Variations in Petrographic and Depositional Characteristics of Lower Millersburg, Hymera and Bucktown Coal Members in Indiana

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Introduction

The Lower Millersburg and its stratigraphic counterpart, the Hymera (No. VI) coal, are two major mineable seams in the Dugger Formation. These seams vary considerably in terms of thickness and structure not only among themselves but also with respect to other seams which are in very close stratigraphic proximity. The present study is designed to investigate various qualitative variations in these seams in order to understand their correlation.

Geologic Setting

Stratigraphy:

The Lower Millersburg, the Hymera and the Bucktown coal members occur in the Dugger Formation which is correlatable with the upper part of the Carbondale Formation in Illinois.

The Dugger Formation has been considered to extend from the top of the Springfield (No. V) coal to the top of the Danville (No. VII) coal. The Hymera and the Lower Millersburg bearing Dugger Formation occurs in four separate blocks which are scattered in six counties. The Hymera (No. VI) coal, according to the geological literature, occurs mainly in the Dugger Formation of Sullivan, Knox and Northern Gibson counties. The Hymera (No. VI) coal form two northern and southern blocks which are separated in the southern part of Gibson, Posey and Warrick counties. These form two eastern and western blocks. (Fig. 1).

Because no lateral geological demarcation between these two coals has been established, there is particular confusion in Gibson County where both of these coals are reported.

A comparative study of the Dugger Formation in these blocks is presented here. It is beyond the scope of this study to evaluate all the available data in these

Table 1. *Characteristics of the Hymera (No. VI) coal bearing Dugger Formation in Sullivan and Knox Counties*

Thickness:	$\bar{x}$ = 121.3 ft.	Depth:	$\bar{x}$ = 188 ft.	Shale/Sand Ratio:	$\bar{x}$ = 6.9:1
	$\bar{s}$ = 16.9		$\bar{s}$ = 60		$\bar{s}$ = 7.8:1
	n = 45		n = 47		n = 23

Limestone: (i) Universal very inconsistent
(ii) Alumcave normally split, a shale band occurs in the middle. Total thickness less than 5 ft.

Nature of the Top: shaley top
occasionally sandy shale

Nature of the Bottom: usually black shale

Remarks: This is considered to be type area for the Hymera Coal.

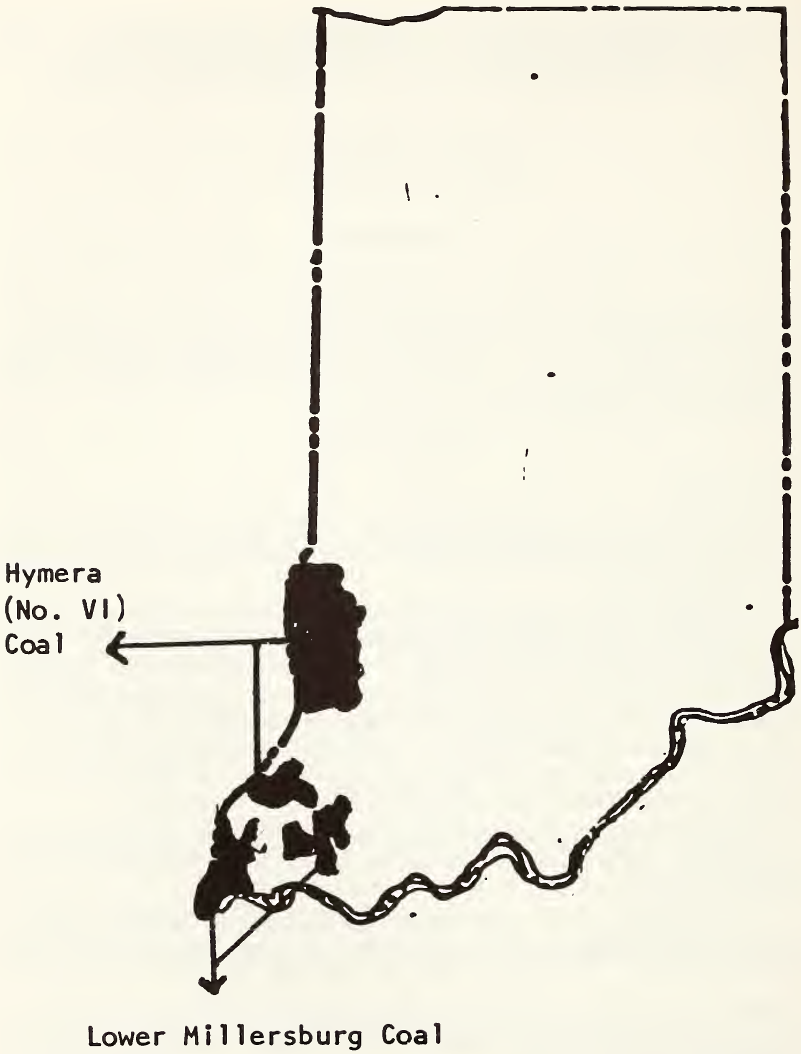

FIGURE 1. *Distribution of Hymera and Lower Millersburg Coal in Indiana*

areas. An effort has been made to maintain the homogeneity of the sample population and also to highlight the geological hetrogeneity in separate blocks.

Characteristics of the upper part of the Carbondale Formation in Illinois:

Lithology of the upper part of the Carbondale Formation which is chronostratigraphically equivalent to the Dugger Formation shows some noticeable variations in lithology. The variations are mainly due to the increasing influence of depth on the sedimentation. Stratigraphic units are usually thicker and relatively more consistent. The interval between the Jamestown (Coal VI in Indiana) and the Coal 7 is is relatively larger. The Bankston Fork Limestone which cor-

TABLE. 2. *Characteristics of the Dugger Formation in Northern Gibson County*

	T.1N.,R.10W.	T.1S.,R.10W.
Thickness:	114 ft.	110 ft.
Depth :	250 ft.	120 ft.

Shale/Sand Ratio: Close to 1:1 ratio in the drill data examined

Limestone: rather consistent limestone bed; Providence present in localized areas

Nature of the Top: sandy shale to shale

Nature of the Bottom: black shale

Remarks: On the basis of the data examined, no discontinuity in the deposition of coal was found. It appears that the Millersburg coals which show a shorter interval between them, compared to the typical VI and VII are the only representatives of that period present.

But the Dugger Formation in general did not show any significant departures from the type area.

TABLE 3. *Characteristics of the Dugger Formation in Southern Gibson County*

	T.2S.R.9W	T.2S.R.10W.	T.2S.R.11W	T.4S.R.10W.
Thickness:	124 ft.	135 ft.	171 ft.	139 ft.
Depth :	103 ft.	174 ft.	294 ft.	165 ft.

Shale/Sand Ratio: Close to 1:1 ratio in the drill data examined

Limestone: rather consistent limestone beds; Providence present in localized areas

Nature of the Top: shale to sandy shale

Nature of the Bottom: black shale

Remarks: No significant difference than the northern part of the county.

TABLE 4. *Characteristics of the Lower Millersburg bearing Dugger Formation in Posey County*

Thickness:	$\bar{x}$ = 258 ft.	Depth:	$\bar{x}$ = 372 ft.
	$\bar{s}$ = 117		$\bar{s}$ = 76
	n = 5		n = 5

Shale/Sand Ratio: 1:1

Limestone: normally well developed; Providence present in localized areas

Nature of the Top: shale

Nature of the Bottom: black Shale

Remarks:

Correlation is very difficult due to:
1. lack of reliable data
2. inconsistent Lower Millersburg
3. well developed Herrin No. 6 coal
4. abnormal variations in depth
5. thickening of strata

TABLE 5. *Characteristics of the Lower Millersburg bearing Dugger Formation in Warrick County*

Thickness:	$\bar{x}$ = 115 ft.	Depth:	$\bar{x}$ = 60.2 ft.
	$\bar{s}$ = 20		$\bar{s}$ = 24.4
	n = 17		n = 17

Shale/Sand Ratio: 1.5:1

Limestone: (i) Universal relatively more consistent
(ii) Alumcave is very thin.

Nature of the Top: sandy shale

Nature of the Bottom: usually black shale

Remarks: This is considerd to be area for the Millersburg Coal

relates with the Universal Limestone in Indiana is more prominent. The interval between the Jamestown and Coal 6 (Vb in Indiana) is rather irregular. The Anna Shale Member which overlies the Coal 6 in a large area is locally replaced by Energy Shale. Also, in some areas Brereton Limestone or even Jamestown coal directly overlie the Coal 6. The upper part of Carbondale in Illinois is relatively more shaley compared to its stratigraphic equivalent in Indiana.

Coal:

In this study of correlation between the Hymera and the Lower Millersburg coal members, the Herrin and the Bucktown coal seams have also been included. This approach is necessary to establish a qualitative index of variability which will act as a safeguard against any bias of local irregularities. Deterministic characteristics in the four blocks of coal occurrences have been evaluated carefully which are presented in the following pages.

TABLE 6. *Characteristics of the Hymera (No. VI) Coal in Sullivan and Knox Counties*

	T.9N.R.8W.	T.9N.R.9W.	T.6N.R.8W.	T.5N.R.10W.
Thickness:	$\bar{x}$ = 6 ft.	$\bar{x}$ = 4.9 ft.	$\bar{x}$ = 5.4 ft.	$\bar{x}$ = 3.8 ft.
	$\bar{s}$ = 1.87	$\bar{s}$ = 1.2	$\bar{s}$ = 0.28	$\bar{s}$ = 0.85
	n = 4	n = 25	n = 2	n = 17
Depth:	$\bar{x}$ = 86 ft.	$\bar{x}$ = 159 ft.	$\bar{x}$ = 130 ft.	$\bar{x}$ = 296 ft.
	$\bar{s}$ = 50.2	$\bar{s}$ = 39	$\bar{s}$ = 39.5	$\bar{s}$ = 18.8
	n = 4	n = 26	n = 2	n = 17
Roof:	shale	shale	shale	shale
Floor:	shale	shale & underclay	shale	shale & underclay
Split:		consistent 3 x split (50% split occurrences)		coal - upper bench gray shale black shale $\bar{x}$ = 9 ft. gray shale coal - lower bench
Interval between VI and VII:		49 ft.	41 ft.	43 ft.

Remarks: Hymera No. VI coal shows split over a wide range of area. Typically, alternating fresh water and marine water type of depositional environment.

TABLE 7. *Characteristics of the Hymera (No. VI) Coal in Northern Gibson County*

	T.1N.R.10W.	T.1S.R.10W.
Thickeness:	2 ft. (split frequently)	3.5 ft.
Depth:	274 ft.	136 ft.
Roof:	shale	shale
Floor:	shale	shale
Split:	frequently split coal — thin parting coal — thick	
Interval between VI and VII:	24 ft.	16 ft.

Remarks: Interval between the two seams are comparatively closer compared to the Sullivan County. The variations in depth do not follow any regular pattern. Probably reflection of an uneven platform.

TABLE 8. *Characteristics of the Lower Millersburg Coal in Southern Gibson County*

	T.2S.R.9W.	T.2S.R.10W	T.2S.R.11W.	T.4S.R.10W.
Thickness:	4 ft.	3.75 ft.	2 ft.	2.5 ft.
Depth:	124 ft.	198 ft.	275 ft.	175 ft. (insufficient data)
Roof:	shale	shale	shale	shale
Floor:	shale	shale	shale	shale
Split:	occasional (in one case up to 6 ft. of parting)	occasional split (1X)	relatively more frequent	insufficient data
Interval between VI and VII:	21 ft.	20 ft.	20 ft.	insufficient data

Remarks: Very similar to the northern part of Gibson County

TABLE 9. *Characteristics of the Lower Millersburg Coal in Warrick County*

Thickness: $\bar{x}$ = 4.3 ft.
$\bar{s}$ = 1.9
n = 111

Depth: $\bar{x}$ = 71.9 ft.
$\bar{s}$ = 27.2
n = 107

Roof: shale to sandy shale

Floor: shale to underclay

Split: occasional split, usually the parting is less than one ft. thick

Interval between VI and VII: 14 ft.

Remarks: Splitting in the Lower Millersburg coal is prevalent. It is very similar to Sullivan and Knox counties except argillaceous limestone replaces the black shale.

TABLE 10. *Characteristics of the Lower Millersburg Coal in Posey County*

Thickness:	usually very thin or absent
Depth:	418 ft.
Roof:	shale
Floor:	shale - sandy shale
Split:	usually very thin to develop any significant splitting
Interval between VI and VII:	40 ft.
Remarks:	Coal Vb or Illinois 6 is present here with an average thickness of 5 ft. at 524 ft. average depth. The roof is black shale. The interval is maximum here.

The Jamestown Coal Member:

The Jamestown Coal Member of Southwestern Illinois has been considered as a stratigraphic equivalent to the Hymera coal in Indiana. In Illinois the Jamestown coal typically occurs between two limestone units: the Conant and Brereton, with shale beds above and below the coal. Locally, where the Brereton and other members such as the Anna and Energy are missing, the Jamestown approaches the contact of the Herrin (No. 6) coal with only a thin shale separation between them. Towards the deeper part of the basin, the Jamestown becomes very thin and typically black shale replaces the coal. In Indiana the sequence of limestone sedimentations above and below the Coal VI was frequently disrupted.

The Herrin (No. 6) Coal (Illinois) and the Bucktown (Vb) Coal Members:

The Herrin (No. 6) coal is probably the most widely studied coal seam in Illinois and the volume of detailed geological literature on this seam is abundant. The Herrin coal is correlated with the Bucktown (Vb) coal in Indiana. Unlike Illinois, the Bucktown coal in Indiana is thin, inconsistent, a coal seam in the same stratigraphic horizon is prominent in thickness and locally consistent. Similarly, in Vermillion County Indiana, the Grape Creek coal which is in the same stratigraphic horizon is locally thick and consistent. In these two isolated seams of Posey and Vermillion counties, the typical blue band of the Herrin is not present.

Environment of Deposition:

The distribution of the Hymera, the Lower Millersburg and the Jamestown coals in combination presents an elliptical form of depositional system prograding southwestward into the deeper part of the basin. This was probably a trend of delta development during the Hymera and Lower Millersburg time. If we consider that these coal seams are part of the same major depositional system then a chronostratigraphic equality can be established, which is a likely possibility.

The depth and nature of the delta platform was not uniform in all places, which created depositional anomalies to the extent that a discontinuous depositional system prevailed. This entire system is part of the same chronostratigraphic unit. Also, the active secondary channels during this period influenced significantly the final geometry of distribution. The physico-chemical identities of deposition in these sub-basins of the major system are preserved and reflected in the variability of the separate coal blocks, which restricted the lithostratigraphic uniformity among these coals. As proposed by Wanless and others, the thin rock-stratigraphic units of the Pennsylvanian are equivalent to the time stratigraphic units, which is in agreement with this model.

Split:

The Lower Millersburg and the Hymera coals exhibit locally very similar splitting characteristics as can be traced in Knox and Warrick counties.

Coal VI	Lower Millersburg
Coal - Upper bench	Coal - Upper bench
Gray shale	Gray shale
Black shale	Argillaceous limestone
Gray shale	Gray shale
Coal - Lower bench	Coal - Lower bench

If we analyze the situation from an environment of deposition viewpoint, it becomes evident that the gray shale is part of a contemporaneous channel active during that time, and the black shale and the argillaceous limestone belong to a transgressive post coal marine environment. The depth, the nature of the restrictions, and the source materials controlled the type rock deposited.

Petrology

Sampling:

For petrographic study to identify the typical characteristics, channel samples of the Hymera (No. VI) coal from AMAX's Minnehaha Mine and the Lower Millersburg coal from Ayrshire Mines were collected. A drill core sample of the Bucktown (Vb) coal from the Minnehaha Mine area was utilized in this study. ASTM standard methodology was followed in the collection and preparation of the samples for making polished sections (pellets). The pellets were preared in the coal laboratory of Southern Illinois University.

Macerals:

Macerals were identified microscopically under oil immersion using reflected light. More than 2,000 points were counted in each pellet. Efforts were made to delineate the following typical maceral components most prevalent in Illinois Basin coals.

Maceral Group	Maceral
Vitrinite	Vitrinite A
	Vitrinite B
Inertinite	Semi-Fusinite
	Macrinite
	Micrinite
Exinite	Sporinite
	Cutinite

Clay and pyritic materials were grouped separately.

The size and shape of the macerals are generally variable and irregular. In terms of reflectance, two types of vitrinites can be delineated. Inclusions of cutinite and/or semi-fusinite are common. Approximately 30% of the vitrinite macerals contain these inclusions. Mainly thin-walled cutinites are present in the sample. Pyrites and clays are the most dominant accessories.

Lower Millersburg Coal:

The sample studied is from the lower bench of the Lower Millersburg coal, sampled from the Ayrshire Mine area. The maceral sizes appear to be smaller and angular to subangular in shape compared to Hymera No. VI. Cutinite bands are comparatively more common. Semi-fusinite macerals are more prevalent. Both vitrinite A and B are present and pyrite grains are distributed evenly.

Bucktown (Vb) Coal:

The sample contains angular macerals which are less densely dispersed in the medium. Two types of vitrinites, A and B, occur with inclusion of cutinite and pyrite.

TABLE 11. *Comparison of Maceral Counts*

	VI	Lower Millersburg	Vb
Vitrinite %	96.9	93.1	93.51
Fusinite %	0.4	—	—
Semi-fusinite %	0.8	2.91	3.19
Macrinite %	—	—	—
Micrinite %	—	—	—
Sporinite %	trace	—	1.0
Cutinite %	0.5	0.3	1.1
Clay %	0.86	2.7	0.9
Pyrite %	1	1	1.2

This represents counts of measurable maceral components. The inclusions of semifusinite, cutinite and other mineral components within macerals are not considered here. (Figures 2 & 3).

Reflectance:

Reflectance measurements to determine the Mean Ro for each seam were made separately in two polished sections from each seam. In order to keep the percentage variations in any two polished sections from a given seam under 2%, six polished sections from three seams were used to obtain Ro.

The Calibration standards used were synthetic glasses with the following specifications:

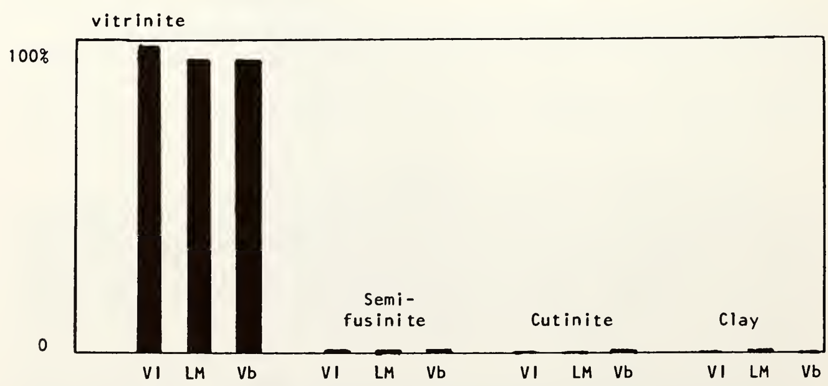

FIGURE 2. *Histogram showing the relative distribution of macerals*

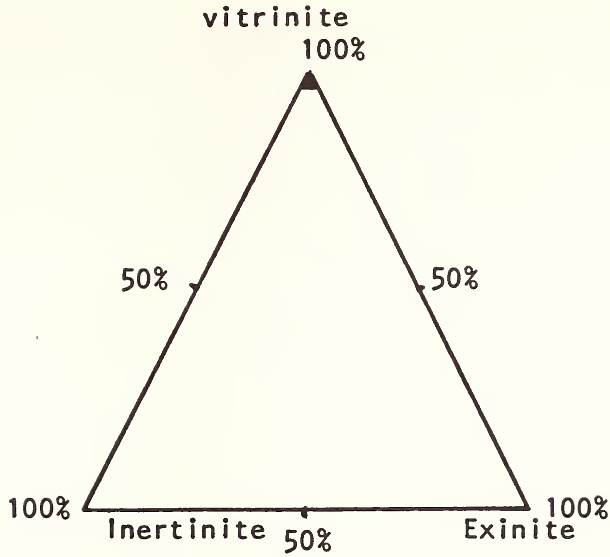

FIGURE 3. *Microlithotypes*

Refractive Index	Reflectance
1.757	0.532
1.856	1.007

Results are as follows:

Lower Millersburg Coal (vitrinite reflectance)

Ro (1)	Ro (2)
$\bar{x}$ = 0.4582	$\bar{x}$ = 0.4663
$\bar{s}$ = 0.0430	$\bar{s}$ = 0.0460
n = 26	n = 25

Hymera (No. VI) Coal (vitrinite reflectance)

Ro (1)	Ro (2)
$\bar{x}$ = 0.4747	$\bar{x}$ = 0.4797
$\bar{s}$ = 0.0364	$\bar{s}$ = 0.0415
n = 27	n = 25

Bucktown (Vb) Coal (vitrinite reflectance)

$\bar{x}$ = 0.4428	$\bar{x}$ = 0.4492
$\bar{s}$ = 0.0248	$\bar{s}$ = 0.0333
n = 28	n = 25
(60 x 120 mesh)	(120 x 0 mesh)

Discussion

In the Indiana geological literature, the Lower Millersburg Coal is typically combined with the Hymera Coal to represent the period between the Danville and the Bucktown Coals. This approach of correlative combination is logical and fits well in the chronostratigraphic framework. But in the field of commercial extraction, the physical parameters or characteristics which define the lithostratigraphic uniformity need to be properly identified for the commercial market.

An approach to resolve this problem of correlation is to assess the probable geological situations related to the contemporaneity and homogeneity of the seams with respect to the established regional geological framework and the data base provided earlier. Four alternative stratigraphic possibilities are presented here to verify the nature and extent of correlativity.

(i) The seams are chrono and lithostratigraphically equivalent

or

(ii) The seams are not chrono and lithostratigraphically equivalent

or

(iii) The seams are chronostratigraphically equivalent but lithostratigraphically unequivalent

or

(iv) The Lower and Upper Millersburg are split units of one single seam.

The chronostratigraphic equality between the Hymera and the Lower Millersburg can be established by considering the index horizons, their relative position in the geological column, and consistency and order of abundance, which are as follows:

a) Systematic occurences between VII and Vb
b) Position between the Universal and the Providence Limestones
c) Black shale position with Hymera sequence
d) Consistency in the relative position of the seams within each block and also the overall nature of the materials in between
e) Position of the Herrin No. 6 and the Grape Creek coals relative to the Hymera and the Lower Millersburg in two dissimilar geological conditions
f) Similar effects of the contemporaneous channel on both seams indicate the parallelism in time.

In order to establish a lithologic correlation for the coal seams, it is essential to define the boundary values or the limits of variability within which lithostratigraphic equality can be justified. This is critical because of the sensitive nature of the coalification process and the resultant characteristics. However a few observations to assess the lithostratigraphic uniformity are presented below:

a) splitting characteristic (not related to coalification process)—in the Millersburg field the marine transgressive phase is characterized by the argillaceous limestone, whereas in the Hymera coal field area, the corresponding facies is a black shale. This is indicative of the restrictive environments of deposition
b) banded nature—banded nature is predominant in both the seams which can be related to the subsidence or elevation of the water level to control the nature of the vegetation (Marchioni, 1980). Dissimilarities in the banded nature of these seams indicate dissimilar depositional environments
c) An overall similarity in the nature and distribution of maceral composition indicates the same general type of source materials.

In localized areas the upper Millersburg has been reported to be underlain by underclay, which in general represents the end of one independent coal unit. Also, the presence of the Universal Limestone in localized areas of Gibson and Warrick counties indicates that the Upper and Lower Millersburg are two different coal sequences.

It is evident that the Hymera and the Lower Millersburg are chronostratigraphically equivalent, but on the basis of inequalities in the physical characteristics, these seams can be considered as two independent members of the Dugger Formation. Hence, it would be appropriate to apply the Lower Millersburg nomenclature where its interval with the Danville No. VII coal is less than 25 feet.

Conclusion

The depositional and petrological characteristics of the Hymera and the Lower Millersburg coal members of the Dugger Formation have been systematically analyzed and compared with each individual block of deposits. The results indicate a chronostratigraphic equality for the two different lithostratigraphic units. The suggested model of depositional environment correlates with the physical condition of deposition. It is proposed that in Warrick and Gibson counties, where the interval between the Hymera equivalent (Lower Millersburg) and the Danville equivalent (Upper Millersburg) is less than 25 feet, the Millersburg sequence of nomenclature wold be appropriate to distinguish it from the normal Danville-Hymera sequence. The abnormal reduction of interval in thickness in restricted areas is not uncommon in the Illinois Basin. Similar situations are recognized in the Jamestown-Herrin interval in Clark County, Illinois and the Herrin-Harrisburg interval in the western part of Cumberland County, Illinois.

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