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DEPARTMENT OF REGISTRATION AND EDUCATION
FRANK G. THOMPSON, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*
URBANA

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STATUS OF THE CARBON-RATIO THEORY IN ILLINOIS

BY
ALFRED H. BELL

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STATUS OF THE CARBON-RATIO THEORY IN ILLINOIS*

By Alfred H. Bell

State Geological Survey, Urbana, Illinois

In a paper entitled "Some Relations in Origin between Coal and Petroleum" published in 1915, David White[1] made some generalizations that have been called collectively the "carbon-ratio theory." During the ensuing 20 years many authors have discussed the carbon-ratio theory and some have questioned its validity with respect to specific areas. The purpose of the present paper is to review the pertinent data on coal and petroleum for the State of Illinois and to consider their bearing on the various parts of the carbon-ratio theory.

The fundamental concept of the carbon-ratio theory is that dynamic metamorphism, acting upon rock strata through past geologic ages, has caused progressive increase in the fixed carbon content of coal and in the Baumé gravity of petroleum. From proximate analyses of coal, giving the percentages of four constituents, namely, moisture, volatile combustible matter, fixed carbon and ash, the "carbon-ratio" or per cent fixed carbon in moisture- and ash-free coal can be calculated. The carbon-ratio of a coal in any locality according to the theory, is an index to the degree of dynamic metamorphism to which the coal and its associated strata have been subjected in that locality. Commercial oil fields, it was found, are confined to areas in which carbon-ratios are not over about 65 (pure coal basis). Some gas fields are located in areas of somewhat higher carbon-ratios but not over 70. No commercial gas or oil are found in areas of carbon-ratio above 70. In some regions a progressive increase in the Baumé gravity of oil (decrease in specific gravity) was noted in going from areas of low carbon-ratio to areas of high carbon-ratio, or from areas of little structural disturbance to those highly disturbed. From these observations it is inferred that dynamic metamorphism acts on oil to change it chemically, making it lighter in gravity until a point is reached at which it is no longer liquid at ordinary temperature and pressure. The boundary between an area in which oil pools occur and an area of higher carbon-ratios in which there are no oil pools is called the "extinction zone." In a recent paper by David White, the extinction zone is placed between carbon-ratios of 61 and 63 (pure coal basis)[2].

If all coals were formed in the same manner from the same original material, and if all determinations of carbon-ratio were made by the same procedure, the variations in carbon-ratio found might be ascribed entirely to varying degrees of subsequent metamorphism. However, it is well known that coals differ greatly in respect to the original material from which they were formed. Methods of sampling coal and of making proximate analyses of coal have differed at different times and in different laboratories. A number of different methods have been used to calculate "carbon-ratios." Consequently much caution must be used in any attempt to use carbon-ratios as an index to the degree of dynamic metamorphism.

A discussion by W. T. Thom[3] of sources of error and of limitations to the use of carbon-ratios has been published. After considering the probable maximum variation of carbon-ratios from the "true norm for the metamorphism which such coal samples have suffered," due to initial differences in coal-forming vegetation at time of burial and to errors in sampling, analysis and computation, Thom says "Carbon-ratios appear to provide a fair qualitative index of local metamorphic intensity, but do not give quantitative measures which can be relied on in drawing isocarb contours of less than 5 per cent (average) differences, even when derived with all possible care."[4]

The relative merits of the various methods of computing "carbon-ratio" were also discussed by Thom in the same paper. According to the usage of David

* Trans. Illinois Acad. Sci. vol. 34, No. 2, pp. 175-179, 1941 (1942); abstract appeared in Trans. Illinois Acad. Sci., 1936.

[1] References are given on page 6.

White and of most writers on the subject, carbon-ratio is the percentage of fixed carbon in dry ash-free coal computed from the proximate analysis. Thom, on the other hand, advocates the definition of carbon-ratio as the percentage of fixed carbon in moist or "as received" ash-free or mineral-matter-free coal because "the moisture reported in the ordinary proximate analysis must be regarded as an actual constituent of the coal, particularly if the fixed carbon content is to be used broadly as a rough index to the intensity of metamorphic action." An additional but minor point in favor of using the carbon-ratio of the moist coal is that one less experimental determination is involved and hence there is one less chance for error.

Table 1 shows four methods of defining and calculating carbon-ratio. An actual coal analysis is taken for an example and carbon-ratio calculated by each of the four methods. It may be noted that carbon-ratios on the dry coal basis are considerably higher numerically than those on the moist coal basis but the numerical differences resulting from the use of mineral-matter-free instead of ash-free coal are comparatively small and of the order of 1 per cent. Hence in making use of carbon-ratios from different sources, those for moist coal must not be compared directly with those on dry coal although it is permissible when studying large regions to use mineral-matter-free and ash-free carbon-ratios on the same map.

In the present study of Illinois carbon-ratios isocarb maps were made for both dry and moist carbon-ratios. Although both maps showed the same broad features, the map of moist carbon-ratios was more consistent and the variations in carbon-ratio were less abrupt in some areas than in the map of dry carbon-ratios.

Figure 1 includes two maps, one showing structure and the other showing carbon-ratios. The structural key horizon in all but eastern Illinois is the top of coal No. 6, and the contour interval 100 feet.

TABLE I.—CALCULATION OF CARBON-RATIO FROM PROXIMATE ANALYSIS OF "AS-RECEIVED" SAMPLE GIVEN THE FOLLOWING ANALYSIS

		"As received" Basis	Moisture Free Basis
Moisture	M_r	15.9 per cent	
Volatile Combustible Matter	VC_r	32.6 per cent	$VC_f = \frac{VC_r}{100-M_r} = 38.8$
Fixed Carbon	FC_r	42.5 per cent	$FC_f = \frac{FC_r}{100-M_r} = 50.5$
Ash	A_r	$\frac{9.0}{100.0}$ per cent	$A_f = \frac{A_r}{100-M_r} = 10.7$
Sulfur	S_r	3.05 per cent	$S_f = \frac{S_r}{100-M_r} = 3.62$

Carbon-Ratio I = Per cent fixed carbon in "pure coal" or dry ash free coal

$$\frac{FC_r \times 100}{100 - (M_r + A_r)} = \frac{42.5 \times 100}{100 - (15.9 + 9.0)} = 56.6$$

Carbon-Ratio II = Per cent fixed carbon in "unit coal" or dry mineral matter free coal

$$\frac{100\ (FC_f - .15\ S_f)}{100 - (1.08\ A_f + .55\ S_f)} = \frac{100\ (50.5 - .15 \times 3.62)}{100 - (1.08 \times 10.7 + .55 \times 3.62)} = 57.8$$

Carbon-ratio III = Per cent fixed carbon in "as-received, ash-free, or moist, ash free" coal

$$\frac{FC_r \times 100}{100 - A_r} = \frac{42.5 \times 100}{100 - 9.0} = 46.7$$

Carbon-Ratio IV = Per cent fixed carbon in "as-received, mineral matter free, or moist mineral matter free" coal

$$\frac{100\ (FC_r - .15\ S_r)}{100 - (1.08\ A_r + .55\ S_r)} = \frac{100\ (42.5 - .15 \times 3.05)}{100 - (1.08 \times 9.0 + .55 \times 3.05)} = 47.5$$

In the area of the LaSalle anticline in eastern Illinois, the key horizon is the base of the Kinderhook-New Albany shale (top of Devonian limestone). The principal structural features shown are the large basin that includes all of the Pennsylvanian area in Illinois and extends beyond the state border into Indiana and Kentucky, the LaSalle anticline and the Duquoin "anticline" or, more appropriately, monocline.

The carbon-ratios shown are the percentages of fixed carbon in moist mineral-matter-free coal (No. IV, Table 1). Datum points are not shown. Each datum point represents one mine and in most cases is an average of the analyses of several face samples. The great majority of the analyses were of coal No. 6. Those in the northern part of the area were of coal No. 5, No. 2 and No. 1. According to Hilt's law, carbon-ratios increase with depth of burial and with geologic age for different coals at the same location. Therefore, if carbon-ratios of different coals are to be used in drawing isocarbs, they should all be referred to a single horizon by adding or subtracting an amount which is the average difference in carbon-ratio of the given coal and of the coal at the reference horizon over an area in which both coals occur. This is difficult, however, because in most districts only one coal is mined, and data are insufficient to obtain a reliable value for the average difference in carbon-ratio between any two coals in the same area. Moreover, there are some instances where an upper coal has a higher carbon-ratio than a lower coal at the same locality. In such cases it is evident that other factors, such as original constitution of the coal-forming material, had more influence in determining carbon-ratio than did depth of burial. Available data show that average differences in carbon-ratio of the various coals used in this study are considerably less than the isocarb contour interval of 5 per cent. Accordingly it was decided not to use a correction to a single reference horizon.

The isocarb map shows progressive increase in carbon-ratio in going from north to south toward the faulted area in southern Illinois. Data are lacking in the central part of the basin and in most of the LaSalle anticline area but the isocarbs have been tentatively drawn to show a "high" in this area, and a "low" in the basin area to the west. A pronounced carbon-ratio high extends northward from the southern part of Williamson County a few miles east of the Duquoin anticline. This coincides in location with a belt of faulting which extends northward into Franklin County. Some of the smaller carbon-ratio highs, however, are not connected with known structural features. Attention is here called to the fact that a majority of the oil and gas pools of the State are located on or near carbon-ratio highs. Those that are not so located as shown by the present map are nearly all in areas where carbon-ratio data are scarce or lacking, as for example the Jacksonville gas field, the Colmar-Plymouth oil field, the Waterloo and Dupo oil fields. There is a suggestion that the carbon-ratio highs were caused by forces of structural deformation which at the same time favored the accumulation of oil and gas.

Figure 2 is a carbon-ratio and structure map of the southern part of Illinois. It is on a larger scale and is more detailed than Fig. 1. Instead of the boundaries of faulted areas, the location of the faults themselves is shown. In addition to the oil and gas fields which are named, the location of important oil shows are indicated. One of these, which was a 2-barrel show in the Ste. Genevieve limestone (Lower Mississippian), is located on a carbon-ratio high.

Variations in oil gravity in Illinois are greater in different stratigraphic horizons in one locality than they are for oil from one stratigraphic horizon in different locations. There is no recognizable relationship between areal variations in oil gravity in Illinois and areal variations in either carbon-ratios or degree of structural disturbance. This lack of correlation may be due largely to the fact that the known oil and gas fields of the State are confined to areas in which the range of carbon-ratio variation and degree of structural disturbance are considerably less than the total range for the whole State.

The data presented above on carbon-ratios and structure in Illinois definitely indicate a relationship between regional variations in carbon-ratio and degree of structural disturbance. However, the

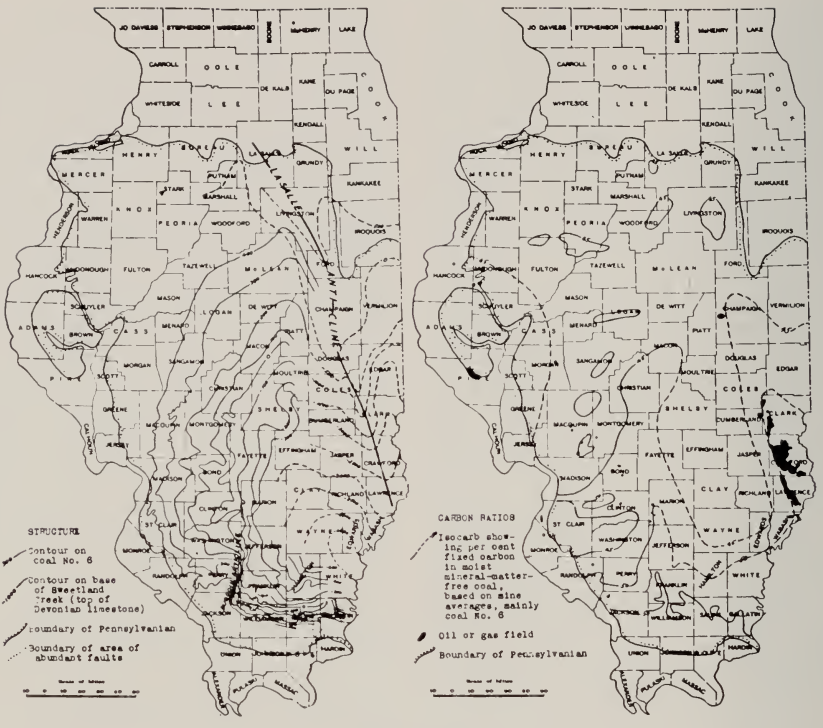

FIG. 1[5]

greatest degree of structural disturbance in the coal basin of Illinois, which occurs in the Illinois Ozarks, falls far short of that in the intensely folded anthracite region of Pennsylvania, and therefore conditions in Illinois are not suited for a complete investigation of the carbon-ratio theory.

Carbon-ratio data may be of some assistance in future prospecting for new oil and gas fields in Illinois by suggesting territory in which probabilities appear greater than in neighboring territory. They cannot be expected to provide as good a basis for recommending definite locations for drilling as detailed structural data. Nor can any part of Illinois be eliminated from consideration as prospective oil territory on the basis of carbon-ratio data.

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[1] David White, Some relations in origin between coal and petroleum: Jour. Washington Acad. Sci., vol. 5, pp. 189-212, 1915.

[2] David White, Metamorphism of organic sediments and derived oils: Bull. Am. Assoc. Petroleum Geologists, vol. 19, No. 5, pp. 589-617, 1935 (see abstract).

[3] W. T. Thom, Jr., Present status of the carbon-ratio theory: Problems of Petroleum Geology, a Symposium, published by the Am. Assoc. Petroleum Geologists, pp. 69-95, 1934.

[4] ....., op. cit., p. 90.

[5] EDITOR'S NOTE: In the legend of the left-hand map of figure 1, the term "Kinderhook-New Albany shale" should be used instead of "Sweetland Creek."

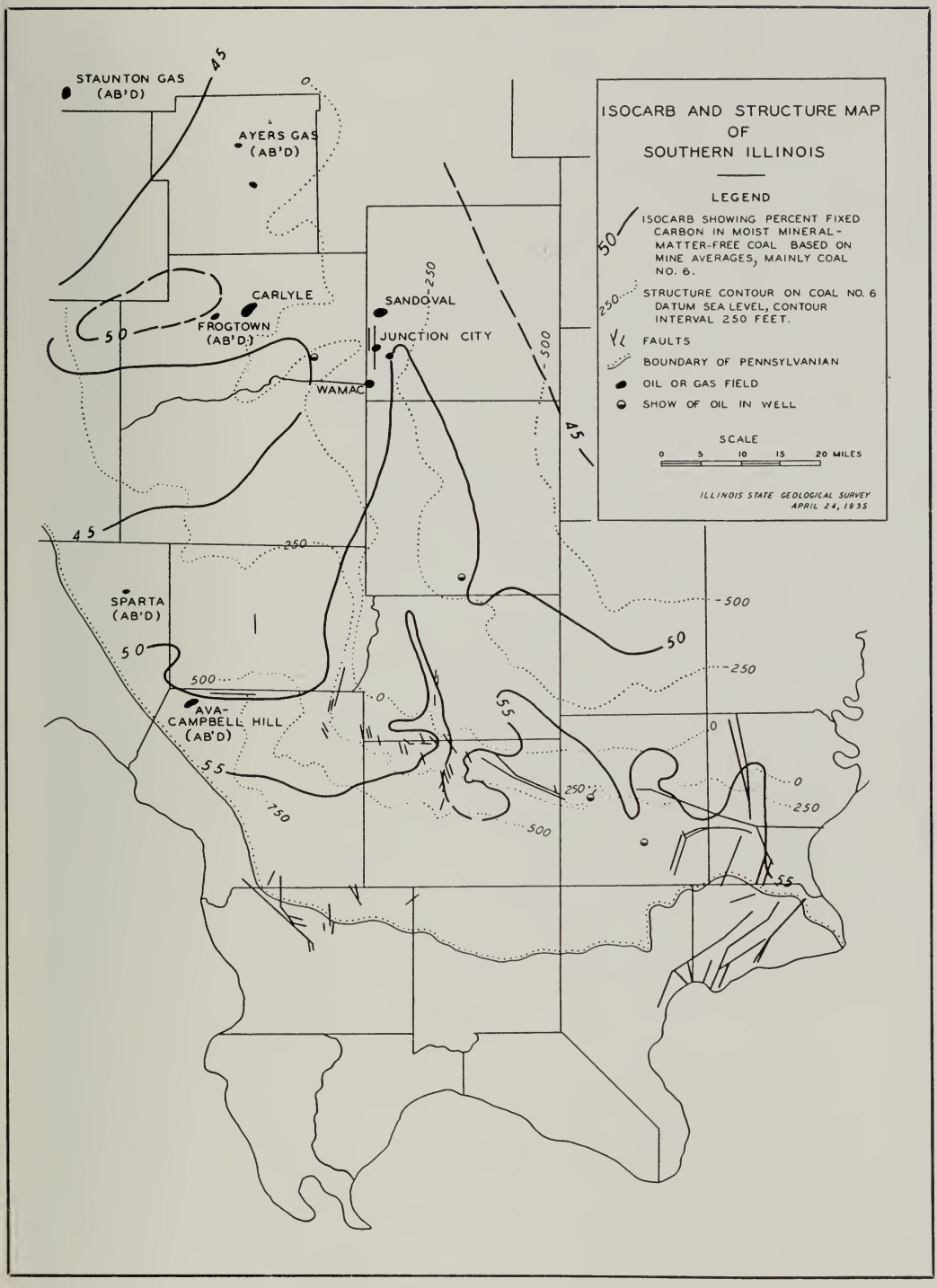
ISOCARB AND STRUCTURE MAP
OF
SOUTHERN ILLINOIS
LEGEND
ISOCARB SHOWING PERCENT FIXED CARBON IN MOIST MINERAL-MATTER-FREE COAL BASED ON MINE AVERAGES, MAINLY COAL NO. 6.
STRUCTURE CONTOUR ON COAL NO. 6 DATUM SEA LEVEL, CONTOUR INTERVAL 250 FEET.
FAULTS
BOUNDARY OF PENNSYLVANIAN
OIL OR GAS FIELD
SHOW OF OIL IN WELL
SCALE
0 5 10 15 20 MILES
ILLINOIS STATE GEOLOGICAL SURVEY
APRIL 24, 1935
STAUNTON GAS (AB'D)
AYERS GAS (AB'D)
CARLYLE
FROGTOWN (AB'D)
SANDOVAL
JUNCTION CITY
WAMAC
SPARTA (AB'D)
AVA-CAMPBELL HILL (AB'D)

FIG. 2.