: one Btu is the amount of heat required to raise the temperature of 1 pound of water 1 degree fahrenheit (in the metric system, heating value is expressed in kilogram-calories per kilogram). Additional tests are sometimes made, particularly to determine the caking, coking, and other properties, such as tar yield, which affect classification or utilization.

Figure 3 compares, in histogram form, the heating values and moisture, volatile matter, and fixed carbon contents of coals of different ranks.

Various schemes for classifying coals by rank have been proposed and used, but the most commonly employed is that entitled "Standard specifications for classification of coals by rank," adopted by the American Society for Testing and Materials (1974) (table 1).

The ASTM classification system differentiates coals into classes and groups on the basis of mineral-matter-free fixed carbon or volatile matter and the heating value, supplemented by determination of agglomerating (caking) characteristics. As pointed out by the ASTM (1974, p. 55), a standard rank determination cannot be made unless the samples were obtained in accordance with standardized sampling procedures (Snyder, 1950; Schopf, 1960). However, nonstandard samples may be used for comparative purposes through determinations designated as "apparent rank."

Fourteen samples listed on tables 2 and 3 show an apparent rank that ranges from subbituminous B to subbituminous A. Because of the lack of definitive information about the distribution of coals of various groups in the Fruitland coal, it is considered to be all between subbituminous B and subbituminous A in rank in the area of the study.

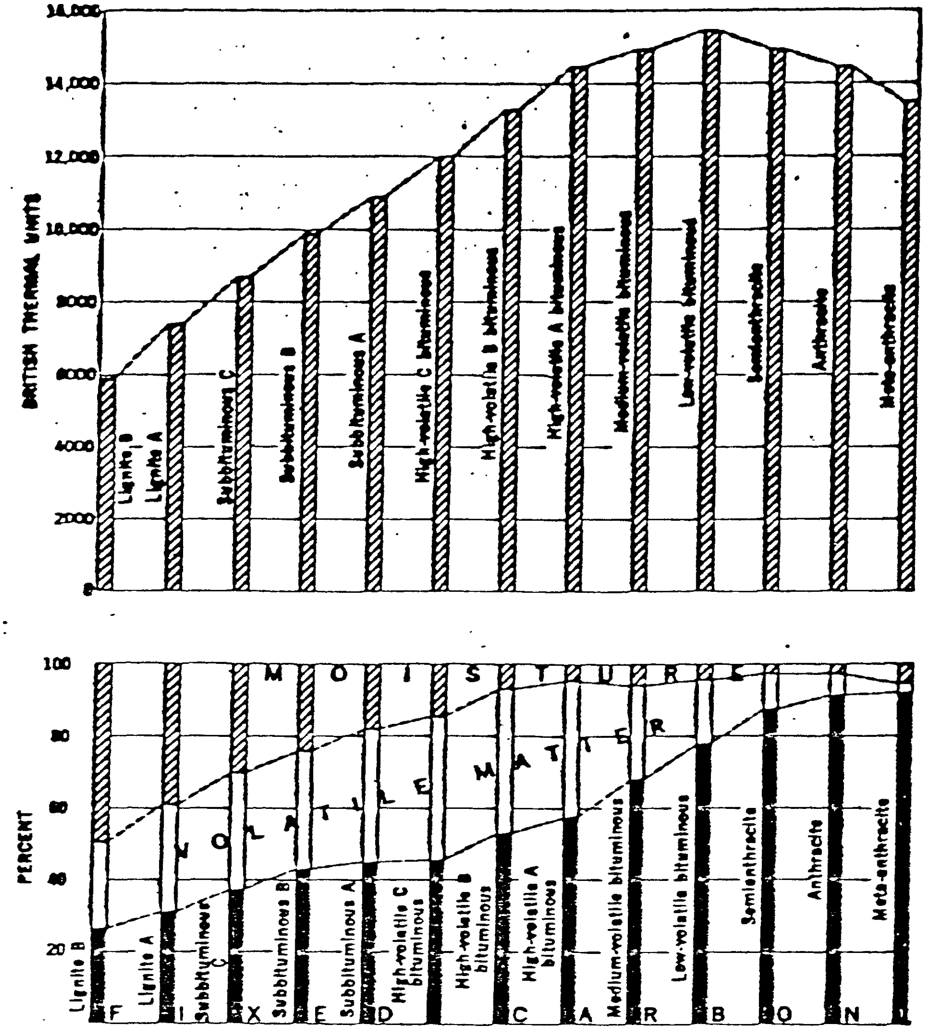


FIGURE 3.--COMPARISON (ON MOIST, MINERAL-MATTER-FREE BASIS) OF HEAT VALUES AND PROXIMATE ANALYSES OF COAL OF DIFFERENT RANKS

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Table 1.--Classification of coals by rank[1]

[American Society for Testing and Materials Standard D388-77 (Reapproved 1978); 1 Btu equals 0.252 kilogram-calories Leaders (---) indicate categroy is not used in rank determination of group]

| Class | Group | Fixed carbon limits, percent (dry, mineral-matter-free basis) | | Volatile matter limits, percent (dry, mineral matter-free basis) | | Calorific value limits, Btu per pound (moist,[2] mineral-matter-free basis) | | Agglomerating Character |
|---|---|---|---|---|---|---|---|---|
| | | Equal or greater than | Less than | Greater than | Equal or less than | Equal or greater than | Less than | |
| I. Anthracitic | 1. Meta-anthracite | 98 | --- | --- | 2 | --- | --- | nonagglomerating |
| | 2. Anthracite | 92 | 98 | 2 | 8 | --- | --- | nonagglomerating |
| | 3. Semianthracite[3] | 86 | 92 | 8 | 14 | --- | --- | nonagglomerating |
| II. Bituminous | 1. Low volatile bituminous coal | 78 | 86 | 14 | 22 | --- | --- | commonly agglomerating[5] |
| | 2. Medium volatile bituminous coal | 69 | 78 | 22 | 31 | --- | --- | commonly agglomerating[5] |
| | 3. High volatile A bituminous coal | --- | 69 | 31 | --- | 14 000[4] | --- | commonly agglomerating[5] |
| | 4. High volatile B bituminous coal | --- | --- | --- | --- | 13 000[4] | 14 000 | commonly agglomerating[5] |
| | 5. High volatile C bituminous coal | --- | --- | --- | --- | 11 500 | 13 000 | commonly agglomerating[5] |
| | | | | | | 10 500 | 11 500 | agglomerating |
| III. Subbituminous | 1. Subbituminous A coal | --- | --- | --- | --- | 10 500 | 11 500 | nonagglomerating |
| | 2. Subbituminous B coal | --- | --- | --- | --- | 9 500 | 10 500 | nonagglomerating |
| | 3. Subbituminous C coal | --- | --- | --- | --- | 8 300 | 9 500 | nonagglomerating |
| IV. Lignitic | 1. Lignite A | --- | --- | --- | --- | 6 300 | 8 300 | nonagglomerating |
| | 2. Lignite B | | | | | --- | 6 300 | nonagglomerating |

[1]This classification does not include a few coals, principally nonbanded varieties, that have unusual physical and chemical properties and that come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.

[2]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[3]If agglomerating, classify in low-volatile group of the bituminous class.

[4]Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis are classified according to fixed carbon, regardless of calorific value.

[5]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class and that there are notable exceptions in the high-volatile C bituminous group.

## Type of coal

Classification of coals by type--that is, according to the types of plant materials present--takes many forms, such as the "rational analysis" of Francis (1961) or the semicommercial "type" classification commonly used in the coal fields of the eastern United States (U.S. Bureau of Mines, 1965, p. 123). However, most of the type classifications are based on the same, or similar, gross distinctions in plant material as those used by Tomkeieff (1954, Table II and p. 9), who divided the coals into three series: humic coals, humic-sapropelic coals, and sapropelic coals, based upon the nature of the original plant materials. The humic coals are largely composed of the remains of the woody parts of plants and the sapropelic coals are largely composed of the more resistant waxy, fatty, and resinous parts of plants, such as cell walls, spore-coatings, pollen, resin particles, and coals composed mainly of algal material. Most coals fall into the humic series, with some coals being a mixture of humic and sapropelic elements and, therefore, falling into the humic-sapropelic series. The sapropelic series is quantitatively insignificant and, when found is commonly regarded as an organic curosity. In common with most of the U.S. coals, those from the Kimbeto EMRIA study site fall largely in the humic series.

## Grade of coal

Classification of coal by grade, or quality, is based largely on the content of ash, sulfur, and other constituents that adversely affect utilization. Most detailed coal resource evaluations of the past do not categorize known coal resources by grade; however coals of the United States have been classified by sulfur content in a gross way (DeCarlo and others, 1966).

Table 2.--USGS sample number, hole number, location and depth interval for 17 coal and shale samples from the Kimbeto EMRIA study site, San Juan County, N. Mex.

[All samples are from the Fruitland Formation of Cretaceous age. One ft = 0.305 m]

| USGS sample number | Hole number | Location | Depth interval, in ft | Description |
|---|---|---|---|---|
| D194012 | 1K | SE¼NW¼ sec. 18 T. 22 N., R. 10 W. | 25.8- 33.8 | coal |
| D194013 | -do- | ----------------do---------------- | 48.4- 50.9 | shale, coaly |
| D194014 | -do- | ----------------do---------------- | 62.2- 65.7 | Do. |
| D194015 | -do- | ----------------do---------------- | 106.0-108.6 | coal, shaley |
| D194016 | -do- | ----------------do---------------- | 116.1-125.5 | coal |
| D194017 | 3K | SE¼SW¼ sec. 7 T. 22 N., R. 10 W. | 78.6- 80.1 | Do. |
| D194018 | -do- | ----------------do---------------- | 82.5- 93.3 | Do. |
| D194019 | -do- | ----------------do---------------- | 134.0-141.0 | coal, shaley |
| D194020 | -do- | ----------------do---------------- | 161.8-169.8 | Do. |
| D194021 | -do- | ----------------do---------------- | 191.2-196.2 | Do. |
| D194022 | -do- | ----------------do---------------- | 206.3-218.4 | Do. |
| D194023 | 6K | NW¼SW¼ sec. 4 T. 22 N., R. 10 W. | 214.0-232.9 | Do. |
| D194024 | -do- | ----------------do---------------- | 245.6-246.2 | Do. |
| D194025 | -do- | ----------------do---------------- | 255.0-258.5 | Do. |
| D194026 | -do- | ----------------do---------------- | 271.1-284.0 | Do. |
| D194027 | -do- | ----------------do---------------- | 318.3-322.1 | shale, coaly |
| D194028 | 8K | SE¼SW¼ sec. 10 T. 22 N., R. 10 W. | 192.8-228.5 | coal, shaley |

Table 3.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determination for 17 coal and shale samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex.

[All analyses except heat of combustion, free swelling index and ash-fusion temperature in percent. For each sample number, the analyses are reported three ways: first, as-received, second, moisture free, and third, moisture and ash free. All analyses by Coal Analysis Section, U.S. Department of Energy, Pittsburgh, Pa. °C = (°F-32) 5/9; Kcal/kg = 0.556 Btu/lb.]

| Sample number | Proximate Analysis | | | | Ultimate Analysis | | | | | Heat of Combustion | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Moisture | Volatile matter | Fixed carbon | Ash | Hydrogen | Carbon | Nitrogen | Oxygen | Sulfur | Kcal/kg | Btu/lb |
| D194012 | 15.0 | 31.7 | 37.4 | 15.9 | 5.6 | 52.4 | 1.1 | 24.4 | 0.6 | 5,140 | 9,250 |
| | --- | 37.3 | 44.0 | 18.7 | 4.6 | 61.6 | 1.3 | 13.0 | .7 | 6,050 | 10,880 |
| | --- | 45.9 | 54.1 | --- | 5.7 | 75.8 | 1.6 | 16.0 | .9 | 7,440 | 13,390 |
| D194013 | 15.4 | 13.1 | 4.3 | 67.2 | 2.9 | 11.1 | .3 | 18.3 | .3 | 1,030 | 1,850 |
| | --- | 15.5 | 5.1 | 79.4 | 1.4 | 13.1 | .4 | 5.5 | .4 | 1,220 | 2,190 |
| | --- | 75.3 | 24.7 | --- | 6.8 | 63.8 | 1.7 | 26.5 | 1.7 | 5,920 | 10,660 |
| D194014 | 13.5 | 21.5 | 19.9 | 45.1 | 4.0 | 30.2 | .6 | 19.7 | .4 | 2,900 | 5,220 |
| | --- | 24.9 | 23.0 | 52.1 | 2.9 | 34.9 | .7 | 8.9 | .5 | 3,360 | 6,040 |
| | --- | 51.9 | 48.1 | --- | 6.0 | 72.9 | 1.4 | 18.6 | 1.0 | 7,010 | 12,620 |
| D194015 | 14.1 | 27.7 | 30.3 | 27.9 | 5.4 | 43.0 | .9 | 22.3 | .6 | 4,200 | 7,570 |
| | --- | 32.2 | 35.3 | 32.5 | 4.5 | 50.1 | 1.0 | 11.4 | .7 | 4,890 | 8,810 |
| | --- | 47.8 | 52.2 | --- | 6.6 | 74.1 | 1.6 | 16.8 | 1.0 | 7,250 | 13,050 |
| D194016 | 15.4 | 32.4 | 41.2 | 11.0 | 5.9 | 57.2 | 1.2 | 24.1 | .6 | 5,540 | 9,970 |
| | --- | 38.3 | 48.7 | 13.0 | 5.0 | 67.6 | 1.4 | 12.3 | .7 | 6,550 | 11,780 |
| | --- | 44.0 | 56.0 | --- | 5.7 | 77.7 | 1.6 | 14.1 | .8 | 7,520 | 13,540 |
| D194017 | 14.9 | 34.5 | 41.3 | 9.3 | 6.2 | 59.4 | 1.2 | 23.3 | .6 | 5,780 | 10,410 |
| | --- | 40.5 | 48.5 | 10.9 | 5.3 | 69.8 | 1.4 | 11.8 | .7 | 6,790 | 12,230 |
| | --- | 45.5 | 54.5 | --- | 6.0 | 78.4 | 1.6 | 13.3 | .8 | 7,630 | 13,730 |
| D194018 | 12.7 | 33.5 | 35.3 | 18.5 | 5.4 | 52.3 | 1.0 | 22.2 | .6 | 5,110 | 9,200 |
| | --- | 38.4 | 40.4 | 21.2 | 4.6 | 59.9 | 1.1 | 12.5 | .7 | 5,850 | 10,540 |
| | --- | 48.7 | 51.3 | --- | 5.8 | 76.0 | 1.5 | 15.9 | .9 | 7,430 | 13,370 |
| D194019 | 13.6 | 28.3 | 28.8 | 29.3 | 4.9 | 42.5 | .9 | 21.9 | .7 | 4,210 | 7,570 |
| | --- | 32.8 | 33.3 | 33.9 | 3.9 | 49.2 | 1.0 | 11.4 | .8 | 4,870 | 8,770 |
| | --- | 49.6 | 50.4 | --- | 5.9 | 74.4 | 1.6 | 17.2 | 1.2 | 7,370 | 13,260 |
| D194020 | 16.8 | 27.0 | 32.0 | 24.2 | 5.1 | 44.0 | .9 | 25.4 | .4 | 4,340 | 7,820 |
| | --- | 32.5 | 38.5 | 29.1 | 3.9 | 52.9 | 1.1 | 12.6 | .5 | 5,220 | 9,390 |
| | --- | 45.8 | 54.2 | --- | 5.5 | 74.6 | 1.5 | 17.7 | .7 | 7,360 | 13,250 |
| D194021 | 15.5 | 25.7 | 25.6 | 33.2 | 4.8 | 37.5 | .8 | 23.2 | .5 | 3,680 | 6,620 |
| | --- | 30.4 | 30.3 | 39.3 | 3.6 | 44.4 | .9 | 11.2 | .6 | 4,350 | 7,830 |
| | --- | 50.1 | 49.9 | --- | 6.0 | 73.1 | 1.6 | 18.4 | 1.0 | 7,160 | 12,900 |
| D194022 | 15.4 | 26.3 | 33.1 | 25.2 | 5.1 | 45.0 | 1.0 | 23.4 | .4 | 4,380 | 7,880 |
| | --- | 31.1 | 39.1 | 29.8 | 4.0 | 53.2 | 1.2 | 11.5 | .5 | 5,180 | 9,320 |
| | --- | 44.3 | 55.7 | --- | 5.7 | 75.8 | 1.7 | 16.3 | .7 | 7,370 | 13,270 |
| D194023 | 13.6 | 32.1 | 32.2 | 22.1 | 5.3 | 48.5 | .9 | 22.7 | .5 | 4,760 | 8,570 |
| | --- | 37.2 | 37.3 | 25.6 | 4.4 | 56.1 | 1.0 | 12.3 | .6 | 5,510 | 9,920 |
| | --- | 49.9 | 50.1 | --- | 5.9 | 75.4 | 1.4 | 16.5 | .8 | 7.410 | 13.330 |

Table 3.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determinations for 17 coal and shale samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex. --Continued

| Sample number | Air-dried loss | Forms of sulfur: Sulfate | Pyritic | Organic | Free swelling | Ash fusion temperature °C: Initial deformation | Softening | Fluid |
|---|---|---|---|---|---|---|---|---|
| D194012 | 9.7 | 0.04 | 0.21 | 0.34 | 0.0 | 1,435 | 1,490 | 1,540 |
| | --- | .05 | .25 | .40 | | | | |
| | --- | .06 | .30 | .49 | | | | |
| D194013 | 11.1 | .04 | .20 | .03 | .0 | 1,435 | 1,490 | 1,540 |
| | --- | .05 | .24 | .04 | | | | |
| | --- | .23 | 1.15 | .17 | | | | |
| D194014 | 8.2 | .01 | .18 | .25 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .01 | .21 | .29 | | | | |
| | --- | .02 | .43 | .60 | | | | |
| D194015 | 9.2 | .01 | .10 | .46 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .01 | .12 | .54 | | | | |
| | --- | .02 | .17 | .79 | | | | |
| D194016 | 9.5 | .02 | .23 | .37 | .0 | 1,400 | 1,455 | 1,515 |
| | --- | .02 | .27 | .44 | | | | |
| | --- | .03 | .31 | .50 | | | | |
| D194017 | 8.5 | .04 | .05 | .55 | .0 | 1,325 | 1,375 | 1,430 |
| | --- | .05 | .06 | .65 | | | | |
| | --- | .05 | .07 | .73 | | | | |
| D194018 | 7.7 | .03 | .07 | .53 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .03 | .08 | .61 | | | | |
| | --- | .04 | .10 | .77 | | | | |
| D194019 | 8.4 | .05 | .16 | .46 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .06 | .19 | .53 | | | | |
| | --- | .09 | .28 | .81 | | | | |
| D194020 | 11.6 | .02 | .04 | .33 | .0 | 1,515 | 1,540 | 1,540 |
| | --- | .02 | .05 | .40 | | | | |
| | --- | .03 | .07 | .56 | | | | |
| D194021 | 10.0 | .02 | .13 | .32 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .02 | .15 | .38 | | | | |
| | --- | .04 | .25 | .62 | | | | |
| D194022 | 10.1 | .03 | .10 | .23 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .04 | .12 | .27 | | | | |
| | --- | .05 | .17 | .39 | | | | |
| D194023 | 8.7 | .03 | .11 | .34 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .03 | .13 | .39 | | | | |
| | --- | .05 | .17 | .53 | | | | |

Table 3.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion-temperture determinations for 17 coal and shale samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex. --Continued

| Sample number | Proximate Analysis | | | | Ultimate Analysis | | | | | Heat of Combustion | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Moisture | Volatile matter | Fixed carbon | Ash | Hydrogen | Carbon | Nitrogen | Oxygen | Sulfur | Kcal/kg | Btu/lb |
| D194024 | 14.3 | 27.6 | 29.6 | 28.5 | 5.0 | 42.6 | 0.9 | 22.4 | 0.5 | 4,220 | 7,600 |
| | --- | 32.2 | 34.5 | 33.3 | 4.0 | 49.7 | 1.1 | 11.3 | .6 | 4,920 | 8,860 |
| | --- | 48.3 | 51.7 | --- | 6.0 | 74.5 | 1.6 | 16.9 | .9 | 7,380 | 13,280 |
| D194025 | 14.1 | 27.4 | 25.8 | 32.7 | 4.9 | 39.6 | .8 | 21.4 | .5 | 3,860 | 6,940 |
| | --- | 31.9 | 30.0 | 38.1 | 3.9 | 46.1 | .9 | 10.3 | .6 | 4,490 | 8,080 |
| | --- | 51.5 | 48.5 | --- | 6.3 | 74.4 | 1.5 | 16.7 | .9 | 7,250 | 13,050 |
| D194026 | 14.7 | 28.0 | 28.7 | 28.6 | 5.2 | 41.9 | .9 | 23.0 | .4 | 4,120 | 7,420 |
| | --- | 32.8 | 33.6 | 33.5 | 4.2 | 49.1 | 1.1 | 11.6 | .5 | 4,830 | 8,700 |
| | --- | 49.4 | 50.6 | --- | 6.3 | 73.9 | 1.6 | 17.5 | .7 | 7,270 | 13,090 |
| D194027 | 11.7 | 12.5 | 8.3 | 67.5 | 2.8 | 12.7 | .3 | 15.1 | 1.6 | 1,210 | 2,170 |
| | --- | 14.2 | 9.4 | 76.4 | 1.7 | 14.4 | .3 | 5.3 | 1.8 | 1,370 | 2,460 |
| | --- | 60.1 | 39.9 | --- | 7.2 | 61.1 | 1.4 | 22.6 | 7.7 | 5,810 | 10,450 |
| D194028 | 13.9 | 32.3 | 32.0 | 21.8 | 5.4 | 48.8 | .9 | 22.5 | .5 | 4,750 | 8,560 |
| | --- | 37.5 | 37.2 | 25.3 | 4.5 | 56.7 | 1.0 | 11.8 | .6 | 5,520 | 9,940 |
| | --- | 50.2 | 49.8 | --- | 6.0 | 75.9 | 1.4 | 15.8 | .8 | 7,390 | 13,310 |

(15)

| Sample number | Air-dried loss | Forms of sulfur | | | Free swelling | Ash fusion temperature C° | | |
|---|---|---|---|---|---|---|---|---|
| | | Sulfate | Pyritic | Organic | | Initial deformation | Softening | Fluid |
| D194024 | 9.3 | 0.03 | 0.11 | 0.37 | 0.0 | 1,515 | 1,540 | 1,540 |
| | --- | .04 | .13 | .43 | | | | |
| | --- | .05 | .19 | .65 | | | | |
| D194025 | 8.8 | .02 | .11 | .36 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .02 | .13 | .42 | | | | |
| | --- | .04 | .21 | .68 | | | | |
| D194026 | 9.9 | .02 | .11 | .31 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .02 | .13 | .36 | | | | |
| | --- | .04 | .19 | .55 | | | | |
| D194027 | 8.2 | .41 | .82 | .33 | .0 | 1,290 | 1,345 | 1,400 |
| | --- | .46 | .93 | .37 | | | | |
| | --- | 1.97 | 3.94 | 1.59 | | | | |
| D194028 | 8.8 | .01 | .12 | .36 | .0 | 1,540 | 1,540 | 1,540 |
| | --- | .01 | .14 | .42 | | | | |
| | --- | .02 | .19 | .56 | | | | |

According to Fieldner, Rice, and Moran (1942), the ash content of 642 U.S. coal samples ranges from 2.5 to 32.6 percent, averaging 8.9 percent, and sulfur content ranges from 0.2 to 7.7 percent, averaging 1.9 percent.

The ash content of the 14 coal samples from the Fruitland coal, on an as-received basis, ranges from 9.3 to 33.2 percent, averaging, 23.4 percent; the sulfur-content ranges from 0.4 to 0.7 percent, averaging, 0.5 percent.

## Estimation and classification of coal resources

Coal resource estimates have been prepared for the Fruitland coal within the Kimbeto EMRIA study site using standard procedures, definitions, and criteria established by the U.S. Geological Survey and U.S. Bureau of Mines for making coal resource appraisals in the United States. The term "coal resources" as used in this report means the estimated quantity of coal in the ground in such form that economic extraction is currently or potentially feasible.

## Tabulation of estimated coal resources

Tables 4 and 5 summarize the estimated coal resources of the Kimbeto EMRIA study site. The resources in the study site are classed as measured, indicated, and inferred according to the degree of geologic assurance of the estimate:

<u>Measured</u> - Resources are computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced and the thickness and extent of coals are so well defined that the tonnage is judged to be accurate within 20 percent of true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of the coal differs from region to region according to the character of the coal beds, the points of observation are no greater than 1/2 mile (0.8

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Table 4.--Estimated identified subbituminous coal resources of the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex. as of January 1, 1979

[Leaders (---) indicate not present. In thousands of tons. 1 foot = 0.305 meters; 1 short ton = 0.907 metric ton]

| | 0-200 ft overburden | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 1/2 - 5 feet | | | | 5-10 feet | | | | 10 ft or more | | | | |
| Location | Measured | Indicated | Inferred | Total | Measured | Indicated | Inferred | Total | Measured | Indicated | Inferred | Total | Section total |
| T. 22 N., R. 9 W. | | | | | | | | | | | | | |
| S ½ sec. 19 | ---- | ---- | ---- | ---- | 96 | 1,357 | ---- | 1,453 | ---- | ---- | ---- | ---- | 1,453 |
| sec. 30 | 13 | 675 | 1,549 | 2,237 | ---- | 689 | 4,983 | 5,672 | ---- | ---- | ---- | ---- | 7,909 |
| T. 22 N., R. 10 W. | | | | | | | | | | | | | |
| sec. 4 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| sec. 5 | ---- | ---- | ---- | ---- | 42 | 3,549 | 3,321 | 6,912 | ---- | ---- | ---- | ---- | 6,912 |
| S ½ sec. 6 | 268 | 1,325 | ---- | 1,593 | 1,980 | 8,277 | ---- | 10,257 | ---- | ---- | ---- | ---- | 11,850 |
| sec. 7 | 688 | 3,120 | ---- | 3,808 | 2,353 | 7,944 | ---- | 10,297 | 3,375 | 13,842 | ---- | 17,217 | 31,322 |
| sec. 8 | ---- | 319 | 117 | 436 | ---- | 4,766 | 5,235 | 10,001 | ---- | 9,934 | 13,925 | 23,859 | 34,296 |
| sec. 9 | ---- | ---- | ---- | ---- | ---- | 303 | ---- | 303 | 791 | 11,345 | ---- | 12,136 | 12,439 |
| SW ¼ sec. 10 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 4,590 | 2,450 | ---- | 7,040 | 7,040 |
| SW ¼ sec. 11 | ---- | ---- | ---- | ---- | ---- | 144 | 632 | 776 | ---- | 765 | 3,240 | 4,005 | 4,781 |
| SW ¼ sec. 13 | ---- | ---- | ---- | ---- | 765 | 2,781 | ---- | 3,546 | 20 | 1,435 | ---- | 1,455 | 5,001 |
| sec. 14 | ---- | ---- | ---- | ---- | 362 | 4,012 | 3,650 | 8,024 | 1,221 | 9,120 | 8,029 | 18,370 | 26,394 |
| sec. 15 | 441 | 2,315 | 739 | 3,495 | ---- | 218 | 48 | 266 | 3,375 | 22,457 | 5,650 | 31,482 | 35,243 |
| Leased sec. 16 | | | | | | (data not released) | | | | | | | |
| sec. 17 | 438 | 3,477 | 624 | 4,539 | ---- | 4,435 | 1,062 | 5,497 | 3,308 | 16,443 | 4,014 | 23,705 | 33,801 |
| sec. 18 | 1,918 | 2,508 | ---- | 4,426 | 3,938 | 10,345 | ---- | 14,283 | 4,155 | 5,620 | ---- | 9,775 | 28,484 |
| sec. 19 | 216 | 1,804 | 1,578 | 3,598 | ---- | 4,760 | 14,467 | 19,227 | ---- | ---- | ---- | ---- | 22,825 |
| sec. 22 | 63 | 1,379 | 2,756 | 4,198 | 324 | 2,447 | 4,405 | 6,976 | 1,145 | 8,136 | 1,986 | 11,207 | 22,441 |
| sec. 23 | 61 | 1,069 | 1,651 | 2,781 | 345 | 5,389 | 6,026 | 11,760 | 1,350 | 6,002 | 365 | 7,717 | 22,258 |
| sec. 24 | 253 | 947 | 83 | 1,283 | 2,701 | 10,735 | 3,632 | 17,068 | 21 | 423 | ---- | 444 | 18,795 |
| sec. 25 | 423 | 3,162 | 387 | 3,972 | ---- | ---- | 17,650 | 17,650 | ---- | ---- | ---- | ---- | 21,622 |
| N ½ sec. 26 | ---- | 73 | 2,055 | 2,128 | ---- | ---- | 7,408 | 7,408 | ---- | ---- | ---- | ---- | 9,536 |
| NE ¼ sec. 27 | ---- | ---- | 1,238 | ---- | ---- | ---- | 3,679 | 3,679 | ---- | ---- | ---- | ---- | 4,917 |
| T. 22 N., R. 11 W. | | | | | | | | | | | | | |
| sec. 12 | 395 | 4,550 | 1,297 | 6242 | ---- | 1,415 | 5,943 | 7,358 | ---- | ---- | ---- | ---- | 13,600 |
| Total for Area | 5,177 | 26,915 | 14,415 | 46,507 | 13,130 | 75,446 | 82,134 | 170,710 | 25,120 | 135,517 | 42,187 | 202,824 | 420,041 |

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Table 4.--Estimated identified coal resources of the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex.--continued

| | | 200-400 feet | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 1/2 - 5 feet | | | | 5-10 feet | | | | 10 feet or more | | | | |
| Location | | Measured | Indicated | Inferred | Total | Measured | Indicated | Inferred | Total | Measured | Indicated | Inferred | Total | Section total |
| T. 22 N., R. 9 W. | | | | | | | | | | | | | | |
| S ½ | sec. 19 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| | sec. 30 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| T. 22 N., R. 10 W. | | | | | | | | | | | | | | |
| | sec. 4 | 361 | 1,058 | 243 | 1,662 | ---- | ---- | ---- | ---- | 3,868 | 23,700 | 10,629 | 38,197 | 39,859 |
| | sec. 5 | 452 | 830 | 20 | 1,302 | ---- | ---- | ---- | ---- | 3,822 | 20,257 | 6,364 | 30,443 | 31,745 |
| S½ | sec. 6 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 1,219 | 6,525 | ---- | 7,744 | 7,744 |
| | sec. 7 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 1,570 | 7,091 | ---- | 8,661 | 8,661 |
| | sec. 8 | ---- | 2,030 | 1,682 | 3,712 | ---- | ---- | ---- | ---- | ---- | 12,730 | 10,667 | 23,397 | 27,109 |
| | sec. 9 | 1,478 | 4,173 | ---- | 5,651 | ---- | ---- | ---- | ---- | 8,947 | 24,849 | ---- | 33,796 | 39,447 |
| SW ¼ | sec. 10 | ---- | 95 | ---- | 95 | 15 | 31 | ---- | 46 | 424 | 1,418 | ---- | 1,842 | 1,983 |
| SW ¼ | sec. 11 | ---- | ---- | ---- | ---- | ---- | ---- | 30 | 30 | ---- | ---- | ---- | ---- | 30 |
| SW ¼ | sec. 13 | ---- | ---- | ---- | ---- | 238 | 1,235 | ---- | 1,473 | ---- | ---- | ---- | ---- | 1,473 |
| | sec. 14 | ---- | ---- | ---- | ---- | 548 | 3,675 | 2,537 | 6,760 | ---- | ---- | ---- | ---- | 6,760 |
| | sec. 15 | ---- | ---- | ---- | ---- | 438 | 4,636 | 936 | 6,010 | ---- | ---- | ---- | ---- | 6,010 |
| Leased | sec. 16 | | | | | | | | | | | | | |
| | sec. 17 | ---- | 360 | 21 | 381 | ---- | ---- | ---- | ---- | 305 | 3,088 | 298 | 3,691 | 4,072 |
| | sec. 18 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 17 | 280 | ---- | 297 | 297 |
| | sec. 19 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| | sec. 22 | ---- | ---- | ---- | ---- | 464 | 2,805 | 2,185 | 5,454 | ---- | ---- | ---- | ---- | 5,454 |
| | sec. 23 | ---- | ---- | ---- | ---- | 486 | 2,952 | 1,787 | 5,225 | ---- | ---- | ---- | ---- | 5,225 |
| | sec. 24 | ---- | ---- | ---- | ---- | 726 | 2,337 | 215 | 3,278 | ---- | ---- | ---- | ---- | 3,278 |
| | sec. 25 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| N ½ | sec. 26 | ---- | ---- | ---- | ---- | ---- | ---- | 310 | 310 | ---- | ---- | ---- | ---- | 310 |
| NE ¼ | sec. 27 | ---- | ---- | ---- | ---- | ---- | ---- | 164 | 164 | ---- | ---- | ---- | ---- | 164 |
| T. 22 N., R. 11 W. | | | | | | | | | | | | | | |
| | sec. 12 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Total for Area | | 2,291 | 9,091 | 1,966 | 13,348 | 2,915 | 18,873 | 9,092 | 30,880 | 20,452 | 103,236 | 28,009 | 151,697 | 195,925 |

Table 5.--Summary of estimated identified subbituminous coal resources of the Kimbeto EMRIA study site as of January 1, 1979

[In thousands of tons]

| | Overburden thickness (feet) | | |
| --- | --- | --- | --- |
| | 0-200 | 200-400 | Total |
| Coal beds 2½ to 5 feet thick | | | |
| Measured resources | 5,177 | 2,291 | 7,468 |
| Indicated resources | 26,915 | 9,091 | 36,006 |
| Inferred resources | 14,415 | 1,966 | 16,381 |
| Total | 46,507 | 13,348 | 59,855 |
| Coal beds 5 to 10 feet thick | | | |
| Measured resources | 13,130 | 2,915 | 16,045 |
| Indicated resources | 75,446 | 13,873 | 94,319 |
| Inferred resources | 82,134 | 9,092 | 91,226 |
| Total | 170,710 | 30,880 | 201,590 |
| Coal beds more than 10 feet thick | | | |
| Measured resources | 25,120 | 20,452 | 45,572 |
| Indicated resources | 135,517 | 103,236 | 238,753 |
| Inferred resources | 42,187 | 28,009 | 70,196 |
| Total | 202,824 | 151,697 | 354,521 |
| Total identified resources | 420,041 | 195,925 | 615,966 |

km) apart. Measured coal is projected to extend as a 1/4 mile (0.4 km) wide belt from the outcrop or points of observation or measurement.

Indicated - Resources are computed partly from specific measurements and partly from projections of visible data for a reasonable distance on the basis of geologic evidence. The points of observation are 1/2 (0.8 km) to 1 1/2 miles (2.4 km) apart. Indicated coal is projected to extend as a 1/2 mile (0.8 km) wide belt that lies more than 1/4 mile (0.4 km) from the outcrop or points of observation or measurement.

Inferred - Quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region, because few measurements of bed thickness are available. The estimates are based primarily on an assumed continuation from measured and indicated coal for which geologic evidence exists. The points of observation are 1 1/2 (2.4 km) to 6 miles (9.6 km) apart. Inferred coal is projected to extend as a 2 1/4-mile (3.6-km) wide belt that lies more than 3/4 mile (1.2 km) from the outcrop or points of observation or measurement.

All of the estimated resources in beds thicker than 5 feet (1.5 m) and at depths of 1,000 feet (305 m) or less fall into a category called reserve base, which is defined as that portion of the identified coal resource from which reserves are calculated. Reserves are that portion of the identified coal resource that can be economically mined at the time of determination. The reserve is derived by applying a recovery factor to that component of the identified coal resource designated as the reserve base. On a national basis the estimated recovery factor for the total reserve base is 50 percent. More precise recovery factors can be computed by determining the total coal in place and the total coal recoverable in any specific locale.

## CHARACTERISTICS USED IN RESOURCE EVALUATION

The coal characteristics that are commonly used in classifying coal resources are: rank, grade, and weight of the coal; thickness of the coal beds; and thickness of the overburden. Rank and grade have been discussed previously.

### Weight

The weight of the coal ranges considerably with differences in rank and ash content. In areas such as the Kimbeto EMRIA study site, where true specific gravities of the coal have not been determined, an average specific gravity value based on many determinations in other areas is used to express the weight of the coal for resource calculations. The average weight of subbituminous coal is taken as 1,800 tons per acre-foot--a specific gravity of 1.30.

### Thickness of beds

Because of the important relationship of coal-bed thickness to utilization potential, most coal resource estimates prepared by the U.S. Geological Survey are tabulated according to three thickness categories. Because the coal evaluated in this report is so close to the bituminous-subbituminous division of rank, the thickness categories used are thin (2.5 to 5 feet, 0.75 to 1.5 m); intermediate (5 to 10 feet, 1.5 to 3 m); and thick (more than 10 feet, 3 m). About 86 percent of the estimated resources of the study area is in the thin category and about 14 percent is in the intermediate category. By way of comparison, Averitt (1975, Figure 5 and page 37) showed the distribution of the estimated resources of 21 states as 42 percent in the thin category, 25 percent in the intermediate category, and 33 percent in the thick category.

## Thickness of overburden

All of the estimated coal resources in the Kimbeto EMRIA site are overlain by 400 feet (120 m) or less of overburden.

## SUMMARY OF RESOURCES

Total estimated identified original resources in the Kimbeto EMRIA site are 615,966,000 tons (558,681,000 metric tons). The coal-bed thickness class of 2.5-5 feet contains 59,855,000 tons (54,288,000 metric tons). The coal-bed thickness class of 5-10 feet contains 201,590,000 tons (182,882,000 metric tons) of the estimated resources. The coal-bed thickness class of greater than 10 feet contains 354,521,000 tons (321,621,000 metric tons) of the estimated resources.

The estimated resources presented in this report are original resources; that is, resources in the ground before the beginning of mining operations.

## CHEMICAL ANALYSES OF COAL AND COALY SHALE IN THE FRUITLAND FORMATION

Fourteen samples of coal and three samples of coaly shale were collected by the U.S. Geological Survey from four core holes in the Kimbeto study area. These samples are briefly described in table 2. Proximate and ultimate analyses, heat-of-combustion, air-dried-loss, forms-of-sulfur, and ash-fusion-temperature determinations for all 17 samples are listed in table 3. These analyses were provided by the Coal Analysis Section of the U.S. Department of Energy, Pittsburgh, Pa. Analyses for ash content, and 32 major and minor oxides and trace elements in the laboratory ash (table 6), and analyses of nine trace elements in whole-coal and shale (table 7) for the samples were provided by the Analytical Laboratories of the U.S. Geological Survey in Denver, Colo. Analytical procedures used by the U.S. Geological Survey are described in Swanson and Huffman (1976). Table 8 contains the data listed in table 6 converted to a whole-coal and shale basis and includes the whole-coal

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Table 6.--Major- and minor-oxide and trace-element composition of the laboratory ash of 17 coal and shale samples from the Fruitland Formation, Kimbeto study site, San Juan County, N. Mex.

[Values in percent or parts per million. Coal ashed at 525°C. L means less than the value shown; N, not detected; B, not determined. S after element title indicates determinations by semiquantative emission spectrography. The emission spectrographic results are to be identified with geometric brackets whose boundaries are part of the ascending series 0.12, 0.18, 0.26, 0.38, 0.56, 0.83, 1.2, etc., but reported as mid-points of the brackets, 0.1, 0.15, 0.2, 0.3, 0.5, 0.7, 0.1, etc. Precision of the spectrographic data is plus-or-minus one bracket at 68 percent or plus-or-minus two brackets at 95 percent confidence level]

| Sample number | Ash (percent) | SiO2 (percent) | Al2O3 (percent) | CaO (percent) | MgO (percent) | Na2O (percent) | K2O (percent) | Fe2O3 (percent) | TiO2 (percent) | SO3 (percent) | Sample number |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D194012 | 18.1 | 60 | 27 | 2.2 | 0.57 | 2.11 | 0.39 | 2.7 | 1.3 | 4.3 | D194012 |
| D194013 | 79.0 | 74 | 19 | .46 | 1.23 | 1.83 | 1.5 | 4.0 | .61 | 1.0L | D194013 |
| D194014 | 52.8 | 74 | 20 | .56 | .84 | 1.77 | .87 | 2.9 | .57 | 1.0L | D194014 |
| D194015 | 28.6 | 64 | 27 | 1.5 | .61 | 1.61 | .48 | 2.2 | 1.2 | 2.9 | D194015 |
| D194016 | 13.5 | 52 | 26 | 2.8 | .77 | 2.91 | .17 | 4.2 | 1.0 | 5.6 | D194016 |
| D194017 | 10.3 | 53 | 22 | 6.3 | .61 | 2.61 | .48 | 3.3 | 1.3 | 11 | D194017 |
| D194018 | 20.8 | 53 | 30 | 3.0 | .42 | 1.34 | .46 | 2.8 | 1.3 | 4.9 | D194018 |
| D194019 | 32.8 | 67 | 23 | 1.4 | .73 | 1.44 | .46 | 3.7 | .98 | 2.6 | D194019 |
| D194020 | 28.9 | 65 | 26 | 1.1 | .64 | 1.61 | .82 | 2.0 | .88 | 2.1 | D194020 |
| D194021 | 36.9 | 65 | 24 | 1.0 | .81 | 1.57 | .82 | 2.4 | .82 | 1.7 | D194021 |
| D194022 | 28.1 | 66 | 23 | 1.1 | .86 | 1.74 | .99 | 2.7 | .90 | 2.6 | D194022 |
| D194023 | 25.3 | 58 | 26 | 2.5 | .52 | 1.21 | .82 | 3.0 | 1.1 | 3.0 | D194023 |
| D194024 | 32.3 | 68 | 21 | 1.3 | .73 | 1.62 | 1.2 | 2.7 | 1.0 | 2.2 | D194024 |
| D194025 | 29.8 | 65 | 23 | 1.3 | .77 | 1.57 | .77 | 2.7 | 1.0 | 2.4 | D194025 |
| D194026 | 33.9 | 66 | 26 | .89 | .70 | 1.59 | .70 | 2.5 | .89 | 1.7 | D194026 |
| D194027 | 75.2 | 73 | 16 | .33 | 1.32 | 1.87 | 2.3 | 5.9 | .68 | 1.5 | D194027 |
| D194028 | 23.8 | 58 | 28 | 2.4 | .47 | 1.47 | .49 | 2.1 | 1.1 | 2.9 | D194028 |

| Sample number | B-S (ppm) | Ba-S (ppm) | Be-S (ppm) | Cd (ppm) | Cu (ppm) | Ga-S (ppm) | Ge-S (ppm) | La-S (ppm) | Li (ppm) | Mn (ppm) | Sample number |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D194012 | 500 | 700 | 20 | 1.0 | 69 | 70 | 30 | 100L | 100 | 54 | D194012 |
| D194013 | 70 | 500 | 3 | 1.0L | 25 | 30 | N | 100L | 30 | 74 | D194013 |
| D194014 | 100 | 500 | 10 | 1.0L | 28 | 20 | 20L | 100L | 41 | 30 | D194014 |
| D194015 | 300 | 500 | 10 | 1.0L | 78 | 70 | N | 100L | 96 | 52 | D194015 |
| D194016 | 500 | 1,000 | 10 | 1.0L | 54 | 50 | 20L | 100L | 232 | 110 | D194016 |
| D194017 | 700 | 1,500 | 30 | 1.0L | 133 | 70 | 50 | 150 | 80 | 310 | D194017 |
| D194018 | 300 | 700 | 3 | 1.0 | 81 | 70 | N | 100L | 105 | 190 | D194018 |
| D194019 | 300 | 500 | 10 | 1.0L | 54 | 50 | N | 100L | 85 | 56 | D194019 |
| D194020 | 300 | 700 | 7 | 1.0L | 43 | 50 | N | 100L | 96 | 52 | D194020 |
| D194021 | 200 | 500 | 15 | 1.0L | 54 | 50 | N | 100L | 72 | 54 | D194021 |
| D194022 | 300 | 700 | 5 | 1.0L | 43 | 50 | N | 100L | 105 | 74 | D194022 |
| D194023 | 300 | 500 | 3 | 1.0L | 60 | 50 | N | 100L | 78 | 210 | D194023 |
| D194024 | 300 | 500 | 15 | 1.0L | 54 | 30 | N | 100L | 109 | 380 | D194024 |
| D194025 | 300 | 500 | 15 | 1.0L | 54 | 70 | N | 100L | 80 | 110 | D194025 |
| D194026 | 200 | 500 | 7 | 1.0L | 37 | 50 | N | 100L | 75 | 40 | D194026 |
| D194027 | 70 | 300 | 3 | 1.0L | 25 | 30 | N | 100L | 41 | 98 | D194027 |
| D194028 | 300 | 700 | 5 | 1.0 | 60 | 70 | N | 100L | 80 | 135 | D194028 |

Table 6.--Major- and minor-oxide and trace-element composition of the laboratory ash of 17 coal and shale samples from the Fruitland Formation, Kimbeto study site, San Juan County, N. Mex.--Continued

| Sample number | Mo-S (ppm) | Nb-S (ppm) | Nd-S (ppm) | Ni-S (ppm) | Pb (ppm) | Sc-S (ppm) | Sr-S (ppm) | V-S (ppm) | Y-S (ppm) | Yb-S (ppm) | Sample number |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D194012 | 10 | 30 | N | 20 | 70 | 30 | 500 | 150 | 100 | 7 | D194012 |
| D194013 | N | 20L | N | 10 | 30 | 15 | 200 | 70 | 30 | 3 | D194013 |
| D194014 | N | 20L | N | 10L | 30 | 10 | 200 | 70 | 50 | 3 | D194014 |
| D194015 | N | 30 | N | 10 | 70 | 15 | 300 | 150 | 50 | 5 | D194015 |
| D194016 | N | 30 | N | 20 | 50 | 15 | 700 | 70 | 70 | 7 | D194016 |
| D194017 | 15 | 30 | 150 | 70 | 75 | 50 | 1,000 | 200 | 150 | 15 | D194017 |
| D194018 | 10 | 30 | N | 15 | 70 | 15 | 300 | 150 | 30 | 3 | D194018 |
| D194019 | 7 | 30 | N | 20 | 60 | 15 | 200 | 70 | 50 | 3 | D194019 |
| D194020 | 7L | 30 | N | 15 | 55 | 10 | 200 | 70 | 50 | 3 | D194020 |
| D194021 | 7L | 30 | N | 15 | 55 | 15 | 200 | 100 | 50 | 3 | D194021 |
| D194022 | N | 30 | N | 15 | 45 | 15 | 300 | 70 | 30 | 3 | D194022 |
| D194023 | 7 | 30 | N | 10 | 60 | 15 | 200 | 70 | 30 | 3 | D194023 |
| D194024 | 7L | 30 | N | 15 | 40 | 15 | 200 | 100 | 50 | 5 | D194024 |
| D194025 | 7 | 30 | N | 20 | 45 | 20 | 300 | 150 | 70 | 7 | D194025 |
| D194026 | N | 30 | N | 10 | 55 | 10 | 200 | 70 | 30 | 3 | D194026 |
| D194027 | N | 30 | N | 20 | 25L | 15 | 150 | 100 | 30 | 3 | D194027 |
| D194028 | 7 | 30 | N | 15 | 70 | 15 | 300 | 150 | 50 | 3 | D194028 |

| Sample number | Zn (ppm) | Zr-S (ppm) |
|---|---|---|
| D194012 | 36 | 500 |
| D194013 | 144 | 100 |
| D194014 | 138 | 150 |
| D194015 | 46 | 300 |
| D194016 | 34 | 300 |
| D194017 | 49 | 300 |
| D194018 | 54 | 300 |
| D194019 | 49 | 200 |
| D194020 | 61 | 200 |
| D194021 | 109 | 200 |
| D194022 | 69 | 300 |
| D194023 | 80 | 200 |
| D194024 | 49 | 200 |
| D194025 | 79 | 200 |
| D194026 | 45 | 150 |
| D194027 | 97 | 150 |
| D194028 | 55 | 300 |

Table 7.--Content of nine trace elements of 17 coal and shale samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex.

[Analyses on air-dried (32°C) coal. Values in parts per million (ppm). B, not determined; L, less than the value shown]

| Sample number | As | Co | Cr | F | Hg | Sb | Se | Th | U | Sample number |
|---|---|---|---|---|---|---|---|---|---|---|
| D194012 | 1.0 | 3.1 | 4.9 | 40 | 0.05 | 1.9 | 2.5 | 5.0 | 4.0 | D194012 |
| D194013 | 2.0 | 6.3 | B | 480 | .10 | 1.3 | B | 12 | 4.7 | D194013 |
| D194014 | 8.0 | 5.6 | B | 180 | .11 | 1.1 | B | 4.0 | 2.7 | D194014 |
| D194015 | 1.0 | 2.3 | 9.6 | 75 | .07 | 1.2 | 2.8 | 6.0 | 5.3 | D194015 |
| D194016 | 2.0 | 1.7 | 3.8 | 20 | .04 | .6 | 1.7 | 4.0 | 2.1 | D194016 |
| D194017 | 1.0 | 5.3 | 5.5 | 30 | .03 | 2.8 | 1.3 | 3.0L | 2.4 | D194017 |
| D194018 | 1.0 | 2.3 | 4.8 | 80 | .07 | .6 | 2.4 | 3.0 | 3.2 | D194018 |
| D194019 | 14 | 2.9 | 8.0 | 105 | .23 | 1.2 | 2.6 | 11 | 4.5 | D194019 |
| D194020 | 1.0 | 2.3 | 5.5 | 85 | .11 | .8 | 1.5 | 5.0 | 3.0 | D194020 |
| D194021 | 1.0 | 5.5 | 8.7 | 155 | .13 | 1.9 | 2.0 | 10 | 5.9 | D194021 |
| D194022 | 1.0 | 2.2 | 7.2 | 110 | .07 | .5 | 1.8 | 6.0 | 3.5 | D194022 |
| D194023 | 1.0 | 2.3 | 6.6 | 110 | .08 | .7 | 2.2 | 6.0 | 3.1 | D194023 |
| D194024 | 1.0 | 3.2 | 11 | 115 | .04 | 1.2 | 2.2 | 9.0 | 3.7 | D194024 |
| D194025 | 1.0 | 4.3 | 11 | 135 | .07 | 1.3 | 2.2 | 9.0 | 4.3 | D194025 |
| D194026 | 2.0 | 1.9 | 6.2 | 125 | .06 | .9 | B | 9.0 | 4.1 | D194026 |
| D194027 | 10 | 8.2 | 26 | 410 | .11 | 1.2 | B | 9.0 | 4.0 | D194027 |
| D194028 | 7.0 | 1.9 | 4.8 | 80 | .10 | .6 | 2.2 | 6.0 | 3.4 | D194028 |

Table 8.--Major-, minor-, and trace-element composition of 17 coal and shale samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex.

[Values in percent or parts per million. As, Co, Cr, F, Hg, Sb, Se, Th, and U values are from direct determinations on air-dried (32°C) coal; all other values calculated from analyses of ash. S means analysis by emission spectrography; L, less than the value shown; N, not detected; B, not determined]

| Sample number | Si (percent) | Al (percent) | Ca (percent) | Mg (percent) | Na (percent) | K (percent) | Fe (percent) | Ti (percent) | As (ppm) | B-S (ppm) | Sample number |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D194012 | 5.1 | 2.6 | 0.28 | 0.062 | 0.28 | 0.059 | 0.34 | 0.14 | 1.0 | 100 | D194012 |
| D194013 | 27 | 7.9 | .26 | .58 | 1.1 | .99 | 2.2 | .29 | 2.0 | 50 | D194013 |
| D194014 | 18 | 5.6 | .21 | .27 | .69 | .38 | 1.1 | .18 | 8.0 | 50 | D194014 |
| D194015 | 8.5 | 4.1 | .31 | .11 | .34 | .11 | .44 | .21 | 1.0 | 100 | D194015 |
| D194016 | 3.3 | 1.9 | .27 | .063 | .29 | .019 | .40 | .081 | 2.0 | 70 | D194016 |
| D194017 | 2.5 | 1.2 | .46 | .038 | .20 | .041 | .24 | .080 | 1.0 | 70 | D194017 |
| D194018 | 5.1 | 3.3 | .45 | .053 | .21 | .080 | .41 | .16 | 1.0 | 70 | D194018 |
| D194019 | 10 | 4.0 | .33 | .14 | .35 | .13 | .85 | .19 | 14 | 100 | D194019 |
| D194020 | 8.8 | 4.0 | .23 | .11 | .34 | .20 | .40 | .15 | 1.0 | 100 | D194020 |
| D194021 | 11 | 4.7 | .26 | .18 | .43 | .25 | .62 | .18 | 1.0 | 70 | D194021 |
| D194022 | 8.7 | 3.4 | .22 | .15 | .36 | .23 | .53 | .15 | 1.0 | 100 | D194022 |
| D194023 | 6.9 | 3.5 | .45 | .079 | .23 | .17 | .53 | .17 | 1.0 | 70 | D194023 |
| D194024 | 10 | 3.6 | .30 | .14 | .39 | .32 | .61 | .19 | 1.0 | 100 | D194024 |
| D194025 | 9.0 | 3.6 | .28 | .14 | .35 | .19 | .56 | .18 | 1.0 | 100 | D194025 |
| D194026 | 10 | 4.7 | .22 | .14 | .40 | .20 | .59 | .18 | 2.0 | 70 | D194026 |
| D194027 | 26 | 6.4 | .18 | .60 | 1.0 | 1.4 | 3.1 | .31 | 10 | 50 | D194027 |
| D194028 | 6.4 | 3.5 | .41 | .067 | .26 | .097 | .35 | .16 | 7.0 | 70 | D194028 |

(26)

| Sample number | Ba-S (ppm) | Be-S (ppm) | Cd (ppm) | Co (ppm) | Cr (ppm) | Cu (ppm) | F (ppm) | Ga-S (ppm) | Ge-S (ppm) | Hg (ppm) | Sample number |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D194012 | 150 | 3 | 0.18 | 3.1 | 4.9 | 12 | 40 | 15 | 5 | 0.05 | D194012 |
| D194013 | 500 | 2 | .79L | 6.3 | B | 20 | 480 | 20 | N | .10 | D194013 |
| D194014 | 300 | 5 | .53L | 5.6 | B | 15 | 180 | 10 | 10L | .11 | D194014 |
| D194015 | 150 | 3 | .29L | 2.3 | 9.6 | 22 | 75 | 20 | N | .07 | D194015 |
| D194016 | 150 | 1.5 | .14L | 1.7 | 3.8 | 7.3 | 20 | 7 | 3L | .04 | D194016 |
| D194017 | 150 | 3 | .10L | 5.3 | 5.5 | 14 | 30 | 7 | 5 | .03 | D194017 |
| D194018 | 150 | .7 | .21 | 2.3 | 4.8 | 17 | 80 | 15 | N | .07 | D194018 |
| D194019 | 150 | 3 | .33L | 2.9 | 8.0 | 18 | 105 | 15 | N | .23 | D194019 |
| D194020 | 200 | 2 | .29L | 2.3 | 5.5 | 12 | 85 | 15 | N | .11 | D194020 |
| D194021 | 200 | 5 | .37L | 5.5 | 8.7 | 20 | 155 | 20 | N | .13 | D194021 |
| D194022 | 200 | 1.5 | .28L | 2.2 | 7.2 | 12 | 110 | 15 | N | .07 | D194022 |
| D194023 | 150 | .7 | .25L | 2.3 | 6.6 | 15 | 110 | 15 | N | .08 | D194023 |
| D194024 | 150 | 5 | .32L | 3.2 | 11 | 17 | 115 | 10 | N | .04 | D194024 |
| D194025 | 150 | 5 | .30L | 4.3 | 11 | 16 | 135 | 20 | N | .07 | D194025 |
| D194026 | 150 | 2 | .34L | 1.9 | 6.2 | 13 | 125 | 15 | N | .06 | D194026 |
| D194027 | 200 | 2 | .75L | 8.2 | 26 | 19 | 410 | 20 | N | .11 | D194027 |
| D194028 | 150 | 1 | .24 | 1.9 | 4.8 | 14 | 80 | 15 | N | .10 | D194028 |

Table 8.--Major-, minor-, and trace-element composition of 17 coal and shale samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex.--Continued

| Sample number | La-S (ppm) | Li (ppm) | Mn (ppm) | Mo-S (ppm) | Nb-S (ppm) | Nd-S (ppm) | Ni-S (ppm) | Pb (ppm) | Sb (ppm) | Sc-S (ppm) | Sample number |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D194012 | 20L | 18 | 9.8 | 2 | 5 | N | 3 | 13 | 1.9 | 5 | D194012 |
| D194013 | 70L | 24 | 58 | N | 15L | N | 7 | 24 | 1.3 | 10 | D194013 |
| D194014 | 50L | 22 | 16 | N | 10L | N | 5L | 16 | 1.1 | 5 | D194014 |
| D194015 | 30L | 27 | 15 | N | 10 | N | 3 | 20 | 1.2 | 5 | D194015 |
| D194016 | 15L | 31 | 15 | N | 5 | N | 3 | 6.8 | .6 | 2 | D194016 |
| D194017 | 15 | 8.2 | 32 | 1.5 | 3 | 15 | 7 | 7.7 | 2.8 | 5 | D194017 |
| D194018 | 20L | 22 | 40 | 2 | 7 | N | 3 | 15 | .6 | 3 | D194018 |
| D194019 | 30L | 28 | 18 | 2 | 10 | N | 7 | 20 | 1.2 | 5 | D194019 |
| D194020 | 30L | 28 | 15 | 2L | 10 | N | 5 | 16 | .8 | 3 | D194020 |
| D194021 | 30L | 27 | 20 | 2L | 10 | N | 5 | 20 | 1.9 | 5 | D194021 |
| D194022 | 30L | 30 | 21 | N | 10 | N | 5 | 13 | .5 | 5 | D194022 |
| D194023 | 20L | 20 | 53 | 1.5 | 7 | N | 2 | 15 | .7 | 3 | D194023 |
| D194024 | 30L | 35 | 120 | 2L | 10 | N | 5 | 13 | 1.2 | 5 | D194024 |
| D194025 | 30L | 24 | 33 | 2 | 10 | N | 7 | 13 | 1.3 | 7 | D194025 |
| D194026 | 30L | 25 | 14 | N | 10 | N | 3 | 19 | .9 | 3 | D194026 |
| D194027 | 70L | 31 | 74 | N | 20 | N | 15 | 19L | 1.2 | 10 | D194027 |
| D194028 | 20L | 19 | 32 | 1.5 | 7 | N | 3 | 17 | .6 | 3 | D194028 |

(27)

| Sample number | Se (ppm) | Sr-S (ppm) | Th (ppm) | U (ppm) | V-S (ppm) | Y-S (ppm) | Yb-S (ppm) | Zn (ppm) | Zr-S (ppm) | Sample number |
|---|---|---|---|---|---|---|---|---|---|---|
| D194012 | 2.5 | 100 | 5.0 | 4.0 | 30 | 20 | 1.5 | 6.5 | 100 | D194012 |
| D194013 | B | 150 | 12.0 | 4.7 | 50 | 20 | 2 | 110 | 70 | D194013 |
| D194014 | B | 100 | 4.0 | 2.7 | 30 | 30 | 1.5 | 73 | 70 | D194014 |
| D194015 | 2.8 | 100 | 6.0 | 5.3 | 50 | 15 | 1.5 | 13 | 100 | D194015 |
| D194016 | 1.7 | 100 | 4.0 | 2.1 | 10 | 10 | 1 | 4.6 | 50 | D194016 |
| D194017 | 1.3 | 100 | 3.0L | 2.4 | 20 | 15 | 1.5 | 5.0 | 30 | D194017 |
| D194018 | 2.4 | 70 | 3.0 | 3.2 | 30 | 7 | .7 | 11 | 70 | D194018 |
| D194019 | 2.6 | 70 | 11.0 | 4.5 | 20 | 15 | 1 | 16 | 70 | D194019 |
| D194020 | 1.5 | 70 | 5.0 | 3.0 | 20 | 15 | 1 | 18 | 70 | D194020 |
| D194021 | 2.0 | 70 | 10.0 | 5.9 | 30 | 20 | 1 | 40 | 70 | D194021 |
| D194022 | 1.8 | 100 | 6.0 | 3.5 | 20 | 10 | 1 | 19 | 100 | D194022 |
| D194023 | 2.2 | 50 | 6.0 | 3.1 | 15 | 7 | .7 | 20 | 50 | D194023 |
| D194024 | 2.2 | 70 | 9.0 | 3.7 | 30 | 15 | 1.5 | 16 | 70 | D194024 |
| D194025 | 2.2 | 100 | 9.0 | 4.3 | 50 | 20 | 2 | 24 | 70 | D194025 |
| D194026 | B | 70 | 9.0 | 4.1 | 20 | 10 | 1 | 15 | 50 | D194026 |
| D194027 | B | 100 | 9.0 | 4.0 | 70 | 20 | 2 | 73 | 100 | D194027 |
| D194028 | 2.2 | 70 | 6.0 | 3.4 | 30 | 10 | .7 | 13 | 70 | D194028 |

Table 9.--Elements looked for but not detected in coal and shale samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex.

[Approximate lower detection limits in coal and shale ash, as determined by the six-step spectrographic method of the U.S. Geological Survey are included for all elements except P; the reported lower detection limit of P is for the x-ray spectroscopic method]

| Element | Lower limit of detection in coal ash (ppm) |
|---|---|
| Ag | 1 |
| Au | 50 |
| Bi | 20 |
| Ce | 500 |
| Dy | 100 |
| Er | 100 |
| Eu | 200 |
| Gd | 100 |
| Hf | 200 |
| Ho | 50 |
| In | 20 |
| Lu | 70 |
| P | 4,400 |
| Pd | 5 |
| Pr | 200 |
| Pt | 100 |
| Re | 100 |
| Sm | 200 |
| Sn | 20 |
| Ta | 1,000 |
| Tb | 700 |
| Te | 5,000 |
| Tl | 100 |
| Tm | 50 |
| W | 200 |

Table 10.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate and ultimate analyses, heat of combustion, forms of sulfur, and ash-fusion temperatures, of 14 coal samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex.

[For comparison, geometric means for 86 Rocky Mountain province coal samples are included (Swanson and others, 1976, table 33a). All values are in percent except heat of combustion and ash-fusion temperatures, and are reported on the as-received basis. C° = (°F-32)5/9; Kcal/kg =9.556 (Btu/lb). Leaders (---) indicate no data]

| | Arithmetic mean | Observed range | | Geometric mean | Geometric deviation | Rocky Mountain province geometric mean |
|---|---|---|---|---|---|---|
| | | Minimum | Maximum | | | |
| | | Proximate and ultimate analyses | | | | |
| Moisture | 14.6 | 12.7 | 16.8 | 14.5 | 1.1 | 10.5 |
| Volatile matter | 29.6 | 25.7 | 34.5 | 29.5 | 1.1 | 35.7 |
| Fixed carbon | 32.4 | 25.6 | 41.3 | 32.0 | 1.2 | 41.5 |
| Ash | 23.8 | 9.3 | 33.2 | 22.0 | 1.5 | 7.7 |
| Hydrogen | 5.3 | 4.8 | 6.2 | 5.3 | 1.1 | 5.6 |
| Carbon | 46.8 | 37.5 | 59.4 | 46.4 | 1.1 | 58.9 |
| Nitrogen | 1.0 | .8 | 1.2 | 1.0 | 1.1 | 1.1 |
| Oxygen | 23.0 | 21.4 | 25.4 | 23.0 | 1.1 | 22.4 |
| Sulfur | .5 | .4 | .7 | .5 | 1.2 | .5 |
| | | Heat of combustion | | | | |
| Kcal/kg | 4,590 | 3,680 | 5,790 | 4,540 | 1.1 | 6,180 |
| Btu/lb | 8,250 | 6,620 | 10,410 | 8,170 | 1.1 | 11,110 |
| | | Forms of sulfur | | | | |
| Sulfate | 0.03 | 0.01 | 0.05 | 0.02 | 1.6 | 0.02 |
| Pyritic | .12 | .04 | .23 | .11 | 1.6 | .11 |
| Organic | .38 | .23 | .55 | .37 | 1.3 | .22 |
| | | Ash-fusion temperatures, °C | | | | |
| Initial deformation | 1,500 | 1,325 | 1,540 | 1,500 | 1.1 | ---- |
| Softening temperature | 1,515 | 1,375 | 1,540 | 1,520 | 1.0 | ---- |
| Fluid temperature | 1,530 | 1,430 | 1,540 | 1,530 | 1.0 | ---- |

Table 11.--Arithmetic mean, observed range, geometric mean, and geometric deviation of ash content and contents of nine major and minor oxides in the laboratory ash of 14 coal samples from the Fruitland Formation, Kimbeto EMRIA study site, San Juan County, N. Mex.

[For comparison geometric means for 79 other San Juan River region coal samples are included (Hatch and Swanson, 1977, table a). All samples were ashed at 525°C; all analyses except geometric deviation are in percent]

| Oxide | Arithmetic mean | Observed range | | Geometric mean | Geometric deviation | San Juan River region geometric mean |
|---|---|---|---|---|---|---|
| | | Minimum | Maximum | | | |
| (Ash) | 26 | 10 | 37 | 25 | 1.4 | 19.4 |
| $SiO_2$ | 62 | 52 | 68 | 61 | 1.1 | 53 |
| $Al_2O_3$ | 25 | 21 | 30 | 25 | 1.1 | 24 |
| CaO | 2.0 | .90 | 6.3 | 1.8 | 1.7 | 3.9 |
| MgO | .66 | .42 | .86 | .64 | 1.2 | .84 |
| $Na_2O$ | 1.7 | 1.2 | 2.9 | 1.7 | 1.3 | 1.4 |
| $K_2O$ | .66 | .17 | 1.2 | .59 | 1.6 | .54 |
| $Fe_2O_3$ | 2.8 | 2.0 | 4.2 | 2.7 | 1.2 | 3.5 |
| $TiO_2$ | 1.1 | .8 | 1.3 | 1.0 | 1.2 | .95 |
| $SO_3$ | 3.5 | 1.7 | 11 | 3.1 | 1.7 | 3.2 |

Table 12.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 35 elements in 14 coal samples from the Fruitland Formation at the Kimbeto EMRIA study site, San Juan County, N. Mex.

[For comparison, geometric means for 79 other San Juan River region coal samples are included. All analyses are in percent or parts per million and are reported on a whole-coal bassis. As, Co, Cr, F, Hg, Sb, Se, Th, and U values used to calculate the statisitics were determined directly on whole coal. All other values were calculated from determinations made on coal ash. L, less than the value shown]

| Element | Arithmetic mean | Observed range Minimum | Maximum | Geometric mean | Geometric deviation | San Juan River region geometric mean |
|---|---|---|---|---|---|---|
| Si | 7.8 | 2.5 | 11 | 7.0 | 1.6 | 4.8 |
| Al | 3.5 | 1.2 | 4.7 | 3.3 | 1.5 | 2.4 |
| Ca | .32 | .22 | .46 | .31 | 1.3 | .54 |
| Mg | .11 | .04 | .18 | .10 | 1.6 | .099 |
| Na | .32 | .20 | .43 | .31 | 1.3 | .203 |
| K | .16 | .02 | .32 | .12 | 2.2 | .088 |
| Fe | .49 | .24 | .85 | .47 | 1.4 | .48 |
| Ti | .16 | .08 | .21 | .15 | 1.3 | .097 |
| | | | Parts per million | | | |
| As | 2.1 | 1 | 14 | 1.5 | 2.3 | 2 |
| B | 100 | 70 | 100 | 100 | 1.2 | 100 |
| Ba | 150 | 150 | 200 | 150 | 1.1 | 300 |
| Be | 3 | .7 | 5 | 2 | 2.0 | 1 |
| Co | 2.9 | 1.7 | 5.5 | 2.7 | 1.5 | 2 |
| Cr | 7 | 3.8 | 11 | 6.6 | 1.4 | 5 |
| Cu | 15 | 7.3 | 22 | 15 | 1.3 | 12.4 |
| F | 90 | 20 | 155 | 79 | 1.4 | 92 |
| Ga | 15 | 7 | 20 | 15 | 1.4 | 7 |
| Hg | .08 | .03 | .23 | .07 | 1.7 | .08 |
| Li | 25 | 8.2 | 35 | 23 | 1.4 | 17.7 |
| Mn | 31 | 9.8 | 120 | 25 | 1.9 | 23 |
| Mo | 1.5 | 1.5L | 2 | 1.5 | 1.3 | 1 |
| Nb | 7 | 3 | 10 | 7 | 1.5 | 2 |
| Ni | 5 | 2 | 7 | 5 | 1.5 | 2 |
| Pb | 15 | 6.8 | 20 | 14 | 1.4 | 11.7 |
| Sb | 1.2 | .5 | 2.8 | 1 | 1.7 | .4 |
| Sc | 5 | 2 | 7 | 5 | 1.4 | 3 |
| Se | 2.1 | 1.3 | 2.8 | 2.1 | 1.3 | 1.9 |
| Sr | 70 | 50 | 100 | 70 | 1.2 | 100 |
| Th | 6.6 | 3.0L | 11 | 6.0 | 1.6 | 4.3 |
| U | 3.8 | 2.1 | 5.9 | 3.6 | 1.3 | 2.2 |
| V | 30 | 10 | 50 | 20 | 1.5 | 20 |
| Y | 15 | 7 | 20 | 15 | 1.4 | 7 |
| Yb | 1.5 | .7 | 2 | 1 | 1.4 | .7 |
| Zn | 16 | 4.6 | 40 | 14 | 1.8 | 11.1 |
| Zr | 70 | 30 | 100 | 70 | 1.4 | 50 |

and shale analyses listed in table 7. Twenty-five additional elements were looked for but not found in amounts greater than their lower limit of detection (table 9).

Unweighed statistical summaries of analytical data on the 14 coal samples in tables 3, 6, and 8, are listed in tables 10, 11, and 12, respectively. For comparison, data summaries of proximate, ultimate, forms-of-sulfur analyses, and heat of combustion for 86 other Rocky Mountain province coal samples (Swanson and others, 1976) and data summaries of major, minor, and trace elements for 79 other San Juan River region coal samples (Hatch and Swanson, 1977), are included. Data summaries for Cd, Ge, La, and Nd were not made because they were detected in an insufficient number of samples to calculate meaningful statistics.

To be consistent with the precision of the semiquantitative emission spectrographic technique, arithmetic and geometric means of elements determined by this method are reported as the mid-point of the enclosing six-step bracket (see headnote of table 6, or Swanson and Huffman, 1976, p. 6, for an explanation of six-step brackets).

## EXPLANATION OF STATISTICAL TERMS USED IN SUMMARY TABLES

In this report the geometric mean (GM) is used as the estimate of the most probable concentration (mode); the geometric mean is calculated by taking the logarithm of each analytical value, summing the logarithms, dividing the sum by the total number of values, and obtaining the antilogarithm of the result. The measure of scatter about the mode used here is the geometric deviation (GD), which is the antilog of the standard deviation of the logarithms of the analytical values. These statistics are used because the quantities of trace elements in natural materials commonly exhibit positively skewed frequency distributions; such distributions are normalized by analyzing and summarizing trace-element data on a logarithmic basis.

If the frequency distributions are lognormal, the geometric mean is the best estimate of the mode, and the estimated range of the central two-thirds of the observed distribution has a lower limit equal to GM/GD and an upper limit equal to GM GD. The estimated range of the central 95 percent of the observed distribution has a lower limit equal to $GM/(GD)^2$ and an upper limit equal to $GM\ (GD)^2$ (Connor and others, 1976).

Although the geometric mean is, in general, an adequate estimate of the most common analytical value, it is, nevertheless, a biased estimate of the arithmetic mean. The estimates of the arithmetic means listed in the summary tables are Sichel's _t_ statistic (Miesch, 1967).

A common problem in statistical summaries of trace-element data arises when the element content of one or more of the samples is below the limit of analytical detection. This results in a "censored" distribution. Procedures developed by Cohen (1959) were used to compute unbiased estimates of the geometric mean, geometric deviation, and arithmetic mean when the data are censored.

## DISCUSSION

The apparent ranks of the 14 coal samples were calculated using the data in table 3 and the formulae in ASTM designation D-388-77 (American Society for Testing of Materials, 1978). The apparent rank ranges from subbituminous B (six samples) to subbituminous A coal (8 samples).

A statistical comparison (students t-test, 95-percent confidence level) of the geometric means of 14 U.S. Department of Energy analyses of coal from the Fruitland Formation of the Kimbeto EMRIA study site with 86 other coal analyses from the Rocky Mountain province shows that coal from the Kimbeto EMRIA study site has a significantly higher ash content and significantly lower contents of volatile matter, fixed carbon, carbon, and a significantly lower heat of combustion. Contents of moisture, hydrogen, nitrogen, oxygen, total sulfur, and sulfate, pyritic and organic sulfur, are not significantly different.

A statistical comparison of the geometric means of the contents of coal ash and contents in ash of nine major and minor oxides from the 14 Kimbeto study site samples with 79 other San Juan River region coal samples, shows that coal from the Kimbeto study area has significantly higher ash content and $SiO_2$ content in ash and significantly lower in CaO, MgO, and $Fe_2O_3$ contents in ash. The contents of $Al_2O_3$, $Na_2O$, $K_2O$, $TiO_2$, and $SO_3$ in ash are not significantly different. When compared at the 99-percent confidence level, the ash content and $Fe_2O_3$ content in ash are not significantly different.

A statistical comparison of the geometric means of the contents of 35 elements in the 14 Fruitland Formation coal samples from the Kimbeto study site with 79 other San Juan River region coal samples shows that coal from the Kimbeto study area has significantly higher contents of Si, Al, Na, Ti, Be, Co, Cr, Ga, Nb, Ni, Sc, U, Y, and Zr and significantly lower contnts of Ca, Ba, Sb, Sr, and Yb. The contents of Mg, K, Fe, As, B, Cu, F, Hg, Li, Mn, Mo, Pb, Se, Th, V, and Zn are not significantly different. When compared at the 99-percent confidence level the contents of Al and Co are not significantly different.

Differences in the oxide composition of coal ashes and the element contents of coal result from differences in the total and relative amounts of the various minerals, the elemental composition of these minerals, and the total and relative amounts of any organically bound elements. The chemical form and distribution of a given element is dependent on the geologic history of the coal bed. A partial listing of the geologic factors that may influence element distributions would include chemical composition of original plants; amounts and compositions of the various detrital, diagenetic, and epigenetic minerals; chemical characteristics of the ground waters that come in contact with the bed; temperatures and pressures during burial; and extent of weathering. No evaluation of these factors has been made for the coal beds in the Kimbeto EMRIA study site.

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