Development of the Mississippian-Pennsylvanian Unconformity in Indiana

By **JOHN B. DROSTE** *and* **STANLEY J. KELLER**

DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY OCCASIONAL PAPER 55

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ABSTRACT

In very early Pennsylvanian time the place now called Indiana was the locus of subaerial erosion. About 8,000 square miles of this landscape is preserved in western Indiana beneath the rocks of the Pennsylvanian System. Data from 20,000 wells provide the evidence to reconstruct this surface and to describe its geomorphology.

Six ancient physiographic regions that show clear relationships of landform to outcropping Mississippian bedrock have been identified. From north to south a distinctive topography is associated with each of the ancient outcrop areas of (1) the Borden Group, (2) the Sanders and Blue River Groups, (3) the West Baden Group, (4) the Stephensport Group, (5) the Tar Springs Formation through the Menard Limestone, and (6) the Palestine Sandstone through the Grove Church Shale.

In northern Indiana the Mississippian-Pennsylvanian unconformity may represent as much as 8 million years of erosion. In southern Indiana that same unconformity may represent less than 3 million years of erosion.

INTRODUCTION

About 325 million years ago the rocks of the Mississippian System lay exposed by subaerial erosion in parts of Indiana, Illinois, and Kentucky. Subsequent burial of this surface by sedimentation during Pennsylvanian time created the regional Mississippian-Pennsylvanian unconformity. In the Midwest the rocks of the Pennsylvanian System lie superjacent to strata as old as Ordovician (St. Peter Sandstone); for example, see Willman and others (1975, p. 170). In Indiana the Pennsylvanian strata lie on rocks as old as Late Devonian; for example, see Gray and others (1987). The geology, including stream-drainage patterns, of this pre-Pennsylvanian landscape has been discussed for more than 35 years (Siever, 1951; Wanless, 1955; Gray and others, 1960; Potter and Desborough, 1965; Bristol and Howard, 1971, 1974; and Gray, 1979). It is our purpose here to describe the general geomorphology of this landscape as it is preserved throughout 8,000 square miles in the subsurface of western Indiana (fig. 1).

In Indiana the Mississippian-Pennsylvanian surface of unconformity crops out along the eroded limit of the Pennsylvanian System from the Ohio River in Perry County northwestward to the Illinois state line in northwestern Warren County (fig. 1). The elevation of this surface in Indiana ranges from more than 900 feet above sea level in Monroe County to more than 1,500 feet below sea level in Posey County (Keller, in preparation). The rock-stratigraphic hiatus in Indiana ranges throughout the entire Mississippian System (fig. 2).

METHODS AND SCOPE

Most of the data used in this study were derived from petroleum- test wells. Almost all of the 20,000 well records examined have a geophysical log or a sample set or both. Driller's logs were used only if no other information was available. All the data were obtained from studying well information on file at the Indiana Geological Survey in Bloomington. Work maps showing well locations, generally at a scale of 1 inch to 1 mile, were used in plotting the data. These data include the elevation of the Mississippian-Pennsylvanian unconformity, the Mississippian stratigraphic unit (fig. 2) at the unconformable surface, and the thickness of the youngest formation preserved beneath the unconformity.

The elevations of the sub-Pennsylvanian surface show the present regional slope of the unconformity, call immediate attention to local variation and irregularity of the unconformity due to post-Mississippian structural activity, and at the local level in many areas display configurations that mimic the ancient topography before burial by sedimentation during Pennsylvanian time.

For the subcrop area of Borden strata no effort was made to determine the stratigraphic rank of the Mississippian rocks below group status because

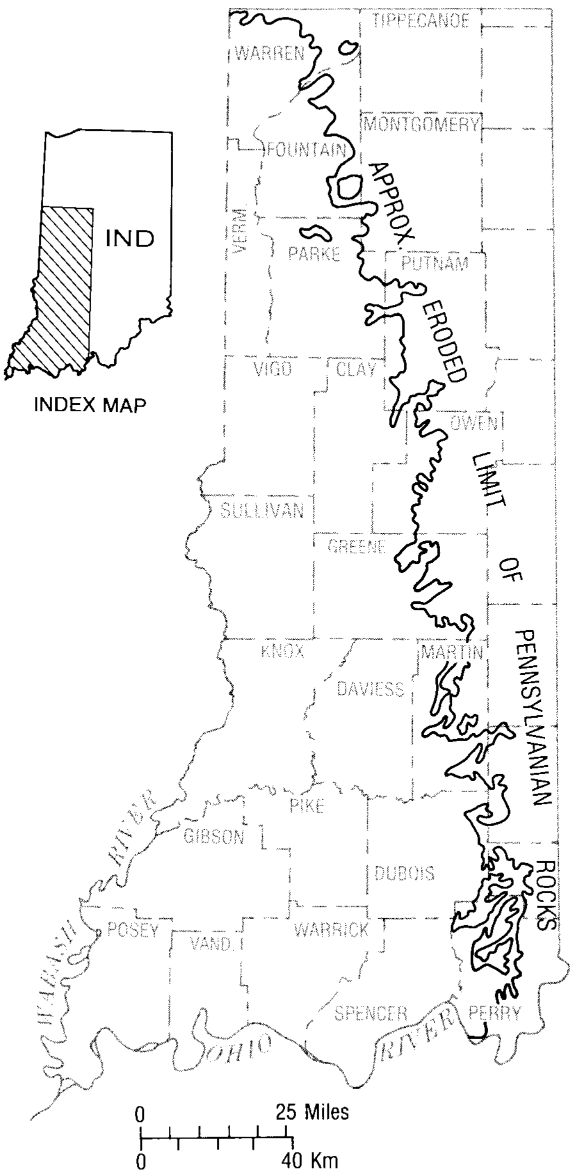

Figure 1. Index map of part of Indiana showing the area of study. The approximate eroded limit of Pennsylvanian rocks is from Gray and others (1987).

System	Group	Formation	Member	Age
MISSISSIPPIAN SYSTEM	BUFFALO WALLOW GROUP	Grove Church Shale		330 M.Y.
		Kinkaid Limestone	Goreville Ls. Mbr.	
			Cave Hill Mbr.	
			Negli Ck. Ls. Mbr.	
		Degonia Sandstone		
		Clore Limestone		
		Palestine Sandstone		
		Menard Limestone		
		Waltersburg Sandstone		
		Vienna Limestone		
		Tar Springs Formation		
	STEPHENSPORT GROUP	Glen Dean Limestone		
		Hardinsburg Formation		
		Haney Limestone		
		Big Clifty Formation		
		Beech Creek Limestone		
	WEST BADEN GROUP	Cypress Formation		
		Reelsville Limestone		
		Sample Formation		
		Beaver Bend Limestone		
		Bethel Formation		340 M.Y.
	BLUE RIVER GROUP	Paoli Limestone		
		Ste. Genevieve Limestone		
		St. Louis Limestone		
	SANDERS GROUP	Salem Limestone		
		Harrodsburg Limestone		
		Muldraugh Formation		
	BORDEN GROUP			355 M.Y.
		Rockford Limestone		
		New Albany Shale (upper part)		365 M.Y.

Figure 2. Chart showing the stratigraphic nomenclature of the Mississippian System used in this report. Dates are from Shaver and others (1985). The Goreville Limestone Member and the Cave Hill Shale Member are informally recognized in Indiana. (See Shaver and others, 1985.)

lithologic variations among formations in the Borden Group are subtle and not easily recognized everywhere in the subsurface. For all other subcrop locations the Mississippian formation at the unconformity was plotted. These data were used to produce an elevation map and a geologic map of the sub-Pennsylvanian surface (Keller, in preparation). The elevation of the unconformity and the geologic map of the sub-Pennsylvanian surface were used together in interpreting topographic relief, the morphology of valleys and uplands, and the outline of a drainage system.

Well spacing in many parts of southwestern Indiana where very extensive drilling for petroleum has occurred provides control for every 10 acres. Particularly for these areas, data on the thickness of the Mississippian formation remaining below the unconformity can help depict direction and magnitude of slope on hillsides and can indicate position of stream valleys across the outcrop (subcrop) of each formation. For areas where control is at least one well per section, the position of valleys and valley-to-upland relief can be estimated by using the elevation of the unconformity and the thickness of each Mississippian formation preserved below the unconformity. Where the well control is reduced to less than one well for each 3 to 4 square miles, the details of topography fade, so that only the location of major valleys can be interpreted and the general configuration of the stream divides can be reckoned.

Even for areas where spacing is about one well per section the true midvalley elevation and position cannot be exactly determined. For example, the well showing the lowest elevation of the unconformity among three wells in adjacent sections may indicate only a position somewhere along the valley wall. At places of uncertainty it was assumed that the long profile of the valley was smooth, and a downvalley section was constructed by using the nearest reliable subjacent limestone as a horizontal structural datum. The position of a well on the profile that suggested that the stream flowed uphill was adjusted.

The general consensus developed during the last decade places Indiana and adjacent states in low southern latitudes during Late Mississippian and Early Pennsylvanian time. The direction "north" in Early Pennsylvanian time was about 45° west of north today.

The names for physiographic features on the ancient landscape were selected from directly overlying modern place names shown on the U.S. Geological Survey topographic map, State of Indiana, scale 1:500,000, 1973 edition.

EVOLUTION OF THE MISSISSIPPIAN-PENNSYLVANIAN UNCONFORMITY

The development of an unconformity requires the creation of a surface of erosion and the burial of that surface by subsequent deposition. The formation of the Mississippian-Pennsylvanian unconformity starts with the running-water gradation and the evolution of a drainage pattern (fig. 3), including major and minor stream valleys. Several streams that occupied the major valleys cut into Mississippian rocks are named here (fig. 3 and table 1), and the locations of many other smaller streams are noted (fig. 3).

In 1971 Bristol and Howard named and defined a series of valleys developed on the Chesterian (Upper Mississippian) rocks that underlay the sub-Pennsylvanian surface in the Illinois Basin. Their sub-Pennsylvanian valleys align with our river system in a compatible manner (fig. 4).

As the late Chesterian sea (fig. 5) regressed southwestward the rivers that delivered terrigenous sand and mud to loci of deposition in the Illinois Basin evolved into the major streams that produced the landscape. The rivers in the most northern, northeastern, and eastern areas began eroding valleys

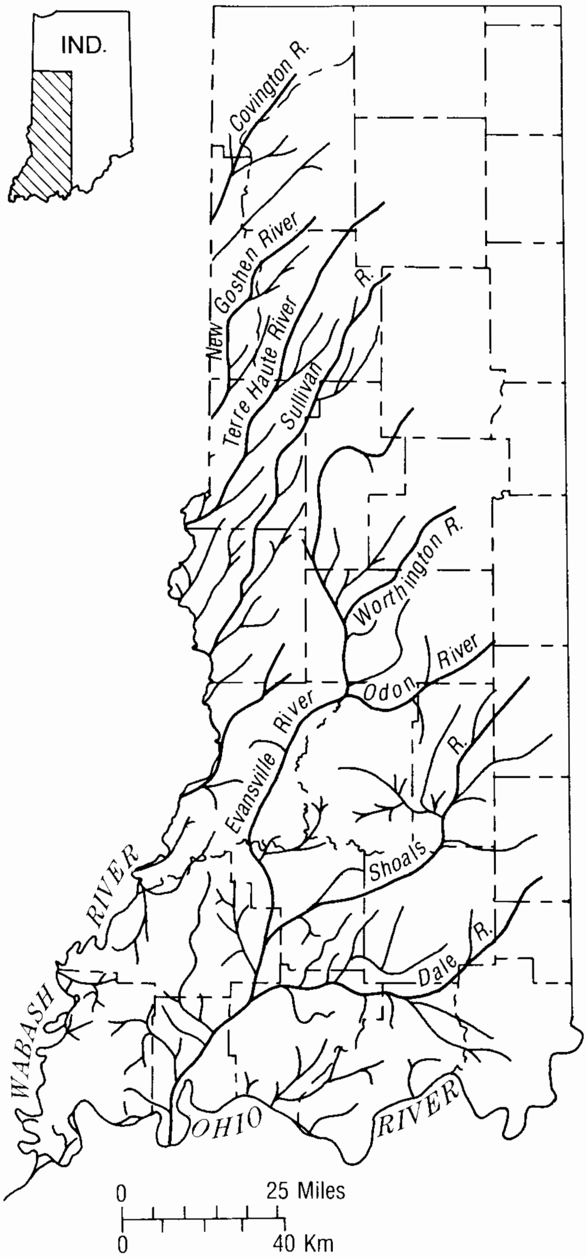

Figure 3. Map showing the drainage system developed on the sub-Pennsylvanian surface. Descriptions of the named rivers are given in table 1.

while the retreating sea still occupied central and southwestern areas. Not only were the lesser streams in the southwest the last to begin forming during maximum sea withdrawal but also they were the first to backfill when sea level rose.

At the point of maximum submergence in late Chesterian time (fig. 5) several rivers drained source lands to the north, northeast, and east. At that time

Table 1. Name, source, and description of rivers shown in figure 3

River name	Source of name	Description
Covington	Covington, Fountain County	From the eroded limit in the northeastern part of T. 21 N., R. 8 W., Warren County, extending southwestward to the Illinois state line in T. 17 N., R. 10 W., Vermillion County.
Dale	Dale, Spencer County	From the eroded limit in the west-central part of T. 1 S., R. 1 W., Orange County, extending westward to its junction with the Evansville River in the east-central part of T. 4 S., R. 9 W., Warrick County.
Evansville	Evansville, Vanderburgh County	From the eroded limit in the southeastern part of T. 13 N., R. 5 W., Putnam County, extending southward to the Kentucky state line in the central part of T. 8 S., R. 11 W., Vanderburgh County. The name "Evansville Channel" was first used by Wanless (1955).
New Goshen	New Goshen, Vermillion County	From the eroded limit in the west-central part of T. 18 N., R. 7 W., Fountain County, extending southwestward to the Illinois state line in the west-central part of T. 12 N., R. 10 W., Vigo County.
Odon	Odon, Daviess County	From the eroded limit in the northeastern part of T. 6 N., R. 3 W., Greene County, extending westward to its junction with the Evansville River in the northwestern part of T. 5 N., R. 6 W., Daviess County.
Shoals	Shoals, Martin County	From the eroded limit in the northeastern part of T. 5 N., R. 2 W., Lawrence County, extending southwestward to its junction with the Evansville River in the southwestern part of T. 2 S., R. 8 W., Gibson County.
Sullivan	Sullivan, Sullivan County	From the eroded limit in the northwestern part of T. 16 N., R. 5 W., Putnam County, extending southwestward to the Illinois state line in T. 6 N., R. 10 W., Sullivan County.
Terre Haute	Terre Haute, Vigo County	From the eroded limit in the west-central part of T. 18 N., R. 5 W., Montgomery County, extending southwestward to the Illinois state line in the southeastern part of T. 10 N., R. 11 W., Vigo County.
Worthington	Worthington, Greene County	From the eroded limit in the western part of T. 10 N., R. 3 W., Owen County, extending southwestward to its junction with the Evansville River in the western part of T. 7 N., R. 6 W., Greene County.

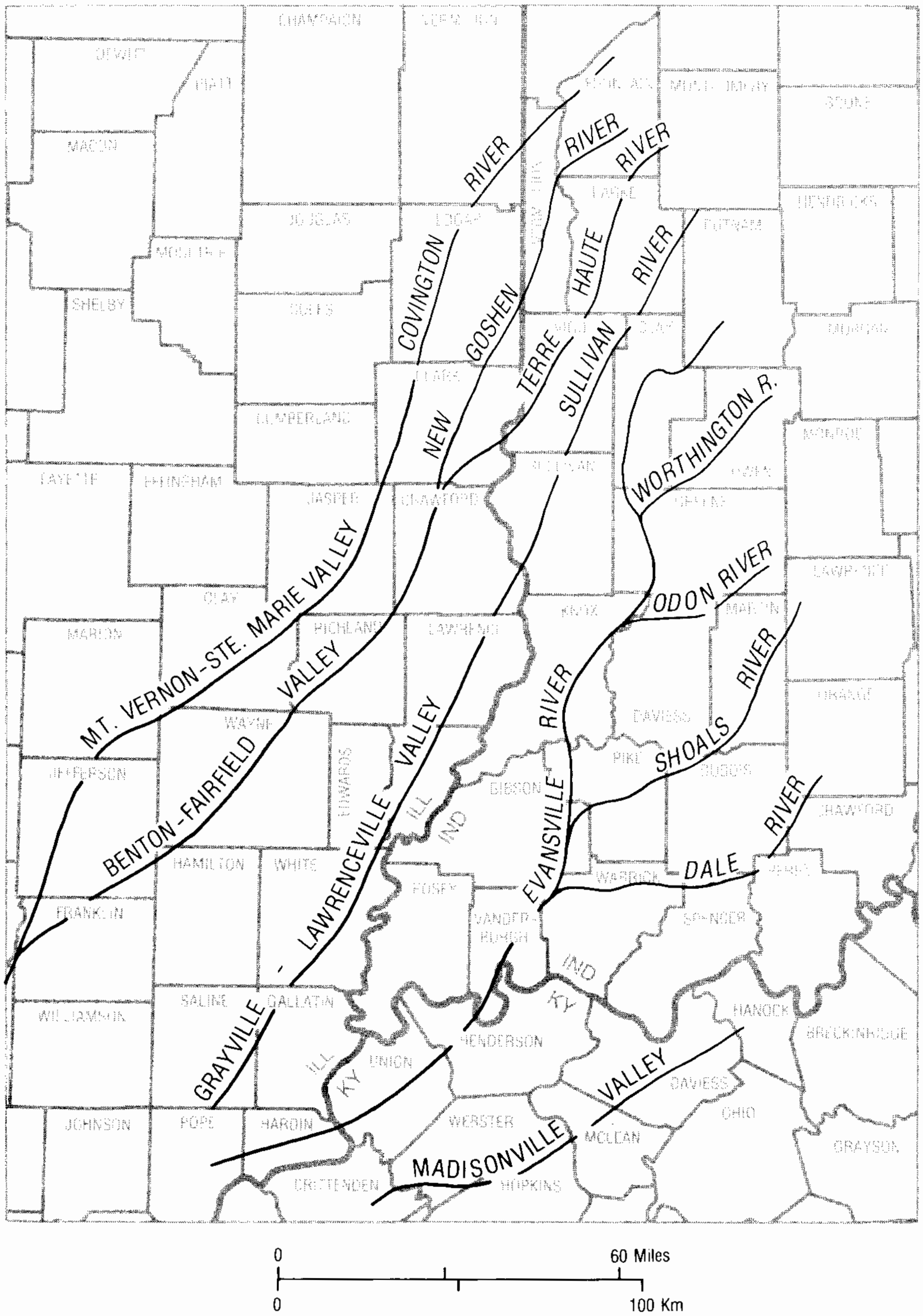

Figure 4. Map showing the named rivers in Indiana and their projected drainage into the sub-Pennsylvanian valleys of Illinois and Kentucky. The named valleys in Illinois and Kentucky are from Bristol and Howard (1971).

several active deltas lay along a shoreline between 50 and 100 miles north and east of the present outcrop of Chesterian rocks. Deltas produced by shifting channels on the upper delta plain resulted in active delta migration through several tens of miles from the stylized location given in the paleogeographic reconstruction (fig. 5). As sea level was lowered the descendants of the drainage system from the north evolved into the surface streams flowing across northwestern Indiana and northeastern Illinois and from there southwestward across Illinois (fig. 4) in the Mt. Vernon-Ste. Marie Valley and the Benton-

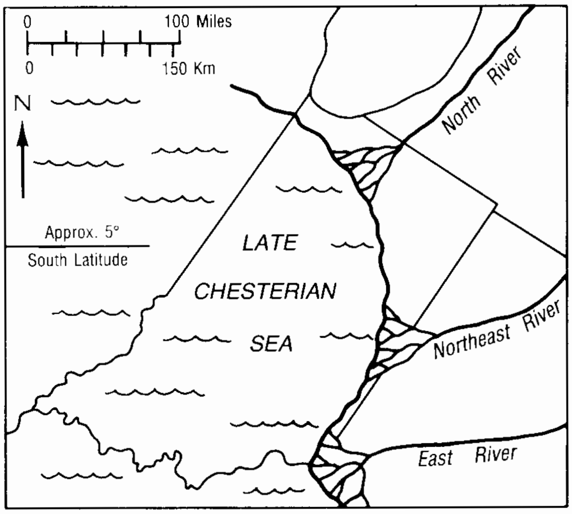

Figure 5. Map showing a generalized paleogeographic reconstruction for Indiana and adjacent states during the highest stand of sea level in Late Mississippian time.

Fairfield Valley of Bristol and Howard (1971). The river system flowing from the northeast developed into the Evansville River (fig. 3) and its tributaries. The eastern river was the ancestral system that gave rise to the surface drainage in Kentucky during the time of basinwide exposure. For example, see the drainage patterns in Kentucky (fig. 4).

The major rivers (fig. 3) generally existed at the same time and in the positions shown just before the onset of Pennsylvanian sedimentation. The sequence of full development of the stream systems, including the strong possibility of stream capture, cannot be documented because the surface is mostly hidden except where exposed in the record of a drilled well.

The very low dip of the Mississippian strata today was even less 325 million years ago. But the gradients of the major streams 325 million years ago were significantly lower than the dip as indicated by the formational contacts that are extensively V-shaped in a downstream direction on the geologic map (Keller, in preparation).

GEOMORPHOLOGY OF THE SUB-PENNSYLVANIAN SURFACE

Six physiographic regions (fig. 6) existed in Indiana before the onset of Pennsylvanian sedimentation. Each region was developed on specific stratigraphic units of the Mississippian System (fig. 2). Three regions of gently rolling countryside separate the two hilly regions in the north (Williamsport Region and Rockville Ridges) from the hilly region in the south (Mt. Vernon Uplands). The overall regional slope was southwestward, and the major rivers flowed southwestward across the regional slope. The Evansville River (fig. 6), the major drainage system for five of the six physiographic regions, flowed into what is now Kentucky and from there beyond the modern eroded limit of Pennsylvanian rocks in western Kentucky and southern Illinois.

The Sullivan, Terre Haute, and New Goshen Rivers (fig. 6) each drained mainly one physiographic region, although they crossed several regions. The Sullivan River flowed southwestward into the stream in the Graysville-Lawrenceville Valley (fig. 4). The Terre Haute and New Goshen Rivers flowed southwestward into the river in the Benton-Fairfield Valley (fig. 4). The Evansville River flowed southwestward through western Kentucky and southern Illinois to the Pennsylvanian outcrop on the southern rim of the Illinois Basin. Therefore, the final destination of the Evansville River cannot be determined now. The Covington River (fig. 6) drained the northeastern region and flowed southwestward into the stream in the Mt. Vernon-Ste. Marie Valley (fig. 4). The physiographic regions that existed in early Pennsylvanian time will be discussed from north to south.

WILLIAMSPORT REGION

The northernmost area on the sub-Pennsylvanian surface, the Williamsport Region (fig. 6), here named for Williamsport in Warren County, was the area mainly of the outcropping Borden Group (fig. 2). In a few small areas beyond the eroded limit of the Borden subcrop, the New Albany Shale lies below Pennsylvanian strata (Gray and others, 1987). Sparse well control precludes a detailed description of the landscape of the Williamsport Region, but several rivers (fig. 6) and their tributaries (fig. 3) have been identified in Fountain and Montgomery Counties, where the distances between valley bottoms range from 3 to 6 miles. The general upland surfaces stood about 150 feet above the general valley bottom lands. More relief may be documented when more wells are drilled between the present control points. Clearly, the region was hilly, and the topography was probably similar to the hilly topography present today in areas where Borden rocks crop out.

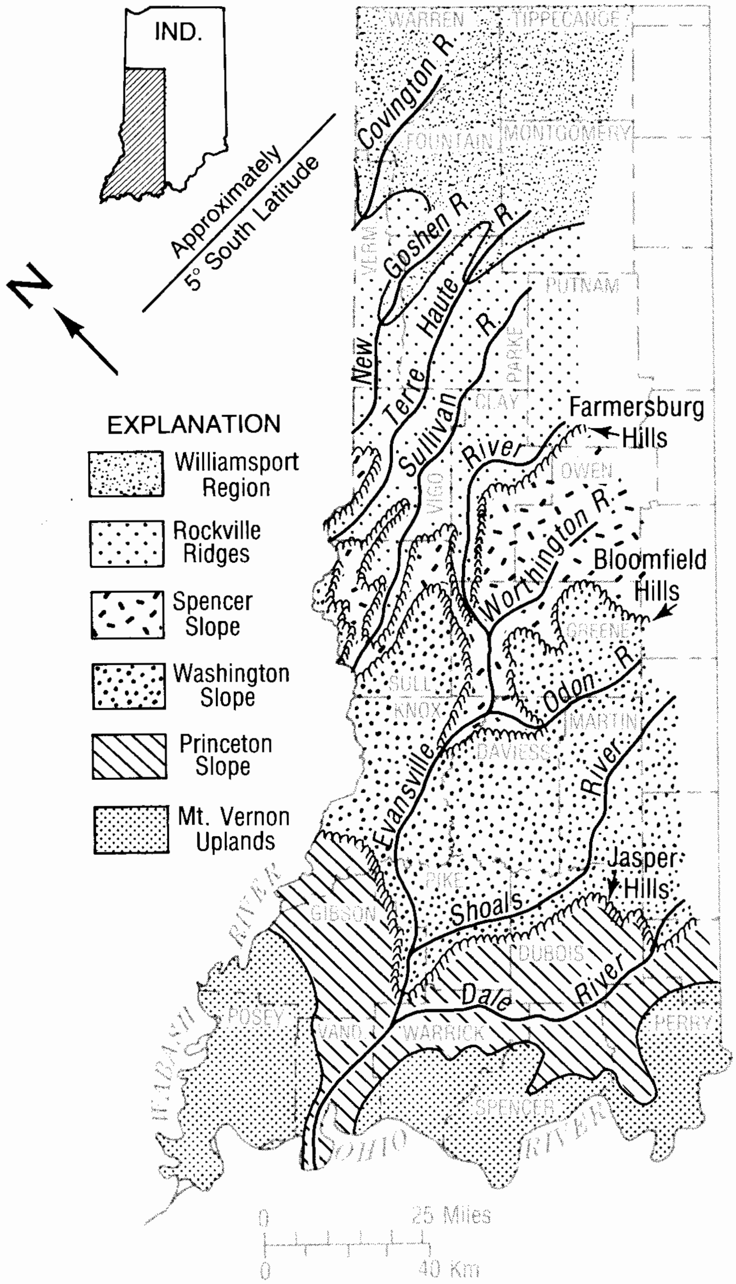

Figure 6. Map showing the major physiographic regions in Indiana about 325 million years ago.

ROCKVILLE RIDGES

The long and moderately straight ridges and valleys of the Rockville Ridges (fig. 6), here named for Rockville in Parke County, were the area of carbonate outcrops of the Sanders Group and Blue River Group. Long, straight valleys lay between prominent long, straight ridges. The well control in this area is good, and details of topography are well documented. In numerous places the ridgetops that lay 2 to 3 miles apart were capped by Ste. Genevieve Limestone and stood as much as 200 feet above valley bottom land floored by the middle part of the Salem Limestone. In some places a nearly full section of the Paoli Limestone capped uplands, a complete section of the Ste. Genevieve Limestone cropped out in the adjacent valley wall, and the lowest several feet of the St. Louis Limestone floored the valley bottom.

The New Goshen River, the Terre Haute River, and the Sullivan River (fig. 6) were the major rivers draining the area. The tributaries to these streams (fig. 3) also occupied long, straight valleys. We suspect that the segment of the Evansville River (fig. 6) that flowed near the southern margin of the Rockville Ridges was originally a tributary to the Sullivan River. The Evansville River captured this upper segment in central Clay County.

Clearly, the surface drainage of the region was integrated, but almost without question sinkholes and other karst features similar to the well-known karst features of the modern outcrop area of these Middle Mississippian carbonate units were present. Even for areas where the well spacing is as close as 10 to 20 acres, sinkholes have not been documented. Even though large, deep sinkholes have not been found, small, shallow sinkholes are suspected. The deep, straight, closely spaced valleys may owe their pronounced orientation to a regional fracture system formed in very early Pennsylvanian time. Perhaps these stress fractures initially enhanced the formation of sinkholes and solution valleys in a preferred orientation. With continued stream erosion an integrated drainage system formed and maintained the preferred orientation generated earlier and resulted in the long, well-oriented, and closely spaced ridges and valleys of the Rockville Ridges, the most striking and picturesque landscape of all the physiographic regions.

SPENCER SLOPE

The Spencer Slope (fig. 6), here named for Spencer in Owen County, was developed on rocks of the West Baden Group (fig. 2). The geomorphic expression in this region was a cuesta configuration with a gentle southwestward-dipping slope. The dissected crest of the cuesta, here named the Farmersburg Hills (fig. 6) for Farmersburg in Sullivan County, was held up by sandstones in the West Baden Group. The Spencer Slope was most extensive east of the Evansville River and was less than 5 miles wide west of the Evansville River (fig. 6). The main reason for the reduced area to the west was the continuation across the Spencer Slope of several of the closely spaced, well-oriented, southwestward-flowing rivers from the Rockville Ridges to the north.

The relief from mile to mile across the dip slope of this region was commonly 25 feet and in a few places as much as 75 feet. The greatest relief was in the Farmersburg Hills, where the relief from the cuesta crest to the base of the scarp generally was 75 feet and in some places as much as 100 feet. The maximum relief was where sandstone in the Sample and Cypress Formations produced a double-crested cuesta.

WASHINGTON SLOPE

The Washington Slope (fig. 6), here named for Washington in Daviess County, lay south of and was separated from the Spencer Slope by a zone of low hills called the Bloomfield Hills, here named for Bloomfield in Greene County. The Bloomfield Hills, like the Farmersburg Hills to the north, were a dissected cuesta. The Washington Slope was the area of outcrop of the Stephensport Group. A large area, about 800 square miles, of the cuesta dip slope was the area of outcrop of the Glen Dean Limestone.

The relief from mile to mile across most of the interstream areas on the Washington Slope was generally 25 feet. In the vicinity of several major creeks (fig. 3), the stream bottoms lay 60 to 75 feet below the general level of the cuesta slope. The relief in the area of the Bloomfield Hills generally ranged from 65 to as much as 100 feet, depending on the distribution of sandstones in the Big Clifty and Hardinsburg Formations. Sandstones in the Big Clifty subcrop range from less than 20 to more than 40 feet in thickness, and the greater thickness is east of the Evansville River. The thickness of sandstone in the Hardinsburg subcrop ranges from less than 25 feet to more than 50 feet, and the greatest thickness is west of the Evansville River. The maximum relief in the Bloomfield Hills was in places along the double-crested cuesta where thick sandstone in the Big Clifty directly overlay thick sandstone in the Hardinsburg. In the area north of the Worthington River (fig. 6) in southeastern Clay County and in southwestern Owen County, several outliers of the Washington Slope stood 30 to 40 feet high above the general surface of the Spencer Slope. The stratigraphy in these outliers includes the Beech Creek Limestone and Big Clifty Formation.

PRINCETON SLOPE

The Princeton Slope (fig. 6), here named for Princeton in Gibson County, was the area bounded on the north by the Jasper Hills and on the south by the Mt. Vernon Uplands. The Jasper Hills are here named for Jasper in Dubois County. The cuesta configuration of the Princeton Slope was the area of outcrop of the lower half of the Buffalo Wallow Group comprising the Tar Springs Formation through the Menard Limestone.

The Jasper Hills were a single- to double-crested cuesta held up by sandstones in the Tar Springs Formation and the Waltersburg Sandstone. East of the Evansville River massive sandstone in the Tar Springs produced a single cuesta in the Jasper Hills with local relief as much as 70 feet. West of the Evansville River massive sandstone in both the Tar Springs and the Waltersburg held up several double-crested cuesta hills with local relief as much as 125 feet. A large area of the Princeton Slope was the locus of outcropping Menard Limestone, which was more than 50 feet thick before erosion. The local relief from mile to mile across this dip slope was generally 25 to 30 feet. The local relief along the Dale River (fig. 6) and along several creeks (fig. 3) in southern Gibson County and in northern Vanderburgh County was more than 50 feet. Stream dissection in these areas of higher local relief cut through the Menard Limestone and exposed variable thicknesses of the underlying Waltersburg in the valley bottoms.

Several large outliers of the Princeton Slope (fig. 6) north of the Shoals River and east of the Evansville River stood as much as 75 feet above the local elevation of the Washington Slope. A few scattered outliers of similar topographic expression were west of the Evansville River in Knox County.

MT. VERNON UPLANDS

The Mt. Vernon Uplands physiographic region (fig. 6), here named for Mt. Vernon in Posey County, was the hilly outcrop area of the upper half of the Buffalo Wallow Group. The Evansville River divided this region into a lower eastern sector and a higher western sector. The high hills of the eastern sector were capped by the Negli Creek Limestone Member of the Kinkaid Limestone (fig. 2). The hillslopes were loci of exposed rocks of the Degonia Sandstone, the Clore Limestone, and the Palestine Sandstone (fig. 2). The upper Menard Limestone cropped out in the bottom of some of the most deeply cut creeks. The caps on some of the lower hills and some hillside benches on the high hills were outcrops of sandstones in the Clore. The relief in some township-size areas (36 square miles) in the eastern sector approached 150 feet, but local relief from mile to mile was generally less than 75 feet. Many of the creeks in this area drained northward into the Dale River (fig. 6). Some of the creeks in the southern part of this area drained southward into a major river in western Kentucky.

The sector west of the Evansville River was regionally a double-benched upland with somewhat higher relief overall than in the eastern sector. The lower bench was held up by the Negli Creek Limestone Member of the Kinkaid Limestone, and the Degonia, Clore, and Palestine rocks were exposed on the hillsides below this bench. The magnitude of slope below the lower bench was as much as 100 feet per mile in numerous places. The upper bench was produced by outcrops of the Goreville Limestone Member of the Kinkaid Limestone. The Cave Hill Shale Member of the Kinkaid cropped out between the lower and the upper bench. The slope of the hillsides exposing the Cave Hill was generally about 50 feet per mile. Very low hills above the Goreville benches were composed of Grove Church Shale. Some deep dissection by creeks (fig. 3) in the southwestern part of the western area produced relief of more than 150 feet from general upland surface to stream bottom. The Graysville-Lawrenceville Valley in Illinois (Bristol and Howard, 1971) (fig. 4) lay just to the west of southwestern Gibson County and northwestern Posey County, Ind. There about 200 feet of relief existed from the upland in Indiana to the valley bottom in Illinois.

Deposits resulting from mass movement are found along the hillsides and in the valleys in the western sector of the Mt. Vernon Uplands and were described as slumps by Bristol and Howard (1971, 1974). In most places in Indiana these features are identified as isolated masses of the Negli Creek Limestone Member of the Kinkaid in juxtaposition with rocks of the Clore or the Palestine. Typical vertical displacement is 50 to 150 feet, and horizontal displacement is less than half a mile. A few deposits along the eastern margin of the western sector of the Mt. Vernon Uplands do not fit the typical slump geometry. Well spacing is too great to detail the horizontal displacement, but the available data suggest that some Negli Creek masses lie on Menard Limestone about $1^1/2$ miles from the nearest outcrop of the Negli Creek. There are several possible explanations: (1) an unknown nearby outlier capped by Negli Creek as the source of the Negli Creek, (2) a rockslide or debris flow rather than a slump as the style of downslope movement, or (3) the remnant of a slump that occurred when the subcrop of the Negli Creek was much nearer to the displaced mass. Perhaps some of the downslope movement was triggered by earthquakes associated with the Wabash Valley Fault System. The major time of faulting, however, was more than 40 million years later.

The geomorphology given above describes a landscape that existed in Indiana about 325 million years ago. This landscape is known only because deposition during the Pennsylvanian Period has preserved the surface.

DISCUSSION

The geomorphology of the sub-Pennsylvanian erosion surface reflects the variation in the stratigraphy of the Mississippian rocks. The physiographic regions (fig. 6) are recognized at least in part by variation in bedrock geology. The hilly landscape with moderate to high relief in the Williamsport Region and the Rockville Ridges contrasts distinctly with the more open rolling countryside of the cuesta configurations on the Spencer, Washington, and Princeton Slopes. The moderate relief of the Mt. Vernon Uplands reflects the subtle difference in stratigraphy and lithology in the upper quarter and lower three-quarters of the rocks in the Chesterian Series. The geology of this buried surface is probably better known than any Paleozoic subscrop unconformity of comparable size anywhere in the world.

The streams that are recognized on this surface (fig. 3) document a well-drained area. The near-equatorial location and good drainage prescribed the existence of a rather low-diversity upland flora of Early Pennsylvanian time. This flora contained such elements as *Cordaites* and lichens, and the coal-swamp flora of that time was not present. The valley-bottom, high-water-table flora in riparian settings was more diverse taxonomically, but extensive areas of lush vegetation were not a common feature of this landscape. The interested reader is referred to Phillips and Peppers (1984) for more information concerning Pennsylvanian flora.

And now for a question that cannot have a detailed answer, but a question worth speculative comment. How long did it take for the surficial gradational processes to produce the landscape? Biostratigraphic data can provide at least a general time frame into which general speculation must fit. Rexroad and Merrill (1985) proposed that in local areas in the Illinois Basin uninterrupted deposition in marine environments prevailed across the Mississippian-Pennsylvanian boundary because fossils in shale and sandstone conformably overlying the Grove Church Shale (fig. 2) in Illinois were earliest Pennsylvanian in age. These workers also stated that on the basis of conodont assemblage zones the Grove Church Shale was of youngest Mississippian age. These data based on biostratigraphy came from outcrop samples in Illinois about 60 miles southwest of southwestern Indiana. We know of no biostratigraphic data from the Grove Church Shale in Indiana, but it is reasonable to assume that this unit in Indiana is the same age as it is in Illinois. Our subsurface data suggest that in Indiana the oldest Pennsylvanian rocks overlie the youngest Mississippian rocks with unconformity. The oldest biostratigraphic data from Pennsylvanian rocks in Indiana are found in the Lead Creek Limestone Member of the Mansfield Formation, and Shaver (1986, p. 74-75) declared the Lead Creek to be late Morrowan in age. In the COSUNA program (for example, see Shaver and others, 1985), the Morrowan Epoch was assigned a duration of about 16 million years.

We assume the following in order to estimate the

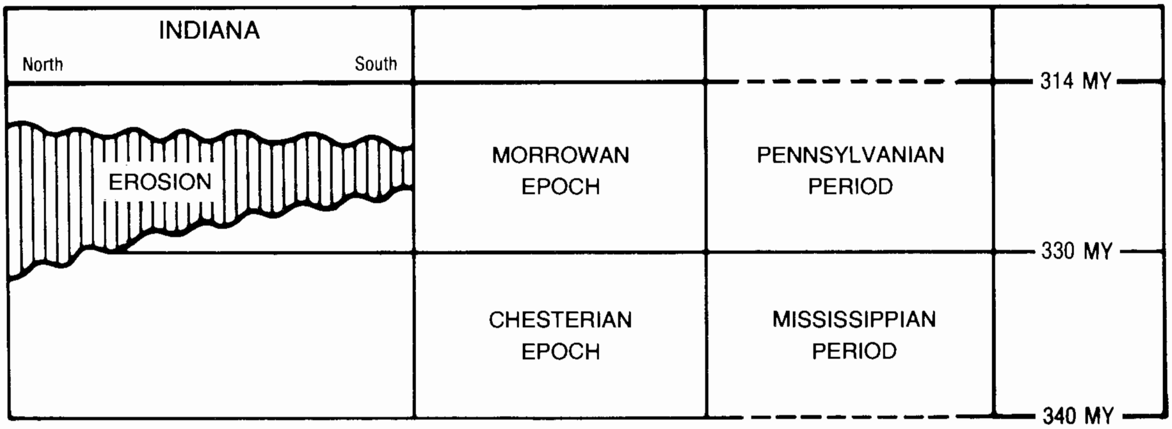

Figure 7. Diagram showing the time of erosion associated with the Mississippian-Pennsylvanian unconformity in Indiana. Dates are from Shaver and others (1985).

time of development of the Mississippian-Pennsylvanian unconformity in Indiana: (1) the Morrowan Epoch is 16 million years in length, and the equal division of the epoch into an early and a late interval is reasonable; (2) the conodont evidence (Rexroad and Merrill, 1985) indicates that subaerial erosion, at least in the central area of the Illinois Basin, did not start until sometime after the beginning of Morrowan time; (3) the Lead Creek Limestone Member of the Mansfield Formation is late Morrowan in age; (4) deposition of the Mansfield Formation began, at least in southwestern Indiana, within the first 6 million years of Morrowan time; and (5) the paleogeographic reconstruction (fig. 5) is acceptable for late Buffalo Wallow time.

When the late Chesterian sea (fig. 5) began retreating within the last million years of Mississippian time, erosion began around the fringe of the basin as the streams followed the shoreline basinward and began downcutting to adjust to the falling base level. The stream erosion that was initiated then eventually spread throughout Indiana as the seas withdrew beyond southern Illinois. Clearly, the time of erosion became younger southward and did not start in southwestern Indiana until after the dawn of Morrowan time had passed (fig. 7). Within early Morrowan time the sea retreated to a maximum position south of Illinois, and a short time later, still within the early Morrowan, sea level began to rise. Stream deposition by backfilling moved northward up the major valleys, and the unconformity began forming. Sea level rose more rapidly than it fell, and the shoreline moved initially up the stream valleys to create estuaries. Some fluvial and transitional marine deposition buried the hills, and the unconformity came into being.

In this explanation (fig. 7) the longest time during which erosion occurred, a time perhaps involving as much as 8 million years, was in northern Indiana. The shortest time represented by the unconformity, a time probably less than 3 million years, was in southern Indiana.

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