OUTCROP FEATURES OF THE MANSFIELD FORMATION IN SOUTHWESTERN INDIANA

by

Henry H. Gray

Indiana Department of Conservation

GEOLOGICAL SURVEY

Report of Progress No. 26

1962

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OUTCROP FEATURES OF THE MANSFIELD FORMATION IN SOUTHWESTERN INDIANA

By Henry H. Gray

ABSTRACT

The Mansfield Formation of early Pennsylvanian age crops out in an area of approximately 1,700 square miles in southwestern Indiana. Three-fifths of the formation consists of sandstone; most of the remainder is finer clastic rocks. Limestone, chert, coal, and iron ore make up approximately 2 percent of the formation. Many similar rock types are found among the several formations upon which the Mansfield unconformably rests, but the assignment of questionable outcrops either to the Mansfield Formation or to an older formation can usually be accomplished with some confidence, because many outcrops contain either diagnostic rock types or indicative rock features.

The various rocks of the Mansfield Formation are, for the most part, arranged in a crudely cyclic pattern. The several cyclic units of a region tend to be similar in makeup and different f rom those of adjacent regions. Three lithofacies that reflect these areal variations can be recognized and are here named: the Shoals Lithofacies is characterized by cross-stratified sandstones, the Bloomfield Lithofacies by gray shales, and the Cannelton Lithofacies by mudstones and thick clays.

The distribution of these lithofacies suggests that these rocks were deposited at or near the shoreline, that there was a fairly large delta in the southern part of the outcrop area, and that this delta was an important factor controlling the sedimentary pattern during early Pennsylvanian time.

INTRODUCTION

LOCATION AND EXTENT OF THE MANSFIELD FORMATION

Beneath the surface soils in the southern part of Indiana and beneath the glacial deposits in the west- central part of the State, in a belt some 5 to 20 miles wide extending from Cannelton on the Ohio River nearly to the Illinois State line a few miles northwest of Attica, lies a sequence of sandstones and shales that are included in the Mansfield Formation (fig. 1). This is the lowest and the oldest of the formations of Pennsylvanian age in Indiana (table 1). The geographic name, taken from the town of Mansfield, about 10 miles

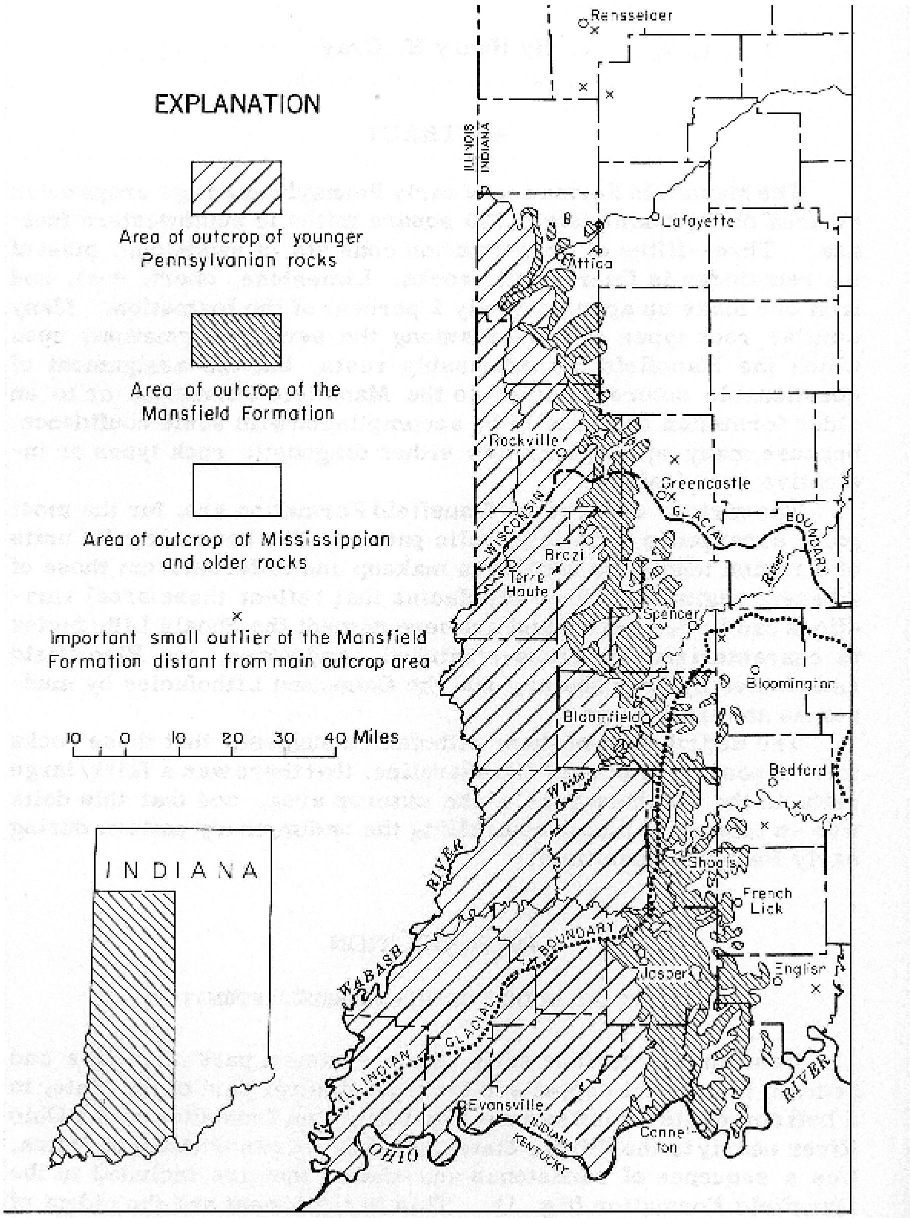

Figure 1. --Map of southwestern Indiana showing extent of the Mansfield Formation.

Table 1.-*Names of rock units of late Devonian, Mississippian, and early Pennsylvanian age in Indiana*

Age	Rock unit		
Pennsylvanian		Brazil Formation	Lower Block Coal
Pennsylvanian		Mansfield Formation	Shady Lane Coal Ferdinand Limestone Fulda Limestone Mariah Hill Coal Blue Creek Coal Pinnick Coal French Lick Coal St. Meinrad Coal
		unconformity	
Mississippian		Kinkaid Limestone Degonia Sandstone Clore Limestone Palestine Sandstone	
Mississippian		Menard Limestone Waltersburg Sandstone Vienna Limestone Tar Springs Formation	
Mississippian	Stephensport Group	Glen Dean Limestone Hardinsburg Formation Golconda Limestone Big Clifty Formation Beech Creek Limestone	
Mississippian	West Baden Group	Elwren Formation Reelsville Limestone Sample Formation Beaver Bend Limestone Bethel Formation	
Mississippian	Blue River Group	Paoli Limestone Ste. Genevieve Limestone St. Louis Limestone Salem Limestone Harrodsburg Limestone	
Mississippian	Borden Group	Edwardsville Formation Floyds Knob Formation Carwood Formation Locust Point Formation New Providence Shale	
Mississippian		Rockford Limestone	
Devonian		New Albany Shale North Vernon Limestone	

southeast of Rockville in Parke County, was first applied to this formation by Hopkins (1896, p. 199). Earlier geologists had used a variety of names, Millstone Grit and Conglomerate being among the most common. Hopkins called the formation the Mansfield Sandstone, but his definition was not entirely clear, and Ashley (1899, p. 95-96), among others, held that the name applied only to lenses and beds of sandstone rather than to an entire formational unit. Cumings (1922, p. 528) more clearly defined the Mansfield Sandstone to include all the rocks above the unconformity at the base of the Pennsylvanian System and below the base of the Lower Block Coal (fig. 2). With the more detailed fieldwork and more extensive subsurface knowledge of later years it became increasingly clear that the formation included a considerable quantity of shale and other rocks, and the more appropriate name Mansfield Formation was proposed (Kottlowski, 1959).

Rocks of the Mansfield Formation are found on outcrop or in the subsurface beneath younger rocks in southwestern and west- central Indiana in an area of approximately 6,000 square miles, or about one-sixth of the area of the State (fig. 1). The area of outcrop is approximately 1,700 square miles. In the northern part of the outcrop area some 300 square miles of the outcrop lies beneath drift of the younger (Wisconsin in age) ice sheet, and in the central part 500 square miles underlies drift of the older (Illinoian in age) ice sheet. In the remaining area of 900 square miles, in southern Indiana, Mansfield rocks crop out or lie just beneath a rather thin soil cover.

About three-fifths of the rocks in the Mansfield Formation are sandstones; these rocks are resistant to weathering, and therefore the outcrop area of the Mansfield is marked by a range of hills. Along the Ohio River just above Cannelton these hills loom as high as 400 feet above the river. Northward the topography of the outcrop belt is somewhat less spectacular. Near French Lick hills capped by Mansfield rocks are generally 300 to 3 50 feet in maximum height; near Spencer, within the area covered by the Illinoian glacier, topographic relief of 250 to 300 feet is the rule; still farther north the upland is mostly obscured by thick drift deposited by the Wisconsin glacier. Where the principal streams cross the outcrop belt of the Mansfield Formation, as at Turkey Run State Park north of Rockville and at Attica, the rugged nature of the buried bedrock surface is revealed in topographic relief of 150 to 200 feet.

Because of the ruggedness of the topography, there are no large towns within the outcrop belt of the Mansfield Formation except along once- navigable rivers, and little farming is carried on except within the flatter area of the younger glacial deposits. Instead, much of the area is sparsely settled, and extensive stands of timber are common, particularly in the southern part.

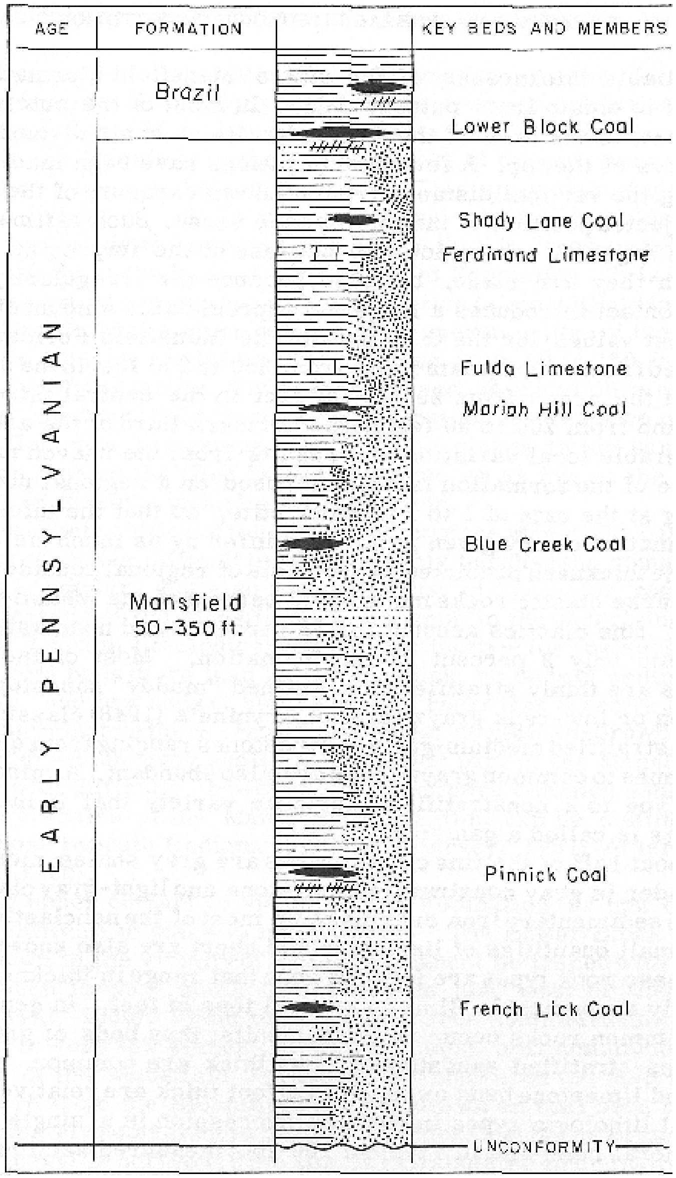

Figure 2. - -Generalized stratigraphic column of the Mansfield Formation in Indiana showing position of principal key beds and members.

THICKNESS AND GENERAL LITHOLOGIC CONSTITUTION

Reliable thicknesses of the entire Mansfield Formation are difficult to obtain from outcrop data. In most of the outcrop area exposures of the base of the formation lie at some distance from exposures of the top. A few determinations have been made by estimating the vertical distance from a known exposure of the base to the projected position of the top, or vice versa. Such estimates are of little regional value, not only because of the imprecise manner in which they are made, but also because the irregularity of the basal contact introduces a large and unpredictable amount of error.

Most values for the thickness of the Mansfield Formation determined from outcrop data range from 350 to200 feet in the southern third of the area, from 250 to 150 feet in the central third of the area, and from 200 to 50 feet in the northern third of the area. The considerable local variation that results from the uneven nature of the base of the formation is superimposed on a regional northward thinning at the rate of 1 to 2 feet per mile, so that the thickness of the formation at any given point may differ by as much as 100 feet from the thickness predicted on the basis of regional considerations.

Coarse clastic rocks make up 60 percent of the Mansfield Formation, fine clastics account for 38 percent, and nonclastic rocks constitute only 2 percent of the formation. Most of the coarse clastics are thinly stratified fine-grained "muddy" sandstones, the common or low-rank graywackes of Kryninel’s (1948) classification. Cross- stratified medium-grained sandstones ranging from quartzose sandstones to common graywackes are also abundant. A minors and stone type is a nonstratified quartzitic variety that in many coal districts is called a ganister.

About half of the fine clastic rocks are gray shales; most of the remainder is gray nonstratified mudstone and light- gray clay. Coal and the sedimentary iron ores make up most of the nonclastic rocks; very small quantities of limestone and chert are also known.

These rock types are found in beds that range in thickness from scarcely recognizable films to several tens of feet. In general the less common rocks occur in thinner units; thus beds of gray shale or cross- stratified sandstone 20 feet thick are common, whereas coal and limestone beds as much as a foot thick are relatively rare. Several lithologic types in vertical succession in a single place is the general rule, and in atypical 100-foot measured section a dozen or so distinct beds are usually found. It is not uncommon, however, to find a few exceptionally thick beds making up a single section.

STRATIGRAPHIC AND STRUCTURAL RELATIONS, PALEONTOLOGY, AND AGE

Basal beds of the Mansfield Formation overlie formations ranging f rom the New Albany Shale of late Devonian age to the Kinkaid Limestone of late Mississippian age (table 1). The older formations underlie the Mansfield in the northern part of the outcrop area, and the younger ones in the southern part. This progressive northward overlap indicates a slight tilting of Mississippian and older rocks before or during the interval of erosion that is represented by the unconformity at the base of the Mansfield Formation. This overlap to a large extent determines which formation is most likely to underlie the Mansfield at a given point, but the uneven nature of the unconformable contact, relief on which ranges from 50 to 150 feet, is a strong modifying factor. Thus, for instance, in the vicinity of Shoals (fig. 1), the Mansfield Formation in most places rests on or close to the Golconda Limestone, but in some places in the same area rocks as high as the Glen Dean Limestone or as low as the Elwren Formation directly underlie the Mansfield.

The exact position of the basal contact of the Mansfield Formation in many places is difficult to pick, not only because the contact surface is irregular, but also because most of the major rock types characteristic of the Mansfield are common in the underlying rocks as well. Certain lithologic types are distinctive; for instance, there are no coal beds more than half a foot thick, no beds of sedimentary iron ore, and few beds of black shale in rocks that directly underlie the Mansfield; and there are no limestones, no reddish-brown shales and few greenish-gray shales in the lower part of the Mansfield. It is only with difficulty, however, that the more common sandstones and gray shales of the Mansfield Formation can be distinguished from those beneath (Indiana Geological Survey, 1957; Atherton and others, 1960).

The upper contact of the Mansfield Formation, as now defined, also is difficult to place in many areas. The Lower Block Coal is well known in the vicinity of Brazil but cannot be traced with assurance much farther south than the area just west of Bloomfield (Kottlowski, 1960). From the Rockville area northward this coal is present in very few places (H. C. Hutchison, oral communication). The top of the Mansfield Formation as shown on the map (fig. 1) southward from the Bloomfield area is drawn on coal beds that are approximately equivalent to the Lower Block Coal of the Brazil area. From Rockville northward the line is extrapolated principally on the basis of the mapped position of the Minshall Coal (Hutchison, 1961), which is stratigraphically some 50 feet higher than the Lower Block.

Regionally in southwestern Indiana the rocks dip westward at approximately 25 feet per mile. Within the area of outcrop of the Mansfield Formation this is generally confirmed, but precise substantiation is difficult to obtain, because few individual beds may be traced over extensive areas and there are numerous local deviations from the regional pattern. Steeper dips, flatter dips, and anomalous northward, southward, and even reverse (eastward) dips are common; in fact, within most small areas anything but the regional dip seems to prevail. It is sometimes necessary to trace beds 5 miles or more to minimize these local variations and to determine a true regional value, but very few beds within the Mansfield may be traced this far. The upper contact is also an unsatisfactory structure horizon for reasons already discussed, and the basal contact, being an unconformity, introduces other uncertainties. Altogether, it seems best to compute regional dips either by taking an average of many local dips or by interpolating between the better known regional dips of the somewhat flatter lying younger rocks to the west and the somewhat steeper dipping older rocks to the east of the Mansfield outcrop belt.

Animal and plant remains are found in the Mansfield Formation but not in abundance. Sparse marine invertebrates characterize the thin limestones and associated shales in the uppermost part of the formation(fig. 2). The fauna includes small brachiopods, fusulinids, and ostracods. There are also remains that may be of marine invertebrate origin in some of the sedimentary iron ores throughout the formation. Nonmarine invertebrates seem to be unknown, but in the stratified siltstones (whetstones) between the French Lick and Pinnick Coals there is an abundance of tracks and trails, of undoubted animal origin, which may have been made by fresh-water arthropods.

Plant fossils are found throughout the formation. There are carbonized leaf imprints in ironstone nodules and in some of the shales; rootlet impressions and *Stigmaria* characterize the ganisters, clays, and mudstones; and conelike structures and molds of stems and trunks of *Lepidodendron* and *Sigillaria* are found in some of the sandstones. The coal beds consist mainly of plant remains, but much of the plant material is unrecognizable as such except by microscopic examination.

These fossils have not yet proved to be of much value in identifying the various beds within the Mansfield Formation, but they are useful in determining the age of the formation. In general, those floras from the Mansfield Formation that have been studied were collected from the lower part of the formation, the whetstone areas near French Lick being by far the most thoroughly known. All authors agree on a Pottsville age for these beds, and in general there is agreement on correlation with the middle part of the Pottsville Series, as known from the Southern Appalachian and Anthracite Coal Fields. There is, however, some difference of opinion on correlation within the Illinois Basin. Franklin (1939), on the basis of a letter from Charles B. Read, suggested that the whetstone area contains the oldest Pennsylvanian beds in the basin, but Bode (1958) stated that equivalent beds do exist near the base of Pennsylvanian rocks in southern Illinois. The marine invertebrates have not been thoroughly studied, but the ostracods appear to indicate an earliest Pennsylvanian age (R. H. Shaver, oral communication).

MAJOR LITHOLOGIC TYPES

SOURCE OF INFORMATION AND SAMPLING PROCEDURES

Data cited in this section of this report are summarized from 171 measured sections, including 3 logs of core holes (fig. 3). These records include 94 dc5-tailed sections and 23 reconnaissance sections, mainly of the Mansfield Formation, measured for this project during 1954-57; 38 sections, mainly of rocks of late Mississippian age, from definitive papers of Clyde Malott (1925, 1952); 8 sections of Mississippian rocks from Perry and Smith (1958); and 5 sections from miscellaneous authors. Altogether, these measured sections record a total of nearly 12, 000 feet of exposed section.

Sampling of rock units as heterogeneous as the Mansfield Formation must be carefully carried out to avoid introduction of bias. The measured sections and logs summarized here, which constitute a sampling of the Mansfield Formation and a part of the underlying rocks, were secured without bias, insofar as possible, and with the specific aim of determining the nature and relative abundance of the various rock types in these formations.

None of the measured sections or core holes summarized spans the entire thickness of the Mansfield Formation, and therefore ordinary facies maps cannot be made for the outcrop area. In order to detect areal variations in overall lithologic constitution of the Mansfield, the outcrop area was arbitrarily divided into 8 districts or sampling areas (fig. 3) of about 12 congressional townships each. The proportions of the various rock types were estimated by summing all the measured sections within each area (table 2). In none of the sampling areas does the proportion of covered interval in the measured sections exceed 10 percent of the thickness of the sections.

For comparison, summaries of four groups of formations of late Mississippian (Chester) age are included. These are, in ascending order, the West Baden and Stephensport Groups and two unnamed younger groups (table 1), here designated Ma, Mb, Mc, and Md, respectively (table 2). The sections of Mississippian rocks are not segregated into sampling areas.

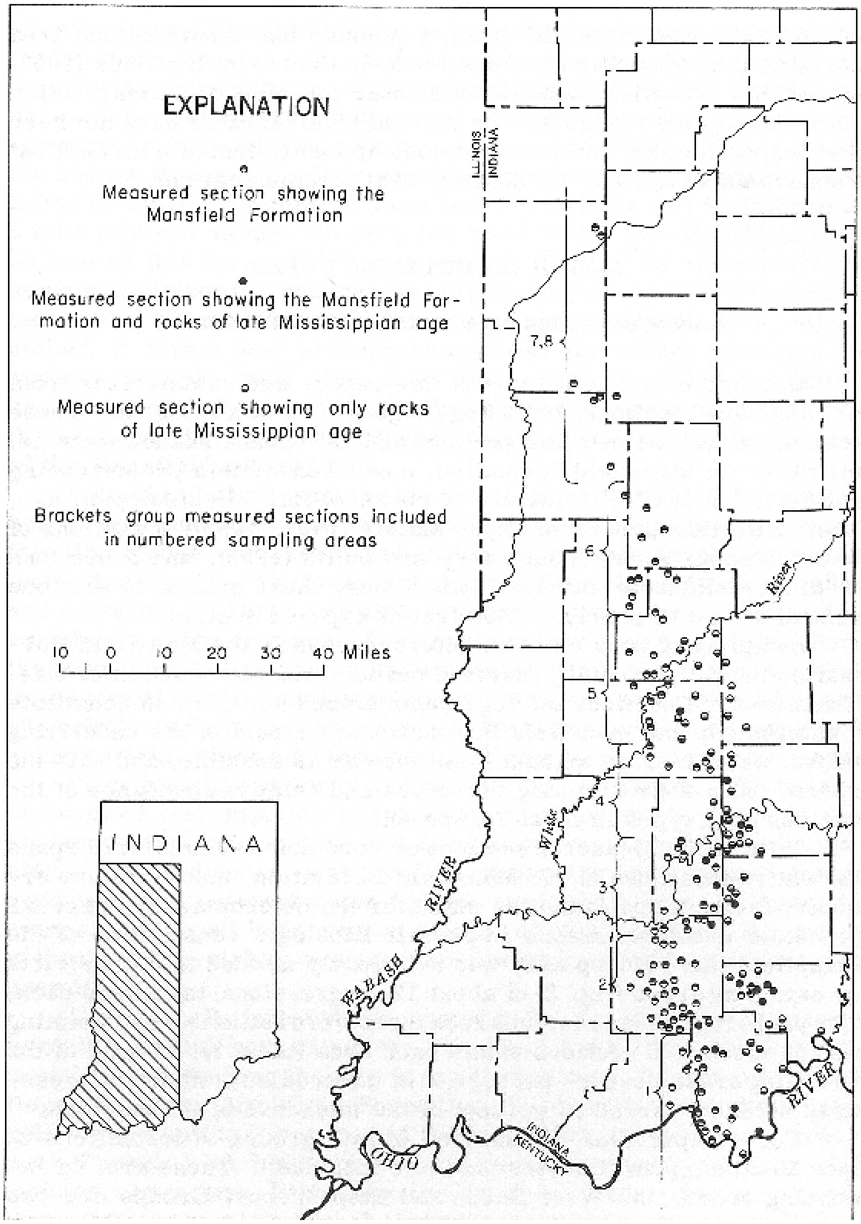

Figure 3. - -Map of southwestern Indiana showing location of measured sections, including three core holes, used in lithologic summaries.

Table 2.-Relative proportions of principal rock types in the Mansfield Formation and four groups of formations of late Mississippian age

	Mansfield Formation								Rocks of late Mississippian age			
	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7-8	Total	M_a	M_b	M_c	M_d
Rock Type (pct.)												
Sandstone, cross- stratified	17	28	26	16	17	21	31	22	25	5	12	1
Sandstone, thinly stratified	36	33	45	50	20	33	32	36	20	38	10	19
Sandstone, other - - - - - - - -	2	1	Tr.	2	5	1	- -	2	1	- -	- -	- -
Shale, gray - - - - - - - - - - - -	8	13	13	23	33	34	36	22	25	10	5	4
Shale, black - - - - - - - - - - -	1	Tr.	Tr.	1	- -	2	- -	1	- -	- -	- -	- -
Shale, other - - - - - - - - - - -	2	1	1	- -	1	- -	- -	1	11	7	66	69
Siltstone and mudstone - - -	23	18	11	2	10	2	Tr.	9	6	3	- -	- -
Clay - - - - - - - - - - - - - - - -	7	4	2	5	11	6	Tr.	5	1	- -	- -	- -
Coal - - - - - - - - - - - - - - - -	2	1	1	1	2	1	1	1	Tr.	- -	- -	- -
Limestone, gray - - - - - - - -	Tr.	Tr.	- -	- -	Tr.	Tr.	- -	Tr.	10	32	4	5
Limestone, yellow-brown	- -	- -	- -	- -	- -	- -	- -	- -	1	5	3	2
Chert - - - - - - - - - - - - - - -	Tr.	1	- -	- -	- -	- -	- -	Tr.	- -	- -	- -	- -
Sedimentary iron ore - - - - -	2	Tr.	1	- -	1	- -	- -	1	- -	- -	- -	- -
Thickness exposed (ft) - - - -	1, 261	1, 296	1, 110	486	533	603	500	5, 789	1, 853	1,163	2,018	521
Thickness covered (ft) ----	135	116	96	41	15	28	0	431	112	85	89	20
Total thickness (ft) - - - - - -	1, 396	1,412	1, 206	527	548	631	500	6, 220	1, 965	1, 248	2, 107	541

' Tr. = trace (less than 1 percent).

In current usage little distinction is made between terms that refer to primary sedimentary layering of sedimentary rocks: bed, lamina, layer, sedimentation unit, and stratum. In this report there is need to distinguish between some of the various levels of observation of sedimentary layering, and tentative working definitions are therefore proposed. The term "bed" will be used to refer to fairly large-scale layered rock units of essentially uniform gross lithology. Such units are useful primarily for subdividing formations for the purpose of field description. Fairly small-scale layered rock units that are megascopically distinguishable on the basis of minor differences in texture, composition, or structure are here referred to as "strata. " In general, a bed is composed of many strata.

DESCRIPTION AND DISTRIBUTION OF THE COARSER CLASTIC ROCKS

Cross-stratified sandstones-A conspicuous lithologic type in the Mansfield Formation may be loosely characterized as the cross-stratified sandstones (Appendix, section 3, bed 1; section 4, bed 3). These are various shades of gray on fresh exposure to yellowish brown where weathered and display even to uneven, thin to medium stratification in small- to large-scale cross-sets of tabular, wedge, and irregular shape. The principal mineral is quartz; subordinate clays are commonly present as aggregate grains or, more rarely, as matrix. Clay chips are abundant in some exposures, and in others quartz pebbles as much as 10 millimeters in diameter are present; the two are rarely found together. In the northern end of the outcrop angular pebbles of chert are seen in places. Most of the sand is medium grained to fine grained and fairly well sorted.

Large impressions of *Lepidodendron* and, more rarely, Sigillaria are found, and inclusions of coal as much as half a foot thick and a few feet across are rather common. Although friable on fresh exposure, cross- stratified sandstones are generally resistant to weathering, in part because circulating ground water carries dissolved iron hydroxides through the permeable sandstone to the outcrop face, where evaporation and oxidation fix the iron as oxides in a sort of case hardening. Where the basal contact of these sandstones is seen, it is sharp and uneven, and fragments of the underlying shale or other rock are commonly found in the basal foot or so of the sandstone. The average thickness of 79 beds of cross-stratified sandstone observed in the measured sections of the Mansfield Formation is about 17 feet.

Although it has sometimes been stated that cross-stratified sandstones dominate the Mansfield, they constitute only 22 percent of the formation (table 2 and fig. 4). Within the several sampling districts they are notably more abundant in areas 2, 3, and 7- 8 than in the others. In almost identical character cross- stratified sandstones are present also in each of the groups of late Mississippian age, and they are at least as abundant in the West Baden Group (Ma, fig. 4) as in the Mansfield.

Sandstones have been studied petrographically for many years with a view to establishing a uniform scheme of classification and nomenclature, yet to date no author has succeeded in clearly defining a category into which the cross -stratified sandstones of the Mansfield Formation may readily be placed. In part this is the result of lumping simply as "matrix" argillaceous materials that have at least three important and distinct modes of occurrence: sand-sized aggregates, coatings on other grains, and interstitial material that is texturally true matrix. I am of the opinion that the aggregated materials are properly considered rock fragments rather than ma-

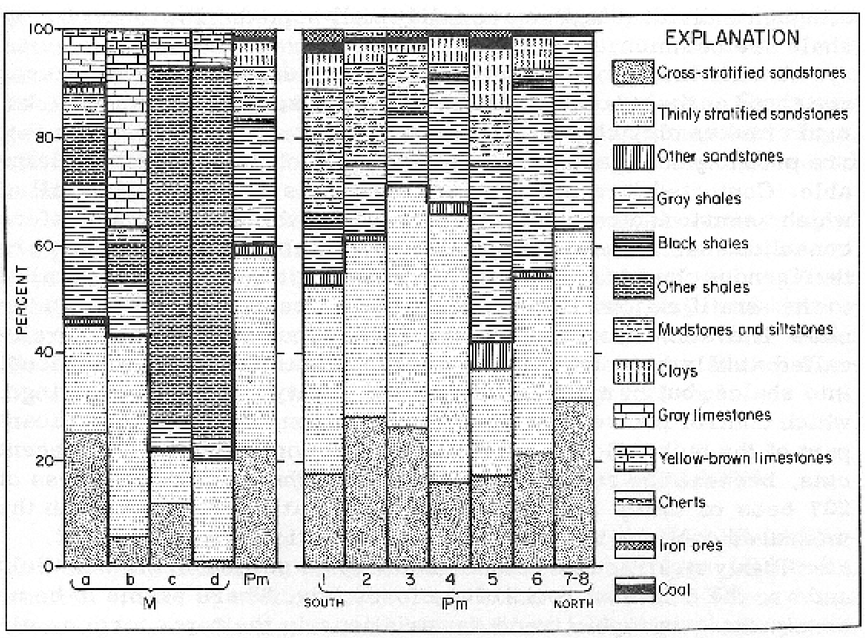

Figure 4. --Graphic representation of relative abundance of the various rock types in the Mansfield Formation and in rocks of late Mississippian age. M_a, West Baden Group; M_b, Stephensport Group; M_c and M_d, unnamed groups of late Mississippian age; IP_m, Mansfield Formation, total. 1-8, south-north sampling areas, Mansfield Formation (fig. 3).

trix and that these sandstones are properly classified as lithic sandstones, protoquartzites, or low-rank graywackes. Other terms have been used by other authors, depending not only on the classification scheme followed, but also on howthe "matrix" is regarded.

Thinly Stratified sandstones.-Possibly the most neglected rock type among the coarser clastics is the thinly stratified sandstones (Appendix, section 1, bed 11; section 2, bed 7). These range from light to dark gray on fresh surface and weather to various shades of yellowish brown. Distinct, thin, commonly wavy stratification characterizes these rocks. The dominant mineral is quartz. Clays are subordinate but abundant and occur largely as matrix, but it is possible that some of this matrix is merely a mass of contorted aggregate grains. Mica flakes litter the bedding surfaces, and carbonized plant debris is sufficiently abundant to color many of these rocks dark gray. Grain size ranges from fine sand through very fine sand perhaps to silt size, and sorting is generally poor in bulk although individual layers are fairly well sorted. Partings of gray shale are common.

A wide variety of depositional and postdepositional structures are found onthe stratification surfaces of these rocks- -ripple marks, mud cracks, clay chips, and trails, tracks, and impressions that are probably of organic origin but that are not immediately explainable. Contorted stratification and flow rolls of many types, all of which seem to indicate some disturbance of the sediment just before consolidation, are abundant. The identifiable fossil remains are terrigenous plant fragments. On weathering the rock splits parallel to the stratification into a mass of small scales and slabs. In the older literature this rock type, if mentioned at all, is generally called a shaly sandstone, and indeed some varieties are transitional into shales, but in most of the rocks of this type the shaly partings, which control the weathering character, constitute an insignificant part of the bulk. Good exposures are not common except in recent cuts, because the rock weathers rapidly. The average thickness of 207 beds of thinly stratified sandstone that were recorded in the measured sections of the Mansfield Formation is about 10 feet.

Thinly stratified sandstones make up 36 percent of the Mansfield and are the dominant rocks of the formation. There seems to be no consistent geographic trend to variations in their proportion, although they are more abundant in the southern part of the outcrop area than in the northern part. They are present in all the groups of late Mississippian age and are at least as abundant in the Stephensport Group (M_b, fig. 4) as in the Mansfield. Many thinly stratified sandstones form small ledges, but only in the Stephensport Group are they prominent cliff formers. The typical sandstones of the Big Clifty Formation and the few cliff-forming sandstones in the

Hardinsburg Formation (table 1) have distinct, even, thin stratification and differ from similar sandstones in the Mansfield principally in that they are somewhat better sorted relative to their grain size. The accompanying greater permeability probably contributes to the weather resistant character of the rock.

Other sandstones.- Most of the sandstones of the Mansfield Formation, where well exposed, can be described either as cross stratified or thinly stratified. Among the sandstones that cannot be so described, only one is volumetrically important. This rock type, a quartzitic sandstone called a ganister in some coal districts, is light gray to light yellowish brown and lacks stratification altogether. Quartz is the only observable mineral, and the grain size ranges from very fine sand to silt with apparently good sorting. The diagnostic structural features of this sandstone are the fairly abundant flattened imprints of plant rootlets, most of which are a few centimeters long and a centimeter or so across. The rock is tough and resistant to weathering, and it characteristically forms a ledge on natural outcrop or weathered artificial exposure. Ganisters are not topographically prominent, however, because their average thickness in the Mansfield Formation is only 3 feet. Ganisters generally grade rather abruptly upward into mudstones and clays, and these three related rock types form the "seat earths" of the coal beds.

Only about 2 percent of the Mansfield Formation is made up of the ganisters. They are found where the other sandstones are of less than maximum abundance, in areas 1, 2, and 4-6. Their greater abundance in areas of abundant mudstone, clay, and chemical rocks is clear. Ganisters are also found in the West Baden Group (Ma, fig. 4), where they are restricted to the Bethel Formation in association with coal, clay, and gray soft shale.

DESCRIPTION AND DISTRIBUTION OF THE FINER CLASTIC ROCKS

Gray 8hale8.-Among the finer clastic rocks of the Mansfield Formation gray shales constitute the dominant rock type (Appendix, section 1, bed 9; section 2, bed 6; section 4, bed 5). These range from light to medium gray and have distinct to indistinct, very thin, even stratification. Characteristically the gray shales are soft and not silty, but some contain noticeable amounts of silt. The siltier shales are less distinctly stratified and weather to a light yellowish brown. Some gray shales contain finelypreserved carbonized plant remains on the stratification surfaces; in others, equally well-preservedand more readily recoverable plant fossils are foundin abundant ironstone concretions. The average thickness of the 113 beds of gray shale in the Mansfield Formation that were measured and described is about 10 feet. These rocks weather readily and are best seen in fresh exposures.

Gray shales make up about 22 percent of the Mansfield Formation. Their relative abundance increases rather uniformly from south to north. Similar rocks are found in all groups of late Mississippian age but are equal in abundance to those of the Mansfield only in the West Baden Group (M_a, fig. 4), where they are found principally in the Bethel Formation.

Black Shales.- One of the few lithologic types by means of which the Mansfield Formation can be distinguished from most of the underlying formations is the black shales. These range from soft argillaceous dark-gray shales in which the abundant organic matter serves only as a coloring agent to highly carbonaceous brittle fissile black shales in which the carbonaceous material is apparently an essential structural constituent. Very thin, even stratification is characteristic and is more distinct in the more highly carbonaceous varieties. The black shales generally occur just above coal beds, which they overlie with sharp and even contacts. A few carbonized plant impressions are found in these "roof shales." Among the rocks of the Mansfield the average thickness of the 12 measured beds of black shale is about 3 feet. The more carbonaceous black shales weather slowly and make weak ledges on slightly weathered exposures; the less carbonaceous varieties weather more rapidly. (Bed 4, section 6, Appendix is a deeply weathered black shale.)

Black shales were not found in the 5,861 feet of measured section of Mississippian rocks summarized in table 2, but in some of the northernmost outliers the Mansfield is known to overlie directly a thick black shale, which is the New Albany Shale (table 1). Unfortunately, the black shales are not sufficiently abundant in the Mansfield to be a very helpful guide. Only in area 6 do they exceed a relative abundance of 1 percent, and in areas 5 and 7- 8 they were not observed at all. The average of 1 percent given for the entire formation (table 2) is somewhat generous. No geographic trend in the distribution of black shales is discernible, nor is there any obvious relation to the relative abundance of any other rock type.

Other shales.-The rocks summarized under this heading include shales described as various shades of grayish green, reddish brown, yellowish brown, and olive gray. Some mudstones and siltstones of these colors also are included, because earlier authors did not recognize these rock types and described such rocks as shales. Indistinct, even to slightly uneven, thin stratification characterizes the true shales; most of the mudstones and siltstones have no observable stratification. In many of these rocks the colors are unevenly distributed, and the terms variegated or mottled are aptly applied. These rocks weather readily to covered slopes.

Most of the shales in the Mansfield Formation that are not gray or black are olive gray. Only 1 percent of all Mansfield rocks fall in this category, and there seem to be no geographic trends and no preferred associate rock types. Twelve beds, averaging 5 feet in thickness, were recorded in the measured sections. In rocks of late Mississippian age shales other than gray have a wider range of colors than those of the Mansfield, and in the two unnamed groups (M_c and M_d, fig. 4) these are the dominant rocks. Shales and mudstones of yellowish, greenish, and reddish hues are thus strongly indicative of Mississippian rather than Pennsylvanian age. No reddish and few greenish shales are known from the Mansfield.

Mudstones, siltstones, and clays.-These related rocks are texturally mixtures of silt and clay. Clays are nonstratified or poorly stratified, unconsolidated, and generally plastic rocks composed mostly of clay-sized particles (Appendix, section 1, bed 4; section 5, bed 5; section 6, bed 2). Most siltstones have thin, even stratification and are composed of silt-sized particles with subordinate amounts of clay (Appendix, section 2, bed 5). In mudstones the proportions of silt and clay are about equal. Most mudstones are nonstratified, but some are poorly stratified (Appendix, section 2, bed 1; section 5, bed 3; section 6, bed 1). All these rocks are light to medium gray to light yellowish brown. In many of the mudstones muscovite is the only megascopically recognizable mineral, and the flakes of this mineral typically have random orientation rather than being aligned parallel to the stratification as in shales. This fabric is reflected in the irregular fracture that characterizes the mudstones. Clays also have irregular fracture, but megascopically visible muscovite flakes are less common in clays, and the fabric is not megascopically discernible. Some stratified siltstones split readily along very thin shale partings; these are the "whetstones, " formerly of considerable economic significance. Other siltstones break less regularly.

Carbonized imprints of plant rootlets are rather common in all these rocks, and in some of the stratified siltstones finely preserved molds of other parts of plants are found. On the stratification surfaces of some of the whetstones are several types of tracks and trails that probably were made by arthropods, but confirming evidence of this is lacking. All these rocks weather readily and are best seen in very f resh exposures. A year or two sometimes suffices to obliterate a good exposure in a roadside bank. In the measured sections of the Mansfield Formation 87 beds of mudstone and siltstone (undifferentiated in the summary, table 2andfig. 4), averaging 8 feet in thickness, and 81 beds of clay, averaging 3 feet in thickness, were recorded.

Mudstones and siltstones make up 9 percent of the Mansfield Formation and clays constitute 5 percent. Both separately and together these classes of rocks show a progressive, but not regular, decrease in abundance northward from area 1, where they are the dominant fine clastic rocks, to area 7-8, where they are absent. A. westward increase also is suggested in the southern areas, where data are most abundant. These rocks are inversely related to the gray shales, but they are clearly associated with each other and with the nonclastic rocks in general. Mudstones and siltstones of distinctive reddish-brown and greenish-gray colors are present also among the rocks of late Mississippian age (Ma, Mb, fig. 4). A minor amount of clay is also found in the Bethel Formation (table 1) of the West Baden Group (Ma, fig. 4).

DESCRIPTION AND DISTRIBUTION OF THE NONCLASTIC ROCKS

Coals.-One of the rock types that serves best to distinguish the Mansfield Formation from older rocks is the coals. These range in luster f rom moderately bright to moderately dull and in structure f rom distinctly and thinly banded to poorly banded (Appendix, section 2, bed 8). Closely spaced blocky fracture is characteristic, and the ground water that circulates through these joints forms springs that in some places mark the stratigraphic position of coal beds on covered slopes. Fairly fresh exposures of coal are, however, rather common, because seepage from the coal makes the underlying clays plastic and slippery. The consequent slumping of both coal and clay is sufficient to prevent the establishment of a cover of vegetation in many road cuts and on the banks of active streams.

Coal makes up only about 1 percent of the Mansfield Formation, but it is distinctive because it is quite rare in the underlying rocks. Only a trace was reported in the nearly 6,000 feet of measured sections of upper Mississippian rocks (table 2); beds less than a foot thick are known in the Bethel Formation (table 1). In the Mansfield Formation, 59 beds of coal, averaging about 1 foot in thickness, were recorded in the measured sections. The relative abundance of coal shows no geographic trend, but larger proportions of coal are clearly associated with larger proportions of clays, mudstones and siltstones, and fine-grained clastic rocks in general.

Limestones and cherts.-Among the less common rock types in the Mansfield Formation are the limestones and bedded cherts. The limestones are various shades of gray, are finely crystalline, and generally lack visible stratification. The sparse fossils include brachiopods, pelecypods, fusulinids, and ostracods. Limestones are mechanically strong and form ledges in road cuts and on the banks of active streams. The bedded cherts are gray when fresh but weather to a light yellowish brown. They also lack stratification and are finely crystalline. In the cherts fossils similar to those of the limestones are preserved as molds. Cherts are brittle and on outcrop are much fractured, but they are resistant to chemical attack, and in many places abundant fragments of chert disseminated through the soil mark the stratigraphic position of a chert bed on an otherwise soil-covered hillside.

Cherts and limestones in the Mansfield Formation average only a foot or two in thickness. Only 10 beds of limestone and 8 beds of chert were found in the more than 100 measured sections of the formation. They are for the most part restricted to the upper part of the formation and the southern part of the outcrop area (table 2 and fig. 4). Together, limestones and cherts makeup less than one-half of 1 percent of the Mansfield Formation.

Limestones are abundant in rocks of late Mississippian age. In general, these limestones are of two types: (1) coarsely crystalline gray fossil-fragmental limestone and (2) finely crystalline clayey or silty limestone that weathers yellowish brown and is sparingly fossiliferous (table 2 and fig. 4). Both types are readily distinguished f rom the limestones of the Mansfield Formation. Bedded chert is unknown in these rocks, but nodular chert is found in some of the limestones of late Mississippian age.

Iron ores.-The one remaining rock type of any appreciable abundance in the Mansfield Formation is the group of naturally occurring iron compounds that is perhaps best called the sedimentary iron ores (Appendix, section 1, bed 3; section 6, beds 7 and 9). These ores include iron carbonates, iron oxides (both hydrous and anhydrous), and perhaps other iron compounds, such as silicates and phosphates. They occur in a variety of forms, both nodular and bedded, with granular, oolitic, or crystalline fabric. Clay and silt-sized and sand-sized quartz are the common subordinate constituents. On fresh surface most of the carbonates are medium gray; on weathering these turn yellowish brown and resemble the oxides. In general, it is these rich yellowish-brown and reddish-brown colors that serve to identify the iron ores. More precise identification and classification are extremely difficult.

The sedimentary iron ores constitute about 1 percent of the rocks in the Mansfield Formation. No geographic trend in their relative abundance is apparent, nor are associations clear. Iron ores were not found in rocks of Mississippian age and are therefore useful in identifying rocks of the Mansfield Formation.

LITHOLOGIC FEATURES DISTINCTIVE OF THE MANSFIELD FORMATION

In summary, the Mansfield Formation contains several rock types that are distinctive or indicative of the formation with various degrees of certainty. In addition, a number of smaller structural features, mineral constituents, and textural attributes are also of value (table 3).

The problem of distinguishing the rocks of the Mansfield Formation from underlying rocks of late Mississippian age has engaged the attention of many geologists, whose interest for the most part has been only casual. No discussion of criteria diagnostic of the Mansfield is to be found, for instance, in Hopkins (1896), Kindle (1896), or Ashley (1899), who first treated the formation in detail. Cumings (1922), in the most complete summary description of the bedrock formations of Indiana, described the formations rather thoroughly but did not tell which features are useful in distinguishing one formation from another. The few authors that have segregated distinguishing criteria from other nondistinctive characteristics include Greenberg (1960) and Atherton and others (1960).

Table 3--*Criteria for distinguishing rocks of the Mansfield Formation from those of late Mississippian age*

(The more reliable criteria are at the top of each list, and the more useful criteria are shown in capital letters.)

	Rock types	Rock features
Indicative of the Mansfield Formation	Bedded chert COAL MORE THAN HALF A FOOT THICK NONSTRATIFIED GRAY MUDSTONES, SILT-STONES, AND CLAYS SEDIMENTARY IRON ORES Nonstratified sandstones (ganisters) Thin finely crystalline gray limestones Black shales	PLANT FOSSILS IN SHALES OR NODULES; *LEPIDODENDRON* OR *SIGILLARIA* IN SANDSTONES Quartz pebbles in sandstones SIDERITE NODULES IN SHALES ABUNDANT MICA Fusulinids in limestones and cherts Carbonaceous materials in sandstones and shales Coarse-grained sandstones
Indicative of the Mississippian age	REDDISH-BROWN AND GREENISH-GRAY SHALES AND NONSTRATIFIED VARI-COLORED MUDSTONES FINELY CRYSTALLINE YELLOWISH-BROWN LIMESTONES FOSSIL-FRAGMENTAL GRAY LIMESTONES	ABUNDANT MARINE FOSSILS OF WIDE VARIETY IN LIMESTONES and less commonly in gray shales

ORIGIN OF THE ROCK SEQUENCES

One of the prominent features of the Mansfield Formation, in common with other formations of Pennsylvanian age in Indiana, is the variety of lithologic types that succeed each other vertically at any given place. On a smaller scale these various beds are found in sequence corresponding to a crudely cyclic pattern; on a larger scale there are lithologic similarities between the several cycles of a given area and differences with respect to cycles in adjacent areas.

CYCLIC SEDIMENTATION

Cyclothems have long been recognized in rocks of Pennsylvanian age in the Illinois Basin (Weller, 1930; Wanless 193 1; Weller, 1956). Most of the essential features of the "typical" Illinois cyclothem are duplicated in the Mansfield Formation, but sequences of the type found in the Mansfield are generally termed "incomplete"; that is, no single vertical sequence contains more than a few of the lithologic units of the "complete" or "typical" cyclothem (fig. 5).

Cyclothems in the Mansfield are rudimentary probably because of their small areal extent. The degree of "completeness" of cyclothems varies directly as the extent of the rocks by means of which the cyclothem is recognized; that is, widespread cyclothems generally include a wide variety of rock types and are thus potentially more "complete" than are cyclothems of smaller extent. This suggests the possibility of simultaneous deposition of different sediments in contiguous areas--one concept of facies.

Cyclic rock sequences in the Mansfield Formation are properly called cyclothems, because they consist of alternations of chemical rock types and elastic rocks. The "typical" cyclothems of Illinois, however, contain less sandstone and more limestone and coal. Disconformable contacts between cyclothems, as recognized in Illinois below the basal sandstone of the cyclothem, are much less prominent in the Mansfield because of the commonness of sandstone.

Cyclic sequences in the Mansfield Formation are stratigraphically identified and areally traced by means of the chemical rock beds that they contain. The extent of most cyclothems in the Mansfield is no more than a few square miles or a few tens of square miles. The most extensive cyclothem is that associated with the Mariah Hill Coal (fig. 2), which can be traced over an area of nearly 200 square miles in parts of Spencer and Dubois Counties (Hutchison, 1959; Hutchison, in preparation).

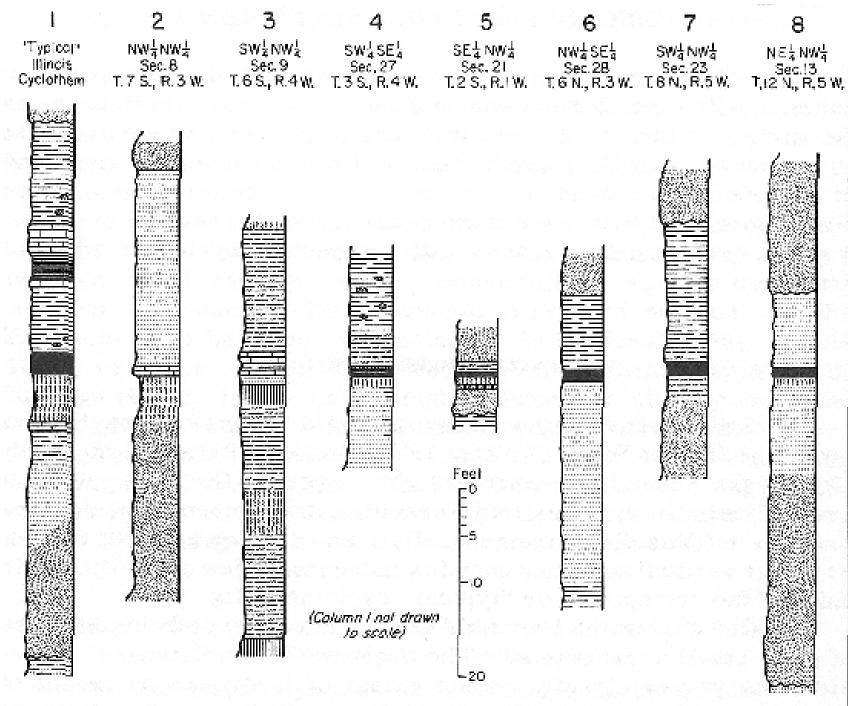

Figure 5. --Graphic comparison of representative cyclic sedimentary sequences in the Mansfield Formation with the "typical" cyclothem of Illinois. See figure 4 for an explanation of lithologic symbols.

REGIONAL VARIATIONS IN LITTIOLOGIC PROPORUONS

Identification of lithofacies in the Mansfield Formation.-One of the principal objects of this study is the delineation of paleogeographic and environmental patterns of which the stratigraphic record constitutes the principal evidence. Ideally such inferences should rest on knowledge of the geographic and stratigraphic distribution of individual bodies of the various types of sandstone, shale, and other rocks. Owing to the complexity of the interrelationships among the rock bodies in the Mansfield Formation and to the large extent of the area studied, this approach cannot be utilized. Secondarily, it might appear desirable to subdivide the Mansfield Formation into several nearly time-parallel slices and analyze statistically the sedimentary variation in each of these slices. The lack of extensive objectively traceable horizons within the formation prohibits this approach.

Yet there remains a need to evaluate the environmental significance of the fact that within the outcrop belt of the Mansfield Formation the several cyclothems of a given area tend to be similarly constituted and different frorn cyclothems of contiguous areas. The remaining possible approach, which has severe limitations but which can result in illustrating some general relationships, utilizes the concept of facies as areally segregated and lithologically distinct parts of a formation. The checkered history of the term facies and its derivatives has been explored by Weller (1958), and following his suggestion, I shall use lithofacies (in the sense of the "Northwestern (University) group, " Weller, 1958, table 1) for this type of facies, a statistically determined, vertically bounded phase or aspect of a formation. Three lithofacies can be identified and mapped in the Mansfield Formation and are here named for convenience only. It is not intended that these names be a part of the officially recognized rock- stratigraphic nomenclature.

The rock types by means of which these lithofacies are distinguished are crossstratified sandstones, mudstones and siltstones. and gray shales. Areas in which crossstratified sandstones are more abundant than mudstones and siltstones or gray shales belong to the Shoals Lithofacies, named for the town of Shoals, Martin County (fig. 6), in the vicinity of which rocks of this lithofacies are well exposed (Appendix, sections 3 and 4). In the Cannelton Lithofacies which is well developed in the vicinity of Cannelton, Perry County, siltstones and mudstones are dominant among the three diagnostic rock types (Appendix, sections 5 and 6). A greater abundance of gray shales characterizes the Bloomfield Lithofacies, named for the town of Bloomfield, Greene County, near which this facies is particularly well developed (Appendix, sections I and 2). Together the three diagnostic rocks make up slightly more than half of the formation, and the dominant rock of these three at any given point is therefore not necessarily the most abundant in the formation as a whole.

Distribution of lithofacies in outcrop area.-Conventional facies-mapping techniques are not applicable to this study, because the entire Mansfield Formation is not included in any single measured section. As an approach to facies mapping, the following technique was used: in each measured section in which 40 feet or more of Mansfield rocks are exposed, the dominant diagnostic rock, cross- stratified sandstone, mudstone and siltstone, or gray shale, is determined as an estimate of the probable lithofacies association at that point. The distribution of these data (fig. 6) demonstrates the areal segregation of the lithofacies and illustrates in somewhat more detail than figure 4 the geographic trends of these rock assemblages. The northward increase in gray shales at the expense of the mudstones and silt

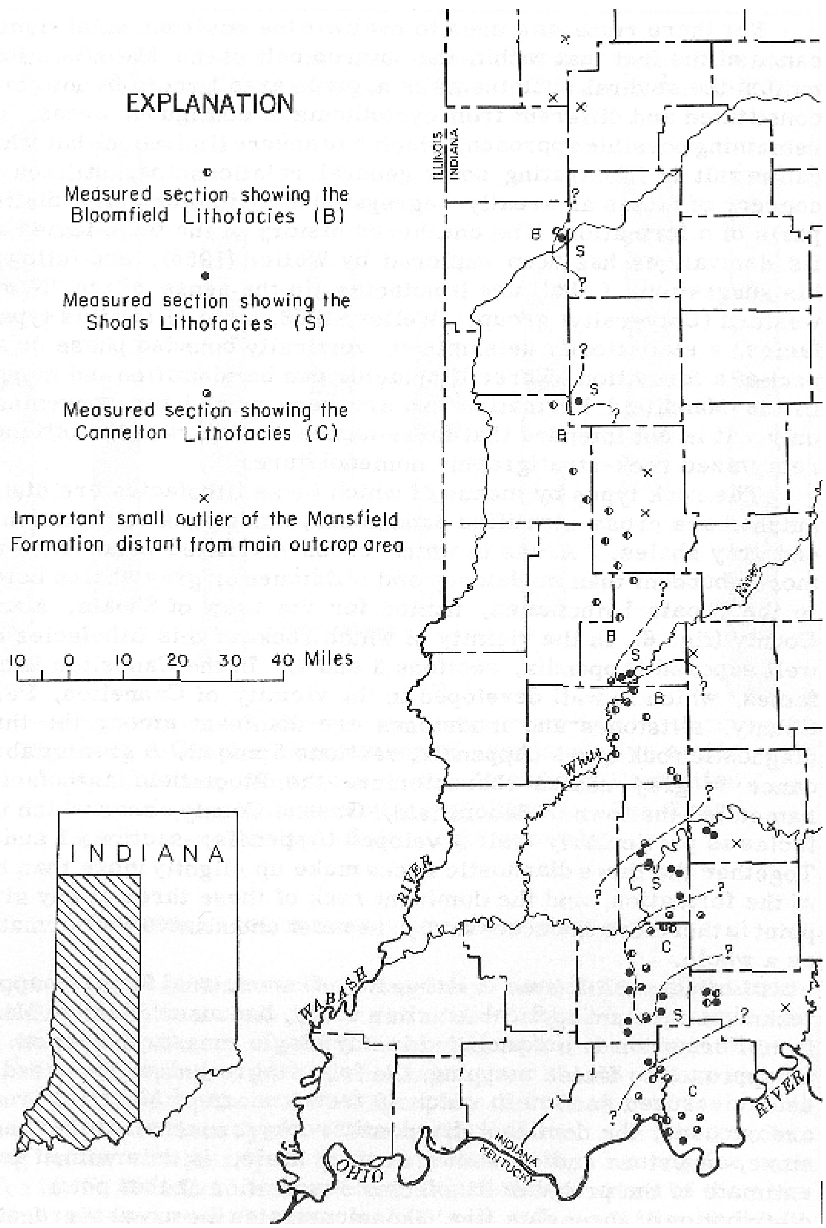

Figure 6. --Map of Southwestern Indiana showing location of measured stratigraphic sections that include 40 feet or more of exposed Mansfield Formation, with lithofacies identified.

stones is shown by restriction of the Cannelton Lithofacies to the southern third of the outcrop area and near - restriction of the Bloomfield Lithofacies to the northern two-thirds. The conspicuous cross-stratified sandstones in districts 2 and 3 (fig. 4) are clearly reflected in the strong expression of the Shoals Lithofacies in these areas. The data from a small number of the points shown in figure 6 is at variance with the data from nearby points and with the lithofacies interpretations mapped. Considering the fragmental nature of the data, however, and the imperfect method of estimating facies associations, I believe that the consistency of the data is good.

Coal beds that are extensive enough to be useful stratigraphic markers are most common in the Cannelton and Bloomfield Lithofacies (fig. 7). Many coal beds may be traced a short distance into the Shoals Lithofacies, but only a few can be followed, with difficulty, through these areas. Thus physical correlation of the coal beds in the Mansfield Formation cannot be accomplished readily or with certainty on a regional scale. The correlations shown in figure 7 are approximate and are based primarily on relative stratigraphic position.

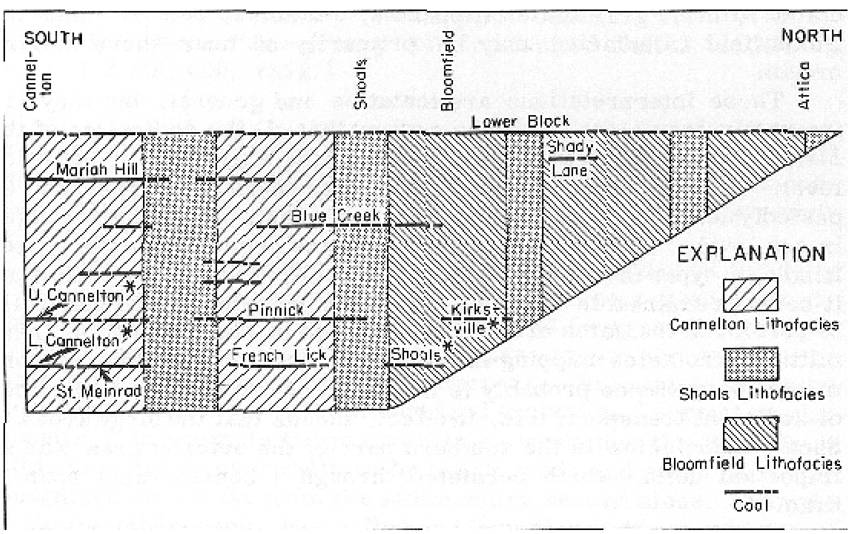

Figure 7. - - Stratigraphic diagram along the outcrop belt of the Mansfield Formation showing relationship of named lithofacies and position of principal named coal beds. Names with asterisks have previously appeared in print but are not officially accepted by the Indiana Geological Survey.

Genetic implications of the lithofacies patterns.-As mapped, the lithofacies distributions are mostly one -dimensional, because only outcrop data have been used. The principal areas of the Shoals Lithofacies appear, however, to trend nearly normal to the outcrop of the Mansfield Formation, thus separating the Bloomfield from the Cannelton Lithofacies. This pattern of distribution, coupled with the coarser average grain size of the Shoals rocks, suggests that this lithofacies outlines principal routes of sediment transport into the Illinois Basin during Mansfield time. This inference is supported by the abundant occurrence of quartz pebbles only within the areas mapped as Shoals Lithofacies and in those small outliers (fig. 6) that are directly up-dip from mapped areas of Shoals.

In the Cannelton Lithofacies the abundance of fossil rootlets, the delicately preserved plant remains, and the numerous examples of standing stumps in the mudstones, siltstones, and clays suggest that this facies is primarily the result of continental deposition in environments such as swamps and flood plains. On the other hand, many of the plant fossils in the gray shales of the Bloomfield Lithofacies are fragmental, and all are detached and show some evidence of transport before burial. In places marine bands are found associated with the gray shales (Appendix, section 1, bed 7). Thus the Bloomfield Lithofacies may be primarily of near-shore marine origin.

These interpretations are tentative and general, but they are internally consistent, and they suggest that all the sediments of the Mansfield Formation were deposited near the shoreline and near sea level. Undoubtedly the shoreline transgressed and regressed repeatedly as a result of mild tectonic movements or eustatic changes in sea level. This shifting of the shoreline accounts for the varied lithologic types in sequence at any one point. Under such conditions it seems remarkable that environmental patterns tended generally to persist in the same areas through much of Mansfield time, permitting lithofacies mapping in the manner used here. This environmental persistence probably is the result of consistency in the lines of sediment transport; this, in effect, means that the large areas of Shoals Lithofacies in the southern part of the outcrop area was an important delta, which persisted through a considerable span of time.

Where may we look for a modern analogue to this depositional pattern? Almost any aggrading shoreline will provide suitable examples, but the Gulf Coast is perhaps best known to us. Three representative Gulf Coast deltas are shown in figure 8. These share three major characteristics: each is a body of relatively coarse sediment, each is aggrading relatively rapidly, and each provides

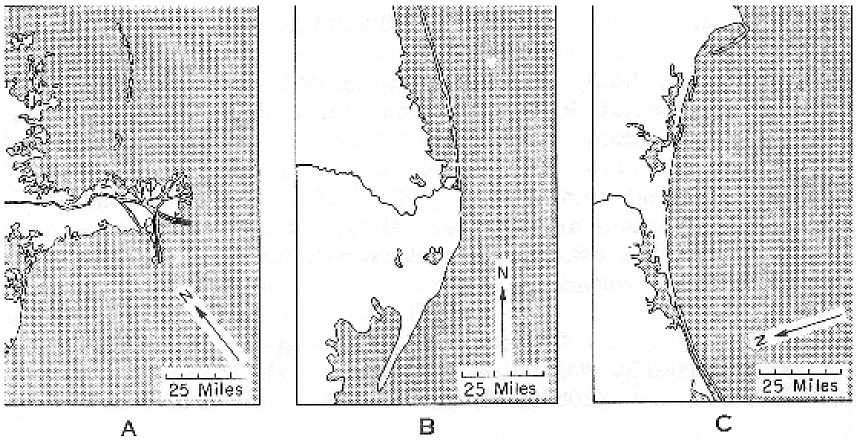

Figure 8. --Three representative deltas along the Gulf Coast of Southern United States. A, Delta of Mississippi River; fluvial processes dominant. B, Delta of Rio Grande River; fluvial and shoreline processes approximately in balance. C, Delta of Choctawhatchee River; shoreline processes dominant. (Somewhat simplified from U. S. Geological Survey map of the United States, scale 1:2, 500, 000, 1932.)

several types of barriers that separate a variety of depositional environments. Within short distances may be found channel, flood-plain, swamp, lake, lagoon, beach, and open-water marine environments.

Which of these examples may most nearly represent the delta of Pennsylvanian age described above? The present state of knowledge does not permit a categorical answer, but I suggest that example B, the intermediate case in which neither stream nor sea has the upper hand, is the most likely counterpart. In example A. fluvial deposition is dominant to the almost total exclusion of normal marine deposits. In example C the river is so weak that the deposits it builds are almost overwhelmed by beach sands and could hardly be recognized as a delta from the sedimentary record alone. Example B, on the other hand, has a fine and complex network of channel and beach sands, an abundance of specialized local environments, and a wide delta-front apron.

The further test of this presently speculative hypothesis must await detailed study of rocks of early Pennsylvanian age in the records of drill holes to the west of the area considered in this report.

LITERATURE CITED

Ashley, G. H., 1899, The coal deposits of Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 23, p. 1-1573, 91 pls., 986 figs. , 7 maps.

Atherton, Elwood, and others, 1960, Differentiation of Caseyville (Pennsylvanian) and Chester (Mississippian) sediments in the Illinois Basin: Illinois Geol. Survey Circ. 306, 36 p., 14 figs., 3 tables, 3 appendices.

Bode, H., 1958, Die floristische Gliederung des Oberkarbons der Vereinigten Staaten von Nordamerika: Deutsche geol. Gesell. Zeitschr., v. 110, pt. 2, p. 217-259.

Cumings, E. R., 1922, Nomenclature and description of the geological formations of Indiana, in Handbook of Indiana geology: Indiana Dept. Conserv. Pub. 21, pt. 4, p. 403-570, 31 figs.

Franklin, D. W. , 1939, Lithologic and stratigraphic study of the lower Pennsylvanian strata, Orange County, Ind. (unpublished M. S. thesis): Urbana, Illinois Univ. , 49 p., 2 pls. , 26 figs.

Greenberg, S. S., 1960, Petrography of Indiana sandstones collected for high-silica evaluation: Indiana Geol. Survey Bull. 17, 64 p. , 1 pl. , 8 figs. , 9 tables.

Hopkins, T. C. , 1896, The Carboniferous sandstones of western Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 20, p. 186- 327, 9 pls. , 7 figs., 2 maps.

Hutchison, H. C., 1959, Distribution, structure, and mined areas of coals in Spencer County, Ind.: Indiana Geol. Survey Prelim. Coal. Map 8.

----- 1961, Distribution, structure, and mined areas of coals in Fountain and Warren Counties and the northernmost part of Vermillion County, Ind.: Indiana Geol. Survey Prelim. Coal Map 9.

----- in preparation, Distribution, structure, and mined areas of coals in Dubois County, Ind.: Indiana Geol. Survey Prelim. Coal Map 10.

Indiana Geological Survey, 1957, Rocks associated with the Mississippian-Pennsylvanian unconformity in southwestern Indiana: Field Conf. Guidebook 9, 42 p., 4 pls., 3 figs.

Kindle, E. M. , 1896, The whetstone and grindstone rocks of Indiana: Indiana Dept. Geology and Nat. Resources, Ann. Rept. 20, p. 328-368, 1 map.

Kottlowski, F. E., 1959, Geology and coal deposits of the Coal City Quadrangle, Greene, Clay, and Owen Counties, Ind.: U. S. Geol. Survey Coal Inv. Map C 28.

----- 1960, Geology and coal deposits of the Switz City Quadrangle, Greene County, Ind.: U. S. Geol. Survey Coal Inv. Map C 41.

Krynine, P. D., 1948, The megascopic study and field classification of sedimentary rocks: Jour. Geology, v. 56, p. 130-165.

Malott, C. A., 1925, The upper Chester of Indiana: Indiana Acad. Sci. Proc. , v. 34, p. 103-132, 11 figs.

----- 1952, Stratigraphy of the Ste. Genevieve and Chester formations of southern Indiana: Ann Arbor, Mich., The Edwards Letter Shop, 105 p., 1 table.

Perry, T. G., and Smith, N. M., 1958, The Meramec-Chester and intra-Chester boundaries and associated strata in Indiana: Indiana Geol. Survey Bull. 12, 110 p., 6 pls., 1 fig.

Wanless, H. R. , 1931, Pennsylvanian cycles in western Illinois: Illinois Geol. Survey Bull. 60, p. 179-194.

Weller, J. M., 1930, Cyclical sedimentation of the Pennsylvanian Period and its significance: Jour. Geology, v. 38, p. 97-135.

----- 1956, Argument for diastrophic control of late Paleozoic cyclothems- Am. Assoc. Petroleum Geologists Bull., v. 40, p. 17-50.

----- 1958, Stratigraphic facies differentiation and nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 609-639.

APPENDIX

Section 1. SE¼ SW¼ sec. 12, T. 14 N., R. 6 W., Parke County, along tributary to Groundhog Branch just east of Groundhog Falls

This section is typical of the Bloomfield Lithofacies in the northern part of the outcrop area. Marine bands, such as that of bed 7, are not uncommon but cannot be traced far.

Bed		Ft
11.	Sandstone, light-gray; distinct, wavy, very thin strata; principally quartz, sub ordinate clay mostly as matrix, minor muscovite and carbonaceous flakes; very fine size sand; very thinly interstratified with gray shale; exposed at top of bank north of stream -	13.0
10.	Sandstone, light-gray; indistinct, even, thin strata; principally quartz, subordinate clay mostly as matrix, minor muscovite and carbonaceous flakes; very fine size sand, poor sorting; well exposed; both contacts sharp and even - - - - - - - - - - -	4.0
9.	Shale, dark-gray; distinct, even, very thin strata; gypsum rosettes on cleavage surfaces; flat marcasite? concretions at base, large siderite ~ concretions throughout bed; well exposed on north bank of creek; bottom contact gradational within 1. 0 It -	14.0
8.	Shale, silty, black; indistinct, uneven, very thin strata; carbonaceous; hard; forms small ledge; bottom contact gradational within 0. 1 It -	1.4
7.	Siltstone, shaly, black; indistinct, uneven, very thin strata; carbonaceous; contains several species of brachiopods, sparse but well preserved; forms weak ledge; bottom contact sharp and even; altitude 720 ft -	0.3
6.	Shale, dark-gray; distinct, even, very thin strata; poorly exposed along banks of stream -	7. 5
5.	Sandstone, light reddish-brown; distinct, uneven, very thin strata; principally quartz, minor clay matrix and siderite? cement; very fine size sand, good sorting; in part interstratified with gray shale; contains finely preserved plant remains; bottom contact interleaved within 0. 5 ft -	2. 1
4,	Clay, shaly, light-gray; indistinct, uneven, thin strata; sparse plant remains at base; well exposed on bank and at waterfall; bottom contact sharp and even - - - - - -	1.5
3.	Iron ore, silty, mediurn-gray; nonstratified; siderite, kaolin, marcasite, chal- copyrite, quartz, and carbonaceous flakes tentatively identified; nodular; poorly exposed; bottom contact sharp -	0.4
2.	Shale, dark-gray; distinct, even, very thin strata; numerous large carbonized plant remains; poorly exposed -	0.3
1.	Sandstone, light-gray; indistinct, uneven, thin strata; principally quartz and clay matrix, minor clay chips; very fine size sand, poor sorting; siderite ? nodules, abundant carbonized plant remains; poorly exposed in bed of creek at bridge - - - - -	1. 1
	Total thickness -	45.6

Section 2. NW¼ SE¼ sec. 28, T. 6 N., R. 3 W., Greene County, at east portal of abandoned railroad tunnel 1 mile west of Owensburg

This section is representative of the Bloomfield Lithofacies in the central part of the outcrop area, although the siltstones of bed 5 resemble the whetstones of the Cannelton Lithofacies. The coal beds cannot be traced far. Greenish-gray and reddish-gray shaly mudstone of Mississippian age 15 feet thick underlies bed 1.

Bed		Ft
10.	Sandstone, light yellowish- brown; thin, uneven strata; principally quartz, subordinate clay mostly as matrix, scattered clay chips; very fine size sand, poor sorting; forms ledge at top of exposure; bottom contact sharp	4.0
9.	Shale, dark-gray; very thin, even strata; papery fracture; bottom contact gradational within 0. 5 it	8.0
8.	Coal, banded, black; bottom contact sharp; altitude 805 ft; abandoned small mine	1.3
7.	Sandstone, medium yellowish- brown; thin, uneven strata; principally quartz, subordinate clay mostly as matrix; very fine size sand, poor sorting; scattered ferruginous concretions; forms series of slopes and ledges; bottom contact inaccessible	22.0
6.	Shale, rnedium-gray; very thin, even strata; smooth, platy fracture; several ones of siderite ? concretions as much as 0. 2 it thick and 1 ft in diameter; bottom contact sharp; well exposed on steep slope	35.0
5.	Siltstone, light-gray; thin, even strata, somewhat contorted at upper and lower contacts; separated by shale partings into slightly flexible laminae 1 to 3 cm thick; bottom contact sharp; forms weak ledge	8.5
4.	Shale, clayey, medium-gray; thin, even strata; platy fracture	0.1
3.	Coal, banded, black	0.5
2.	Clay, shaly, medium-gray; thin, even strata; plastic; thin bands of vitrain in lower 0. 1 ft	0.5
1 .	Mudstone, medium-gray; nonstratified; hackly fracture; abundant root impressions; upper 2 cm is carbonaceous	0.5
	Total thickness	80.4

Section 3. SE¼ SE¼ sec. 21, T. 4 N., R. 2 W., Lawrence County, on south bank of county road on east side of Gardner Mine Ridge

This short section is typical of the Shoals Lithofacies. The base of the Mansfield Formation is at or just below the base of this exposure.

Bed		Ft
1.	Sandstone, light yellowish -brown; thick sets of thin cross-strata in lower part, irregular strata in upper part; principally quartz, subordinate clay mostly as aggregates, minor quartz pebbles and clay chips; medium size sand; scattered piant impressions; friable; upper part better cemented; base of bed at 750 ft altitude	45.0
	Total thickness	45.0

Section 4. SW¼ NW¼ sec. 25, T. 2 S., R. I W., Crawford County, on south side of track near center of cut on the Southern Railroad

In this section rocks typical of the southern area of the Shoals Lithofacies are exposed. The contorted strata of -any of the beds in this section show that the upper beds have slid a little to the southwest over the underlying beds.

Bed		Ft
7.	Siltstone, dark-gray; uneven, very thin strata, much contorted; bottom contact gradational within 0. 2 ft -	6.0
6.	Sandstone, light yellowish-brown; nonstratified; principally quartz, subordinate claymostlyas matrix, minor muscovite, carbomceous flakes, and clay chips; very fine size sand; forms prominent ledge; basal contact sharp and slightly uneven -	5.0
5.	Shale, silty, dark-gray; indistinct, uneven, very thin strata; upper part contains thin lenses of sandstone and stratification is much contorted; bottom contact transitional within 0.1 ft -	9.5
4.	Sandstone, dark to light yellowish-brown; uneven, thin strata; principally quartz, subordinate clay mostly as matrix, in part heavily impregnated with iron oxides; fine size sand; forms series of weak ledges; bottom contact transitional - - - - - - - - - -	12.0
3.	Sandstone, mediura yellowish-brown; thin tabular sets of thin cross-strata, dip southwest in most sets; principally quartz, subordinate clay mostly as aggregates and gray shale chips; abundant iron oxide concretions, especially at top; medium, to coarse size sand, poor sorting; friable, but forms steep walls in the lower part of cut; much contortion of strata in lower part, involving a zone of iron ore, lenses of coal, and parts of the underlying shale; bottom contact sharp and irregular, altitude approximately 740 ft -	30.0
2.	Sandstone, dark reddish-brown; indistinct, uneven strata; principally quartz, subordinate clay as aggregates and greenish-gray and reddish-brown siltstone and claystone chips, minor streaks of coal; very coarse size sand; bottom contact sharp and uneven; 0 to 8 ft thick -	4.0
1.	Shale, silty, mediurn-gray; indistinct, thin**,** even strata, in places complexly contorted; 0 to 8 ft thick; not exposed where bed 2 reaches maximum thickness - - - - - - - - - - - -	4.0
	Total thickness -	70.5

Section 5. NW¼ NW¼ sec. 16, T. 2 S., R. 4 W., Dubois County, on east bank of county road

Rocks typical of the northern area of the Cannelton Lithofacies are exposed in this section.

Bed		Ft
7.	Sandstone, light yellowish- brown; distinct, uneven, thin strata; principally quartz, subordinate clay mostly as matrix; very. fine size sand, poor sorting; friable; poorly exposed in ditch and bank; bottom contact sharp; sandy iron ore in float probably comes from near base of bed -	8.5
6.	Coal, shaly, black; weathered; bottom contact gradational within 0. 2 ft; 0. 2 to 0. 7 ft thick; altitude 545 ft -	0.5
5.	Clay, silty, light-gray; nonstratified in lower part; indistinct, uneven, very thin strata in upper 2 ft, which is carbomeeous; root impressions common; well exposed in ditch -	8.5
4.	Covered; probably occupied by mudstone -	7.5
3.	Mudstone, shaly, light-gray; indistinct, even, very thin strata, more distinct in upper part; lower two-thirds smooth and clayey, upper one-third contains many very thin silty strata; prominent vertical joints with limonite diffusion bands; well exposed; bottom contact sharp and even -	34.5

Bed		Ft
2.	Sandstone, light yellowi sh- brown; distinct, uneven, thin strata; principally quartz, subordinate clay mostly as aggregates; clay chips abundant in several zones; very fine size sand, poor sorting; poorly exposed in ditch; basal contact interleaved within approximately 0.5 ft -	2.0
1.	Sandstone, light yellowish-brown; distinct, uneven, thin strata; principally quartz, subordinate clay mostly as matrix, minor clay chips; fine size sand, good sorting; poorly exposed -	1.5
	Total thickness -	63.0

Section 6. NE¼ SE¼ sec. 13, T. 6 S., R. 3 W., Perry County, in ditch on north side of dead-end county road

This section is representative of the type area of the Cannelton Lithofacies.

Bed		Ft
Il.	Sandstone, light yellowish- brown; indistinct, uneven, thinstrata; principally quartz, subordinate clay matrix, minor muscovite; very fine size sand, poor sorting; forms small ledge in ditch at bend of road; bottom contact sharp, slightly irregular -	1.0
10.	Sandstone, light yellowish-brown to white; indistinct, uneven, thin strata; principally quartz and clay matrix; very fine size sand, poor sorting; bottom contact sharp -	3.0
9.	Iron ore, septarian; poorly exposed in weak ledge -	0.5
8.	Mudstone, light to medium yellowish -brown; indistinct, uneven, thin strata; hackly fracture; bottom contact sharp and slightly uneven -	1.0
7,	Iron ore, sandy, medium yellowish -brown; nodular; nonstratified; bottom contact sharp and uneven -	0.5
6.	Coal, clayey, black; poorly exposed; altitude 595 ft -	0.1
5.	Mudstone, shaly, medium yellowish-brown; indistinct, even, thin strata; upper 2 ft clayey and contains numerous root impressions; well exposed in deeply gullied ditch -	16.0
4.	Shale, carbonaceous, light purplish-brown; distinct, even, very thin strata; abundant poorly preserved plant remains; bottom contact sharp and even - - - - - - - - - - -	2.9
3.	Coal, shaly, black; poorly exposed -	0.1
2.	Clay, shaly, medium-gray; indistinct, uneven, thin strata; plastic; poorly exposed; bottom contact sharp -	3.0
1.	Mudstone, shaly, medium yellowi sh- brown; indistinct, even, thin strata; platy fracture; well exposed in deeply gullied ditch -	19.0
Total thickness	- -	47.1