Relation of the Carbon/Oxygen Ratio in Coal to Igneous Intrusions in the Somerset Coal Field, Colorado

GEOLOGICAL SURVEY BULLETIN 1477-A

Relation of the Carbon/Oxygen Ratio in Coal to Igneous Intrusions in the Somerset Coal Field, Colorado

By JOHN R. DYNI *and* DAVID L. GASKILL

CONTRIBUTIONS TO GEOCHEMISTRY

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A study of the carbon-to-oxygen ratio in coals metamorphosed to higher than normal rank by igneous plutons

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METRIC-INCH-POUND SYSTEM EQUIVALENTS

Metric unit	*Multiply by*	*To give inch-pound system equivalent*
Meter (m)	3.28	feet (ft)
Kilometer (km)	.62	mile (mi)
Cubic meter (m^3)	35.31	cubic feet (ft^3)
Meter per kilometer (m/km)	5.28	feet per mile (ft/mi)
Calories, gram per gram	1.8	British thermal unit (Btu) per pound
Degrees Celsius (°C)	(1.8×°C)+32	degrees Fahrenheit (°F)

CONTRIBUTIONS TO GEOCHEMISTRY

RELATION OF THE CARBON/OXYGEN RATIO IN COAL TO IGNEOUS INTRUSIONS IN THE SOMERSET COAL FIELD, COLORADO

By JOHN R. DYNI and DAVID L. GASKILL

ABSTRACT

The carbon/oxygen ratio in weight percent of coal in the Upper Cretaceous Mesaverde Formation increases progressively eastward and northeastward from about 5.5 to 30 across the Somerset coal field, western Colorado. This increase is attributed to geothermal heating of the coal by igneous laccoliths and sills that intruded the coal-bearing strata in the eastern part of the field during Oligocene time.

In the Somerset field, coal having a carbon/oxygen ratio greater than about 7.5 has marginal or better coking qualities, whereas coal having lower values is noncoking. Isopleths of carbon/oxygen values show that marginal coking coal is present in the eastern and northern parts of the field and that noncoking coal is present in the southern and western parts.

Other applications of the carbon/oxygen ratio are outlining boundaries of buried intrusives, detecting geothermal areas, and prospecting for areas of methane-rich coal for underground gasification.

INTRODUCTION

Coal researchers have known for many years that the weight-percent ratio of carbon to oxygen in coal increases with progressive metamorphism of coal. In an early study, Hickling (1931, fig. 5) showed that the carbon/oxygen ratio in coal increases linearly between the ranks of lignite (carbon/oxygen ratio of about 2.1) and medium-volatile bituminous (carbon/oxygen ratio of about 12–14) (fig. 1). During this stage of coalification, the coal loses oxygen mainly in carbon dioxide and water. At a carbon content of about 85–86 percent (rank of medium-volatile bituminous coal), the carbon/oxygen curve steepens asymptotically toward the zero line for oxygen. At this point the loss of oxygen is markedly reduced, and the loss of hydrogen, chiefly as methane, becomes quantitatively important. This point is the beginning of the "second coalification jump" (Teichmüller and Teichmüller, 1975, fig. 24; Teichmüller, 1975,

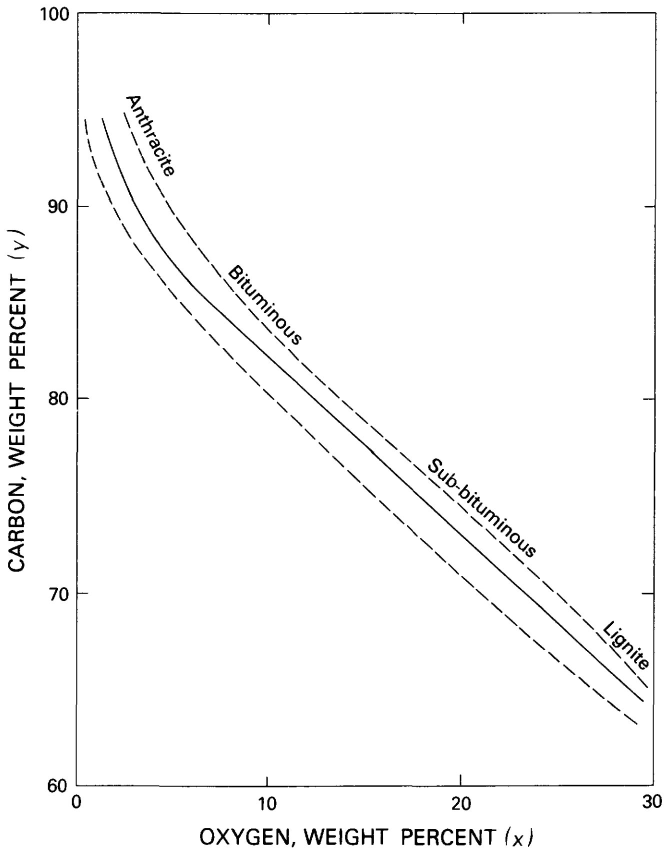

FIGURE 1.—Carbon versus oxygen content (dry, ash-free basis) of about 1,200 coals ranging in rank from lignite to anthracite. Field of data points is enclosed by the dashed lines; approximate regression curve shown by the solid line. Approximate equation for assumed linear regression curve between carbon values of 65 and 85 percent: $y=-0.92x+91.5$. Modified from Hickling (1931, fig. 5).

p. 198–200). Figure 1 indicates that the useful range of the carbon/oxygen ratio as a coal-rank parameter is greater than any parameter now being used. (See Teichmüller and Teichmüller, 1975, table 4.)

A plot of the carbon content against the oxygen content (dry, ash-free basis) for a variety of Cretaceous and Tertiary coals in Colorado (fig. 2) was found to closely parallel the straight-line portion of Hickling's curve in figure 1, indicating that the rate of change of the carbon/oxygen ratio with progressive metamorphism is predictable and similar for most coals.

One would expect that the original composition of the coal would have an effect on the carbon/oxygen ratio. A sapropelic coal, for ex-

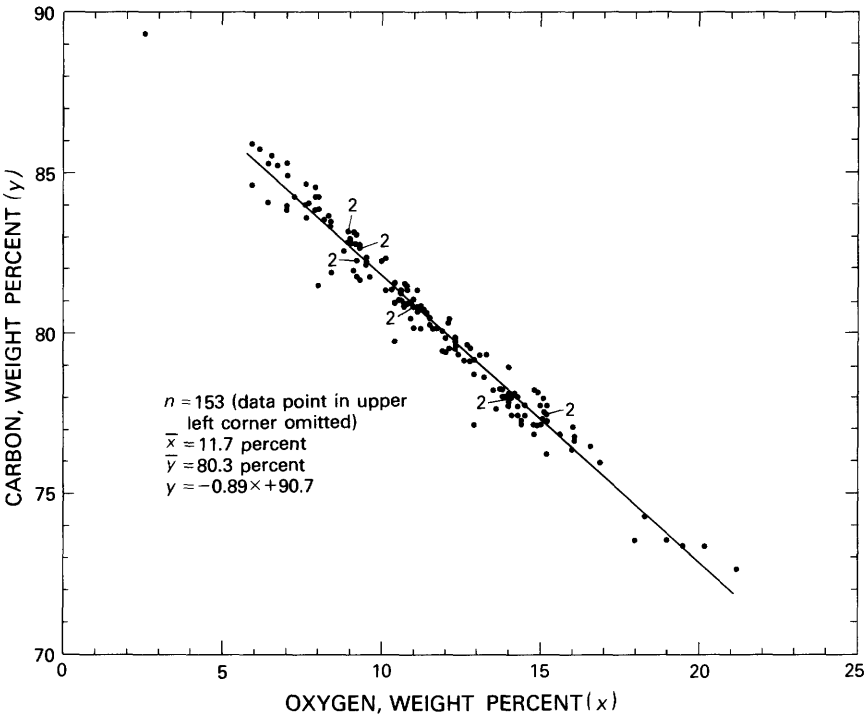

FIGURE 2.—Carbon versus oxygen content (dry, ash-free basis) for 154 samples of Cretaceous and Tertiary coals in Colorado. Data from Aresco and Haller (1953), Aresco, Haller, and Abernethy (1955, 1956a, 1956b, 1957, 1958, 1959, 1960, 1961, 1962), Aresco and Janus (1967, 1969), Aresco, Janus, and Walker (1963, 1965, 1966), Janus and Shirley (1973), and Snyder and Aresco (1953). More than one sample per data point is indicated by number.

ample, which has a relatively low oxygen and high hydrogen content, would have a higher carbon/oxygen ratio that a humic coal of comparable rank. Therefore, carbon/oxygen ratios should not be applied indiscriminately as a coal-rank parameter without knowledge of the coal type. Despite this limitation, the carbon/oxygen ratios for Colorado coals follow a generally predictable path with progressive metamorphism when compared to another coal-rank parameter, the calorific value of the coal (fig. 3).

The fact that the carbon/oxygen ratio is an indicator of coal rank suggests its use in an area where the coal varies significantly in rank. The Somerset coal field in western Colorado seemed to be an ideal area to examine the use of the carbon/oxygen ratio because the coal in the field ranges from high-volatile bituminous B to semianthracite. Furthermore, many analyses of coal from drill holes, mines, and prospects were available for study.

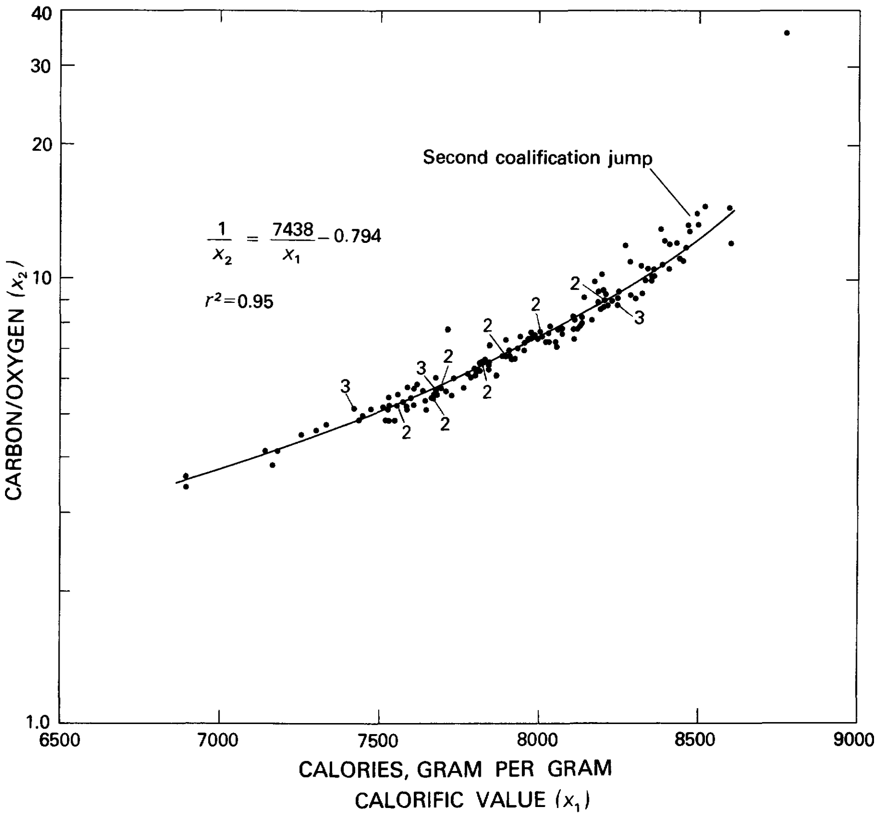

FIGURE 3.—Carbon/oxygen ratio (dry, ash-free basis) compared with the calorific value (dry, ash-free basis) of 153 samples of Cretaceous and Tertiary coals in Colorado. Data from Aresco and Haller (1953), Aresco, Haller, and Abernethy (1955, 1956a, 1956b, 1957, 1958, 1959, 1960, 1961, 1962), Aresco and Janus (1967, 1969), Aresco, Janus, and Walker (1963, 1965, 1966), Janus and Shirley (1973), and Snyder and Aresco (1953). More than one sample per data point is indicated by number.

In an early study of Cretaceous coal fields in western Colorado, Lee (1912) noted a west-to-east increase in Btu (British thermal unit) values of coal through the Somerset field, which he attributed to heating by nearby igneous intrusions. Johnson (1952) made an interesting study of some properties of the Somerset coal, including oxygen content and the coking and agglutinating indexes. He showed how these properties related to the coking qualities of coals in the eastern part of the Somerset field. Johnson believed that the coking qualities of these coals were related to thermal metamorphism caused by nearby intrusions and to subsequent oxidation of some beds by surface weathering and by oxygen-bearing ground waters. Dutcher, Campbell, and Thornton (1966), who studied the local physical and chemical alteration of coal beds intruded by igneous sills in the Somerset field, found that the total carbon content (dry, ash-free basis), percent ash, and reflectance values for coal increased toward the sills, whereas the amounts of volatile matter, moisture, and hydrogen decreased. They concluded that the parameter of coal reflectance most accurately recorded the degree of thermal alteration of the coal. Regional variations of several coal-rank parameters for coals of the Mesaverde Formation along the Grand Hogback north of the Somerset field were studied recently by Collins (1976).

Carbon/oxygen ratios in coal in the Somerset field were found to be a sensitive and accurate measure of coal rank. Isopleths of the carbon/oxygen ratios show how the coals in general are metamorphosed to progressively higher rank eastward and northeastward across the field, with local variations, in response to heating by igneous intrusives. The carbon/oxygen ratio can be used to predict areas of coking and noncoking coal in the field. Other possible applications of the carbon/oxygen ratio include delineating the boundaries of buried intrusives, prospecting for geothermal areas, and prospecting for thermally altered methane-enriched coal for underground gasification.

The authors gratefully acknowledge the informal discussion of this paper with Manuel L. Gomez, U.S. Bureau of Mines, and Archie Carver, U.S. Geological Survey.

SOMERSET COAL FIELD

GEOLOGIC SETTING

The Somerset coal field is located in western Colorado in rugged terrain on the west side of the West Elk Mountains and Elk Mountains in eastern Delta and western Gunnison Counties (fig. 4).

The Somerset field includes the area occupied by the Mesaverde Formation along the North Fork of the Gunnison River in eastern Delta and western Gunnison Counties, Colo. (pl. 1). The Mesaverde Formation is a marine and continental sequence of shale, carbonaceous shale, siltstone, sandstone, and coal having a maximum thickness of about 700 m. The formation is underlain by the marine Mancos Shale of Late Cretaceous age and is overlain by continental Tertiary rocks of the Ohio Creek and Wasatch Formations.

Igneous rocks of Oligocene age form a complex of laccoliths and sills, which intrude parts of the sedimentary sequence of rocks just described, around the east and south sides of the coal field. Most of these igneous bodies intrude the Mancos Shale, but some of the largest laccoliths intrude the Mesaverde Formation and younger strata. Mafic dikes and sills, genetically related to the basaltic flows capping Grand Mesa north of the area of plate 1, intrude the coal-bearing strata of the Mesaverde Formation and the Wasatch Forma-

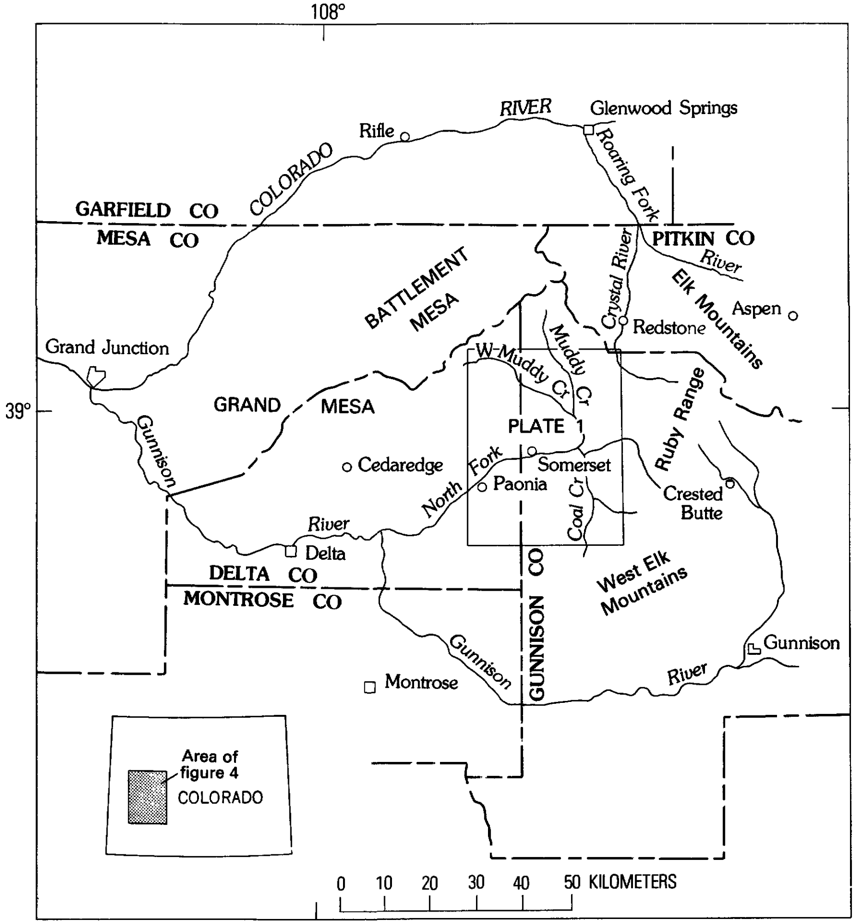

FIGURE 4.—Location of the Somerset coal field (area of pl. 1) in western Colorado.

tion in an area several kilometers north and west of Somerset, and in the Muddy Creek drainage basin on the north side of the area of plate 1.

The coal field lies in the southeast corner of the Piceance Creek sedimentary and structural basin. The main structural element of the field is the northwest-plunging Muddy Creek syncline (pl. 1). Mesaverde strata on the southwest limb of the syncline dip 45–65 m/km northeastward toward the synclinal axis.

COAL DEPOSITS

The principal coal beds in the Somerset field are in the lower part of the Mesaverde Formation in a sequence of interbedded sandstones, siltstones, and shales about 135–185 m thick. Six of the thickest beds of coal, designated A–F in ascending order, are commonly 0.5–5.2 m thick and locally are 7.6 m thick (Johnson, 1948). Many mines in these beds are located along the outcrop of the coal-bearing rocks on both sides of the North Fork of the Gunnison River. Other thin beds of coal are scattered through the coal-bearing sequence.

Most of the coal in the Somerset field is high-volatile B bituminous, but a small amount in the vicinity of the Bowie mine is ranked as high-volatile A bituminous. The ash content of coal mined in the field ranges from 4 to 10 weight percent and averages about 6 percent. Sulfur is uniformly low (0.4–0.6 weight percent) and averages 0.5 percent. The moisture content of the coal is from 5–10 weight percent and averages about 6 percent, with the notable exception of the Bowie mine, where the average moisture content of the coal is only 4.5 percent.

In terms of utilization, the coal in the Somerset field ranges from noncoking steam coal of good quality to coal of marginal coking quality. The coal currently mined from the B bed in the Somerset mine is of marginal coking quality and is blended with high-quality coking coal from the Coal Basin district north of the map area to make coke for making steel (Collins, 1976, p. 70–71; C. R. Dunrud, oral commun., 1976). The same bed in the Bowie mine, 6.4 km to the west, is probably of similar quality. The C bed in the Bear mine has poorer coking qualities than the B bed. The E bed in the Hawk's Nest mine is of marginal coking quality and is blended with other coals to make coke for use in blast furnaces at Pueblo, Colo. (Archie Carver, oral commun., 1976). The three main coal beds in the eastern part of T. 13 S., R. 89 W. were judged by laboratory tests made by the U.S. Bureau of Mines to have coking qualities comparable to coal from Sunnyside, Utah, which is blended with coal from Coal Basin to make coke. The same beds in the western part of the same township, however, are noncoking (Toenges and others, 1952). In the south half of T. 13 S., R. 90 W., in the vicinity of Minnesota Creek and south of Somerset, core drilling by the U.S. Bureau of Mines revealed the presence of large reserves of minable, but noncoking, coal (Toenges and others, 1949). The variability in the coking qualities of coal from different parts of the field is believed to be controlled primarily by the extent to which the coals were metamorphosed by geothermal heat from the nearby igneous intrusions.

METHODS

Carbon/oxygen ratios in coal in the Somerset field were calculated on a dry-coal basis from ultimate and proximate analyses of samples obtained mainly from mines and drill holes. Weathered coals exposed in outcrops and prospect pits commonly have low carbon/oxygen values; analyses of such coals were mostly omitted. Many analyses were published by the U.S. Bureau of Mines between 1953 and 1970 in a series of bulletins and reports of investigations. Some very useful analyses of coal in the Minnesota and Coal Creek areas (pl. 1) were published by Toenges and others (1949, 1952). Some analyses of coal from drill holes and prospect pits were published by Hanks (1962). Some unpublished analyses of coal from exploratory holes drilled under now-expired Federal coal leases, which are in the files of the U.S. Geological Survey, were also used.

The carbon/oxygen ratios were computed on a dry-coal basis, because many of the analyses were available only in that form. In future studies, carbon/oxygen determinations made on an "as-received" basis may be preferable because of the seemingly improved accuracy of the data.

Carbon/oxygen ratios were also determined empirically from proximate analyses using the visually plotted curve shown in figure 5. A good correlation was found for Somerset coals in a plot of the calorific value (calories, gram per gram, as-received basis) versus carbon/oxygen ratio (dry basis) divided by the sum of percent ash and percent moisture. Inasmuch as many more proximate analyses than ultimate analyses are available, the graph of figure 5 proved to be useful in determining carbon/oxygen ratios for coals in the Somerset field. The curve in figure 5 may not be directly applicable to coals in other fields, but a similar curve based on analyses of coals in a given field probably could be prepared.

The carbon/oxygen ratios were averaged for each mine, prospect, and drill hole for which analyses were available. The carbon/oxygen ratio for a given mine or prospect commonly is an average of several analyses of a single bed of coal; whereas the carbon/oxygen ratio for a drill hole is commonly the average ratio for several beds of coal that were penetrated by the drill hole. Isopleths of the carbon/oxygen ratios are shown on plate 1. These isopleths are generalized in areas where data are lacking, especially in the northern part of the map area and near the laccoliths where the greatest change in carbon/oxygen ratios is expected. The area north of the Bowie mine is par-

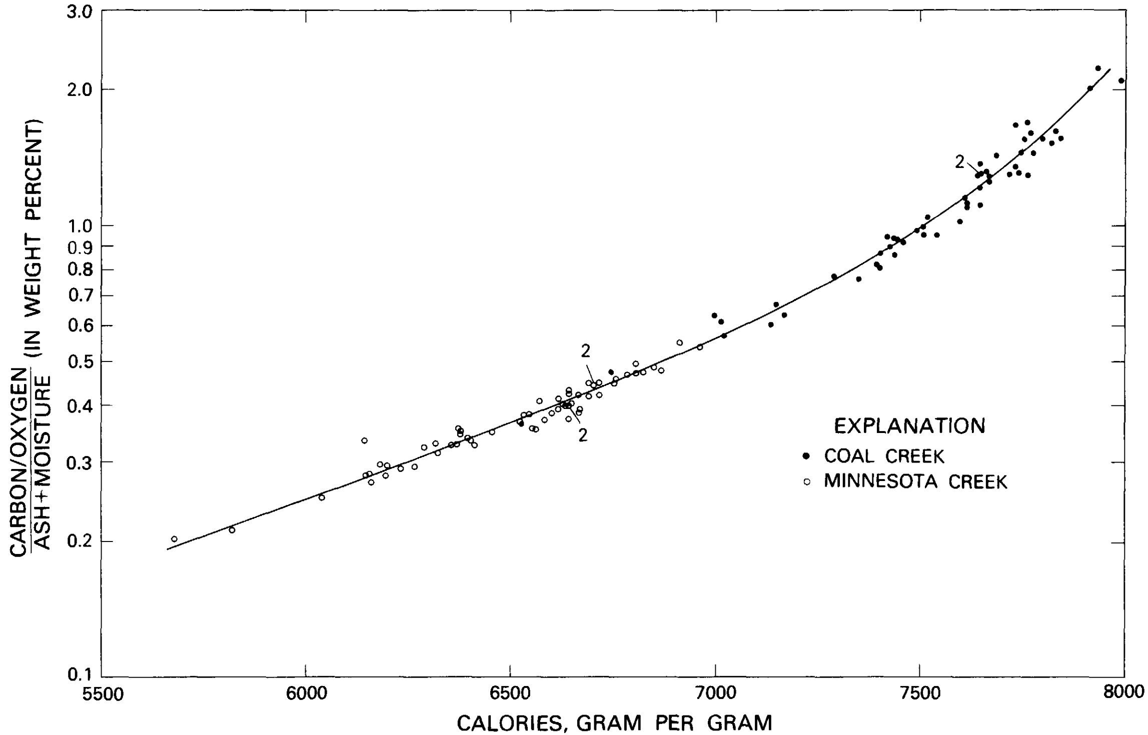

FIGURE 5.—Calories, gram per gram (as-received basis) versus carbon/oxygen (dry basis) divided by the sum of percent ash and percent moisture for 116 samples of coal from core holes drilled by the U.S. Bureau of Mines in the Somerset coal field. Data from Toenges and others (1949, 1952).

ticularly difficult to evaluate because some coal beds are locally intruded by igneous sills. Coal beds close to these sills have carbon/oxygen ratios as high as 20–40; some of the highest values were omitted in order to reduce the localized thermal effects of these sills.

TRENDS IN CARBON/OXYGEN DATA

The carbon/oxygen ratios of coal beds in the Somerset field increase with depth but not at the same rate in all parts of the field. In the vicinity of Minnesota Creek, south of the town of Somerset (pl. 1), the carbon/oxygen ratio of successively deeper coal beds penetrated by 11 drill holes increases at rates ranging from 0.36 to 0.62 per 100 m of depth. The average rate of increase for the 11 drill holes is 0.56 per 100 m. Data on 17 coal beds for a typical core hole in the Minnesota Creek area are plotted in figure 6. Variations in the carbon/oxygen ratios for individual coal beds about the regression line in figure 6 may be due to differences in maceral and mineral content, and perhaps to oxidation of the coal.

In the vicinity of Coal Creek on the east side of the Somerset field (pl. 1), in contrast to Minnesota Creek, the carbon/oxygen ratios increase at a greater rate with depth. Here, the coal beds are distributed through a stratigraphic interval that is too thin to obtain a meaningful plot of carbon/oxygen ratios of the coal beds versus their depths in an individual core hole. Therefore, the mean value for the carbon/oxygen ratios of all coal beds analyzed in a drill hole was plotted against the mean depth of the coal-bearing sequence in that drill hole. Such data for 20 drill holes in the Coal Creek area are shown in figure 6. If a linear relationship between carbon/oxygen and depth is assumed between the surface and a depth of about 427 m, the carbon/oxygen ratio increases at a rate of 0.92 per 100 m of depth, or 1.6 times the average increase in the Minnesota Creek area. The data suggest that these coal beds were heated to higher than normal temperatures by a source of heat other than that associated with the normal geothermal gradient. The three carbon/oxygen values for the deepest coals at depths of 610–671 m are seemingly too low. These coal beds may be structurally too low to have been heated significantly by the nearby intrusives, or perhaps they were partly oxidized by oxygen-bearing ground waters, causing their carbon/oxygen ratios to be lowered.

The carbon/oxygen ratios show pronounced areal trends in the Somerset coal field. The ratios increase to the east and northeast from a minimum value of about 5.5 in the Minnesota Creek–Jumbo

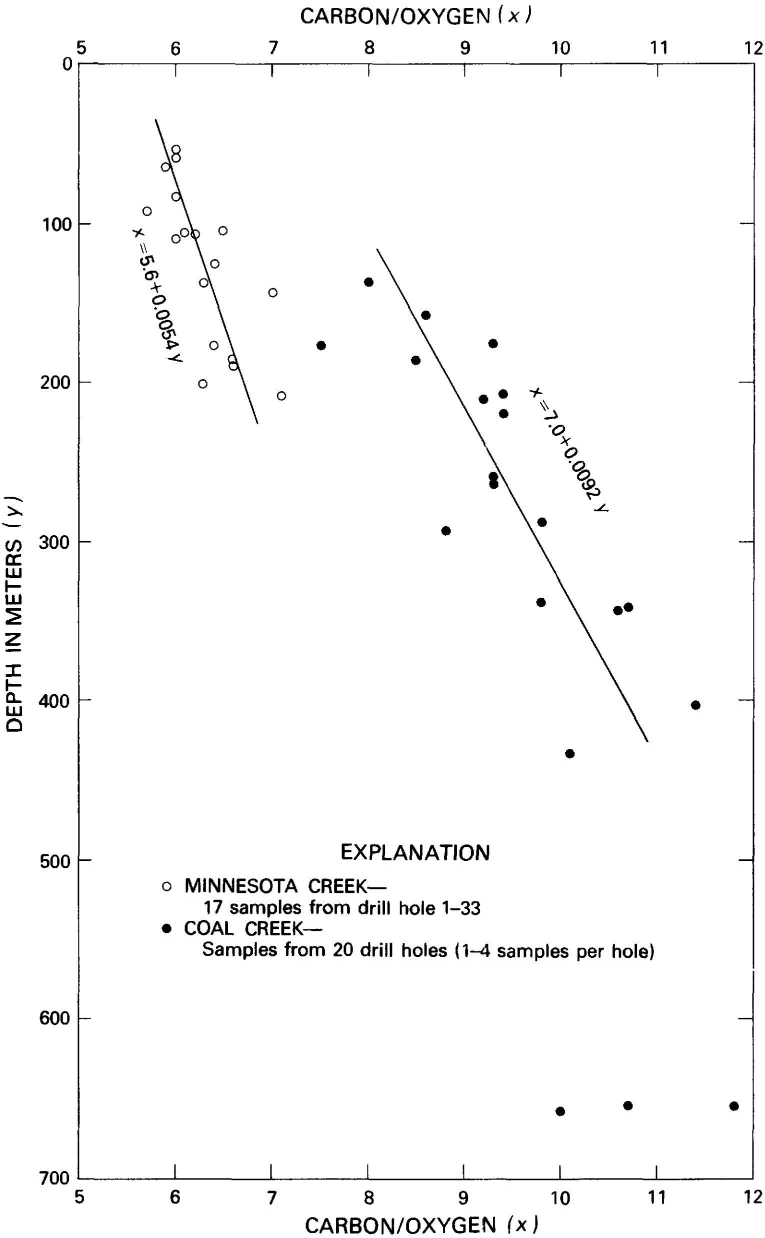

FIGURE 6.—Carbon/oxygen ratio (dry coal) versus depth of coal beds below the surface in the Minnesota Creek and Coal Creek areas of the Somerset field. Data from Toenges and others (1949, 1952).

Mountain area southwest of Somerset to about 30 on the north side of Chair Mountain (pl. 1). Coals having high carbon/oxygen values persist several kilometers northward beyond the study area of plate 1 to Coal Basin in T. 10 S., R. 89 W., where some of the best coking coal in the State is currently produced. Here, coal beds have carbon/oxygen values of about 12–55 (calculated from analyses published by Collins (1976)). Analyses of coal from a drill hole near the center of sec. 28, T. 10 S., R. 89 W., about 5 km north of the map area and just south of Coal Basin, show carbon/oxygen ratios which range from 14 to 56 and average about 25 (Hanks, 1962, p. 150, 153, 154). Although carbon/oxygen values of coal in the drainage basin of Muddy Creek in the northern part of the map area are largely conjectural, several analyses of coal from two oil and gas test wells (sec. 17, T. 12 S., R. 89 W., and sec. 27, T. 11 S., R. 90 W.) along the axis of the Muddy Creek syncline indicate that the ratio for coals in this area averages 10 or higher (Hanks, 1962, p. 150, 153, 154).

Coal in the vicinity of the Bowie mine has locally higher carbon/oxygen values, of as much as 8. The carbon/oxygen isopleths in this area are interpreted to trend northeasterly, and roughly parallel to a northeast-trending mafic dike(?) that may be present in the subsurface about 3 km north of Somerset. The carbon/oxygen values decrease westward from an average value of 8.1 at the Bowie mine to about 5.4 at the Delta "W" (Fitzsimons) mine in the SW¼ sec. 27, T. 13 S., R. 92 W., about 3 km west of the map area. Low carbon/oxygen values persist westward to the Cedaredge area in T. 13 S., Rs. 94–95 W., in the eastern part of the Grand Mesa coal field. Here, the coals have carbon/oxygen values of about 5.5–5.7. These values are typical for coals in the Mesaverde that have not been affected by abnormal geothermal temperatures.

The carbon/oxygen ratios for Mesaverde coal near the Mount Gunnison laccolith seem unusually low. In drill hole 4-10 (sec. 10, T. 14 S., R. 90 W.) the average carbon/oxygen ratio is 6.1, yet the hole is only 3.4 km from the laccolith. Possibly, the laccolith intruded rock younger than the coal-bearing strata, and the coal beds were relatively unaffected by heat from the intrusion.

CARBON/OXYGEN RATIO AND COKING QUALITY

Most metallurgical cokes are currently made from blends of semicoking and coking coals ranging in rank from high-volatile bituminous to semianthracite. The rank and maceral content of a coal determine to a large extent its physical and chemical properties, and its behavior in the coke oven. Other raw-coal properties that are important in making metallurgical coke are the amounts of ash, minerals, alkali metals, sulfur, and phosphorus in the coal and the degree to which the coal has oxidized prior to its use in the coke oven.

Coking coals are classified commonly by (1) rank, as determined by reflectance values of the vitrinite component of the coal, and by (2) the ratio of reactive to inert macerals in the coal. These two parameters have been correlated with important coke properties including dilatation and strength (coke stability factor). Generally, the higher the vitrinite content, the better the coke. In this regard, Collins (1976, p. 42) found that coals in the Mesaverde Formation along the Grand Hogback from Coal Basin, just north of the Somerset field, to Meeker, Colo., have a high vitrinite content and a notably uniform group-maceral content. The means and standard deviations of the volume percentages of the group macerals in 19 samples of coal from this area were found by Collins to be: vitrinite, 71.8±8.5; exinite, 13.7±7.5; and inertinite, 11.3±4.6. Mineral matter amounted to 3.1±2.7 percent. It is reasonable to assume that the coals in the Somerset field are similar in composition.

Coking coals have vitrinite reflectances of about 1.15–1.6 percent according to Teichmüller and Teichmüller (1975, fig. 25). Low-volatile bituminous coal having vitrinite reflectances between 1.40 and 1.65 percent have excellent coking qualities and are used in amounts of as much as 30 percent in blends of coking coal (Thompson and Benedict, 1976, and written commun., 1976). Cameron (1974, p. 60, fig. 8) reported that medium-volatile bituminous coal with vitrinite reflectances above about 1.0 percent, and with a reactive maceral content greater than about 60 percent, can yield cokes having stabilities of 50 percent or more. Such stabilities are required for blast furnace use. These comparisons of coal and coking properties were made largely on Carboniferous coals and may not be strictly applicable to Cretaceous coals in the Rocky Mountains, but they do serve as a point of departure for classifying coking coals in the Somerset field.

Vitrinite reflectances are compared to carbon/oxygen ratios in figure 7. The carbon content of the vitrinite was reported by the cited authors, and the value for oxygen used to compute the carbon/oxygen ratio was determined from the data of Hickling (1931, fig. 5). Although the calculated carbon/oxygen ratios in figure 7 are too low for pure vitrinite, they are probably not in gross error, because the Carboniferous coals in Europe studied by Hickling are relatively high in vitrinite (about 70 percent) and are similar to the Mesaverde coals as reported by Collins (1976).

If vitrinite reflectances of about 1.1–1.64 are selected for coals having fair to good coking properties, this approximates a range in carbon/oxygen values of about 16–31. This range may be somewhat

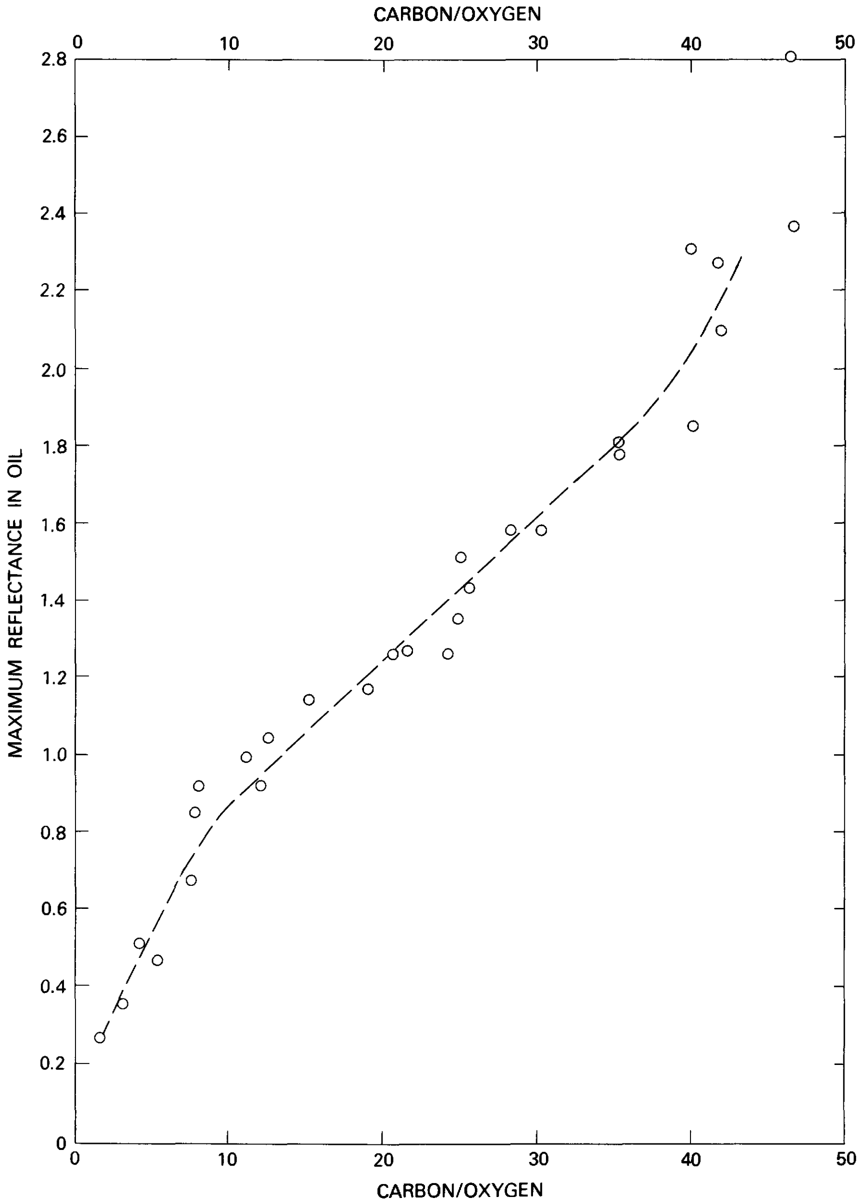

FIGURE 7.—Reflectance values compared with carbon/oxygen ratios (dry, ash-free basis) for several vitrinites. Selected data from Huntjens and van Krevelen (1954, table 3) and Broadbent and Shaw (1955, table 5). Oxygen values, which were not given in the preceding references, were estimated from Hickling (1931, fig. 5). Dashed line is approximate correlation line.

low; however, with some exceptions, this is approximately the range of carbon/oxygen values for the coking coals of reported high quality in Coal Basin, just north of the study area (pl. 1).

A range of carbon/oxygen ratios for coals of marginal coking quality is suggested by the data on the coking properties of coals from the Somerset field and from Sunnyside, Utah, listed by Toenges and others (1949) and Toenges and others (1952). In the Minnesota Creek area on the west side of the Somerset field, 11 of 12 samples of coal representing 11 coal beds, and ranging from 5.9 to 6.6 in carbon/oxygen ratios, would not form coke; one sample (carbon/oxygen=6.9) produced a poor coke of low strength. Two samples of coal from the Mesaverde Formation near Sunnyside, Utah, having a carbon/oxygen value of 8.2, yielded a coke of moderate strength; whereas four samples from the Coal Creek area on the east side of the Somerset field having carbon/oxygen ratios of 9.5–9.7 gave equal to slightly better results. Thus, the lower limit for marginal coking properties seems to lie between carbon/oxygen values of 6.9 and 8.2. The average of these values, about 7.5, is suggested as a lower approximate limit for coal of marginal coking power in the Somerset field.

APPLICATIONS

AREAS OF COKING COAL

Using the carbon/oxygen isopleths of plate 1, areas of marginal-quality coking coal (carbon/oxygen ratios between 7.5 and 16) in the Somerset field are in the drainage area of Coal Creek and in most of the area of plate 1 north of the North Fork of the Gunnison River and Anthracite Creek. Coking coal of fair or better quality may exist in parts of T. 11 S., Rs. 89–90 W., and T. 12 S., R. 89 W., and extend north of the map area into Coal Basin. Coal of marginal or better quality is also indicated in the Robinson Creek drainage in the southeastern part of the map area. Additional drill holes are needed around the flanks of the Mount Gunnison laccolith to determine whether coal of marginal or better quality is present. Noncoking coal is present to the south of Somerset in the vicinity of Minnesota Creek and westward from a point between the Paonia Farmers mine and the Gelwick mine in T. 13 S., R. 91 W., to Cedaredge, Colo., about 29 km west of the Somerset field.

The carbon/oxygen ratios for coal beds in the area of the mines shown on plate 1 in T. 13 S., Rs. 90–91 W., must be interpreted with care, inasmuch as the ratios are for specific beds and are not average values for the entire coal zone. For example, coal of marginal coking quality is indicated at the Hawk's Nest mine in sec. 11, T. 13 S., R. 90 W. This coal is the E bed, the stratigraphically highest bed mined in the area. Presumably, the underlying coal beds would have higher carbon/oxygen ratios and better coking qualities.

DETECTION OF INTRUSIVE BODIES

Carbon/oxygen ratios may be useful in delineating the boundaries of buried intrusive rocks. For example, the sharp rise in carbon/oxygen values in the northwest part of T. 13 S., R. 89 W., suggests a post-Cretaceous thermal front associated with an igneous intrusion at depth. Carbon/oxygen ratios combined with geophysical measurements might be used to infer the size, extent, and possibly the depth of igneous intrusive bodies. Carbon/oxygen data for coal in the vicinity of the laccoliths might be particularly useful in determining the nature of the contact of the igneous body. If the carbon values show no appreciable increase in approaching the laccolith, such as on the north side of the Mount Gunnison laccolith, a steep contact between the intrusive and country rock might be inferred, or perhaps the coal-bearing strata dip beneath the laccolith and were not heated sufficiently to increase the carbon/oxygen ratio.

Some areas of Cretaceous coal elsewhere in Colorado and Utah that have higher than expected carbon/oxygen values which may be due to a secondary source of heat from intrusive igneous rocks are Coal Basin just north of the map area; the Durango and the Trinidad-Walsenburg areas of southern Colorado; Cameo, about 16 km east of Grand Junction, Colo.; and Sunnyside, Utah.

GEOTHERMAL AREA

A carbon/oxygen anomaly in the vicinity of the Bowie mine is interpreted to coincide approximately with a northeast-trending mafic intrusion that may be present at depth a short distance east of the northeast corner of T. 13 S., R. 91 W. The carbon/oxygen value of the coal (B bed) in the Bowie mine averages 8.1 and, as was previously noted, the coal has a lower moisture content and a higher rank than in nearby mines. According to Archie Carver, U.S. Geological Survey (oral commun., 1974), part of the Bowie mine was reported by local miners to be "uncomfortably warm." An area in the west part of the Somerset mine is also warm, according to Mr. Carver. A sample of coal from the B bed having a carbon/oxygen ratio of 7.4 was collected by Mr. Carver in the Somerset mine near the northeast corner of the SE¼SW¼ sec. 12, T. 13 S., R. 91 W., where the temperature of the freshly exposed coal measured 88°C. Freshly exposed coal several hundred meters west of this point measured as high as 120°C. The above data suggest the possibility that a buried intrusive lies beneath the Bowie and Somerset mines and is still warm. Alternatively, the heat may be generated from a fire that started naturally at the outcrop of the coal bed near Hubbard Creek. Outcrops of burned and clinkered rocks are common in Hubbard Creek and vicinity (G. H. Horn, oral commun., 1974). One might determine the source of this heat by making a temperature survey in bore holes drilled along Hubbard Creek from the point where the B bed crops out southward to the North Fork Gunnison River. If a temperature anomaly exists in non-coal-bearing rocks beneath the B bed, the source of the heat is probably an igneous intrusion.

UNDERGROUND GASIFICATION OF METHANE-BEARING COAL

In some areas of the Somerset coal field, the coal may have been metamorphosed sufficiently to produce large quantities of methane, as in Coal Basin, north of the map area. Here, as much as 227,000–283,000 m^3 of methane are released daily from five coal mines (Collins, 1976, p. 69), indicating that the coal beds are permeable as well as rich in methane. Maximum generation of methane during coal metamorphism occurs when the hydrogen content of the coal reaches its maximum value. For coals of the Rocky Mountain region, this value is nearly 6 percent (Parry, 1950, fig. 7), and it corresponds to a carbon/oxygen ratio of about 12.

Relatively large quantities of gas under high pressure were encountered in several core holes drilled by the U.S. Bureau of Mines along Coal Creek (Toenges and others, 1952, p. 9). The carbon/oxygen ratios of the coal beds penetrated by these core holes range between 8.5 and 9.5. Core holes in the eastern part of the Coal Creek area, where the coal has even higher carbon/oxygen ratios that range as high as 12, did not encounter significant quantities of gas. Perhaps the gas in this area migrated updip to the west or was lost through fractures.

At depths where coal is too deep to mine by conventional methods, it may be possible to recover the natural methane along with the synthetic gas produced by in situ gasification of the coal. Carbon/oxygen ratios suggest that a large area along the Grand Hogback between the North Fork Gunnison River and the Colorado River to the north, including most of Tps. 6–12 S., Rs. 89–91 W., has potential for underground gasification of methane-enriched coal. Carbon/oxygen values of 25 or more are known from a few localities in this area. This suggests that large amounts of methane were generated during coal metamorphism in coal beds and in associated carbonaceous shales. If the methane is still in the coal beds, it might be recoverable. Perhaps gas wells could be drilled to a selected coal bed, then whipstocked and drilled downdip within the coal bed. This could provide hundreds of meters of gas-productive rocks.

SUMMARY

Carbon/oxygen ratios were used to study the metamorphism of coal in the Somerset coal field, western Colorado. As shown by carbon/oxygen isopleths, the coal in the Somerset field has been metamorphosed to progressively higher rank, generally eastward across the field, as a result of heating from nearby igneous intrusions. The carbon/oxygen ratio is used to delineate areas of coking coal of marginal or better quality in the northern, eastern, and southeastern parts of the Somerset field. A possible geothermal area near the Bowie and Somerset coal mines is suggested by locally high carbon/oxygen values and high temperatures in these mines. High carbon/oxygen values for coal in a large area between the North Fork Gunnison River and the Colorado River to the north suggest that large quantities of methane were formed during metamorphism of the coal and may be available as a coproduct of mining or underground gasification of the coal.

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