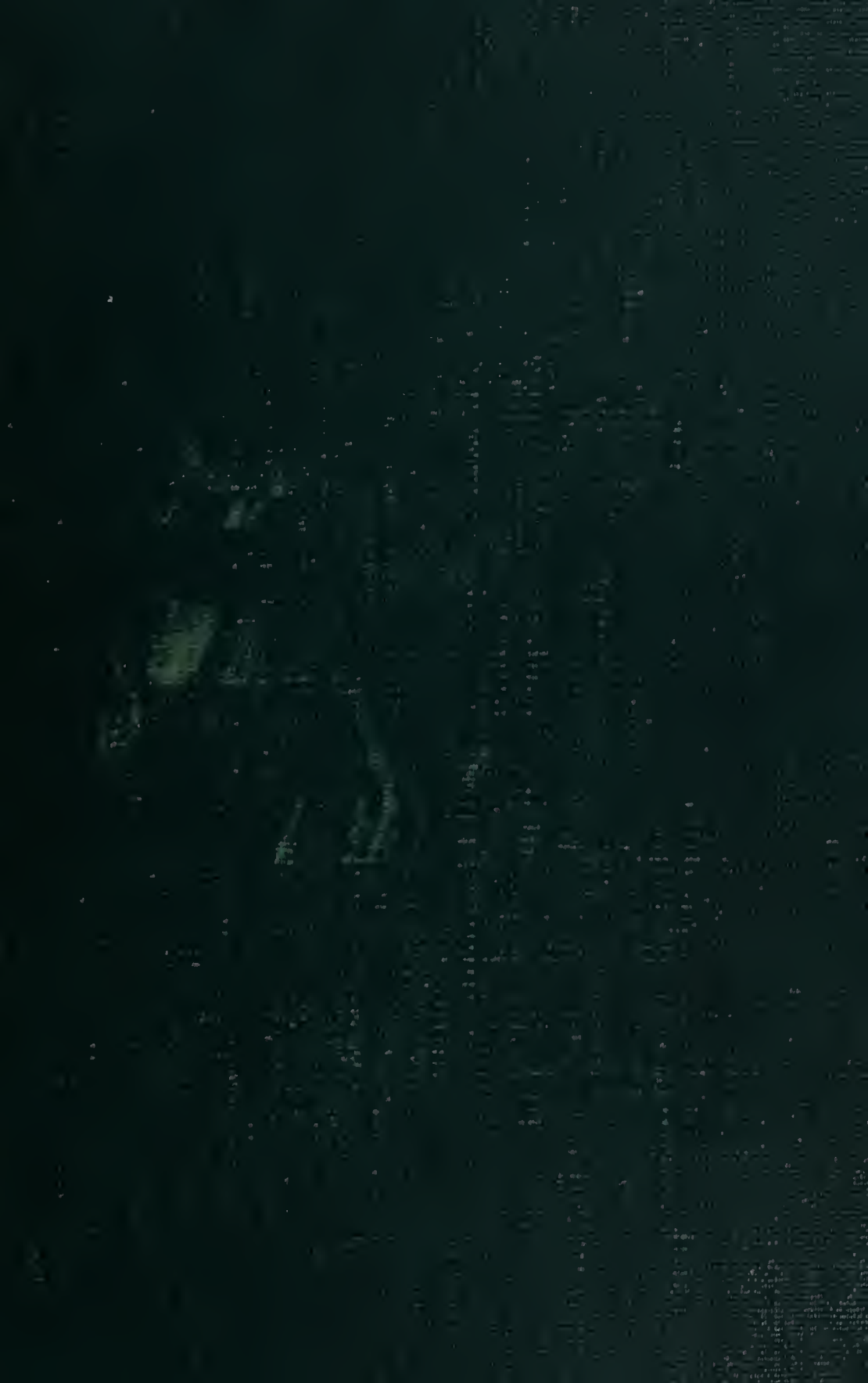

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
A. M. SHELTON, *Director*

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

REPORT OF INVESTIGATIONS—NO. 4

CARBON RATIOS AND PETROLEUM IN ILLINOIS

BY
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INTRODUCTION

In the decade since White[1] first called attention to the interrelation of the effects of metamorphism on coal and petroleum, the relation has been further investigated in several of the important oil producing states. Thus far, carbon ratios (the ratio of Fixed Carbon to the sum of Fixed Carbon plus Volatile Matter) have been very useful in pointing out areas in which the processes of metamorphism have been so pronounced that the chances of finding commercial accumulations of petroleum are slight. The possiiblity of their use in locating areas of greater deformation favorable to oil occurrence in regions of slight folding, has not been stressed, but also deserves consideration.

Petroleum investigations in Illinois are greatly hampered by the occurrence of the thick cover of glacial drift and the shallow dissection of the surface. Detailed determinations of structural conditions have depended largely upon the interpretation of well logs. For considerable areas in the State, such information is scanty and not very reliable. Consequently, it seems desirable to investigate carbon ratios in Illinois coals to assist in delineating areas in which general deformation has occurred. In such areas the chances of finding structures suitable for the accumulation of petroleum would be greater than in relatively undisturbed areas, and special attention would be deserved.

In addition to the question of choice of areas for further investigation, carbon ratios have possibilities in helping to solve several related problems such as: (1) consideration of possibilities of oil production in the faulted area in southern Illinois; (2) the deepest horizon which should be tested in favorable structures in various regions of the State; (3) relation between carbon ratios and moisture content of coals; (4) the effects of depth of burial and unconformities on carbon ratios, and (5) the reason for the dominance of gas production in western Illinois as contrasted with that of oil in eastern Illinois.

USE OF DATA

Sources of Information

For a number of years Illinois has held an important place as a coal producer. Consequently, a large amount of information is available concerning the character of the coal. Most of the analyses have been compiled

[1] White, David, Some relations in origin between coal and petroleum: Wash. Acad. Sci. Jour. Vol. 6, pp. 189-212, 1915.

and published.[2] Carbon ratios were computed from the original analyses for about 350 mines, and in most cases the result used was an average of three or more analyses. All of the analyses used were made either by the U. S. Bureau of Mines or the Fuel Laboratory of the University of Illinois. The close agreement of results obtained by these two laboratories is probably not excelled by any other two in the country. For that reason the data used are of uniformly high quality.

Accuracy of Carbon Ratios

The uncertainty in carbon ratio value corresponding to permissible variations in the results of analysis was calculated in order to determine the minimum change in carbon ratio which should be considered significant. The method of computing this minimum is as follows:

Let A be the volatile matter, B the fixed carbon, and D the ash plus moisture. Then $A + B + D = 100$ per cent and $B / (A + B) =$ the carbon ratio. In order to determine the variation due to permissible errors in analysis, the use of simple differential calculus is advisable. The equations which follow show the steps taken in deriving the formula.

$$\frac{B}{A+B} = \frac{100-(A+D)}{100-D}$$ (Two expressions for the carbon ratio)

Differentiating:

$$d\left(\frac{B}{(A+B)}\right) = \frac{(100-D)\ (-dA-dD) + (100-A-D)\ dD}{(100-D)^2}$$

or

$$d\left(\frac{B}{(A+B)}\right) = \frac{(100-D)\ dA - 100dD + DdD + 100\ dD - AdD - DdD}{(100-D)^2}$$

Combining like terms gives $\frac{(100-D)\,dA + AdD}{(100-D)^2} = \frac{dA}{100-D} + \frac{AdD}{(100-D)^2}$

or the uncertainty of carbon ratio $= \frac{dA}{100-D} + \frac{AdD}{(100-D)^2}$ in which dA is the permissible error in volatile matter and dD is the permissible error in noncombustible matter.

For Illinois coals the standard limits of error give the values dA=1.00 per cent, and dD=0.8 per cent. By using these values and taking the value for D and A from the analyses of various Illinois coals, the uncertainty in carbon ratio was found to vary from 1.18 to 1.38 according to the local condition of the coal.

If each datum point on the map (fig. 3) had only one analysis as its source of information, variations in carbon ratios of 1.25 per cent would be of doubtful significance. The values used, however, were the result of

[2] Hawley, G. W., Analyses of Illinois coals: Ill. Min. Investigations Bull. 27A, 1923. (Includes analyses previously published by the U. S. Bureau of Mines.)

averaging several analyses. This process reduced the probable error to at least one-half the computed limit. Accordingly, variations of one per cent in carbon ratio are considered significant, and fairly uniform changes of smaller value are worth notice. In order to show all authentic details of carbon ratio variation, isocarbs were drawn at intervals of two per cent.

The law of Hilt, that there is a progressive increase of fixed carbon in successively older coal beds in passing downward in a stratigraphic section, was considered in Illinois. David White[3] cites several exceptions. If the law is exact, the increase in carbon ratio from one coal to the next in a conformable series would depend on the stratigraphic interval. If an unconformity occurs between two coals, the lower should show an abrupt increase in carbon ratio.

In Illinois several coal beds are important enough to be mined. In a few localities samples from two or more coals have been analysed. These analyses have been compared to check the law of Hilt and to determine the carbon ratio correction for coals other than No. 6. Although in certain cases modifications of results were probably introduced by errors in coal correlation, a preliminary suggestion of the effects on carbon ratios was obtained. These are shown in Table 1. Illinois coals have been given consecutive numbers beginning with No. 1 at the bottom.

TABLE 1. *Variations of carbon ratios between the various coals in Illinois*

County	Coal	Carbon ratio	Comments on variations
Fulton	No. 5	51.7	No significant difference
	No. 1	51.8	
McLean	No. 5	48.8	No significant difference
	No. 2	49.6	
Gallatin	No. 6	57.4	Increase of 1.3 marks unconformity
	No. 5	58.7	
Vermilion	No. 7	50.8	Increase of 2.3 marks unconformity
	No. 6	53.1	
Jackson	No. 6	57.4	Increase of 2.8 marks unconformity
	No. 2	60.2	

As a result of a consideration of the available data in Illinois, it appears that the effect of the difference in depth is not significant if the series is con-

[3] White, David, The origin of coal: U. S. Bur. Mines Bull. 38, pp. 125-127, 1913.

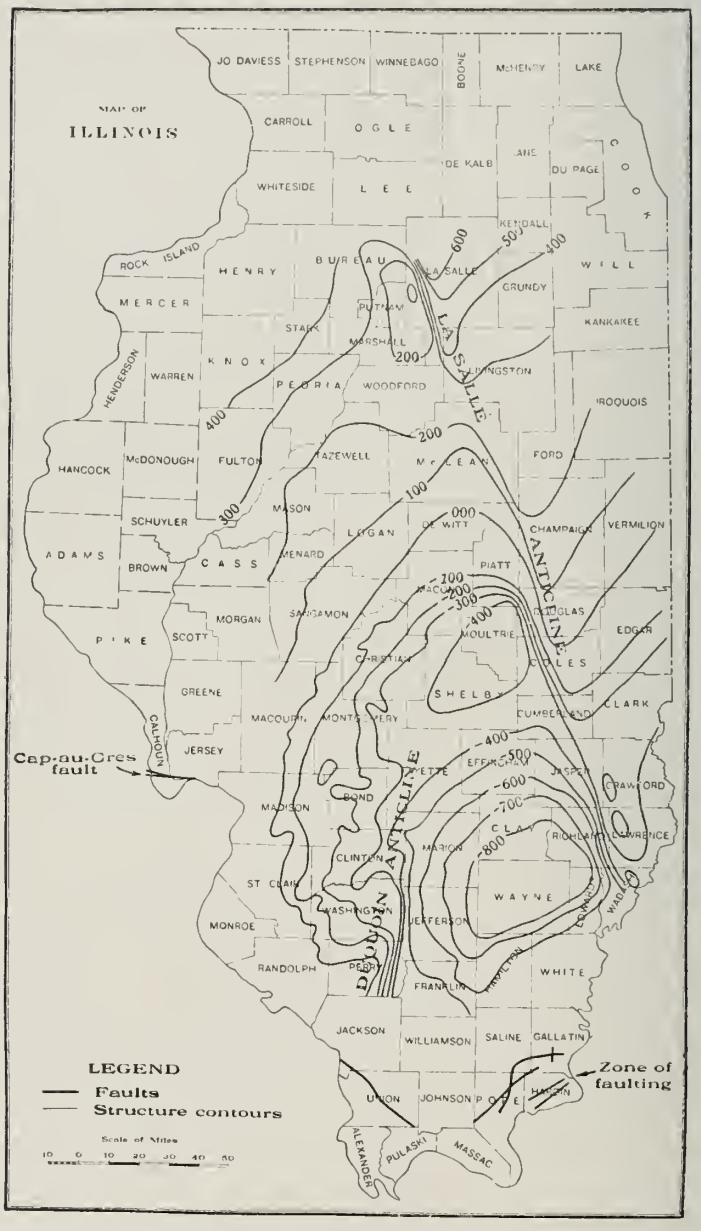

FIG. 1. Generalized structure map of Illinois. Contours on approximate horizon of No. 2 coal.

FIG. 2. Illinois oil and gas fields.

formable. This apparent exception to the law of Hilt may arise from the small thickness of beds between the coals sampled (about 250 feet, maximum) or may be due to a lack of critical data. In case the coals are separated by an unconformity, however, there is a marked increase in carbon ratio of the lower coal. These differences seem to be pronounced enough to be of value in coal correlation.

No. 6 coal was chosen as the standard, for it is one of the most extensive beds in the State. Because the No. 6 coal is separated from both the underlying and overlying coals by an unconformity, a correction is necessary in the carbon ratios of the other coals in order that the results may be comparable. The following corrections were applied to reduce results to No. 6 coal:

Gallatin County—Subtract 1.3 from carbon ratios of No. 5 coal.
Vermilion County—Add 2.3 to carbon ratios of No. 7 coal.
Jackson County—Subtract 2.8 from No. 2 coal carbon ratio.

These ratio corrections were also applied to coals in the vicinity of the places for which they were determined.

STRUCTURAL FEATURES OF ILLINOIS

In order to appreciate fully the significance of the carbon ratios in Illinois, it is first desirable to have a general idea of the main known structural features of the State (fig. 1), so that the relation between these features and the configuration of the isocarbs will be apparent.

The La Salle anticline is one of the most prominent structural features of Illinois. It may be traced from the north central part of the State in a direction a little east of south for most of the length of the State to a point where it crosses Wabash River into Indiana. The structural contours (fig. 1), show that the dip on the west limb of the fold is much steeper than that on the east. The folding along this axis began in pre-Pennsylvanian time, but was continued at the end of the Pennsylvanian deposition, so that the structure in the lower rocks is similar to that of the coals, but is more pronounced.

The Duquoin anticline is another prominent fold. It extends through the south central portion of the State in a north-south direction. In this case, the steeper dip is on the east side of the fold. As figure 1 shows, the west side is rather indefinite, and is not marked by west dips.

The interior basin lies between the steeply dipping east limb of the Duquoin anticline on the west, and the steeply dipping west limb of the La Salle anticline on the east, and, as the map shows, includes a large part of the State. In most portions of the basin the coals are at a considerable depth. This is due to both the structural depression and greater thickness of the Pennsylvanian sediments. The greater thickness of the sediments and the greater abundance of finer clastic materials point to the existence of this basin during the early Pennsylvanian at least.

The southern zone of faulting was the scene of more vigorous dynamic adjustments. Complex faulting and minor igneous activity characterize this region. As a result of greater relative uplift, the Pennsylvanian has been largely removed from this area. Only along the north edge of the zone of faulting is it possible to determine carbon ratios. Although much of the faulting may be post-Chester and pre-Pennsylvanian, a large part of it occurred after the close of the Pennsylvanian. Only a few of the major faults are indicated in figure 1.

RELATION OF OIL FIELDS TO STRUCTURAL FEATURES

Fields Along the La Salle Anticline

As might be expected in an area of moderate disturbance, the principal oil fields are located along one of the principal lines of folding. More than ninety per cent of the present oil production of the State comes from these fields on the La Salle anticline. For various reasons, the producing area has been nearly continuous along much of the fold. This relation is strikingly brought out by a comparison of figures 1 and 2, which show the location of the La Salle anticline and the producing area respectively. The producing horizons include the Trenton, the Kinderhook and the Mississippian lime of the lower Mississippian, the Chester, and the Pennsylvanian.

Minor Western Fields

Three of the minor pools in Illinois are located on and near a broad northern extension of the Duquoin anticline. The other pools in the western part of the State are located on folds which have no established connection with the major structural features of the State.

RELATION OF COAL CHARACTER TO STRUCTURAL FEATURES

Carbon Ratios

A comparison of the structural contours in figure 1 and the isocarbs in figure 3 shows that the zones disturbed by folding are closely followed by increases in the carbon ratios in the coal. The folding of the La Salle anticline and the Duquoin anticline in particular have caused zones of high carbon ratios which project for many miles into areas of lower carbon ratios.

The isocarb map also shows clearly that the disturbances accompanied by faulting in the southern part of the State caused a greater regional metamorphism than is general in the central and north parts of the State.

One of the most interesting features brought out by the isocarb map is the tongue of high carbon ratios which extends northwest from central Tazewell County to Rock Island County. The existence of this area of higher ratios had not been suspected because there is no structural feature of major importance known there. It would appear that the carbon ratios

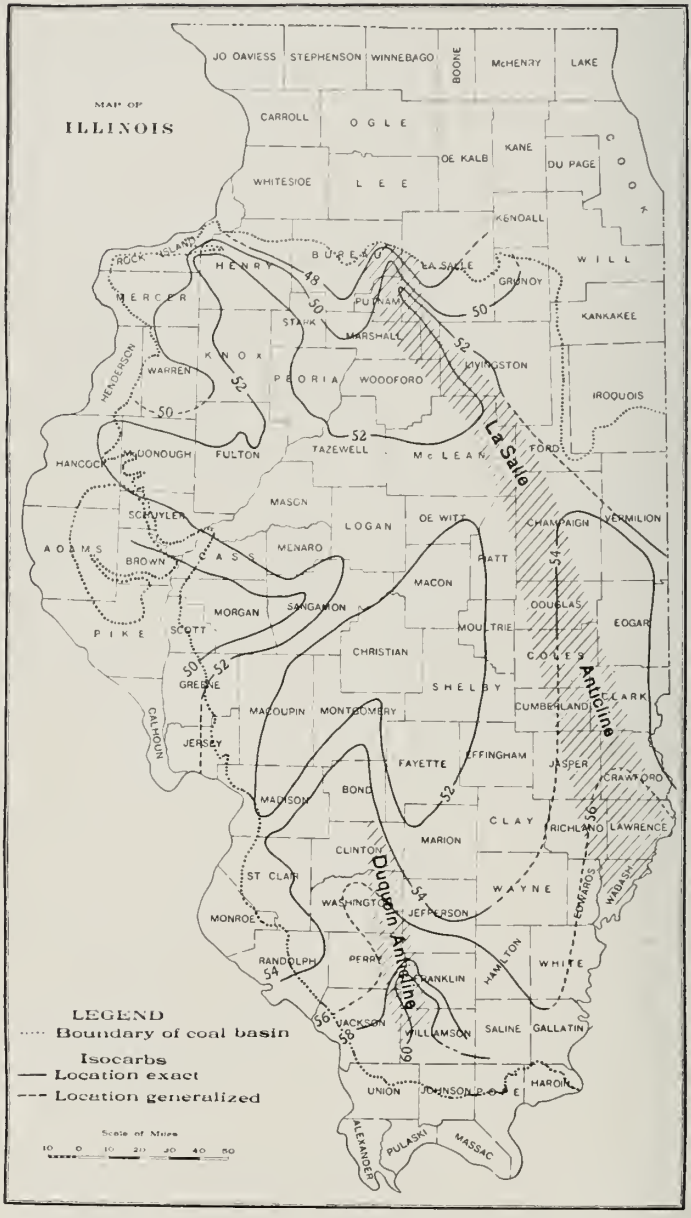

FIG. 3. Isocarb map of Illinois for No. 6 coal.

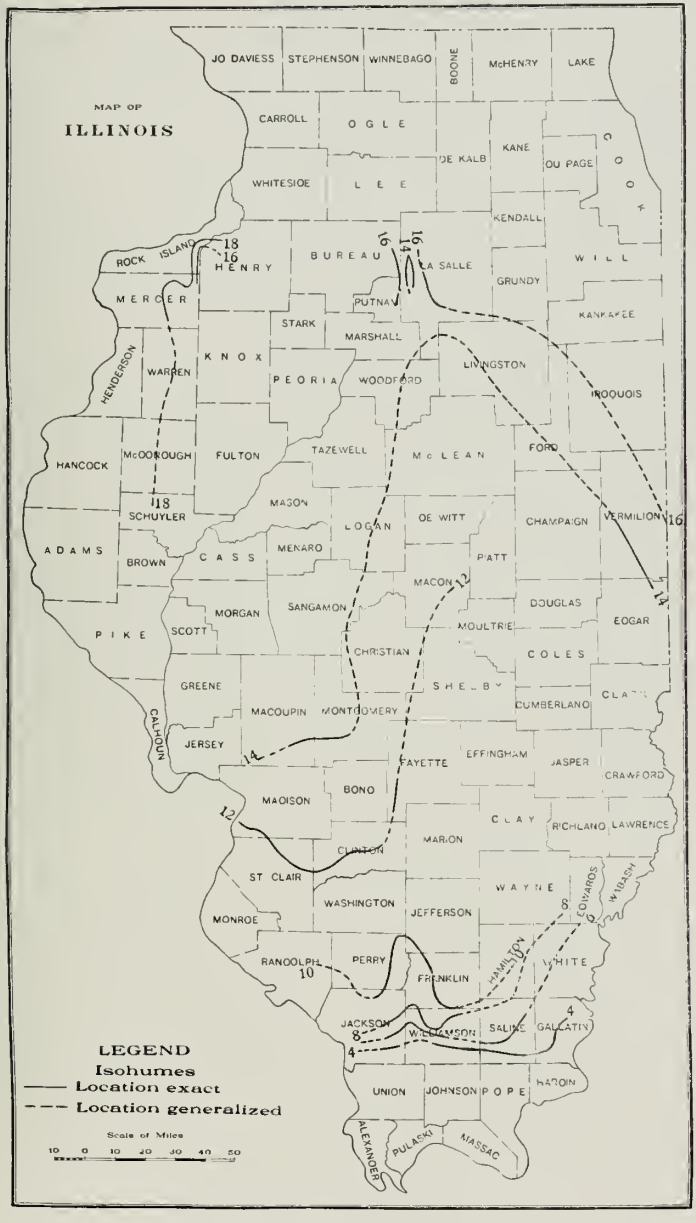

FIG. 4. Isohume map of Illinois coal.

in this instance will be useful in pointing out a locality deserving more thorough investigation.

Moisture Content

An unpublished map drawn by G. H. Cady suggested the possibility of using the moisture content of coals as a means for interpreting the effectiveness of metamorphism. A new map has been prepared, making use of more recent available data. The mapping of the moisture content of Illinois coals did not give as satisfactory results in all parts of the State as the carbon ratios did, due probably in part to the lack of consistent handling and treatment of the samples before analysis. In Franklin and Williamson counties the results were more satisfactory. As a large number of analyses would tend to help average out errors, such regions should show the best results.

In analysis, the permissible error in moisture determination is 0.3 per cent for coals of the type found in Illinois. An examination of the results of moisture determinations suggests that ordinarily variations of 1.5 per cent may be considered significant. Accordingly, the lines connecting points of equal moisture content were drawn at intervals of two per cent.

For convenience, it is proposed to call the lines connecting points of equal moisture "isohumes". The isohumes shown in figure 4 are very closely parallel to the isocarbs (fig. 3). It should be noted that the value of the isohumes decreases as regions of greater metamorphism are approached, and that this is in direct contrast to the changes in carbon ratios. Also, the value of the isohumes is subject to more considerable variations as the critical carbon ratios are approached. This is well shown in southern Illinois, where the isohumes are closer together than the isocarbs.

ISOHUME DETERMINATIONS FROM CARBONACEOUS SHALES

Several points should be considered in connection with the possibility of using the moisture content of coals and other carbonaceous rocks, as an indicator of the effectiveness of metamorphism. First, the carbon ratios of impure coals and carbonaceous shales are subject to great variation, due to permissible errors in analysis. As an example, may be cited a coal with a carbon ratio of 50 per cent, and with noncombustible material making up 90 per cent of the whole. From the formula previously derived, the possible variation in carbon ratio is found to be 13 per cent. This fact may be the explanation of the failure of attempts to use carbon ratios from rich organic shales.

The moisture determination would not be affected in a similar manner, and should still be dependable within a limit of 1.5 per cent. These considerations suggest that standard methods for the sampling of fine shales and the determination of moisture content should be established, in order to test

this possible means of measuring the effectiveness of metamorphism in regions which have no coal. In view of the fact that changes in metamorphism near the critical limit for petroleum accumulation have a marked effect on the moisture content, this method of attacking the problem seems to have great possibilities.

CONCLUSIONS CONCERNING OIL POSSIBILITIES

Choice of Limiting Ratios

The effect of metamorphism at depths below the coals is a variable factor which may be a serious obstacle to the unrestricted use of carbon ratios in outlining the possible oil areas in Illinois. The numerous unconformities to be found in the stratigraphic section require some rough evaluation so that conclusions can be reached regarding depths to which drilling is advisable for any given carbon ratio. Probably the simplest and most reliable method for making such determinations is to examine conditions in the producing fields of the State, and, using these conditions as a standard, to detect the presence of local variations which demand an adjustment in the carbon ratio limit for possible oil production. From such information, it is proposed to estimate the effects of depth and unconformities in terms of oil possibilities.

According to available information, most of the Illinois oil production comes from areas with carbon ratios lying between 54 and 57 for the No. 6 coal. Table 2 shows the highest carbon ratios known near producing areas for each of the oil sands.

Table 2. *Relation of carbon ratios to sand and oil character*

Age	County	Depth	Character	Carbon ratio	Gravity of oil
					Degrees Baumé
Chester	Jackson	850	Porous sand	56 (mainly gas)	.....
Chester	Wabash	1400	Porous sand	57 (probably)	35
Mississippian lime	Clark	700	Soft	55	32
Mississippian lime	Lawrence	1700	Open limestone	56	.....
Lowest Mississippian (Kinderhook)	Clark	1400	Fine sandy siltstone	55	38.7
Silurian	McDonough	430	Open sandy lime	52	.....
Trenton	Clark	2300	Hard, tight	55	37
Trenton	Monroe	500	Coarsely crystalline	53	30.1

FIG. 5. Horizons with oil possibilities according to carbon ratios.

Certain relations are suggested by the tabulated information. First, it seems probable that the Trenton of eastern Illinois has not been a good oil producer, because the metamorphism active there made a substantial reduction in the natural porosity of the rock. In Monroe County, metamorphic effects were not as great, so the Trenton is more open and productive. The carbon ratios indicate this relation. Second, the difference in the character of the production found in the Chester in Wabash and in Jackson counties may be explained as due to a greater amount of pre-Pennsylvanian movement in the latter place. Certainly in southwestern Illinois, there was pre-Pennsylvanian folding, and recent work indicates that it was accompanied by faulting.[4] Nothing very definite is known about the transition in southeastern Illinois, but the occurrence of heavier oil is suggestive of milder conditions. If this variation leads to the conclusion that such a difference in effectiveness of the pre-Pennsylvanian movements did exist, then it is necessary to take a lower carbon ratio for the limit of possible Chester production in the southwestern part of the State than in the southeastern. Accordingly, figure 5 showing zones with various possible producing horizons does not have the boundaries of those zones strictly parallel to the isocarbs.

In determining the lowest horizon with possibilities of oil production, the following carbon ratios were chosen as limits:

TABLE 3. *Limiting carbon ratios for oil producing horizons in certain localities*

Horizon	Limiting value	Locality
Pennsylvanian	62	Southern Illinois
Chester	58	Southwestern Illinois
Chester	59	Southeastern Illinois
Lower Mississippian	56	Southwestern Illinois
Lower Mississippian	57	Southeastern Illinois
Silurian-Devonian	55	Southwestern Illinois
Silurian-Devonian	56	Other parts
Trenton	54	Southwestern Illinois
Trenton	55	Other parts

AREAS APPEARING TO HAVE SPECIAL MERITS

In searches for new oil pools in Illinois, it will probably be advisable generally to limit consideration to areas having oil possibilities at least in the Chester, and preferably in the lower rocks as well. Further, a concentration

[4] Ekblaw, G. E., Post-Chester, pre-Pennsylvanian faulting in the Alto Pass area: State Acad. Sci., Springfield Meeting, 1925.

of attention on certain zones of locally higher carbon ratios is desirable and justified. Such areas are the central part of the La Salle anticline, the northern part of the Duquoin anticline, and the area of high carbon ratio extending from Tazewell County to Rock Island County.

Value of Carbon Ratios

Carbon ratios of Illinois coals change in such a manner that the isocarbs parallel the structural contours. On the basis of the carbon ratios, it is possible to eliminate deep testing in certain areas, and to eliminate other areas entirely as probable oil producers, even if favorable structural features should be found. An equally useful result is that some of the areas of greatest promise are outlined.