EFFECT OF IGNEOUS INTRUSIVES ON THE CHEMICAL, PHYSICAL, AND OPTICAL PROPERTIES OF SOMERSET COAL

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Introduction

Examination of exploratory drill cores taken from a limited area near Somerset, Colorado, disclosed some coal beds associated with sills, or horizontal bodies, of monzonite and diorite rock. These sills, or igneous intrusions, were formed when the rock, in a molten state, invaded the coal-bearing strata. The coals range in rank from high-volatile bituminous through anthracite to natural coke. The material transformation of coal to coke produces chemical, physical, and petrographic changes. This investigation was conducted to determine to what extent variations in the chemical, physical, and petrographic data can be used to assess the deleterious effect of the intrusives on the coking quality of the coal.

Materials and Experimental Work

Samples of coals and natural coke were selected from three 6-inch cores from exploratory diamond-drill holes near Somerset, Colorado. A map of the Somerset area of Delta County, Colorado, Figure 1, shows the location of the holes from which the cores were obtained. The B-1 coal was sampled from holes 1 and 2, the B-2 and C coals were sampled from hole 3. A thin coal between the B-1 and A coals was sampled in hole 1. The 35 core segments sampled were chosen to include similar material and to accent major changes in the coal seams.

Proximate and ultimate chemical analyses and reflectance, and resistivity measurements were performed for each sample. Since these chemical and physical properties of coal change by thermal treatment, these properties are used as indications of the degree of thermal metamorphism. Ordinarily, chemical data alone should suffice to indicate the degree of thermal alteration; however, the coal samples frequently proved to be of high ash yield and not suitable for routine coal-chemical tests.

To relate the temperature involved in the thermal alteration of coal by igneous intrusions, samples of unaltered coal from the seams were thermally treated in the laboratory. Ten 15-gram samples of minus 8-mesh Somerset coal were carbonized in covered crucibles in an electric box furnace at a heating rate of 5.4 F per minute to predetermined temperatures ranging from 212 F to 1832 F. A portion of each carbonized sample was then analyzed for reflectance, resistivity, and hydrogen content.

The following analytical procedures were followed in analyzing both the drill-core and laboratory-carbonized samples. The average reflectance in oil was based on 50 reflectance determinations per sample. The resistivity values were determined for half-gram, minus 65-mesh samples dried for 24 hours at 212 F and tested at 20,000 psi. All chemical data were determined by standard laboratory procedures.

Equations were developed and correlation coefficients were determined for the relationships of temperature with reflectance, resistivity, and hydrogen content of the coals, Table I.

Results and Discussion

When coal and/or associated rocks in place in the earth are invaded by molten rock, the resulting alteration of the coal is similar to the thermal alteration produced in commercial carbonization processes. For this reason chemical and physical changes produced in laboratory-carbonized coals can be compared with similar changes in coals that have been thermally altered by igneous intrusions. In addition, the thickness of the intrusion and its distance from the coal seam have been related to the degree of coal alteration so that the damage sustained by the coal or coals can be approximated with a minimum of analytical test data.

In the following discussion the physical and chemical properties of the drill-core samples are compared with those of coals carbonized in the Laboratory at various temperatures. Following this, the relation of the degree of coal alteration to the source of heat is discussed.

Physical and Chemical Changes in Thermally Altered Coal

The optical reflectance, electrical resistivity, and hydrogen content were determined for Somerset high-volatile coal carbonized at different temperatures in the laboratory. The reflectance increases and the resistivity and the hydrogen content decrease as the carbonization temperature increases, as shown in Figure 2. The Somerset high-volatile rank coal, which has not been altered thermally, has a reflectance of about 0.7 percent, a resistivity of about 4.2×10^{11} ohm-cm, and a hydrogen content of about 5.9 percent. When coal has been altered to a reflectance greater than 2.0 percent, a resistivity of 6.5×10^{7} or more, and a hydrogen content of less than 4.0 percent, it can be considered as non-coking. In the laboratory samples the variations in the reflectance, resistivity properties, and hydrogen content have been related to the temperature of carbonization because temperature was the variable in the sample preparation. The correlation coefficients for the relation of temperature to both reflectance and hydrogen is $R^2 = 0.99$ and for the temperature-to-hydrogen relation is $R^2 = 0.96$. The reflectance, resistivity, and hydrogen measurements on the drill specimens from the cores were used to estimate the temperature to which the coal had previously been heated, Figure 3. Equations expressing the relationships of temperature with reflectance, resistivity, and hydrogen content, Table I, developed for coal carbonized in the laboratory were used in calculating temperature involved in the thermal altering of the coal and coke in the core samples. The core samples range from virtually unaltered coal to coke that has been thermally altered at a maximum temperature of not less than 1580 F or more than 2200 F. Indirectly determined temperatures in and near intrusions[1)*] and directly determined temperatures for lava[2)] are within this range. It appears that coal may be used as a maximal geothermometer. However, the temperatures calculated from reflectance are higher than those calculated from resistivity and these in turn are higher than those calculated from the hydrogen content, Figure 3.

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* See references.

Part of this discrepancy is due to the large percentage of ash-forming materials, which affect the resistivity and hydrogen measurements. Reflectance is considered as the most accurate indicator of rank changes resulting from thermal alteration since it is not affected by ash-forming minerals in the samples. However, when coals of different rank are carbonized under the same conditions, the highest-rank coal will produce coke with the highest reflectance. In this study, the coal carbonized in the laboratory is the same rank as the unaltered coal recovered in the drill core.

The visible changes that occur in the transformation of coal to coke are shown in Figure 4. The reflectance, resistivity, and hydrogen data are also shown to associate these changes with the visible changes in the coal and coke structure. The photomicrographs shown in Figure 5 illustrate altered and unaltered coal in a single sample of coal, pyrolytic carbon (carbon from cracked hydrocarbon gases) and mineral matter intruded into the coal.

Relation of the Thermal Alteration of Coal
<u>To the Position and Thickness of the Intrusive</u>

The changes in reflectance, hydrogen and volatile-matter content with distance from the intrusions in the samples taken from different depths in the four drill holes are shown in Figures 6, 7, 8, and 9. In hole 1, B-1 seam (Figure 6) is intruded near the top by two sills of nearly equal thickness for a total of 1.5 feet. The heat from the sills was sufficient to bring 8.0 feet of the 14-foot seam to a reflectance of 2 percent or more. In the middle of the coal column the reflectance drops abruptly (in only 0.8 foot) from more than 5 to less than 2 percent. The base of the seam, consisting of about 6.0 feet of coal, was only slightly altered by metamorphism and can be considered as coking coal.

In hole 3, B-2 seam (Figure 7) is in contact near the top with an 8.5-foot sill overlaid by 2.8 feet of shale and 3.7 feet of coke, which is in turn overlaid by 11.2 feet of intrusive rock. In this coal column, the entire 7.8 feet of coal has coked completely. The reflectance decreases as the distance from the sill increases.

In hole 3, C-seam (Figure 8) is thermally metamorphosed in the bottom third of an 11.6-foot coal column. Comparison of the sample intervals with the driller's log shows that 1.2 feet is unaccounted for at the base of the column. It was assumed that the intrusive occurs in this position. Approximately 3.6 feet of the basal portion of the column exceeds 2 percent reflectance. The remaining 8.0 feet of coal is only slightly altered and should be considered coking coal. The reflectance drops from 5 to less than 2 percent in an interval of about 2.0 feet. Thus the change from coke to coal is abrupt.

In hole 2, B-1 seam (Figure 9) is not in direct contact with an intrusion but is separated from an overlaying sill by 38.6 feet of shale. The intrusion totals 26.9 feet; however, a 7.5-foot unit of natural coke splits the sills and only 15.9 feet of sill was considered effective in the thermal metamorphism of the coal. The entire 11.4-foot column has been altered to anthracite and is non-coking. There are virtually no vesicles developed in this coal. This coal has probably been subjected to less rapid heating or greater pressures than the coals in which the coke structure developed.

The graphic presentations show that intense changes in a coal by contact with intrusions extend only a short distance from the contact. However, the amount of coal alteration, while undoubtedly related to the temperature of the intrusion, is also related to the thickness of the intrusion and its distance from the coal. Blignault,[3] in his investigation of the dolerite intrusions in the Natal Coalfields, found that as the ratio of the distance (D) from the coal to the thickness of the intrusive (T) decreases, the volatile matter (daf)* of the coal decreases from the unaltered coal. For these relationships to hold true, the intrusive temperature must have been nearly constant. Data from the present investigation were used to test the applicability of Blignault's findings, but reflectance was used as the rank parameter in preference to volatile matter.

The relation of D/T to the reflectance is shown in Figure 10. Distance is taken from contact of the intrusion to the center of the individual coal units. The following sill thicknesses were used in the calculation: 1.5 feet for B-1 seam in hole 1, 8.5 feet for B-2 seam, and 1.2 feet for C seam in hole 3, and 15.9 feet for B-1 seam in hole 2. The data shown in Figure 10 indicate that the ratio of the distance of the intrusive from the coal to the thickness of the intrusion increases as reflectance decreases.

Coal alteration in coal-bearing strata associated with intrusions should be useful in establishing distance from intrusive centers and the direction of the leading edge of an intrusive body as well as in establishing the deleterious effects sustained by the individual coals in a coalfield.

Summary

Examination of coal-bearing strata obtained from drill-core samples taken from the Somerset area indicated that portions of the coal have been thermally altered as a result of exposure at some time to molten rock (igneous intrusion). The degree of alteration of the coal was such that the coking properties of the coal have been affected. In the investigation, it was found that measurements of reflectance, electrical resistivity, and hydrogen content could be used to determine the degree of alteration of the coal. The data indicate the alteration of the coal was related to thickness and distance of the intrusive from the coal bed. In addition it was found that, within limits, coal may be used as a maximal geothermometer.

References

1. T. S. Lovering, "Temperatures In and Near Intrusions," Economic Geology, Fiftieth Anniversary Volume, pp. 249-281, 1955.

2. E. Ingerson, "Methods and Problems of Geologic Thermometry," Economic Geology, Fiftieth Anniversary Volume, pp. 341-410, 1955.

3. J. J. G. Blignault, "Field Relationships of the Dolerite Intrusions in the Natal Coalfields," Transactions of the Geological Society of South Africa, Volume 55, pp. 19-31, 1952.

* dry, ash free.

Table I

Equations Used to Express the Relationships of Temperature with Reflectance, Resistivity, and Hydrogen Content

1. Temperature, F = $222.6514 + 641.1268\ R_o - 147.9204\ R_o^2 + 12.6124\ R_o^3$

   R_o = maximum reflectance in oil

2. Temperature, F = $1497.4304 - 75.9517\ R - 5.9162\ R^2 - 0.5102\ R^3$

   R = electrical resistivity in ohm-cm

3. Temperature, F = $2279.1012 - 749.1191\ H + 178.4985\ H^2 - 17.0855\ H^3$

   H = hydrogen content, weight percent (daf)

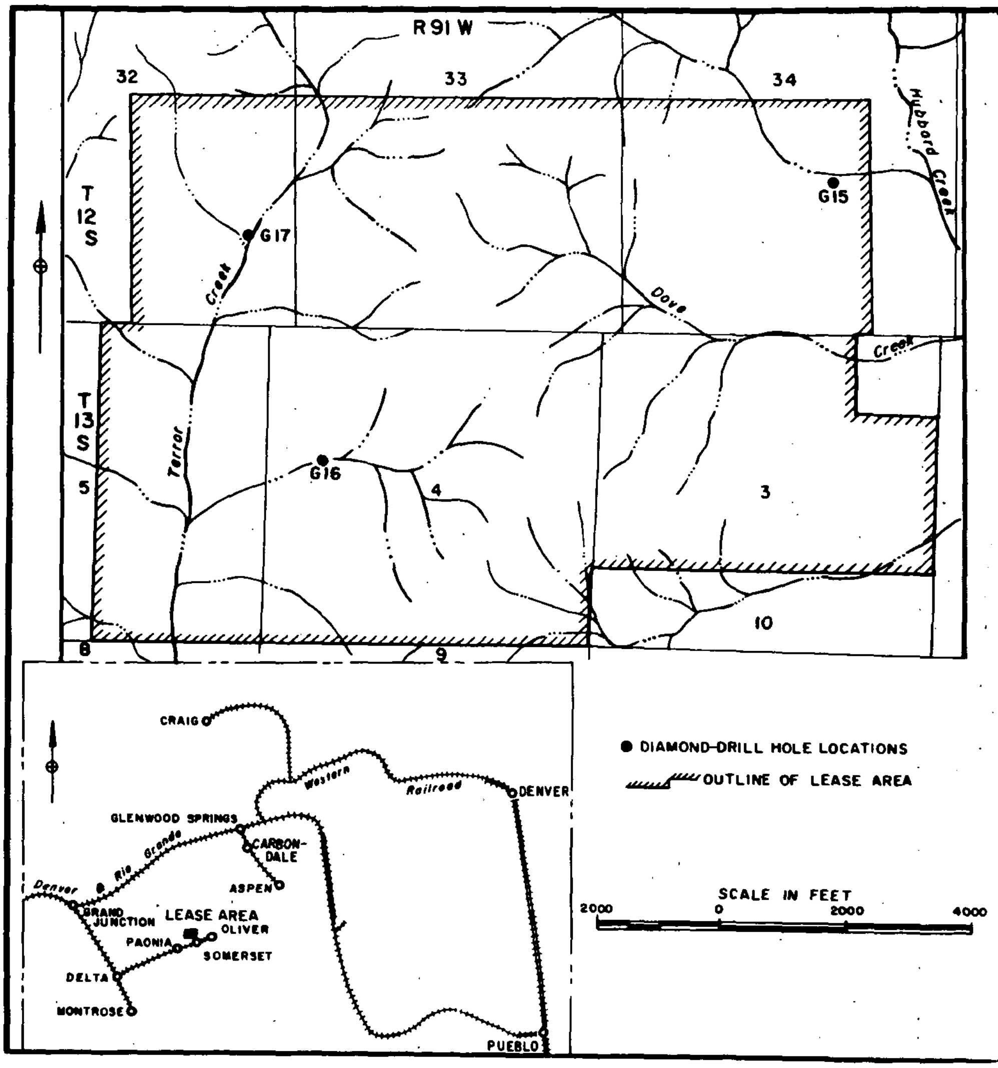


Figure 1. Location of Diamond-Drill Holes in Somerset Area, Colorado

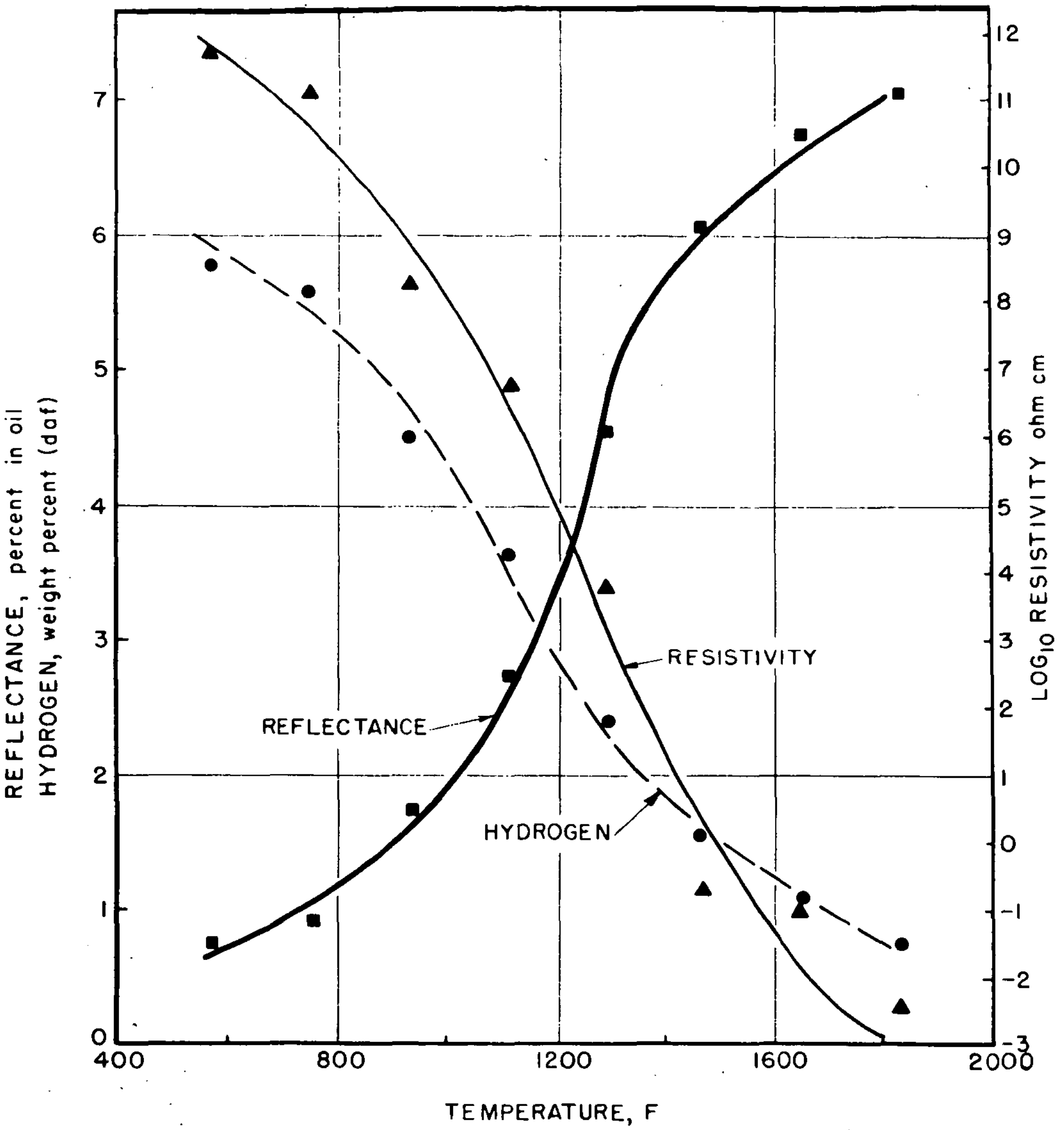


Figure 2. Relation of Temperature to Reflectance, Resistivity, and Hydrogen for Coal Carbonized in the Laboratory

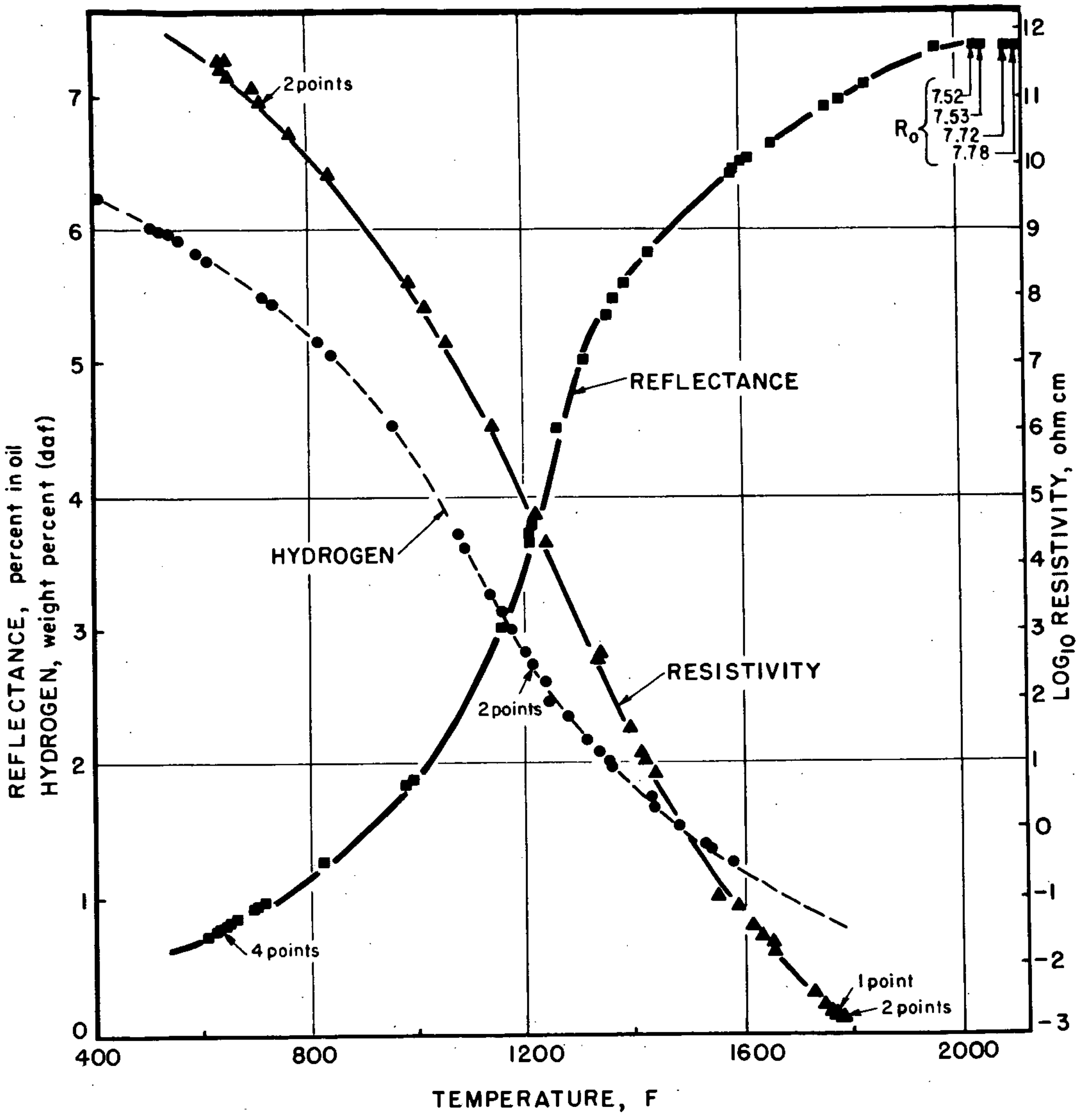
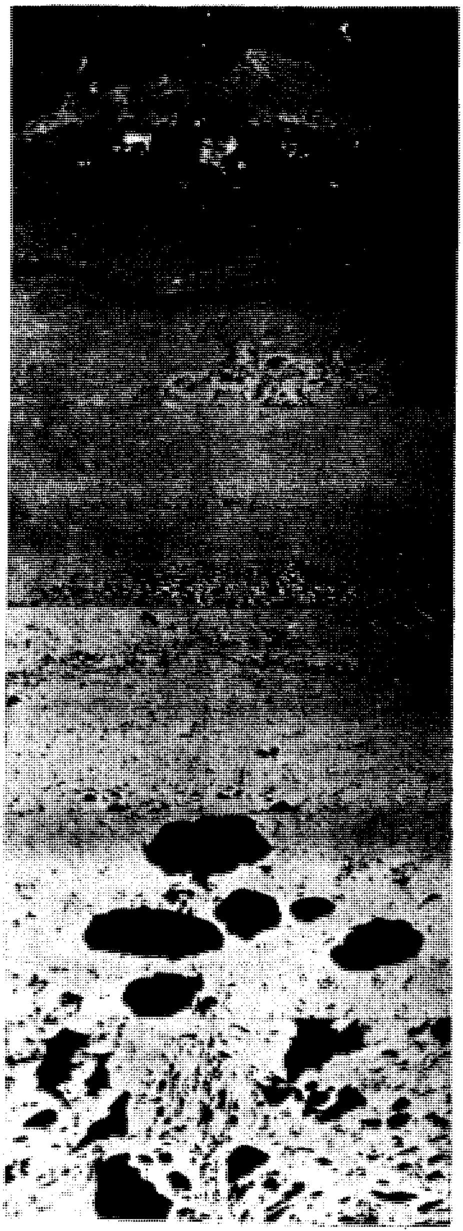


Figure 3. Relation of Calculated Temperature to Reflectance, Resistivity, and Hydrogen for Drill Core Samples of Coal



Reflectance, percent	Resistivity, ohm cm	Hydrogen, wt percent	Description
0.7	3.0×10^{11}	6.2	Coal is unaltered
0.9	8.4×10^{10}	5.5	Coal increases in reflectance but vacuole development has not occurred.
3.0	2.1×10^{7}	3.6	Small pinpoint vacuoles develop.
4.5	2.0×10^{4}	2.8	Vacuoles increase in size.
5.6	1.3×10	2.5	Vacuoles continue to increase in size.
7.5	2.9×10^{-2}	1.3	Anisotropic coke structure develops.

Figure 4. As the Thermal Metamorphism of Coal Increases, the Extent of Vacuole Development Increases and the Reflectance Increases, While Resistivity and Hydrogen Decrease. Reflected light, X300.

Particles of coal showing wide variation in reflectance in a single sample representing a 1.7-foot coal interval. This is evidence of abrupt changes in the degree of thermal metamorphism.

Coke (pyrolytic carbon) produced from cracking of hydrocarbons or incomplete combustion of gas.

Mineral matter derived from the diorite intruded into the coal.

Figure 5. Photomicrographs Show Thermally Metamorphosed Coal, Pyrolytic Carbon, and Intruded Mineral Matter. Reflected light, X300.

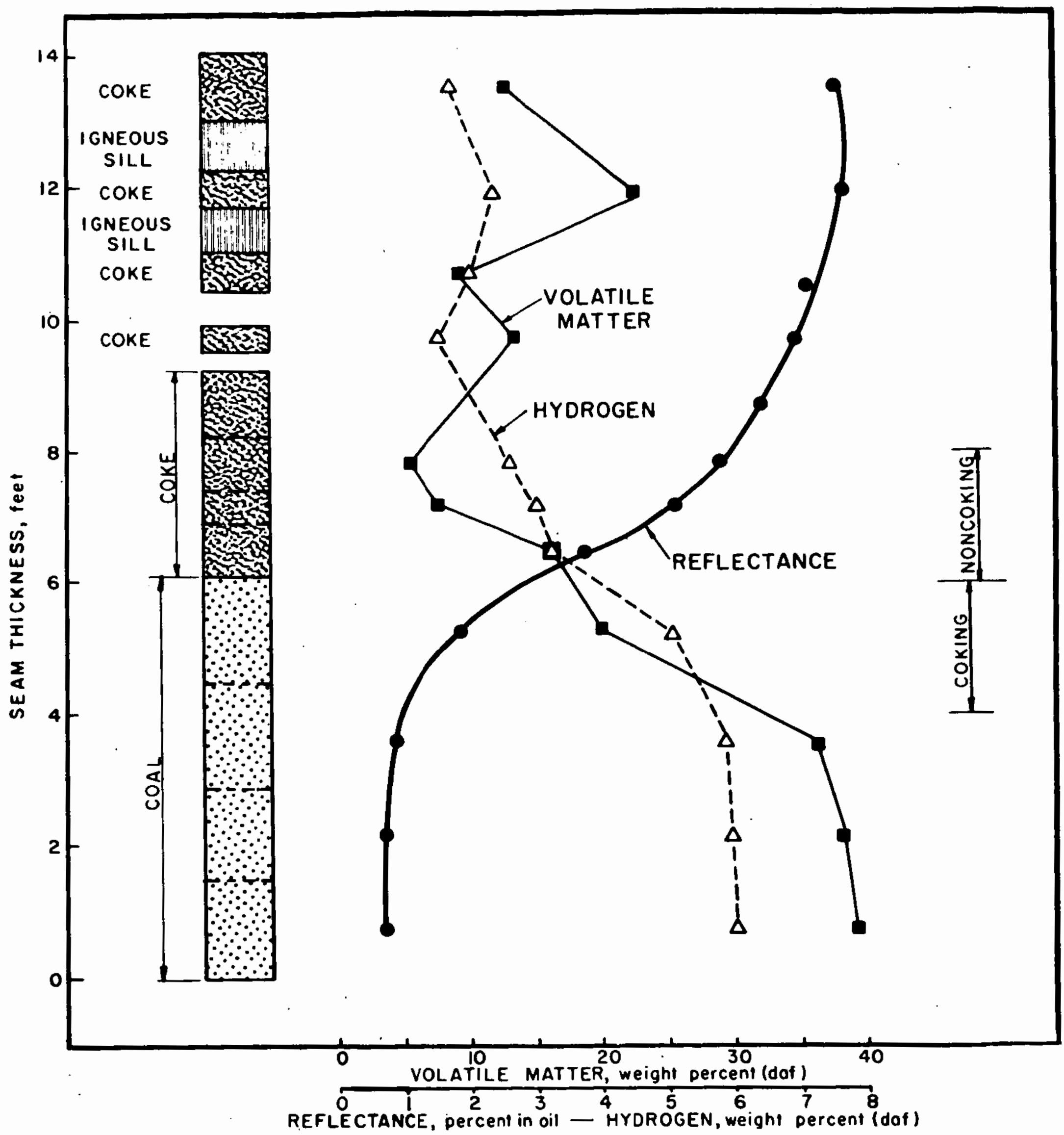


Figure 6. Profile of Coal and Sills with Reflectance, Hydrogen, and Volatile Matter for Indicated Coal Units, B-1 Seam, Hole G-15.

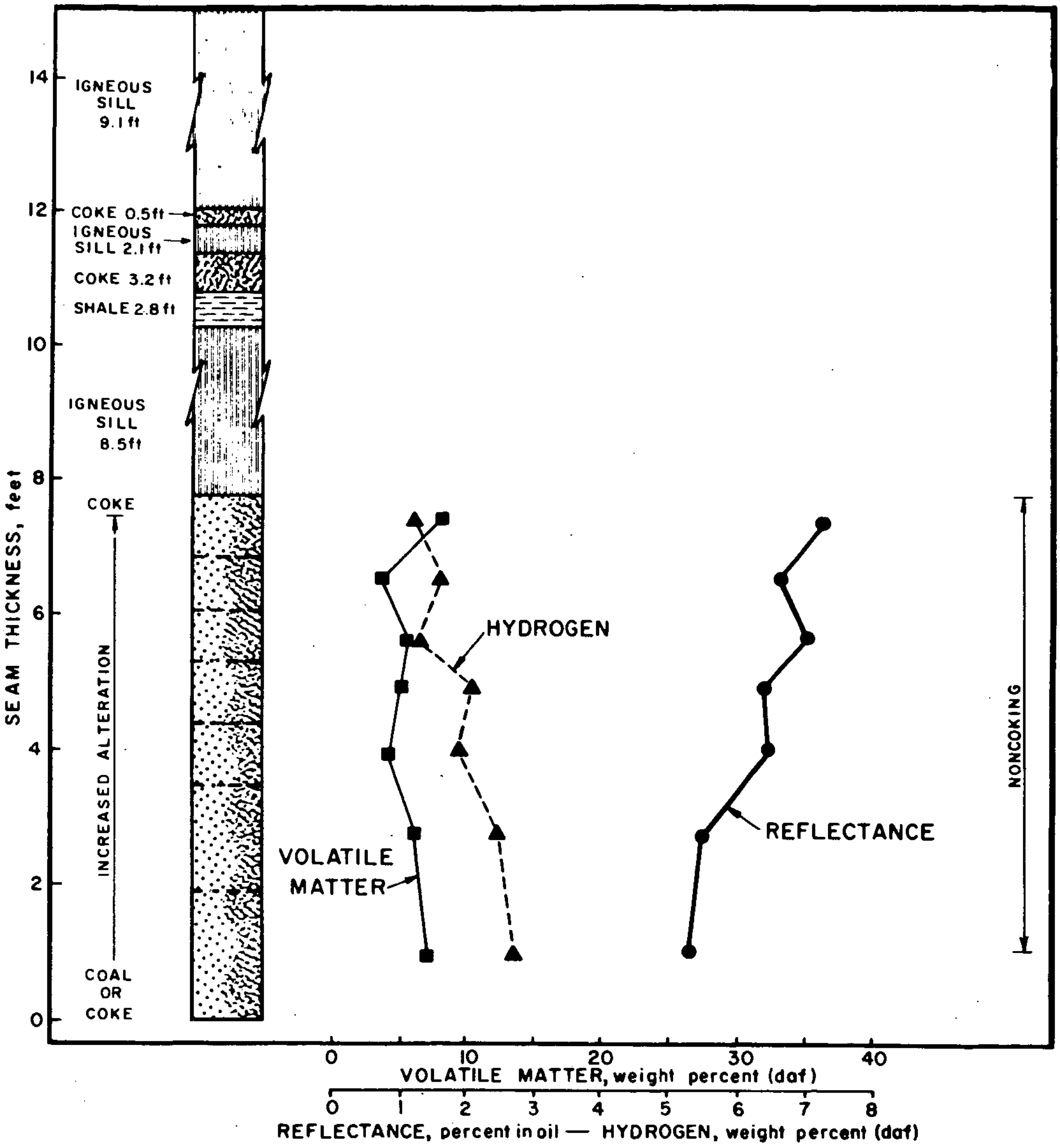


Figure 7. Profile of Coal and Sills with Reflectance, Hydrogen, and Volatile Matter for Indicated Coal Units, B-2 Seam, Hole G-16.

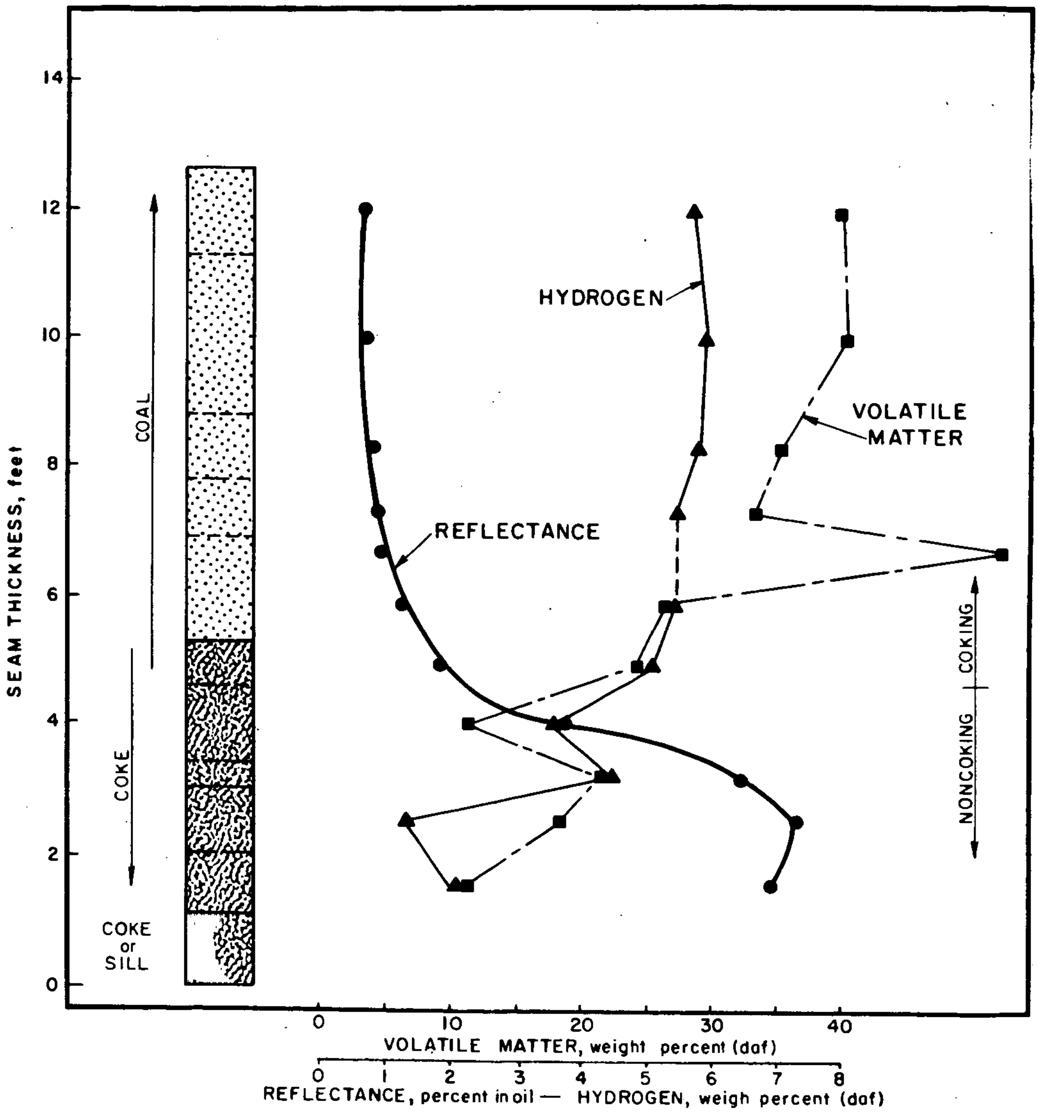


Figure 8. Profile of Coal and Sills with Reflectance, Hydrogen, and Volatile Matter for Indicated Coal Units, C Seam, Hole G-16.

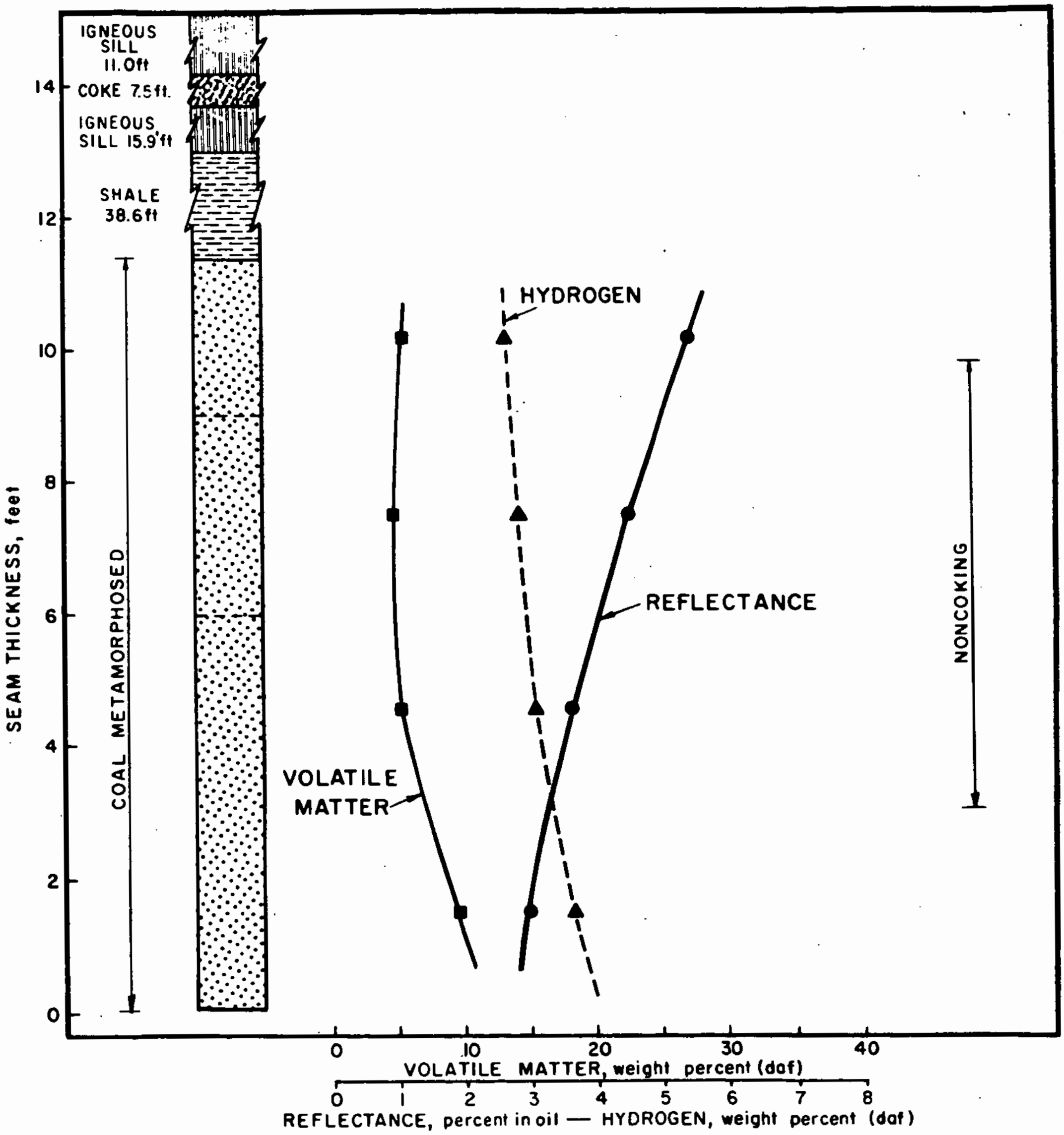


Figure 9. Profile of Coal and Sills with Reflectance, Hydrogen, and Volatile Matter for Indicated Coal Units, B-1 Seam, Hole G-17.

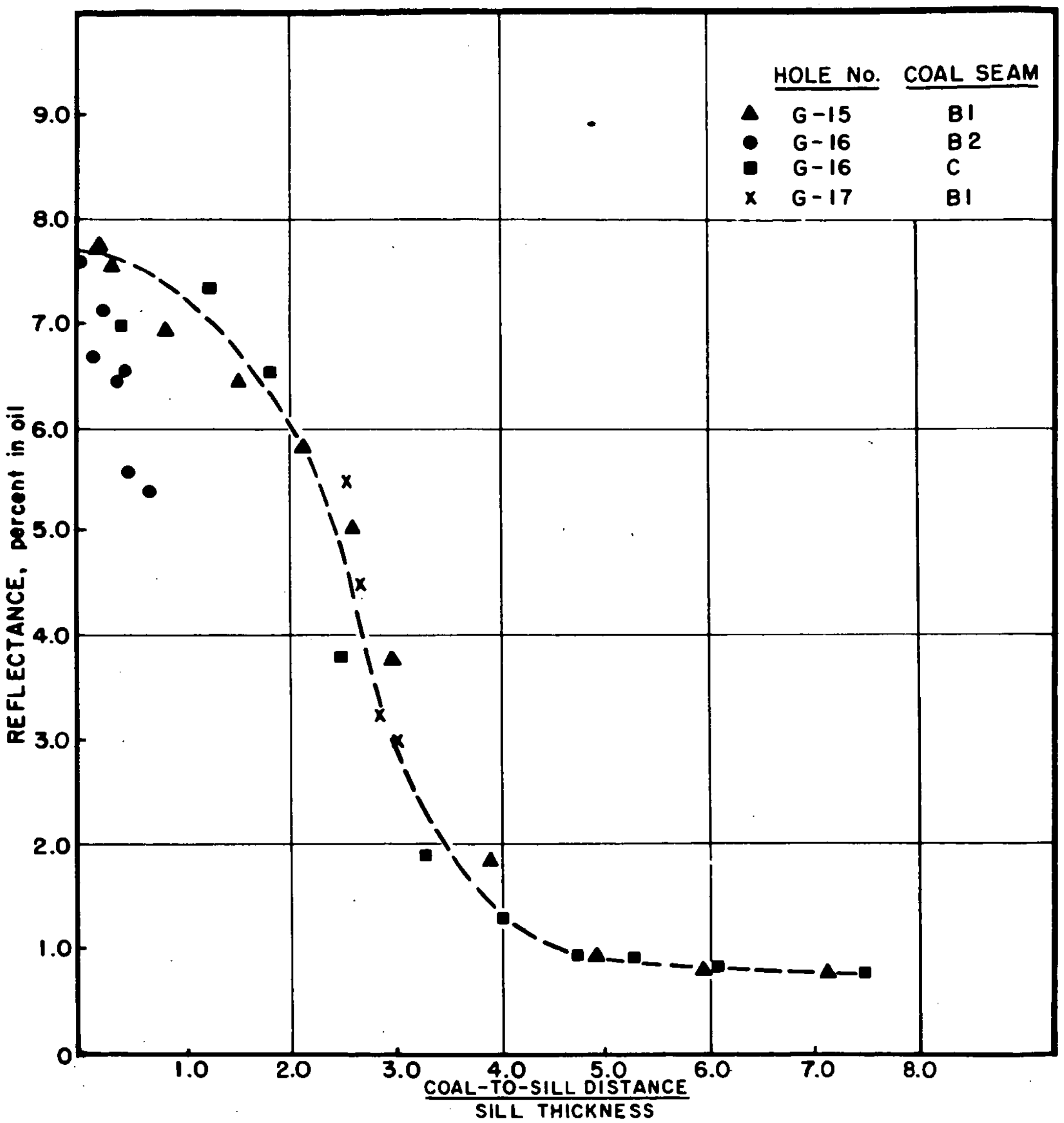


Figure 10. Reflectance Versus Ratio of Coal-to-Sill Distance to Sill Thickness for Thermally Altered Somerset Coal