ISSN 2642-1550, Volume 1, 2019

From Backbones to Sliding Plates—A History of Thought on the Geologic Structure of Indiana and the Midwest

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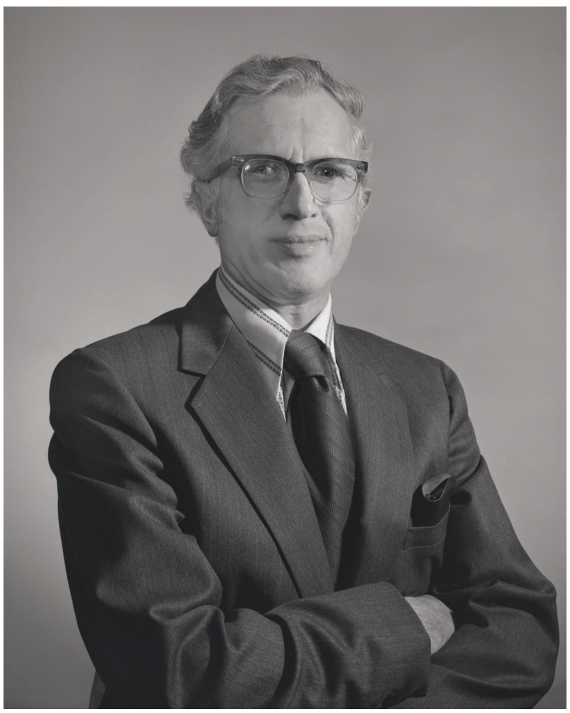
Received 02/27/2019
Accepted for publication 02/28/2019
Published 08/08/2019
Suggested citation: Gray, H. H., 2019, From backbones to sliding plates—a history of thought on the geologic structure of Indiana and the Midwest: Indiana Geological and Water Survey, Indiana Journal of Earth Sciences, v. 1. DOI 10.14434/ijes.v1i0.26878



Henry H. Gray, then a stratigrapher at the Indiana Geological Survey, presented this talk on May 18, 1972, to the Indiana-Kentucky Geological Society meeting at Bloomington, Indiana, in connection with a field trip to the Mt. Carmel Fault.

It's not my intention here to give you a mental chiropractic adjustment, nor to give a sales pitch on "the new global tectonics." Instead, I simply wish to outline some of the advances in knowledge of the structural geology of Indiana and the Midwest, and in that way to place a broad frame around the rather detailed look at the Mt. Carmel Fault that we will have tomorrow—barring bad weather, hangovers, flat tires, and other acts of God.

From almost the earliest days of geologic exploration, structural features have engaged the attention of geologists in Indiana. Early development of structural concepts was hampered, however, not only by lack of information, but also by primitive illustrative techniques. Cross sections generally were crude, and structure contour maps were unknown. Nevertheless, David Dale Owen, the first State Geologist of Indiana, noted in 1838 that "the general dip of the rocks is very gradual toward the west, or centre of the basin," and that because the strata dip eastward in Ohio, there is along the boundary between these two states, as he put it, "a kind of back-bone." Owen was thus one of the first to understand the basic geologic structure of a substantial part of Indiana.

Owen's structural inferences came from observations in the southern part of the state. Early knowledge of bedrock structure in drift-covered northern Indiana came later, principally from scattered exposures along the Wabash River and from the few water wells that had been driven to bedrock. The exposures, however, proved more confusing than enlightening. The generally flat-lying strata are interrupted by numerous knobs and small domes that we now know to represent reef-like accumulations on the floor of the Silurian sea, but lacking subsurface data to show that these are superficial features and do not extend to any depth. State Geologists Maurice Thompson and S.S. Gorby interpreted them, in the 1880s, as evidence of "ancient hills and mountains," "distorted and tilted," "ancient upheavals," and a "notable disturbance."

A reasonable knowledge of the structural situation in northern Indiana did not come until after the Findlay gas field blew in, in 1885. Within a few years, the volume of geologic information increased explosively and when in 1889 Edward Orton assembled the data into one of the very earliest of structure maps, a northward dip of the rocks in the northeastern corner of the state became evident. A very similar map was prepared a year later by A.J. Phinney, a medical doctor whose grasp of the geologic setting of the Indiana oil and gas field was as good as any professional geologist's of his time.

At this time, the U.S. Geological Survey was barely ten years old, and the contour technique sponsored by Director John Wesley Powell for topographic mapping had not yet been applied to the illustration of geologic structure. Thus Orton and Phinney used patterns to indicate the altitude of their structural horizon, the top of the Trenton Limestone. A multicolor version of this technique was presented in 1894 by E.P. Cubberly, who made the first attempt to summarize the structure and subsurface stratigraphy of the entire state of Indiana, "as revealed by the drill." In addition to the map, he presented a set of colored cross sections and went on to suggest a physical model of the major structural features of Indiana. "Cut out a small outline map of our State," said Cubberly, "and pick it up by taking hold of it near Liberty, on the eastern border, with the right hand, and at the point where the Kankakee River enters Illinois on the western with the left hand." The inclination of the model toward the unsupported northeastern and southwestern corners of the state, said Cubberly, fairly represents the dip of the rocks into what are now known as the Michigan and Illinois Basins.

Since the time of Orton, Phinney, and Cubberly, numerous structure maps of Indiana have been drawn, on many other horizons as well as the Trenton Limestone. As much as these maps have added to our detailed knowledge, and despite their use of vast amounts of additional data and more advanced illustrative techniques, none of them have shown the larger structural features of Indiana any more convincingly than the earlier, more primitive ones, although details of interpretation have varied through incorporation of additional data and through differences in contour interval and scale. The major contributions of later mapping are to our structural concepts of the basins, because a real knowledge of the magnitude of the basins awaited development of techniques that were not available to earlier generations. Early estimates of basin depth always were too shallow—partly because the amount of thickening of many of the units into the basin was underestimated, and partly because it was not generally understood (indeed, is sometimes still debated) that there are present in the depths of the basins whole units of rocks that do not extend to the outcrop. Deepest parts of the Michigan and Illinois Basins have not yet been fully plumbed by the drill, although they are technologically within reach, and our current best estimates of the depth of the sedimentary accumulations are based on seismic data.

This illustrates that since the time of Owen there has been a gradual, but radical shift in geologic perspective. Whereas earlier geologists, largely limited as they were to surface observations, recognized basins but tended to emphasize arches in their thinking, today, principally as a consequence of the immense quantity of subsurface data generated by the petroleum industry, geologic thought tends to be basin-oriented. Today, arches often are viewed simply as sills that separate the structural basins in which geologic interest is centered, but this concept fails to grant the positive features an equal status and does not lead to a well-integrated view of the relationships among the various kinds of structural features.

The present regional structural setting of Indiana and adjacent states is well displayed on two published maps of recent date. Structure is shown by contours on several horizons on the 1962 *Tectonic Map of the United States*, and contours on the basement complex—Precambrian in most areas—are shown on the 1967 *Basement Map of North America*.

In common these maps portray the Midwest states as part of a broad structural platform bounded on the southeast and southwest by structurally complex and deep linear troughs, and punctuated by two large and roughly circular subsident areas of considerably less depth than that of the adjoining basins. The axes of the positive or less subsident areas are not well defined, but in a general way the positive features form two hollow

DOI 10.14434/ijes.v1i0.26878

squares about 350 miles on each side and with one side in common. Let us look briefly at the history of the names and concepts of some of these features.

The Cincinnati Arch was, of course, named for the Queen City and was first illustrated by interpretation of rock exposures along the Ohio River upstream and downstream from that town. It acquired a third dimension with the study of exposures in central Kentucky and Tennessee, but a good understanding of its northward continuation awaited the advent of subsurface data. It is now considered to be a composite feature that includes the Nashville and Jessamine Domes as subordinate parts, and its most certain extent is from northern Alabama to Cincinnati. Some geologists continue it northeastward to connect with or include the Algonquin Arch, a structural promontory that stretches out from the Canadian Shield; others extend it northwestward to connect with or include a poorly defined protruberance from the so-called Wisconsin Arch or Wisconsin Dome.

The concept of this arch, the archetype of all arches, goes back at least to the time of Owen and the name, originally Cincinnati Arch, but later also Cincinnati Anticline, or Cincinnati Geanticline, or Cincinnati Anticlinal, is itself at least a hundred years old. In 1873 Edward Orton used the term as though it were already well known among geologists, but the evidence seems to be that the name was his, probably from an obscure publication of 1871. It is among the earliest structural features in North America to have been recognized and to have received a name.

Unfortunately, it has since been much abused. Consider its inferior position on the *Tectonic Map of the United States*—in small print and shoved into the backwoods of southern Kentucky, this honorable name that was in use before J.D. Dana coined the term "geosyncline."

North of Cincinnati, the arch splays out into a large triangular area that structurally is so broad and flat as to seem quite featureless. Total structural relief in this area of 6,000 square miles is less than 500 feet, both on the Trenton Limestone and on the basement complex. Over wide areas the dip is less than 10 feet per mile, and in whole counties the rocks are so flat-lying that regional trends in dip cannot be perceived. Although these facts have long been known, it was only in 1957 that Darsie Green saw the need to recognize this feature as a means of avoiding fruitless arguments over axial trends that do not exist. Unfortunately, the name he proposed, Indiana-Ohio Platform, is cumbersome and insufficiently specific. A new name should be suggested.

Part of the old Lima-Indiana oil and gas field occupies the northern edge of this platform. The remainder of this field extends along a northeastern extension from the platform, the Findlay Arch. This feature becomes a distinct arm of the Cincinnati Arch somewhere between Lima and Findlay, Ohio, where an axial trend can be identified. To the south, the platform merges with the Jessamine Dome, the north flank of which is marked by a slight but consistent northward dip at about the Ohio River. The close relationships among these features and the difficulty of separating one from another substantiates the concept that all are part of a single structure complex. The Chatham Sag in southern Ontario separates the Cincinnati Arch, Findlay arm, from the Algonquin Arch, and a much less prominent saddle, sometimes called the Logansport Sag but in reality merely the downthrown side of the Royal Center Fault, terminates the platform and the Cincinnati Arch on the northwest.

Early concepts of the Kankakee Arch are variously attributed to Gilbert Cady in 1920, to George Pirtle in 1932, and to George Ekblaw in 1938. Neither Cady nor Ekblaw, however, were considering the structure that has been generally referred to by that name. Cady's "Morris-Kankakee anticline" is a minor flexure and is not of regional significance. In some mysterious way, however, this became Ekblaw's "Kankakee Arch," but this was a paleogeographic feature predicated upon inferred geologic history and the sedimentary record, rather than a present structure. Both of these features bear a striking similarity in location and trend to the structure now known as the Sandwich Fault, and those who would trace the present Kankakee Arch to these sources are misled.

The structural feature now generally known as the Kankakee Arch was introduced by Pirtle in 1932, who described, identified, and named the feature quite clearly on the basis of present structure on the Trenton Limestone. His discussion of the history of the structure reveals the then-current state of knowledge, and on his structure-contour map the axes of folds were rather too sharply and idealistically drawn, but his basic concept of the arch was correct in all important respects, and it is the concept that has been widely adopted since.

The Kankakee Arch is an arm or spur from a broad structural platform that extends from northern Illinois into Wisconsin and Minnesota. The platform is usually called the Wisconsin Arch or Wisconsin Dome, but it in no way resembles the Cincinnati Arch or the Jessamine or Nashville Domes, and some other generic name would be more appropriate. At the southeastern corner of this platform, near the town of Kankakee, Illinois, a slight constriction of the structure contours makes it possible to establish, rather broadly, an axial trend to the southeast. This trend roughly parallels the trend of the Sandwich Fault, but it does not connect with the

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fault, nor is it an extension of the fault. The fault should be considered a minor feature of the platform area.

What is now known as the Illinois Basin was early recognized in an economic sense as simply a coal basin—note that Owen used the term "basin" as a sort of counterpart to "back-bone." When nationwide coal resource studies were made, as for example by Marius Campbell in 1917, it became necessary to categorize the separate coal-bearing areas and this became the

"Interior province, eastern region." Subsequently, this was shortened in common use to "Eastern Interior coal basin," or simply "Eastern Interior basin."

The first important use of the term "Illinois basin" appears to have been that of Marvin Weller and Al Bell in 1937, just about a year after renewed oil interest in the area. They seem to have been unconscious of the fact that they were introducing an important change in name, and in fact they made some synonymous use of the older term. The newer term, however, being both more concise and more precise, has had increasing use and today the older term is used mainly in its original sense in coal resource studies and probably should be avoided entirely.

The Michigan Basin has not been a major coal producer, and the term used by Campbell in 1917, "Interior province, northern region," gained little foothold except in coal resource studies. Pirtle in 1932 probably was not the first to use the modern term, but his paper, the earliest comprehensive structural study of the Michigan Basin, was timely because it was published just at the beginning of a rapid increase in oil activity. Not having serious competition, the new term quickly grew in favor.

Both the Michigan and Illinois Basins have been given a number of *ad hoc* boundaries, each of which has admittedly been arbitrary, but there has been a rather general tendency to include all areas in which the rocks show decided dip into the basins—say, 20 feet per mile or more. This has left only relatively narrow areas of low dip for the positive features. The basins are subcircular or subelliptical in outline and about 300 miles in diameter, and in both basins the rate of dip increases gradually almost to the center of the basin, so that the flat area there is of very small extent. Thus the basins have the general shape of a broad vortex, but we must not let the structure contours mislead us—drawn to true scale and 6 feet wide, the maximum structural relief that these basins would show in cross section is about half an inch,

Transverse to the major structural trend of the Cincinnati Arch and the Illinois Basin, and just south of Indiana but nevertheless influential in the structural story of our area, is a fault system of major dimensions that consists of the Kentucky River, Rough Creek, and Ste. Genevieve Fault Zones. More than 400 miles long overall, these zones are slightly *en echelon*, have slightly different trends, and may have slightly different histories—but no doubt are closely related. An extension of this fault system beneath the gentle folds of the Alleghany Plateau was suggested by Woodward in 1961. At almost exactly the place that the fault system emerges from beneath the plateau structures, the Folded Appalachians change in structural style and become southwestward a series of imbrecate thrust sheets, with the Pine Mountain Overthrust 'way out front.

It has been suggested that this change in Appalachian style is due to differences in thickness and competence of the strata involved in the folding and thrusting; perhaps the change in style and trend of the Kentucky River-Rough Creek fault system is unrelated and simply marks the edge of the craton. S.K. Clark and J.S. Royds in 1948 indicated that the Rough Creek faulting was produced by lateral slip, but Donald Sutton has recently called the zone a compressional fold, a strongly faulted anticline. Whatever its origin, it is unique in this region.

The Wabash Valley Fault System crosses, or at least intersects, the Rough Creek system in southern Illinois. This zone is only about 100 miles long, but there is now some evidence that it extends beneath the Mesozoic and younger rocks of the Mississippi Embayment for perhaps another 100 miles. Not only the trend, but also the faulting style here is different from that of the Rough Creek zone. Clark and Royds referred to these faults as "normal diagonal shears." Pointing out that many of the faults tend to die out upward, and that projected axial planes of adjoining folds intersect projected fault planes at the basement surface, they suggest that these faults originate from vertical movement along faults in the basement.

Several large isolated faults with displacements of 100 feet and more and lengths exceeding 50 miles are known on and adjacent to the arch areas—the Sandwich, Royal Center, Bowling Green, Fortville, and Mt. Carmel Faults. Though these differ in orientation, they seem similar in tectonic style—in all of them it appears that the downthrown block is essentially a small flap that shows a sort of trapdoor type movement, so that the faulting constitutes only a minor interruption of the normal regional dip. According to a 1965 paper by Rudman, Summerson, and Hinze, a scarp (of unknown origin) exists in basement rocks beneath the Mt. Carmel Fault. If this is true of the others as well, it will not do to analyze these faults in terms of structure on the Trenton or other shallower horizons; they will be related to basement trends.

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I do not have time to discuss some of the smaller features—the Kentland Disturbance, which we now are quite sure is an impact structure; the anomalous, small, and isolated Georgetown Fault; and splinters from the Rough Creek Fault that enter southern Indiana. I have to ignore these because I want to go on to say what few words I can about the history and origin of the structures.

Generally, it is regarded that the Illinois and Michigan Basins were not formed and did not influence depositional patterns until late Niagaran time, when they became evident more in influencing reef location than in thickness developments. From Devonian time onward, the basins became more and more distinct, and tectonic activity became more and more varied. In part this surely represents our much greater knowledge of later Paleozoic than of earlier Paleozoic sediments, but it nevertheless also must be related to accelerating and spreading orogeny in the Appalachian area. Recurrent movement through Mississippian and Pennsylvanian time characterizes many structures in the Midwest, and late in the Paleozoic (certainly after Caseyville and Tradewater deposition early in the Pennsylvanian), the Pascola Arch rose and closed the south end of the Illinois Basin. Still later this arch became the locus of subsidence in the Mississippi Embayment, so that some 2,000 feet of Cretaceous and Tertiary sediments now conceal the older structures that connect the Ozark Dome to the Cincinnati Arch.

Early in the Paleozoic, depocenters wandered around quite a bit. In Cambrian time, 3,000 feet of sandstone was deposited in northern Illinois, and during Knox and mid-Ordovician time, 8,000 feet of dolomite and limestone accumulated in western Kentucky. Toward the end of the Ordovician, however, a far eastern source and depocenter are indicated by the eastward-thickening wedge of the Maquoketa Group. This drastic shift in pattern is a reflection of a turning point in the history of the Appalachian Geosyncline, a change, as Marshall Kay put it in 1951, from miogeosynclinal to eugeosynclinal sedimentation. Henceforth, Paleozoic terrigenous sediments in the Midwest had primarily an eastern source.

Eastern orogenic movements diminished somewhat in Silurian and Devonian times and in the Midwest sedimentation was mainly authigenic. Dolomite and limestone, along with evaporite in the Michigan Basin, accumulated to a total thickness of several thousand feet in the Michigan Basin, less in the Illinois Basin. Toward the end of Devonian time, a clastic wedge began to advance from the east, and with a few generally short-lived interruptions, mixed clastic and carbonate sedimentation continued until near the end of Pennsylvanian time. These sediments aggregate several thousand feet in the Illinois Basin, less in the Michigan Basin. The generally increasing clasticity and accelerating depositional rate of the late Paleozoic reflect quite precisely the orogenic history of the Appalachian mountain system.

There are two developments of rather recent date that I think should be mentioned in passing for the new ideas that they interject into our train of structural thought. Lineback in 1969 showed that early in Mississippian time the Illinois Basin was sediment-starved. Though the basin itself probably was tectonically stable after an initial subsidence, infilling was not uniform but proceeded episodically, first from the northwest, then from the northeast, then from the south, and finally into the center. I think this study warns eloquently against too-easy acceptance of the thought that depocenters coincide with basins, and it also should settle the old chicken-egg controversy by showing that, in this case at least, subsidence clearly preceded sedimentation, and therefore that the Illinois Basin did not subside primarily in response to sedimentary accumulations but is a genuinely tectonic feature in its own right. Second, I wish to recall Woodward's 1961 paper in which he introduced the possibility that a major fault, now concealed under the gentle folds of the Alleghany Plateau, has affected early Paleozoic sedimentation. Southeast of this possible fault are lower and middle Cambrian rocks that are unknown elsewhere in the Midwest—except that a similar discovery seems now shaping up south of the Rough Creek Fault Zone in southernmost Illinois. These intriguing facts surely are trying to give us a major message on the geologic history of our region, and not the least important aspect of that message is that there is a great deal that we do not know about the tectonics of the Midwest.

Today there swirl around us the pros and cons of "the new global tectonics"—which from the distance at which we view it has some of the aspects of a professional wild west medicine show. I say "swirl around us" because tectonically stable Indiana is not directly involved and, indeed, is never mentioned in the controversy. If I can make a gross overgeneralization, it is that plate tectonics works exquisitely well with a handful of new, mostly geophysical data gathered from the poorly-known sea floor, but it ignores and fails to explain a great mass of old, well-established continental facts. For details see the February issue of the AAPG Bulletin [1972, v. 56, no. 2], which is devoted entirely to this subject. One of the areas that plate tectonics explains poorly or not at all is eastern North America, including the Gulf Coast and the continental interior.

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Nevertheless, I think we can bend Murphy's law just a bit—Murphy, you know, is the one who first said "If something can go wrong, it will"—and rephrase it "If plate movement can occur, it has." Appalachia as a continental mass has long been inconceivable, but as a northwestward-moving oceanic plate (or, conversely, a southeastward-drifting continent), it may be valid. The island arc-miogeosynclinal-eugeosynclinal concept of Appalachian structure also seems to have stood the test of time. Perhaps the craton-margin fault system—including Woodward's "steep continental face" and Sutton's concept of the Kentucky River-Rough Creek faulting as compressional in nature—turns at depth into a thrust, a zone of subduction, to use the new lingo. Perhaps our arches and basins are cratonic wrinkles in response to this compression and/or subduction and/or mantle flow. Perhaps all our other major faults reflect recurrent movement of older basement structures, and boy, the new global tectonics hasn't really tangled with the Precambrian as yet!

These are, however, the idle speculations of a pretty rusty armchair structural geologist. Just let me conclude by saying that continental interior or not, out of the tectonic mainstream or not, we do have a lot of facts that must be accounted for by "the new global tectonics." Let the drifters be warned—with our little slingshots we may yet shoot them down unless they take us into account.

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